Chapter 16

Citrus pests in a global world

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16.1 Introduction

The agro-ecological citrus system is characterized by richness and abundance of phytophagous species as well as their natural enemies. However, only about 20 of these pests can be considered key, in part due to effective biological control. As early as the fourth century, Chinese citrus growers were known to distribute arboreal nests of the weaver ant, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae) to manage pests, such as citrus stink bugs [*Rhynchocoris humeralis* (Thunberg) (Hemiptera: Pentatomidae)], leaf beetles [*Podagricomela nigricollis* Chen (Coleoptera: Chrysomelidae)], weevils [*Hypomeces squamosus* (Fabricius) (Coleoptera: Curculionidae)], and larvae of citrus butterflies and fruit borers (*Anomala cupripes* Hope (Coleoptera: Scarabaeidae)] (Yang, 2002). This practice continued into the 20th century in some parts of Southeast Asia, Burma, and China (Li, 1982). Another early well-known example is the first successful introduction to California of an exotic natural enemy, *Rodolia* (=*Novius*) *cardinalis* (Mulsant) (Coleoptera: Coccinellidae) from Australia to control the cottony cushion scale *Icerya purchasi* (Maskell) (Hemiptera: Monophlebidae) a pest of Asian origin (Fig. 16.1). *R. cardinalis* has now been introduced worldwide with the result that *I. purchasi* is rarely considered more than an occasional pest.

Citrus cultivation has been exported throughout the world's tropics and subtropics from origins in Southeast Asia, unfortunately along with many of its pests but not their natural enemies. This process continues at an accelerated pace in concert with increasing international commerce and travel. Consequently, many citrus pests are now worldwide in distribution and citrus industries have suffered from these and vectored diseases, notably huanglongbing (HLB) and citrus tristeza virus transmitted by psyllids and aphids, respectively. Two other vector and disease combinations: citrus variegated chlorosis (CVC) and citrus leprosis are transmitted by certain Cicadellidae and *Brevipalpus* (Acari: Tenuipalpidae) mites, respectively, and threaten to spread from their origins in South America.

Ever-increasing citrus pest diversity plus evolving pest control methods have resulted in continuously changing management models. The earliest was based on classical biological control, focusing on the introduction and establishment of exotic natural enemies from Southeast Asia to new citrus-growing regions. The next stage following WWII was marked by the growing use of synthetic pesticides capable of controlling principal pests but often without consideration for auxiliary fauna. Secondary pest outbreaks, pesticide resistance, and growing public awareness of health and environmental problems associated with pesticides led to the third stage of integration centered on biological control and selective chemistry. However, the appearance of the insect- and mite-transmitted diseases mentioned above, particularly HLB, has given way to a most recent stage of citrus pest management characterized by a return to intensive pesticide use for vector control.

While globalization and increased international traffic of raw materials have facilitated the distribution of many citrus pests throughout the world, the absence of some of these in specific areas and the influence of different climates and management options vary among zones. In this chapter, citrus pests and their management are detailed for five major citrus-growing areas of the world, Asia, the Mediterranean basin, North America, South America, and Africa. In each of these zones, pests have been classified based on three levels of control: (1) *key pests* for which chemical or biorational intervention is usually necessary, (2) *occasional pests* requiring occasional intervention, and (3) *secondary pests* generally controlled by natural enemies unless upset by the overuse of pesticides.

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FIG. 16.1 Adults of the predator *Rodolia cardinalis* preying upon nymphs of the cottony cushion scale *Icerya purchasi. Photography courtesy of Jose Catalan, IVIA.*

16.2 Citrus pest management in Asia

Citrus is originally from Asia and produced in most Asian countries. The main citrus producers include China, India, Indonesia, Iran, Japan, Korea, Malaysia, Pakistan, Syria, Thailand, and Vietnam, together with approximately 38% of the total area planted to citrus worldwide. China is the world's greatest citrus producer with an estimated 2.5 million ha producing 36.6 million tons in 2015. Another large citrus producer is India, with close to a million hectares and production of over 7 million tons (Santoshkumar et al., 2013). Iran and Pakistan also produce over 2 million tons of citrus, while Indonesia, Syria, Vietnam, Korea, Japan, and Thailand produce over 0.5 million tons per year (Qi and Qi, 2016). Most Asian citrus fruit is oriented to fresh consumption. The requirement of high exterior quality necessitates frequent insecticide and acaricide use for citrus pest management.

Major citrus pests vary by country with over 800 pest species recorded from China. However, only a few of these are widely distributed and have consistently caused economic loss during the past 40 years. Similarly, 250 species of insects and mites have been reported infesting different species of citrus in India (Santoshkumar et al., 2013). Most infest young flush, hampering citrus growth and fruit development.

Inappropriate pest control of pests adversely affects citrus quantity and quality including size, brix, and appearance. Management tactics include physical, chemical, biological, and cultural approaches. Chemical control is often preferred because it is easy to use and provides quick results. However, overuse of pesticides disrupts natural biological systems, induces pest resistance, and eventually leads to a resurgence of pest populations. Increasing resistance to common insecticides such as organophosphates, pyrethroids, and neonicotinoids has led to more frequent applications. The overuse of pesticides has also raised serious environmental and human health concerns. Thus, alternative control options, such as physical, cultural, and biological measures, are always needed and have been evolving, particularly during the past few decades. Among these control measures, biological control has been favored by both scientists and citrus growers.

Biological control of citrus pests has a long history in Asia long before the presence of chemical insecticides. As mentioned above, the use of the golden weaver ant (*O. smaragdina*) for pest control was first recorded in *Plants of the Southern Regions* (Nanfang Caomu Zhuang, or 南方草木状) written in AD 304 by Ji Han in China). Given the diversity and abundance of natural enemies in Asian citrus orchards, natural control would be effective if not disrupted by chemical insecticides (Chen, 1985). Predacious mites have also been mass reared and released for citrus mite pests control in Asia (Huang, 2011). *Amblyseius* species (Phytoseiidae) such as *Amblyseius nicholsi* Ehara et Lee, and *Amblyseius deleoni* (Muma & Denmark) (Acarina: Phytoseiidae) are the most abundant predacious mites in citrus orchards in China. These species can be reared on pollen and were successfully used for citrus red mite control during the 1980s (Huang, 1989). However, production was limited by the availability of quality pollen. *Amblyseius cucumeris* (Oudemans) and *Amblyseius barkeri* (Hughes) (Acarina: Phytoseiidae) have been successfully cultured with factitious prey since the early 2000s, and are effectively used in the organic culture of citrus in China (Zhang et al., 2003; Pei et al., 2014).

Cultural control also has an important role in citrus pest management. The use of organic fertilizers is reported to reduce populations of many pest species, such as mites, scales, aphids, and whiteflies (Pang and Dong, 2012). Citrus interplants with a common weed, *Ageratum conyzoides* Linn. (Asteraceae), reportedly provide refuge and pollen for predatory mites



FIG. 16.2 Adult of the Asian citrus psyllid, *Diaphorina citri*.

and is used for citrus red mite control (Huang, 2011). Citrus interplanted with guava [*Psidium guajava* Linn. (Myrtaceae)] is used to reduce the Asian citrus psyllid (ACP) *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) populations in Viet Nam (Gottwald et al., 2007) (Fig. 16.2). Windbreaks were found to reduce ACP population in citrus orchards (South China Agricultural College, 1981).

Mineral oils are widely used for citrus integrated pest management (IPM) in Asia. As early as the 1920s, oil-emulsifiable formulations were produced and sold for spider mite control (Ota, 2013). Petroleum spray oils were developed and promoted since the 1980s in China for control of mites, scales, whiteflies, and aphids (Cen et al., 1999). However, these oils were mainly used for winter sprays when citrus trees are in dormancy because of the high risk of phytotoxicity. Two research projects, "Citrus IPM in China," and "Citrus IPM in China and Southeast Asia" funded by Australian Centre for International Agricultural Research (ACIAR) were carried out from 1993 to 2000 in China, Vietnam, Thailand, Indonesia, and Malaysia. High-quality horticultural mineral oils characterized by narrow boiling point ranges and low levels of phytotoxic aromatic ring compounds were shown to be safe to crops and to control citrus pests such as ACP, citrus leafminer, and oriental fruit fly, mainly due to behavioral effects (Rae et al., 1996, 1997, 2000; Beattie et al., 2002; Ouyang et al., 2010). Since then, oils have been widely promoted for citrus pest control in Asia.

HLB was first described from south China and has been recognized as a major threat for citrus production in Asia during the last 50 years. Insecticidal control of the ACP and *Cacopsylla citrisuga* (Yang & Li) (Fig. 16.3) is a key measure for HLB management. Neonicotinoid, pyrethroid, organophosphorus, and carbamate insecticides are widely used for dormant (winter) season sprays and also applied two to three times during flushing periods for ACP control. One unwanted result of increased pesticide use has been an upsurge of acaricide sprays against the now resistant citrus red mite *Panonychus citri* (McGregor) (Acari: Tetranychidae) (Chen et al., 1980) (Fig. 16.4), with up to 58 applications a year being recorded, one-third of which were acaricides. Most insecticides used for ACP control disrupt beneficial arthropod populations, and copper compounds commonly applied for canker control suppress entomopathogens of citrus red mite. Thus, the demands of ACP and canker control have come into conflict with citrus red mite management in citrus culture in Asia.



FIG. 16.3 The psyllid *Cacopsylla citrisuga* is mainly present in southwestern China at high altitude and it has been found to vector HLB.



FIG. 16.4 Female and male citrus red mite, *Panonychus citri*.

16.3 Citrus pest management in the Mediterranean basin

The citrus industry in the Mediterranean basin represents approximately 20% of total citrus production worldwide. Commercial citriculture is found in Spain, Italy, Cyprus, Greece and France, Morocco, Egypt, Algeria and Tunisia, Turkey, and Israel. The Mediterranean industry is mainly oriented to fresh consumption requiring high-quality standards, especially in the main producing countries such as Spain, Turkey, and Morocco serving export markets. The Spanish industry provides an example as it exports more than 56% of its production. Consequently, "cosmetic thresholds" have been developed for some of the most important pests (Jacas and Urbaneja, 2010; Jacas et al., 2010).

Another important factor in the Mediterranean panorama is the absence until now of HLB, CVC and citrus canker, obviating a need to control psyllids, sharpshooters (Cicadellidae), or apply inordinate amounts of copper (Vacante and Gerson, 2012; Urbaneja et al., 2017). The remaining pests can be managed with a minimum of pesticide treatments compared to citrus-growing areas where these diseases are present. In addition, restrictions on the availability of active ingredients since January 2014 (EC, 2009), has stimulated the development of pest management programs based on conservation of natural enemies (Zappalà, 2010; Magrama, 2014; Mazih, 2015). These programs place a special emphasis on minimizing pesticide use in concert with consumer demand for high-quality citrus without pesticide residues. This is especially true in Northern Europe, which is the destination for most exported fruit.

As in many other citrus industries, the Mediterranean has been challenged by introductions of exotic pests. The response since the early 20th century has been numerous introductions of exotic natural enemies. Many have established stable populations and become highly valuable members of the natural fauna. The result has been better plant health compared to many other citrus-producing areas in the world.

Secondary pests controlled by natural enemies below economic injury levels (EILs) in the Mediterranean include *I. purchasi* and *Lepidosaphes gloverii* (Packard) (Hemiptera: Diaspididae) (Table 16.1). Occasional pests whose natural control is generally but not always satisfactory include *Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae), *Panonychus citri*, *Planococcus citri* Risso (Hemiptera: Pseudococcidae), and *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae). Key pests whose population oscillations that typically exceed EILs include *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) (Fig. 16.5), *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae), *Tetranychus urticae* Koch (Acari: Tetranychidae), and *Aphis spiraecola* Patch. (Hemiptera: Aphididae) in Clementine mandarins. The key to successful pest control is to maintain key pests below EIL without undoing suppression of natural enemies that would result in outbreaks of secondary and occasional pests. Pesticide timing and choice for efficacy and selectivity is critical to provide adequate control while avoiding disruption of biological control.

There has been a growing interest in recent years to promote and increase ecological infrastructures that enhance and preserve the action of natural enemies. In particular, cover crop management has minimized the use of pesticides of key

TABLE 16.1 Main citrus pests in the principal citrus production areas, Asia, the Mediterranean basin, North America, South America, and Africa in order of decreasing economic importance.

	Asia	Mediterranean Basin	North America	South America	Africa
Key pests	*Panonychus citri* *Diaphorina citri* *Phyllocnistis citrella* *Phyllocoptruta oleivora* *Aphis citricola* *Toxoptera citricidus* *Toxoptera aurantii* *Aphis gossypii* *Papilio xuthus* *Papilio polytes* *Anoplophora chinensis* *Bactrocera dorsalis*	*Ceratitis capitata* *Aonidiella aurantii* *Pezothrips kellyanus* *Delotococcus aberiae*[1] *Aphis spiraecola*[2] *Tetranychus urticae*[2] *Prays citri*[3]	*Diaphorina citri*[1,2] *Phyllocnistis citrella*[1] *Phyllocoptruta oleivora*[1] *Diaprepes abbreviatus*[1] *Aonidiella aurantii*[2,3] *Coccus pseudomagnoliarum*[3] *Scirtothrips citri*[3] *Eutetranychus banksi*[3] *Panonychus citri*[2,3]	*Diaphorina citri* *Brevipalpus* spp.[1] *Phyllocoptruta oleivora* *Polyphagotarsonemus latus*[2] *Gymnandrosoma aurantiana* *Ceratitis capitata* *Anastrepha fraterculus* *Phyllocnistis citrella*[3] *Cicadellinae (Sharpshooters)*[4]	*Ceratitis capitata* *Ceratitis rosa* *Thaumatotibia leucotreta* *Bactrocera dorsalis* *Trioza erytreae* *Aonidiella aurantii* *Scirtothrips aurantii* *Planococcus citri*
Occasional pests	*Cacopsylla citrisuga*[1] *Dialeurodes citri*[2] *Aleurocanthus spiniferus* *Parlatoria pergandii* *Chrysomphalus ficus* *Aonidiella aurantii* *Unaspis yanonensis* *Icerya purchasi* *Planococcus citri* *Scirtothrips citri* *Scirtothrips dorsalis* *Myzus persicae* *Eotetranychus kankitus* *Eutetranychus orientalis*[2] *Aleurocanthus woglumi*[2] *Bactrocera minax* *Chelidonium argentatum* *Nadezhdiella cantori* *Buzura suppressaria benescripta* *Anomala cupripes* *Rhynchocoris humeralis* *Platymycteropsis mandarinus* *Sympiezomias citri* *Hypomeces squamosus*	*Aspidiotus nerii*[3] *Aphis gossypii*[2] *Planococcus citri* *Phyllocnistis citrella* *Aceria sheldoni* *Paraleyrodes minei* *Lepidosaphes beckii* *Parlatoria pergandei* *Aleurothrixus floccosus* *Ceroplastes sinensis* *Coccus hesperidum* *Panonychus citri*	*Aculops pelekassi* *Panonychus citri* *Solenopsis invicta* *Eutetranychus banksii* *Aphis spiraecola* *Aphis gossypii* *Papilio cresphontes* *Toxoptera citricidus* *Unaspis citri* *Anastrepha suspensa*	*Planococcus citri* *Unaspis citri* *Parabemisia myricae* *Aleurothrixus floccosus* *Aleurocanthus woglumi* *Tetranychus mexicanus* *Panonychus citri* *Frankliniella occidentalis*[1] *Scirtothrips citri*[2] *Oxydia apidania* *Toxoptera citricidus* *Aphis spiraecola* *Toxoptera aurantii* *Naupactus* spp.	*Helicoverpa armigera* *Aceria sheldoni* *Lozotaenia capensana* *Panonychus citri* *Aleurothrixus floccosus* *Aphis gossypii* *Empoasca distinguenda* *Eutetranychus orientalis* *Lepidosaphes beckii* *Naupactus godmani* *Papilio* spp. *Phyllocoptruta oleivora* *Phyllocnistis citrella* *Prays citri* *Chrysomphalus aonidum* *Pseudococcus longispinus* *Toxoptera citricidus*

(Continued)

TABLE 16.1 Main citrus pests in the principal citrus production areas, Asia, the Mediterranean basin, North America, South America, and Africa in order of decreasing economic importance—cont'd

	Asia	Mediterranean Basin	North America	South America	Africa
Secondary pests	*Lepidosaphes beckii* *Nipaecoccus vastator* *Cappaea taprobarensis* *Ceroplastes rubens* *Parlatoria zizyphus* *Oraesia emarginata* *Oraesia excavata* *Adris tyrannus* *Adoxophyes cyrtosema* *Homona coffearia* *Bactrocera tsuneonis* *Bactrocera zonata*[2] *Papilio demoleus*[2] *Eudocima fullonia*[2] *Cappaea taprobanensis* *Diaphorina communis*[3]	*Saissetia oleae* *Toxoptera aurantii* *Chrysomphalus dyctiospermi* *Ectomyelois ceratoniae* *Cacoecimorpha pronubana* *Icerya purchasi*	*Saissetia oleae* *Chrysomphalus aonidum* *Parlatoria pergandei* *Lepidosaphes beckii* *Lepidosaphes gloverii* *Planococcus citri*	*Icerya purchasi* *Cornuaspis beckii* *Chrysomphalus aonidum* *Selenaspidus articulatus* *Parlatoria cinerea* *Parlatoria ziziphus* *Orthezia praelonga*	*Icerya purchasi* *Coccus hesperidum* *Ceroplastes brevicauda* *Ceroplastes destructor* *Ectomyelois ceratoniae* *Pulvinaria aethiopica* *Nipaecoccus viridis* *Delottococcus aberiae* *Saissetia oleae* *Anoplolepis custodiens* *Pheidole megacephala*

Key pests: their numbers exceed every season the economic injury level (EIL); occasional pests: EIL are exceeded every 2–4 years, secondary pests: EIL are rarely exceeded. Within each group pests are ordered by importance from top to bottom.
Asia: [1]Mainly present in southeastern China with high elevation, and was found associated with HLB. [2]Key pests in India. [3]Mainly on lemons in Yunnan Province, China.
Mediterranean Basin: [1]Only present in Middle East of Spain. [2]Mainly on Clementine mandarins. [3]Mainly on lemons.
North America: [1]Major pest in Florida. [2]Major pest in Texas. [3]Major pest in California.
South America: [1]Only in Oranges. [2]Mainly in fruits for fresh market. [3]Associated with the citrus canker. [4]*Acrogonia citrina*, *Oncometopia facialis*, and *Dilobopterus costalimai*.



FIG. 16.5 Female of the Mediterranean fruit fly, *Ceratitis capitata*.



FIG. 16.6 Colony of the green citrus aphid, *Aphis spiraecola.*

pests such as *T. urticae* and *A. spiraecola* in Clementine mandarins (Fig. 16.6). Establishment of a monoculture ground cover of the grass *Festuca arundinacea* Schreb. (Poaceae) has promoted an increase of specific predators of Tetranychidae and hindered the transfer of spider mites between the citrus canopy and the ground cover due to feeding specialization (Aguilar-Fenollosa et al., 2011a,b). Similarly, a sown grass cover enriched with wild forbs serves as host for alternate prey to build populations of aphid predators that later move into the citrus canopy (Gómez-Marco et al., 2016a,b). These positive results have strengthened conservation biological control in the Mediterranean citrus industry and reduced chemical treatments. In response, the Valencian Community (Eastern Spain) has launched an area-wide program against the Mediterranean fruit fly, *C. capitata*, based on sterile insect release (Juan-Blasco et al., 2014). Biorational control strategies are also being employed for control of California red scale (CRS), *A. aurantii*, including mass release of the parasitoid *Aphytis melinus* (Tena et al., 2015) and use of pheromones for mating disruption (Vacas et al., 2010).

Unfortunately, pest management in the Mediterranean is too often disrupted by exotic pests, most recently the mealybug *Delottococcus aberiae* (De Lotto) (Hemiptera: Pseudococcidae) (Fig. 16.7) and the thrips species *Pezothrips kellyanus* (Bagnall) (Thysanoptera: Thripidae) and *Chaetanophothrips orchidii* (Moulton) (Thysanoptera: Thripidae). The urgency to control these pests with insecticides compromises conservation biological control. Detection of HLB or its vectors would undoubtedly change the rules of the game. Prevention is the best way to forestall what could otherwise spell disaster for the Mediterranean fruit industry.



FIG. 16.7 Infested fruit with nymphs of *Delottococcus aberiae*. *Photography courtesy of Alejandro Tena, IVIA.*

16.4 Citrus pest management in North America

Citrus production in the United States is confined primarily to three regions: Florida, Texas, and California including southern Arizona. Mexico, Costa Rica, the Dominican Republic are also significant players in North American process and fresh fruit industries. The Florida citrus industry is largely oriented toward orange juice production (ca. 90%), whereas the other two regions in the United States supply the fresh fruit market with the full gamut of citrus types. Production of oranges in Florida has been second only to Brazil but has plummeted in recent years due to HLB first detected in 2005. Therefore, control of the HLB vector, the ACP *D. citri,* has become the primary goal of insect pest management in the state as well as in Mexico, Central America, and the Caribbean. At the other extreme, ACP is still found only in relatively small areas of California with HLB confined to dooryard citrus. Monitoring and control of ACP there is thus a growing concern, although traditional pest management is still a major goal. The situation in the smaller south Texas industry is intermediate, with HLB well established already.

16.4.1 Florida

First detected in 1998, ACP swept through Florida in record time with speed comparable to the spread of citrus leafminer *P. citrella* 5 years earlier (Fig. 16.8). Movement of both pests was aided by commercial transport of plants throughout the state. HLB or citrus greening disease was detected 7 years later in pomelos in the extreme southeast of the peninsula. Subsequent delimiting surveys discovered positive citrus trees well up the east coast and across the state. Tree removal proved ineffective, and so began a protracted battle with vector control and tree health management as basic tools, gradually aided by a reactivated breeding program.

Management of ACP in the United States is primarily through insecticidal control. This is a year-round endeavor for all commercial citrus in Florida and Texas, whereas control in California and Arizona is primarily in response to ACP presence



FIG. 16.8 Citrus leaf infested with the citrus leafminer, *Phyllocnistis citrella*. *Photography courtesy of Elena LLácer, IVIA.*



FIG. 16.9 Orange fruit damaged by the citrus rust mite, *Phyllocoptruta oleivora.*

as determined by monitoring. Key to the management of ACP in Florida are the so-called "dormant sprays" during winter when bearing trees are generally not flushing and psyllids must, therefore, survive as adults on hardened foliage or alternate hosts (Qureshi and Stansly, 2010). The objective is to reduce populations as much as possible before the spring flush when conditions are most favorable for ACP reproduction and subsequent spread of HLB. Another advantage of dormant sprays is conservation of predatory insects such as ladybeetles and lacewings that are generally absent from the groves due to lack of prey associated with a young flush. For this and reasons of economy and efficacy, broad-spectrum insecticides such as organophosphates and especially pyrethroids are products of choice whereas neonicotinoids are discouraged due to their importance as soil-applied systemic insecticides in young plantings. More selective insecticides are recommended during the growing season, both to address occasional or secondary pests as well as to conserve beneficial arthropods (Qureshi et al., 2014). Such secondary pests include citrus leafminer, *P. citrella*, the citrus rust mite *Phyllocoptruta oleivora* (Ashmead) (Fig. 16.9) and *Aculops pelekassi* (Keifer) (Acari: Eriophyoidea) and the red spider mites *P. citri* and *Eutetranychus banksi* (McGregor) (Acari: Tetranychidae). Leafminer is of special concern due to its role of exacerbating the spread of citrus canker disease by facilitating entry of the causative bacteria, *Xanthomonas axonopodis* pv. *citri* (Xanthomonadales: Xanthomonadaceae). Another pest of concern is the weevil *Diaprepes abbreviatus* L. (Coleoptera: Curculionidae), whose larvae are voracious root feeders exacerbating root loss from HLB and *Phytophthora* spp. (Peronosporales: Peronosporaceae).

Effects of natural enemies on ACP survival in Florida prior to widespread insecticide use were evaluated by Michaud (2002, 2004) and Qureshi and Stansly (2009) using exclusion techniques. Mortality of 90% or greater was attributed to predators such as ladybeetles, lacewings, syrphid flies, and spiders. A later study by Monzo et al. (2014) showed significant effects of insecticides on three classes of beneficial arthropods in response to different regimes and intensities of insecticide use in the field. These studies signaled the largely untapped potential of beneficial arthropods to contribute in a significant way to ACP control if fewer and more selective insecticides are used. Economic thresholds for mature trees with high incidence of HLB based on "tap" sampling (Monzo et al., 2015) have been shown to be effective in reducing insecticide use and optimizing profits (Monzo and Stansly, 2017).

New plantings represent the future of the industry and a special challenge for ACP control due to frequent flushing and susceptibility to HLB. Effective soil-applied systemic insecticides are largely confined to the neonicotinoid (4A) class, although cyantraniliprole (group 28) is effective but expensive. Thus, rotations with foliar-applied products are necessary to forestall selection for resistance. A cultural practice that is gaining acceptance in Florida is the use of metalized reflective polyethylene film as a ground cover in the plant row (Croxton and Stansly, 2014; Stansly et al., 2016). The mulch mirrors the sky, reflecting all visible wavelengths including UV, disrupting insect flight. The effect is reduced ACP infestation and incidence of HLB. This and the advantages of additional light and efficiency of the required drip irrigation, fertigation, and chemigation system results in increased growth rate and early yield.

16.4.2 California and Texas

In contrast to Florida with its cool dry winters and wet hot summers, the climate in California is Mediterranean with cool wet winters and hot dry summers. Likewise, the citrus industry there is also primarily fresh fruit. It is not surprising then, that the pest complex is similar in California and the Mediterranean region. Major pests in California not adequately controlled biologically include CRS *A. aurantii* (Fig. 16.10) and the citrus thrips *Scirtothrips citri* (Moulton) (Thysanoptera: Thripidae). In addition, the citricola scale, *Coccus pseudomagnoliarum* (Kuwana) (Hemiptera: Coccidae) and the citrus red mite, *P. citri*, can also be considered key pests under certain conditions of cultivation (Table 16.1). Therefore, a combination of biological, chemical, and cultural controls is needed for these pests.



FIG. 16.10 Citrus fruit infested by California red scale *Aonidiella aurantii*. *Photography courtesy of Alejandro Tena, IVIA.*

CRS is a key pest in California and Texas, causing significant damage to all aerial parts of the tree and causing the fruit to be culled if infested with more than 10 scales. Pheromone-baited sticky traps are used for monitoring populations, although correlations with female numbers can be problematic, necessitating visual inspection. *A. melinus* DeBach, *A. lingnanensis* Compere (Hymenoptera: Aphelinidae), and *Comperiella bifasciata* (Howard) (Hymenoptera: Encyrtidae) are important parasitoids of CRS in different regions of California. Mass release of *A. melinus* is a viable management tactic in most regions, although generally incompatible with carbamates or organophosphate insecticides. The insect growth regulators buprofezin and pyriproxyfen are effective and compatible with parasitoids but suppress Coccinellidae, especially vedalia beetles needed for control of cottony cushion scale. Spirotetramat is active against all scale stages and compatible with parasitoids but suppresses predacious mites. Oil is least damaging to natural enemies and effective against young scale stages, although this tends to synchronize scale populations, later creating a dearth of susceptible third instar hosts needed by parasitoids.

A similar pest complex occurs in Texas with *A. aurantii*, *P. citri*, and *E. banksi* (McGregor) (Acari; Tetranychidae) as key pests. However, ACP was found in Texas in 2001 and HLB confirmed in commercial citrus in 2012. Thus, ACP control has become the main thrust of citrus pest management in the Lower Rio Grande Valley, employing similar strategies to those used in Florida.

16.5 Citrus pest management in South America

The citrus industry of South America (SA) represents approximately 38% of the total citrus production worldwide and includes oranges, grapefruit, tangerines, and lemons. Citriculture is important to the economies of Brazil, Argentina, Uruguay, Venezuela, and Peru. About 80% of the citrus production in SA is oriented to processing with no reason to create a standard of high external quality fruit.

The major pest management problem is the ACP, *D. citri*, a vector of HLB first detected in Brazil in 2004, and now also present in Argentina and Venezuela. ACP with HLB is capable of infecting and killing large numbers of plants in a relatively short time even at very low density. In response to this threat, the use of insecticides has intensified to 36–40 sprays a year applied at regular intervals in an attempt to wipe out the vector.

Unlike other countries where ACP is a recent invader, the citrus in Brazil has lived with the psyllid for at least 76 years as documented by the entomologist Angelo da Costa Lima (Costa Lima, 1942). Long residence in Brazil probably resulted in a biological balance with predatory arthropods compared to what is seen in the United States, Mexico, and elsewhere in the Americas (Huffaker et al., 1984). Given the rapidity with which HLB appeared in other countries following the establishment of ACP, it is likely that the disease was introduced in recent times, probably in plants or plant parts brought into the country. Curiously, the parasitoid *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) was never found in South America before the detection of HLB (Gravena et al., 1996). Thus, a recent introduction of the parasitoid by the same process seems likely.

Development and application of citrus IPM began in the late 1970s and improved until 2004. Only two key pests were present before 1987, both mites: (1) a complex of *Brevipalpus* spp. (Acari: Tenuipalpidae) that transmit citrus leprosis



FIG. 16.11 Leprosis virus symptoms on fruits and branches transmitted by the tenuipalpid citrus mite complex *Brevipalpus* spp.

virus (Fig. 16.11) and (2) Citrus Rust Mite, *P. oleivora*. Little insecticide was used as only acaricides were needed which controlled these pests with little impact on beneficial insects. The first major change occurred in 1987 with the discovery of CVC transmitted by sharpshooters (Cicadellinae), mainly *Acrogonia citrina* Marucci & Cavichioli, *Oncometopia facialis* (Signoret), and *Dilobopterus costalimai* Young (Hemiptera: Cicadellidae). Insecticides were used to forestall transmission of the bacterial disease caused by *Xylella fastidiosa* (Xanthomonadales: Xanthomonadaceae) inhabiting the xylem. The bacteria caused dieback in the canopy that could be controlled by the timely pruning of symptomatic branches. IPM continued despite this setback, albeit with greater difficulty due to imbalances caused by the multiple sprayings of insecticides, mainly during the formation of new orchards.

The "Pest Sampler" organization was formed in 1977 consisting of about 6000 professionals dedicated to monitoring insect and mite pest populations in Brazilian citriculture. Many short courses for Samplers and Citrus IPM Managers were taught at the Paulista State University (UNESP) until 1993 and for another 12 years by a private company. The IPM program consisted of four subsystems focusing on the key and some secondary pests: (1) conservation and increase of natural enemies, (2) sampling with regard to levels of action and inaction, (3) use of selective insecticides/acaricides, and selective application, and (4) environmental pest management. Thus, most orchards among about 750,000 ha of citrus, during the 1980–1990s, were managed with some level of IPM. An average of only one to two annual sprays were applied until 1987 and five to six sprays from 1987 until 2004 when HLB was first detected in Brazil. But, now the bacterium is almost totally extinct from Brazilian citriculture according to Fundecitrus.

Everything changed for pest management in the citrus industry of SA with detection of HLB. Instead of selective sprays based on EILs as before, applications followed preestablished spraying schedules with up to 36–40 sprays a year using broad-spectrum insecticides. It was assumed that these sprays also controlled the other pests, although secondary pest outbreaks occurred due to unavoidable imbalances and evidence of resistance by ACP and other insects such as citrus rust and citrus leprosis mites (*Brevipalpus* spp.)

Brevipalpus mites are the number 1 key pest after ACP in orange orchards in Brazil because they vector leprosis virus that can cause devastating damage to citrus in São Paulo and Minas Gerais states and has spread as far as southern Mexico. The sample units for this pest are: (1) two inner canopy and two outer canopy fruits of the present season or in their absence of the previous season and (2) 30 cm of two productive external branches with a young fruit at the tip. The recommended procedure is to first focus on the peduncle, then the blossom end of the fruit, and finally the rest of the fruit using a 10× loupe. One adult mite is sufficient to consider the fruit infested. The IPM unit is a block of 2000–3000 plants (or 10 ha) of which 1% is sampled. An acaricide is applied when mites are found on 10% of the fruits and leprosis is present or at 15% in the absence of virus symptoms. The average number of sprays using this system was 1.5/year. Orchards, where acaricides are not applied on the day after reaching EIL, use a lower EIL (3%–5% infestation). Leprosis is not a problem in mandarins, lemons, and limes in Brazil and SA (Gravena, 2005).

Rust mite is key pest number 2 in orchards under IPM in Brazil, SA, as it is in Mexico and Florida. Damage is mechanical and fruits of all ages are monitored by size. Rust mite damage is primarily a concern for the fresh fruit industry, but in extreme cases may cause significant loss of weight and juice. A 10× loupe is recommended with 1 cm^2 of the field of view to estimate the number of mites. The lens is positioned on a side of the fruit where mites will most likely be present. Three external fruits per plant and 1% of the plants in a block are monitored. Five or more mites per cm^2 on 20%–30% of the fruit signals a spray for either fresh or juice; 20 or more mites per cm^2 on 10% of the fruit for fresh; and 30 or more mites/cm^2 on 10% of the fruit for juice. The sampling frequency is 7 days in spring and summer and 10–15 days in autumn and winter

for both key mite pests (Gravena, 2005). Two or three applications for rust mite using sulfur, abamectin or another approved acaricide has been an average using this system.

Balanced against the need for practically eliminating ACP to avoid the demise of whole orchards is the considerable risk posed by toxic insecticide residues in fruits and juice as well as catastrophic effects on the citrus agroecosystem. One option might be a combination of management systems: one for ACP and another for the rest of the pest complex. Clearly, the usual IPM program in use since 1970–2004 will no longer function the same, but the system of scheduled sprays could be improved by alternating chemical groups to avoid resistance in ACP and other pests, mainly *Brevipalpus* spp. For example, broad-spectrum sprays for ACP could be replaced by biopesticides or IGRs to mitigate harmful effects to natural enemies. Thus, a new IPM is needed that encompasses ACP until genetically based technologies are available to manage the causal bacterium *Candidatus* Liberibacter asiaticus.

16.6 Citrus pest management in Africa

Citrus is grown only for local or regional consumption in most of Africa south of the Sahara because of warm tropical conditions that do not permit sufficient color break to compete in international markets. However, citrus production from approximately 17°S southward that includes Zimbabwe, South Africa, and Eswatini is largely directed at lucrative export markets (Grout and Moore, 2015).

Distinct approaches to pest management are required for local vs export destinations. Production pests that reduce crop yield are more important than cosmetic pests for fruits destined for local consumption, especially when harvested green. Pesticides are seldom required and input costs are low, opening the door for biological control. In contrast, cosmetic pests are important where the fruit is produced for export or local high-quality consumption, requiring more intensive control measures with costs that must be offset by higher yields. In addition, some pests of minor importance for local markets may be of phytosanitary concern at the export destination, requiring levels of control incompatible with natural enemies. Biorational techniques are thus preferred to avoid disruption of biological control of secondary or occasional pests.

16.6.1 Production pests

The African citrus psyllid *Trioza erytreae* (Del Guercio) (Hemiptera: Triozidae) is a vector of the African citrus greening disease (African HLB) caused by the bacterium *Candidatus* Liberibacter africanus (Khamis et al., 2017) (Fig. 16.12). *T. erytreae* is a key pest in cooler climates in Africa where maximum temperatures seldom reach 35°C. Pest status is low where this psyllid occurs in the absence of greening, for example, the Eastern Cape Province of South Africa (Rwomushana et al., 2017). This is also the case for low altitude, hot parts of East Africa where ACP is reported but not either form of HLB (Roberts et al., 2017). However, vector control is essential in the presence of HLB and whenever new foliage is present or production declines over a period of 4–10 years until the orchard is no longer profitable. For this reason, the larger citrus orchards at low altitude are more viable where HLB is not present.



FIG. 16.12 Adult of the African citrus psyllid, *Trioza erytreae*. *Photography courtesy of Peter R. Stephen, CRI.*

The CRS, *A. aurantii*, is widespread in Africa but is usually not much more than a cosmetic pest due to biological control by *Aphytis africanus* Quednau (Hymenoptera: Aphelinidae) and coccinellid beetles. However, when these are eliminated by disruptive chemicals or dust from nearby roads, high populations can cause fruit drop, twig dieback, and even tree death. This can also happen to a lesser degree with cottony cushion scale *I. purchasi* when *Rodolia* spp. ladybeetles are compromised by sprays.

Internal feeders such as fruit flies and lepidopteran fruit borers cause preharvest fruit drop although their role as phytosanitary pests is often of greater concern. The color break does not occur until shortly before harvest in the tropics, so fruit is less attractive to fruit flies than in the subtropics where the attack begins 2 months before harvest. False codling moth, *Thaumatotibia leucotreta* (Meyrick) (Lepidoptera: Tortricidae), can often be maintained at subeconomically damaging levels for local market fruit by timely destruction of infested fruit while sparing egg and larval parasitoids. However, high populations may cause significant fruit drop from 6 weeks after petal fall to harvest where alternative hosts such as chilies or paprika are grown nearby.

16.6.2 Cosmetic pests

The citrus thrips, *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae), is widespread in Africa and causes different types of fruit damage depending on when feeding occurs. Most severe damage occurs under the calyx or at the bottom of the fruit soon after petal fall. However, late-season populations can build up on new foliage and then move to the fruit, causing scribbling and russeting that resembles mite damage and reduces pack out. The citrus rust mite, *P. oleivora*, can be a serious cosmetic pest in warm, humid climates if not controlled. The fungicide mancozeb used to manage leaf spot of citrus (*Pseudocercospora angolensis* (T. Carvalho & O. Mendes) Crous & U. Braun (Capnodiales: Mycosphaerellaceae)) and citrus black spot (*Phyllosticta citricarpa* (Kiely) (Botryosphaeriales: Phyllostictaceae)) will also control citrus rust mite, although resistance has developed in parts of South Africa (Grout and Stephen, 2002). Lepidopteran pests such as leafrollers (Tortricidae) and the African bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), can cause sporadic cosmetic damage soon after petal fall in the form of deep scars in developing fruitlets. Feeding by the African mealybugs, *Nipaecoccus viridis* (Newstead) (Hemiptera: Pseudococcidae) and *D. aberiae*, causes bumps on citrus fruit but these species are rare compared with the citrus mealybug, *P. citri*. Mealybug feeding can also result in red spots on the rind if the weather turns cold before harvest and sooty mold residues can be a cosmetic problem. However, rind damage from leaf spot of citrus may be worse than any caused by arthropod pests in tropical Africa if rain falls on developing fruitlets (Harling et al., 2010).

16.6.3 Phytosanitary pests

Internal fruit pests pose the greatest phytosanitary threat because of strict tolerance requirements at the export destination and difficult postharvest detection. In addition, pests like Fuller's rose beetle, *Naupactus godmani* (Crotch) (Coleoptera: Curculionidae) are not considered economically damaging to citrus but are phytosanitary pests for certain Asian countries and thus require control (Mo and Stevens, 2013; Morse and Grafton-Cardwell, 2013).

Internal fruit pests are mostly controlled in Southern Africa using biorational techniques. False codling moth *T. leucotreta* is managed by sterile insect release, mating disruption during summer months, as well as attract and kill, and sprays of granulovirus. Nevertheless, importing countries often demand postharvest control, usually in the form of cold treatments (Moore et al., 2017).

Several species of fruit fly (Tephritidae) attack citrus fruits shortly before harvest in Africa. *C. capitata* is the most widespread, occurring in all climatic regions of Africa. *Ceratitis rosa* Karsch (Diptera: Tephritidae) attacks citrus on the eastern side of the continent at lower elevations, but declines in dry weather. The oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) (Fig. 16.13), has spread throughout Africa south of the Sahara with the exception of the southern and western parts of South Africa, although citrus is not considered a good host (Theron et al., 2017). Fortunately, most fruit flies can be controlled with sparsely applied protein bait spray droplets containing a toxicant with little disruption of IPM. Bait stations and attract-and-kill approaches are also available. Unfortunately, the sterile insect technique is only feasible in some parts of the Western Cape Province of South Africa where only *C. capitata* is dominant. Some importing countries demand postharvest cold treatments for citrus grown in Africa to control fruit flies but these requirements are less stringent than for false codling moth which is often also present.



FIG. 16.13 Female of the oriental fruit fly, *Bactrocera dorsalis*.

16.7 Epilogue

The citrus industry has always met pest management challenges in the past and will doubtless find effective solutions for the current hurdle of HLB. While the anticipated genetic solution for citrus susceptibility to Liberibacter is still pending, growers in affected areas can still survive thanks to higher prices needed to finance better vector control and enhanced horticultural practices that maintain production levels. Areas still vector free need to step up vigilance to prevent or delay entry of either of the two HLB vectors as long as possible. At the end of the day, continued demand for citrus fruits, juice, and other derived products will provide the impetus necessary to develop appropriate technologies that deal effectively with this and future problems threatening the citrus industry.

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