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Global strategies to manage huanglongbing (HLB) and its vectors: insights and implications for the Mediterranean region

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Abstract: Huanglongbing (HLB), also known as citrus greening disease, poses a severe threat to the global citrus industry. This disease is caused by three species of bacteria, '*Candidatus* Liberibacter asiaticus', '*C.* L. africanus', and '*C.* L. americanus'. The primary pathogen vectors are the Asian citrus psyllid (*Diaphorina citri* Kuwayama, Hemiptera: Psyllidae) and the African citrus psyllid (*Trioza erytreae* Del Guercio, Hemiptera: Triozidae). The disease is incurable, and its management relies on reducing vector densities and the adverse effects of bacterial infections on host trees. Managing psyllid vectors, especially *D. citri*, has proven exceptionally challenging due to its rapid spread and subsequent difficulty in containing and suppressing newly detected populations. This article reviews strategies developed to manage HLB and its vectors in different regions of the world with a focus on the challenges likely to be faced by the Mediterranean region. *Diaphorina citri* has recently invaded the Mediterranean region and *T. erytreae* has been encroaching via the northern Iberian Peninsula for several years. Currently, HLB has not been detected in this important citrus production area. Therefore, this area must implement preventive measures and proactively prepare for potential invasions by *D. citri, T. erytreae*, and HLB-causing pathogens by developing and adopting comprehensive management strategies in advance of anticipated invasion events.

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Moreover, this review highlights the need for coordinated research and policy frameworks to combat HLB and its psyllid vectors at regional, national and international levels within the Mediterranean region.

Keywords: *Diaphorina citri*; *Trioza erytreae*; *Tamarixia*; huanglongbing; integrated pest management; citrus disease management

1 Introduction

Huanglongbing (HLB), also known as citrus greening disease, is the most severe and economically damaging disease affecting citrus globally (Bové 2014; Urbaneja et al. 2020; Wang 2019). It is considered to be among the top challenges facing plant pathology for the next decade (Wang et al. 2024). This disease, caused by bacterial pathogens from the phloem-limited α-proteobacterium *Candidatus* Liberibacter genus, particularly *C.* L. *asiaticus* (*C*Las), *C.* L. *africanus* (*C*Laf), and *C.* L. *americanus* (*C*Lam), has ravaged the citrus industry in major citrus-growing regions across several continents (Bové 2006; da Graça et al. 2016). Currently, there are no effective HLB management approaches when trees become infected. Two main vectors primarily transmit the causal pathogens of this disease: Asian citrus psyllid (ACP) *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) and African citrus psyllid (AfCP) *Trioza erytreae* Del Guercio (Hemiptera: Triozidae) (Cocuzza et al. 2017; Grafton-Cardwell et al. 2013). Managing both vectors is challenging, especially for *D. citri*, which facilitates the rapid spread of *C*Las, complicating disease containment efforts.

The geographic expansion of invasive vectors that transmit HLB-causing pathogens into non-endemic areas where citrus is grown has heightened the urgency to develop comprehensive management strategies. Detections of AfCP in the north of Spain and Portugal and ACP in Cyprus and Israel (EPPO Global Database 2022, 2023) highlight the invasiveness of these vectors across diverse climatic conditions. This underscores the imminent threat to major citrus-producing areas in the Mediterranean, which currently remain free from HLB (Wang 2020). This situation is exacerbated by the complex interactions between vectors, pathogens, and host plants, necessitating new research approaches on pathogen-vector dynamics and host resistance/tolerance mechanisms (National Academies of Sciences 2018). Recent work indicates strong possibilities for managing vectors, pathogens, and disease development. Classical biological control programs targeting ACP and AfCP have been successfully implemented in California and Spain using parasitoids in the genus *Tamarixia* (Hymenoptera: Eulophidae). Genetic and molecular studies have improved the understanding of the immune mechanisms of citrus plants against HLB-causing bacteria. These findings suggest potential pathways for developing HLB-resistant/tolerant varieties. New therapies, such as antimicrobial peptides and various plant defense inducers, as well as existing therapies like antibiotics, are enhancing development of management plans for HLB. Additionally, molecular and other emerging new techniques, such as the real-time on-site detection of the three *C*L species associated with HLB using a rapid validation method, have advanced the detection capabilities. This progress is crucial for effective disease management. Despite recent promising advances, there is no indication of a potential 'silver bullet' solution being developed in the short term to address this serious issue for citrus. What is clear from observing the global impact of this complex pathosystem is that international cooperation is essential because the impact of HLB transcends national borders. Policies and regulations that facilitate rapid responses to the detection of vector and pathogen species and collaborative research initiatives are crucial for effectively managing the spread of HLB.

The main objective of this review is to summarize global strategies for managing HLB and its psyllid vectors and the socio-economic and environmental impacts caused by HLB under these strategies. Then, this information can be used to focus on the specific challenges likely to be faced by the Mediterranean Basin, where the two vector species, ACP and AfCP, have been recently detected. Finally, future directions for managing psyllids and HLB-causing pathogens are outlined, and challenges facing the development of effective control of HLB and its vectors are identified.

2 Management of HLB and its vectors around the world

This section explores comprehensive global strategies for managing HLB and its vectors across different regions of the world, including detailed case studies that highlight both successful and unsuccessful implementations of these strategies.

2.1 South and Southeast Asia

Both *C*Las and ACP, are likely native to north-west South Asia, and citrus species and hybrids are unlikely to be the original hosts (Gottwald 2010). HLB associated with *C*Las has devastated citrus production in Asia since the late 1800s (Leong et al. 2022). Although the form of HLB caused by *C*Las was first recognized as transmissible in China (Bové 2006), the first unambiguous description of symptoms caused by the disease is from Husain & Nath (1927) who ascribed damage to ACP: small and insipid fruit, dieback, and death of trees caused by a 'toxin' injected into plant tissues by the psyllid. *C*Las did not originate in mainland China or Taiwan, as often stated (Leong et al. 2022).

ACP was first recorded in Java in 1900 after it was introduced from India, probably on *Bergera koenigii* L. *C*Las likely moved from Malaysia to Macau and Taiwan on host plants carried on ships. *C*Las was introduced to mainland China in the early 1930s, possibly on citrus from India or southern Việt Nam (Bové 2006). The widely grown ornamental, *Murraya paniculata* (L.) Jack (orange jasmine), one of four species within the *Murraya paniculata* Complex is a favored host of ACP (Beattie 2020) and a transient host of *C*Las (Cifuentes-Arenas et al. 2019). Citrus species and hybrids vary in susceptibility to *C*Las and suitability for ACP. Australasian citrus species are the least susceptible to both the vector and pathogen infection (Beattie 2020; Folimonova et al. 2009; Ramadugu et al. 2016).

ACP has a high capacity for population growth. Heavy rainfall, particularly monsoon rains, wash eggs and nymphs off plants. Monthly rainfall above 150 mm is detrimental to ACP survivorship rates (Leong et al. 2022). UV-B may also be a detrimental abiotic factor (Parajuli et al. 2023), and ACP and HLB are rarely observed at elevations above 1200 m in Bhutan, where orchards occur up to 1700 m, and a naturally occurring citrus hybrid grows at elevations around 2000 m (Holford et al. 2022; Om et al. 2021).

In much of Asia, low incomes restrict management options. Insecticides help minimize ACP populations but do not prevent the spread of HLB-causing bacteria. Up to 53 sprays have been applied annually in Thailand to control ACP (Catling 1996). Purveyors of insecticides commonly profit from plying their products to farmers who have limited knowledge of pests, diseases, and the action of pesticides. Misuse of insecticides disrupts biological control of ACP and other pests (Beattie 2020). Mineral oils can act as biorational alternatives to synthetic pesticides and effectively reduce feeding and oviposition by ACP and other pests (Leong et al. 2022; Rae et al. 1997; Yang et al. 2013). Productive orchards based on certified *C*Las-free trees may survive 15–20 years, but often survive < 8–10. Orchards established with uncertified seedlings may not bear fruit. Areawide management programs are essential for managing ACP-*C*Las, but this is rarely feasible due to the high proportions of small farms across which coordination of insecticide treatments would be necessary. Natural enemies include two primary parasitoids, the ectoparasitoid *Tamarixia radiata* (Waterston) and the endoparasitoid *Diaphorencyrtus aligarhensis* (Shafee, Alam & Agarwal) (Hymenoptera: Encyrtidae), and predators that include coccinellids and the weaver ant, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae) (Beattie 2020; Beattie & Holford 2022).

2.2 China

ACP was first reported in China in 1934 and the first authentic record of HLB presence in mainland China was in 1938 (Leong et al. 2022). Two species of psyllids [*D. citri* and *Cacopsylla citrisuga* (Yang & Li) (Hemiptera: Psyllidae)] are vectors of *C*Las in China, with *D. citri* being the primary vector (Guo et al. 2012). Generally speaking, HLB is considered to be under control in China due to a region-wide comprehensive implementation of roguing infected trees, tree replacement, and insecticide applications for vector control (Yuan et al. 2021). However, the rapid development of the navel orange belt in south Jiangxi-south Hunan-north Guangxi has resulted in a significant upward trend in HLB epidemics. Psyllid populations have been moving northward annually, which poses a serious risk to citrus production in the Yangtze River region, and mandarin production in western Hubei and western Hunan. The main HLB control strategy relies on the "Three Basic Measures" system; production and distribution of HLB-free nursery trees, timely removal of HLB-infected trees, and large-scale management of psyllids. HLB management strategies have been complemented by village rules and people's covenants, technician-driven management, high-density plantings, windbreaks, and killing summer flush growth, which is needed by ACP for oviposition, with chemicals (Zhou 2020).

State-level cooperation is the first priority in China. The secondary "State Key R&D Plan" Project funded by the central government between 2021–2024 prioritizes: 1) screening/generating of small molecular compounds/nanodrugs with the potential for curing *C*Las infections, 2) transgenic technology and/or gene-editing technology for creating new varieties of citrus with tolerance or resistance to *C*Las, and 3) use of AI technology for real-time monitoring of psyllid populations. For those areas where HLB occurrence is approaching or currently at low epidemic levels, it is recommended to utilize best management practices with a priority on prevention and for growers not to be misled by the misconception that HLB can be "easily cured" once it is detected.

2.3 South Africa

ACP and *C*Las are not present in South Africa. However, since the 1920s, the South African citrus industry has faced challenges from HLB associated with *C*Laf, referred to locally as "citrus greening", vectored by the indigenous AfCP (Buitendag & Van Broembsen 1993). Greening caused severe production losses in cooler growing areas in the north and northeast in the 1970s (Buitendag & Van Broembsen 1993). Since the mid-1980s, effective chemical vector control measures reduced the incidence and spread of citrus greening. To date, some citrus-producing regions in the provinces of Western Cape, Eastern Cape, and Northern Cape are free of citrus greening. Buitendag & Van Broembsen (1993) recommended a "three-pronged strategy" for the management of citrus greening: (1) production of certified disease-free nursery trees, (2) reduction of *C*Laf inoculum, and (3) vector control using systemic insecticides. A well-established Citrus Improvement Scheme successfully supported this management strategy, supplying disease-free propagation material.

A new threat now looms with the potential for the introduction of a second HLB disease associated with *C*Las and ACP, both of which are present on the African continent (i.e., Kenya) and in the Indian Ocean islands of Mauritius and Reunion (Aidoo et al. 2023; Ajene et al. 2020a, b; Rwomushana et al. 2017; Sétamou et al. 2023).

To address this threat, an action plan for *C*Las and ACP was developed (CRI 2023a) and a multi-stakeholder ACP-*C*Las steering committee was formed to oversee the roll-out of the action plan. The action plan provides guidance for early detection and rapid response measures for incursion scenarios with *C*Las or ACP only, or *C*Las and ACP combined (CRI 2023). South African legislation was amended to provide for the regulated control of *C*Las and ACP in alignment with the action plan (DALRRD 2021). An HLB Safe System for production of citrus nursery trees free from *C*Las and ACP was developed and makes provision for permitted movement of nursery trees from compliant nurseries in HLB/ACP quarantine zones (CRI 2023b). Since 2019, surveillance of ACP through the use of yellow sticky traps has been undertaken in targeted regions (Manrakhan et al. 2021). South Africa is also collaborating with neighboring countries to monitor the spread of ACP from Kenya and Tanzania.

Modeling studies were initiated to identify corridors for natural range expansion of ACP from East Africa to enable focused surveillance efforts in at-risk areas. Surveillance and diagnostics are complicated by the presence of indigenous *Diaphorina* species on surveillance traps, as some species have very similar morphology to ACP (Manrakhan et al. 2021), and the presence of sub-species of *C*Laf that cross-react with the *C*Las PCR diagnostics (da Graça et al. 2022). Ongoing research focuses on these and other issues, such as effective vector control with fewer available or market-accepted systemic and contact insecticide options for ACP control.

While the incursion of HLB associated with *C*Las and ACP into South Africa seems inevitable given the proximity of ACP-*C*Las within Africa, the current strategy aims to prevent and delay incursions, proactively prepare stakeholders for anticipated incursions, and to enhance early detection systems to enable rapid response actions when required. The three-pronged management strategy, including area-wide vector control, that was effectively implemented in Brazil (Bassanezi et al. 2020), forms the basis of recommendations for the management of HLB associated with *C*Las in South Africa.

2.4 Eastern Africa

The optimal production of citrus fruit is adversely affected by numerous pests and diseases, and a major threat to citrus production in eastern Africa is HLB (da Graça et al. 2022). African citrus greening disease is associated with *C*Laf, and its vector, *T. erytreae* (AfCP), is widespread in eastern Africa, causing yield losses ranging between 25 and 100% (Khamis et al. 2017; Rasowo et al. 2019; Richard et al. 2018). Compounding the problem in the already dwindling citrus industry is *C*Las, and its vector, *D. citri*, in eastern Africa (Ajene et al. 2020a, b; Rwomushana et al. 2017; Saponari et al. 2010). This double threat posed by AfCP-*C*Laf and ACP-*C*Las demands urgent attention if sustainable intervention strategies against the spread of the disease and its vectors in the region are to be developed and implemented.

On the continent of Africa, eastern Africa is regarded as an epicenter of the diversity of Liberibacters and their vectors (da Graça et al. 2022). Recent surveys in this region have revealed the widespread distribution of AfCP in citrus-producing areas at various altitudes. The invasion of ACP onto mainland Africa adds to the already complex pathosystem (da Graça et al. 2022). Moreover, ACP in Ethiopia shows a closer genetic resemblance to ACP in the Americas than to ACP in Kenya and Tanzania, which are genetically similar to ACP in Southeast Asia, suggesting multiple invasions from different source populations have occurred (Ajene et al. 2022; Ajene et al. 2020c). Recently, there has been a shift in the Liberibacter pathosystem, particularly in eastern Africa, where '*Ca.*L. africanus subsp. clausenae' (*C*lafCl) was reported as the most dominant Liberibacter in Uganda and Kenya, having replaced *C*Laf (Rasowo et al. 2019). To date, the impact of this new subspecies is unknown, and whether its significance will be greater or lesser than *C*Laf remains to be seen.

The detection of *C*Las in field populations of AfCP in Ethiopia (Ajene et al. 2019) and the subsequent confirmation that AfCP efficiently transmits *C*Las (Reynaud et al. 2022), underscores the need for sustainable management strategies for this vector. These strategies may include the use of biopesticides, behavior modification, and natural enemies, which have the potential to be combined for use in IPM programs. For instance, the primary parasitoids *Tamarixia dryi* (Waterston) (Hymenoptera: Eulophidae) and *Psyllaephagus pulvinatus* (Waterston) (Hymenoptera: Encyrtidae) have been identified attacking AfCP nymphs in eastern Africa (Rasowo et al. 2021). Additionally, some hyperparasitoids such as *Tetrastichus* sp. (Hymenoptera: Eulophidae), *Aphidencyrtus cassatus* Annecke (Hymenoptera: Encyrtidae), and *Charipinae* sp. (Hymenoptera: Figitidae), have also been detected in association with these primary psyllid parasitoids (Rasowo et al. 2019). Lemon terpenes have been identified as potential options for applying an attract-and-kill strategy against adult AfCP in combination with other management options such as exploitation of visual cues, and targeting flushing regimes of citrus plants to minimize psyllid oviposition (Antwi-Agyakwa et al. 2019). Fungal-based biopesticides such as *Metarhizium anisopliae* (Metschnikoff) Sorokin have been reported to cause mortalities of between 82 to 97.5% in AfCP adults in laboratory studies (Aidoo et al. 2021), and fenpropathrin and naturally derived molecules such as pyrethrum extract have been tested for the management of ACP (Antolínez et al. 2023). Optimization of pest management options are crucial in halting the spread of HLB because, if left unchecked, psyllid populations in the region will increase the incidence of HLB in citrus production regions, and infestations of psyllids and HLB-causing bacteria may possibly act as invasion bridgeheads threatening additional citrus production areas within and outside of the African continent.

2.5 South America (Brazil)

The first plants with symptoms with HLB or greening disease in Brazil were reported in March 2004 in the Araraquara region of São Paulo State, Brazil (Coletta-Filho et al. 2004; Teixeira et al. 2005a, b). The first tests carried out with PCR for the bacteria *C*LAf and *C*Las resulted in an unexpected result, indicating the detection of a new HLB-causing bacterium, *C*Lam (Teixeira et al. 2005a). However, *C*Las was also identified, indicating the presence of both bacteria in Brazil. From the first report of HLB in the 2004/05 season (2004) until the 2007/08 season, *C*Lam was the most prevalent species associated with infected citrus plants in Brazilian orchards and in citrus trees and orange jasmine located in non-commercial orchards (Lopes et al. 2010). After the 2008–2009 season, *C*Las became the most common bacterial species associated with HLB in Brazil's infected citrus plants, reaching nearly 100% of diseased plants (Bassanezi et al. 2020).

In Brazil, both *C*Las and *C*lam are transmitted by ACP (Yamamoto et al. 2006). ACP was reported in Brazil in 1936 (Costa Lima 1936). Brazil is the only country in the Americas where there was a long interval (> 60 years) between the introduction of the insect vector and the detection of *C*las, which occurred in 2004 (Bové 2006).

In the early years, when *C*Lam predominated, the expectation of successful management was high, with infection rates remaining low. However, with the increase in incidence of *C*Las, management has intensified with an increase in the use of insecticides to reduce vector densities. The incidence of infection in the citrus-producing regions of São Paulo and Minas Triangle and Southwestern Minas in southeastern Brazil was ~38% in 2023, which corresponds to ~77 million diseased trees out of a total of ~202 million orange trees comprising the citrus belt (Fundecitrus 2023). In addition to São Paulo and Minas Gerais, HLB has also been reported in Paraná, Mato Grosso do Sul, and Santa Catarina (Cidasc 2022; Gasparoto et al. 2022).

Due to the impacts of HLB, and hot, dry weather, the orange harvest in the citrus belt of São Paulo and Triângulo/Southwest Mineiro in 2024/25 was estimated to produce 9,512 Mt. This represents a drop of ~24% compared to the previous cycle, marking the lowest citrus production in the last 36 years. In this region, the 2024 inventory indicates ~208 million citrus plants, with orchards of all varieties occupying 399,279 ha, which represents a decrease of 0.03% compared to the previous year. Although the number of plants has not been decreasing due to the density of planting, the area planted has been reduced.

Management of HLB requires exclusion and eradication of vectors, pathogens, and infected plant material. Protective management practices include: a) the planting of healthy disease-free nursery reared plants; b) frequent reduction of pathogen inoculum sources via plant removal; and c) vector control (Bassanezi et al. 2020). From 2004 to 2009, management measures were concentrated almost exclusively on commercial orchards. However, after 2009, such measures extended beyond the edges of commercial properties, with control programs being carried out in neighboring backyards around orchards, abandoned orchards, and citrus within urban areas (Bassanezi et al. 2020).

Control of ACP is considered one of the main tactics for effective HLB management. Although several studies report the high efficacy of various insecticide chemical groups (i.e., pyrethroids, carbamates, organophosphates, neonicotinoids, and diamides) against ACP, the large number of applications required for effective population suppression has had unintended consequences. For example, selection of resistant ACP populations has been observed with bifenthrin (pyrethroid), imidacloprid (neonicotinoid), and malathion (organophosphate) use in Brazil (Amaral et al. 2023).

Despite the high adoption of HLB management tactics, the incidence of both ACP and HLB has increased in Brazil, which is worrying producers and industry personnel. Until a definitive solution is discovered, management tactics must be adopted to slow the spread of ACP and *C*Las and the progression of HLB in infected plants.

2.6 United States of America

2.6.1 Florida

In Florida, ACP and HLB were identified in 1998 and 2005, respectively (Grafton-Cardwell et al. 2013). Despite efforts to control the disease, HLB spread widely in the state due to the mobility of the vector, favorable environmental conditions for both vector and pathogen, and the long latent period during which initial symptoms went undetected. During the initial decade of HLB management in Florida, vector suppression with coordinated calendar spraying of insecticides on a regional scale was standard practice (Qureshi et al. 2014). By 2010, insecticide susceptibility of ACP populations in Florida decreased to several commonly used active ingredients (Tiwari et al. 2011). Biological control of ACP never played an important role in decreasing the effects of HLB in Florida citrus groves, most likely because ACP management relied almost exclusively on insecticides (Shrestha et al. 2021). Management of ACP with insecticides can improve yield under conditions of near 100% HLB infection, however, overspraying for ACP reduces profit (Monzo & Stansly 2017). Therefore, in Florida, where HLB is widespread, it has been possible to reduce the number of required chemical applications for ACP based on implementation of nominal thresholds which trigger sprays when 0.2 to 1.0 adult psyllids are found per 20 tree samples (Chen et al. 2022). This has reduced the number of insecticide applications from 12 to between 4–6 per year while maintaining equivalent yields.

Antibiotics are thought to be a potential stop-gap measure for maintaining commercial production of citrus viable in Florida (Blaustein et al. 2018) until possible HLB- or vector-tolerant trees are developed and released [ex: Mishra et al. (2023)]. Antibiotics were initially suggested for HLB management in the 1970s following the discovery of *C*Las bacteria associated with diseased trees (Bové et al. 1980). Three commercial antibiotics were approved for HLB treatment in Florida in March 2016 in response to significant economic losses: Fireline (oxytetracycline HCL), Mycoshield (oxytetracycline Ca), and Firewall (streptomycin sulfate). Unfortunately, initial tests with these foliar formulations of oxytetracycline (OTC) and streptomycin were unsuccessful; these treatments did not prevent or sufficiently reduce infection of trees under field conditions at the rates and frequencies of application evaluated (Roldán et al. 2023). More recent evaluations of trunk-injected OTC have yielded much more encouraging results, including reduced *C*Las titers in trees, as well as improved tree health and yield (Stelinski et al. 2024).

It was recently demonstrated that HLB is a pathogen-triggered immune disease which causes systemic and chronic immune response including production of reactive oxygen species (ROS) and callose deposition in the phloem tissue, resulting in phloem cell death and subsequent HLB symptoms. Therefore, suppressing ROS-mediated cell death with phytohormones, such as gibberellic acid (GA), could mitigate HLB symptoms (Ma et al. 2022). Following these findings, Singh et al. (2022) recently demonstrated in Florida that the repeated treatment of 'Valencia' trees with GA sprays improved the yield of HLB-affected trees and enhanced profit on average by \$2,500 per ha. Current efforts are focused on evaluating foliar GA treatment, in combination with trunk-injected OTC treatments and vector management with insecticides, as a strategy to maintain the productivity of trees with HLB. Finally, in the absence of other effective control measures for ACP, growing entire blocks of citrus orchard within enclosed structures as a method to completely exclude the vector and pathogen has gained increasing acceptance among smaller fresh fruit citrus growers in Florida. Similarly, newly planted seedling trees intended for juice production can be protected from infection by enveloping these resets within individual mesh cages, which exclude the vector from trees during the first two years after planting (Gaire et al. 2022).

2.6.2 Texas

Similar to many other citrus growing areas in the world, the tandem occurrence of both *C*Las and its vector, ACP, in Texas represents a significant threat to the sustainability of citrus production in the state. ACP was first reported in Texas in 2001 (French et al. 2001). Unfortunately, this detection did not trigger targeted control efforts, thus allowing ACP populations to increase and spread. It was not until the first report of the presence of HLB in Florida in 2005 that Texas initiated early detection surveys for *C*Las. Efforts to control ACP began in 2010 with the launch of the areawide psyllid management (AWM) program (Sétamou 2020a). In January 2012, *C*Las was first detected in Texas (Da Graça et al. 2015). Although AWM led to a substantial decrease of vector populations (Sétamou 2020a), the spread of *C*Las was not contained from its first detection in the state. Indeed, the number of *C*Las-positive trees and groves exponentially increased during the first five years following detection (Sétamou et al. 2020b), despite the systematic rogueing and destruction of infected trees that tested positive for *C*Las. It is generally accepted that significant asymptomatic spread of the disease occurred prior to the first detection of *C*Las in Texas (Graham et al. 2020).

Given the increasing number of *C*Las-positive trees detected during intensive surveys and the seemingly low impact of the disease on tree productivity during the earlier years of the epidemic, economic analyses indicated that removal of 18–20% of commercial trees would lead to negative returns, resulting in grove abandonment by growers which will impede the implementation of AWM. Thus, in 2016, the requirement of mandatory removal of HLB affected trees was lifted in groves with fruit bearing trees (i.e. > 4 years of age), but removal is still highly recommended for infected trees < 4 years of age.

Currently, *C*Las is present in almost all mature groves with an average HLB incidence of ~25% (range 5–60%), but the incidence in younger groves remains below 1% because of strict HLB mitigation programs for young trees. This proactive management program incorporates aggressive psyllid control with the application of soil-systemic insecticides every two months and/or ACP exclusion with protective covers placed over individual trees for the first two years post-planting. HLB scouting and removal of infected trees is practiced during the first three years of grove establishment. In mature groves, the psyllid AWM program utilizes two dormant sprays applied in late autumn and late winter and targeted sprays at the onset of leaf flush cycles during the growing season. The main goal of this program is to limit the further spread of *C*Las and tree re-infection by reducing psyllid population growth in groves. Ongoing research aims to refine the psyllid control program by incorporating tree phenology and the risk of *C*Las infection as determinants affecting the timing of spray applications. Hence, an understanding of the population dynamics of infected and infective ACP and factors governing successful *C*Las inoculation of trees are required if this initiative is to be successful. Concurrently, horticultural practices are being evaluated for their ability to maintain the productivity of HLB-affected groves. Overall, annual citrus production in Texas has declined by 6.2% during the decade since *C*Las was detected when compared to the previous decade when *C*Las was presumably absent.

2.6.3 California

In Aug. 2008, ACP was discovered infesting citrus growing in urban areas in San Diego County. In 2009, large widespread populations were found 195 km north in Los Angeles County, suggesting a second invasion had occurred. In March 2012, *C*Las was discovered in urban citrus in Los Angeles County. By 2015, *C*Las was found in urban citrus in Orange County, then Riverside (2017), San Bernardino (2020), San Diego (2021), and Ventura (2023) Counties. Currently, all *C*Las finds are confined to urban citrus, and as of April 2024, 7,679 *C*Las-infected trees have been removed and destroyed. Area-wide management programs operate in southern California counties, and 2–3 times per year, insecticide applications are made to suppress very low-density ACP populations in commercial production areas. Current discussions are assessing whether or not these insecticide-intensive management programs should be maintained. As of April 2024, there are no permanent populations of ACP in the Central Valley, where approximately 85% of commercial citrus is grown. *C*Las has not been detected in the Central Valley.

The initial responses to *D. citri* detections were the establishment of quarantine and insecticide treatment boundaries which attempted to contain and eradicate infestations in urban areas. This insecticide-based program, initiated on a large scale in summer 2011, ceased in October 2012, due to ineffectiveness, cost, and homeowner dissatisfaction (Hoddle & Pandey 2014). The classical biological control program targeting *D. citri* with *T. radiata*, sourced from Punjab Pakistan, commenced in December 2011 when the first releases were made in urban citrus (Kistner et al. 2016). This host specific parasitoid established immediately, spread rapidly, and has, in part, contributed to declines, ≥ 75%, in *D. citri* population densities throughout infested areas (Milosavljević et al. 2021). Impacts of ACP natural enemies in citrus orchards can be greatly enhanced through the control of invasive Argentine ant (*Linepithema humile* Mayr) using low-toxicity baiting programs. This ant species protects *D. citri* and other honeydew-producing pests from natural enemies (McCalla et al. 2023). Provisionment of floral resources that provide nectar and pollen, significantly increase natural enemy impacts, especially those from predatory syrphid flies, on colonies of ACP nymphs (Irvin et al. 2021). Given that 12 years have elapsed since *C*Las was detected in California, it seems very unlikely that the California citrus industry will experience a catastrophic decline because of this plant pathogen. California's Mediterranean climate and effective ACP natural enemies, have likely contributed to this positive outcome.

2.7 Caribbean region and surrounding areas

In this review, the Caribbean region is defined as the geographic area that includes the islands and coastal territories in and around the Caribbean Sea, characterized by its tropical climate. Information is included from some countries that, despite not having all their production in the Caribbean zone, do have a significant portion of it cultivated under these conditions, such as Colombia and Venezuela. Due to its global significance, the Mexican Caribbean region is included in the section dedicated to Mexico.

The first detection of ACP in the Caribbean was in Guadeloupe in 1998 (Halbert & Nuñez 2009) and the first detection of *C*Las was in Cuba in 2006 (Luis et al. 2009). ACP has been detected in all Caribbean countries, and the disease has spread widely. The last *C*Las detection was documented in Saint Vincent and the Grenadines in 2023 (St. Vicent Times 2023), but it has not yet been detected in the Bahamas.

After the detection of HLB, management programs were proposed that included the use of certified disease-free propagation material, the eradication of diseased plants, and vector control. These programs were carried out at the national level or through joint projects, such as those sponsored by OIRSA and FAO (FAO 2011; OIRSA 2009). Since the detection of ACP-*C*Las, various investigations have been carried out to better understand this pathosystem under Caribbean conditions. Research findings indicate several ribosomal groups of phytoplasmas in citrus growing in Puerto Rico, Cuba, Jamaica, and Guadeloupe cause HLB-like symptomatology (Caicedo et al. 2015; Luis-Pantoja et al. 2021). Rootstock studies in Guadeloupe indicated that the tetraploid Swingle citrumelo (*C.* ×*aurantium* L. × *Citrus trifoliata* L.) confers better tolerance to HLB than the diploid rootstock (Sivager et al. 2022). Additionally, assessments of the genetic diversity of ACP in Puerto Rico, using the mitochondrial genetic marker CO1, revealed that the Caribbean haplotype is unique and is more related to southeast Asian haplotypes than to other ACP from different geographic regions (Santiago-Rosario et al. 2023).

The impact of HLB on Caribbean citrus crops has been devastating. Significant reductions in citrus production and planted areas have been reported. The magnitude of the effects is reflected in the following examples. In Cuba, in 2022, the acreage under cultivation and production of citrus fruits decreased to 33% and 16%, respectively, of values reported in 2013 (ONEI 2023). In Honduras, there was a 40% reduction (Ávila & Genao 2018). Jamaica experienced a 34% decline in citrus production between 2009 and 2013 (Barret 2024). Venezuela also underwent a 50% reduction in acreage and production (Morales et al. 2020). In Ponedera Colombia, 85% of citrus growers lost more than 50% of their plants due to HLB and a lack of supplies for managing vectors (Gómez-Correa et al. 2021). Although small producers have been more affected in Costa Rica, large producers have managed to coexist with HLB, and an increase in yields is expected by 2030 (USDA 2023). HLB threatens the survival of commercial and backyard citriculture in the Caribbean region and surrounding areas. Research need to focus on developing cost-effective ACP-*C*Las management under citrus growing conditions of the Caribbean. These efforts need to result in the implementation of sustainable integrated pest management programs for ACP-*C*Las, and regional collaborations are essential for managing HLB and for enabling the recovery of the citrus industry in Caribbean countries.

2.8 Mexico

The citrus sector faces risk from HLB, now detected nationwide since its first appearance in Tizimín, Yucatan, in 2009 (Díaz-Padilla et al. 2018). ACP was previously detected in the state of Campeche and Quintana Roo in 2002 and spread rapidly throughout the country (Mora-Aguilera et al. 2014).

Since its initial detection, *C*Las has rapidly spread nationwide (Díaz-Padilla et al. 2018). Despite efforts implemented since 2010, HLB management has primarily focused on evaluating and applying insecticides in an attempt to reduce ACP population densities (Cortez et al. 2010). The establishment of Phytosanitary Epidemiological Management Areas (AMEFIs), led by ACP-HLB scouts and farmers, has enabled vigilant monitoring of ACP populations and timely implementation of necessary control measures (Zapata-Contreras et al. 2022). However, despite these efforts, it has been confirmed once again that relying only on chemical control is insufficient for managing and controlling this complex pathosystem.

The presence of HLB in Mexico's citrus orchards has caused crop losses ranging between 30 and 100% (Mora-Aguilera et al. 2014). Despite numerous challenges, Mexico has been proactive in managing HLB. The eradication of diseased trees, vector control, and the use of certified disease-free planting material have been implemented (Mora-Aguilera et al. 2014). The release of *T. radiata* is conducted by two mass-rearing facilities established to facilitate coordinated parasitoid releases across various citrus-producing states (Arredondo 2013). The influence of different rootstocks on disease incidence has been investigated to search for resistance/tolerance to ACP and *C*Las. However, conclusive results are still pending (Sáenz-Pérez et al. 2020). Similarly, plant defense inducers have been tested, with the bacterium, *Azospirillum brasilense* Tarrand, Krieg & Döbereiner, showing promising results (Trinidad-Cruz et al. 2019). Furthermore, studies have investigated the effects of chemical fertilization applied to the soil in combination with foliar fertilization with zinc sulfate, iron, copper, manganese, and borax, aimed at increasing flowering in plants affected by *C*Las (Hernández-Morales et al. 2021). These studies have failed to demonstrate mitigating effects on *C*Las. Recently, studies predicting future distributions of HLB in Mexico in relation to climate change have been completed (Rodríguez-Aguilar et al. 2024). However, model outcomes are uncertain, as HLB incidence changes from year to year, depending on rootstocks, citrus variety, agronomic management practices, and environmental conditions.

Current recommendations for ACP-*C*Las management in Mexico are to strengthen preventive measures, start new plantings with disease-free trees from certified nurseries, conducting soil and plant analyses for adequate and balanced nutrition to minimize the impacts of HLB, and trying to increase plant resilience. Cultural, biological, and chemical management of ACP should be emphasized. However, insecticides must be used judiciously to minimize the development of resistance. Despite all these efforts, current research is focussing on how best to coexist with HLB. This approach, however, will not be a viable long-term solution.

2.9 Mediterranean region

The most important factor favoring Mediterranean citrus production is the current absence of HLB-causing pathogens and other important diseases such as citrus variegated chlorosis and citrus canker, which collectively results in reduced insecticide use (Urbaneja et al. 2020). This low use of insecticides, combined with pest management strategies based on conservation biological control, means that key pests are managed with minimal insecticide treatments compared to areas where these diseases (especially HLB) are present. Given this favorable situation, HLB is potentially one of the greatest future threats to Mediterranean citrus cultivation (Urbaneja et al. 2020; Wang 2020).

However, significant concerns were raised in 2014 when AfCP was detected in the northwest of the Iberian Peninsula, an area where citrus is not produced but harbors numerous lemon trees in the backyards of private properties and public gardens (Pérez-Otero et al. 2015). Two independent introductions are suspected; one in North Portugal and the other in Galicia (northwest Spain), both likely originating from the Canary Islands. The incursion into the Canary Islands likely originated from Madeira, with the ultimate source of infestation probably being South Africa (Ruíz-Rivero et al. 2021). AfCP quickly spread north along the Cantabrian coast and south along the Portuguese Atlantic coast, reaching Algarve in 2021, just 120 km from the province of Huelva, a key cultivation area for Spanish citrus and the near-continuous beginning of the Mediterranean citrus corridor.

The detection of the AfCP in the Iberian Peninsula prompted the implementation of contingency plans to halt its expansion (MAGRAMA 2023). Chemical control was quickly dismissed as a viable solution in the backyards of private properties in the northwest part of the Iberian Peninsula. Among all the control measures explored (Molina et al. 2022; Urbaneja-Bernat et al. 2020), the most successful has been the implementation of a classical biological control program targeting AfCP with the nymphal parasitoid *T. dryi* (Pérez-Rodríguez et al. 2019). After demonstrating that it is a highly specific parasitoid (Urbaneja-Bernat et al. 2019), *T. dryi* was first released in the Canary Islands, where AfCP has been present since 2002. In this region, *T. dryi* significantly reduced AfCP populations, making it very difficult to find this pest today (Pérez-Rodríguez et al. 2024). Following this success, *T. dryi* was introduced onto the Iberian Peninsula through three initial release points in Galicia, where the parasitoid demonstrated a high capacity for establishment, dispersal, and host location, and very high efficacy with significant reductions in the incidence and densities of AfCP (Tena et al. 2022). Subsequently, *T. dryi* has been released in numerous locations in Galicia, along the Cantabrian coast, and the Portuguese Atlantic coast. From there, *T. dryi* has spread unassisted to new areas, reaching distances of more than 80 km, where it has substantially reduced vector densities. Currently, populations of AfCP are almost undetectable in the Iberian Peninsula and distribution of AfCP has not expanded since 2021. In addition to the high efficacy of the parasitoid, recent studies suggest that the high temperatures and low humidity in most citrus growing areas of the Mediterranean region would not be conducive to the establishment of AfCP (Godefroid 2024).

In 2021, the Mediterranean citrus industry faced another serious threat when ACP was detected in the Mediterranean region for the first time, specifically in Israel (EPPO Global Database 2022), and one year later in Cyprus (EPPO Global Database 2023). In Israel, ACP was detected in July 2021 in the Emek Hefer region, where citrus plantations are abundant. Eradication attempts were unsuccessful, and ACP spread to other citrus-growing areas of Israel, such as the Jordan Valley. A similar situation occurred in 2022, in Cyprus, where, after initial detection and failed eradication attempts, ACP established in most parts of the country. Israel and Cyprus are implementing a classical biological control program with the introduction of the parasitoid *T. radiata*, sourced from the successful program that was run in California (Hoddle & Pandey 2014).

The current situation with ACP in the Mediterranean region is complicated because eradication has not been possible in either Israel or in Cyprus. Consequently, it is expected that the spread of ACP will continue through the citrus corridor that exists throughout the Mediterranean region. Therefore, proactive measures for *C*Las management, such as classical biological control of ACP with *T. radiata*, and the establishment of early detection programs, need to be enacted promptly to minimize vector densities in advance of the anticipated and eventual detection of *C*Las in this area. Coordination among Mediterranean countries will be needed to facilitate the implementation of these measures.

3 Rapid response and a long-term strategic vision for HLB management in the Mediterranean: a big audacious plan

Sustainable long-term management of HLB requires a comprehensive and adaptive approach, leveraging advances in biotechnology, integrated pest management, and regional, national, and international cooperation. When detected, the importance of long-term, multi-site, large-scale epidemiological studies for managing HLB cannot be overstated. These studies will provide the foundation for understanding the spread and impact of HLB, enabling the development of predictive models and risk assessments that inform all aspects of disease management with a specific focus on the Mediterranean region (Ellis et al. 2024). Epidemiological research helps identify critical points for intervention, assesses the effectiveness of different control strategies, and optimizes resource allocation. By integrating data from various sources, including environmental conditions, vector behavior, efficacy of control measures, and disease progression, epidemiological studies facilitate a proactive rather than reactive approach to managing HLB-pathogen vectors and the disease. Proactive preparedness is crucial for preventing widespread outbreaks and minimizing economic losses to the citrus industry

While significant challenges remain, ongoing research and innovation hold promise for sustainable solutions that can protect not only the Mediterranean citrus industry but also the global citrus industry from this devastating disease. However, as made clear throughout this review, there is no immediate solution, nor is one expected soon. In light of the looming threat of HLB, and in advance of *Candidatus* Liberibacter detections in any citrus-growing area within the Mediterranean citrus belt, the Mediterranean region should establish a comprehensive and ambitious plan to mitigate the potential devastation of its citrus industry.

3.1 Establishment of a Joint Mediterranean Multinational HLB Working Group

To effectively monitor, manage, and mitigate the risks associated with HLB and its vectors, a joint Mediterranean Multinational HLB Working Group (WG) should be established. Robust funding from the European Union, individual countries, and citrus commodity groups should ideally support this WG. The primary objectives of this WG would include surveillance, early detection, rapid response, containment, and management of ACP and AfCP populations and the HLB pathogens these vectors spread. The WG should be led by a steering committee composed of scientists and technical representatives of Plant Health Services from each member country, experts from international agricultural organizations, and key stakeholders from the citrus industry. Decisions should be made through a consensus-driven approach, ensuring that the interests and needs of all member countries are considered. A rotating chairperson from different countries would oversee the implementation of member agreed-upon decisions. Long-term funding should be secured, for example, through proportional contributions based on the amount of citrus grown in each country. An equitable funding model will ensure that all countries are committed to the initiative. This level of buy-in is essential because a lack of committed participation in a particular area will provide a refuge for vectors and pathogens. This vector-pathogen reservoir will function as an invasion bridgehead, continuously presenting an incursion threat to neighboring regions. Each member country should be required to submit regular reports on the status of HLB and psyllid populations. These reports should be reviewed twice a year by the steering committee. The reports would be short and follow a standardized, digitized template that ensures uniformity of data reporting across all member groups. Transparency of report findings must be paramount in this working group, and reports should be made accessible online to authorized personnel.

3.2 Proactive actions and biocontrol measures

Several measures should be initiated promptly in the Mediterranean region as a containment strategy to suppress vector populations.

3.2.1 Immediate deployment of effective biocontrol agents to suppress incipient psyllid populations

Emphasizing proactive biological control (Hoddle 2024), the WG should secure pre-approval to immediately release *T. radiata* and *T. dryi* parasitoids into urban areas where ACP and AfCP have been detected, and it has been determined that populations cannot be eradicated. Due to the difficulty and time delays in obtaining permits for releasing exotic natural enemy species in some European countries, efforts should be made to obtain permits in advance of the anticipated incursion of HLB-pathogen vectors. This proactive strategy would allow the immediate release of these parasitoids following the first detection of ineradicable psyllid populations, thereby immediately suppressing rates of psyllid population growth and spread. Establishing mass-rearing facilities for *T. radiata* and *T. dryi* in countries where *D. citri* and *T. erytreae* are detected is crucial for responding to psyllid detections in new areas should pest populations spread. These facilities should be designed to support large-scale rearing operations, ensuring a continuous and reliable supply of biological control agents that can be released into infested areas. Following the example started in California with *T. radiata*, releases of mass-reared parasitoids are regularly made into psyllid-infested areas and those identified as at high risk of psyllid invasion and HLB establishment. Further, it is imperative to maintain the genetic diversity of parasitoid colonies within mass-rearing facilities to prevent adaptation to mass-rearing conditions, which can result in subsequent reductions in parasitoid fitness and field efficacy.

3.2.2 Standardized monitoring programs and proactive IPM programs

Developing standardized monitoring protocols across all working group countries is essential to ensure consistent and comparable approaches for documenting parasitoid releases, establishment, spread, and impacts on psyllid populations. These protocols should be meticulously designed to facilitate accurate data collection and analysis, enabling coordinated and effective management strategies to enable standardized comparisons across management programs. At this point, it is key to develop reliable diagnostic methods for identifying ACP and AfCP (both molecular and morphological) and *Candidatus* Liberibacter species (molecular). Molecular analyses may provide insight into areas of origin and patterns for the spread of vector and pathogen species, which could guide the identification and management of incursion pathways.

Furthermore, it is critical to implement proactive integrated pest management (IPM) programs adaptable to urban and commercial citrus production areas. These IPM programs should be based on fundamental pest management principles yet be customizable to suit local conditions and specific challenges (PreHLB 2021). WG recommendations could enhance program effectiveness and sustainability in managing psyllid populations and mitigating the threat of HLB by tailoring these programs to each region's unique urban, environmental, and agricultural contexts and the concomitant risk of vector-HLB incursions.

3.2.3 Coordinated incursion monitoring and response to detections

Developing standardized incursion monitoring and response plans that are coordinated across infested regions and uninfested neighboring countries is essential for effective HLB management. These standardized plans ensure uniformity in response efforts, data collection, and comparisons, which prevent discrepancies and uncertainties that could undermine the overall efficacy of management strategies. To further strengthen this approach, enhancing regional coordination is crucial. Regional, national and international coordination helps mitigate the spread of vectors and pathogens that cause HLB by facilitating quick and efficient responses to new invasions. Maintaining a well-prepared rapid response effort can be achieved through regular training sessions and simulation exercises for all member countries, ensuring that each country is prepared and capable of implementing the standardized response plans effectively (PreHLB 2021). Such coordinated efforts are vital for maintaining a unified and robust defense against HLB and its vectors.

3.3 Long-term research and international collaboration

Developing a comprehensive long-term adaptive research plan for psyllids-HLB that is specific to the Mediterranean is essential to addressing regional challenges posed by HLB. This Mediterranean-centric plan should focus on innovative approaches, such as plant breeding programs aimed at developing disease-resistant citrus varieties that are best suited to Mediterranean growing conditions (Pérez-Hedo et al. 2024), and the design of advanced diagnostic tools for early detection and management of HLB (Morán et al. 2023). This vision will be achievable by fostering robust collaboration with international HLB research programs within the Mediterranean and other citrus production regions (e.g., Brazil, California, Florida, or South Africa). Such collaborations will ensure synergy and the rapid dissemination of research findings, enabling the Mediterranean region to promptly adopt and implement the most advanced and effective management strategies available. By leveraging global expertise and resources, the Mediterranean can stay at the forefront of HLB management research and application, significantly bolstering the region's efforts to combat this devastating citrus disease.

3.4 Public awareness and education

Launching comprehensive public awareness campaigns is essential to educate farmers, stakeholders, and the general public about HLB, its vectors, the value of commercial citrus and the benefits of urban backyard production, and the critical importance of early detection and reporting, either in person, online or phone, to appropriate management agencies. These campaigns should be designed to disseminate clear and actionable information through various media channels, community outreach programs, and educational materials. Increased awareness ensures that all affected parties are informed about the risks posed by HLB and the necessary steps to mitigate its spread. Moving forward, it is essential to continue investing in multidisciplinary HLB management research that integrates plant pathology, entomology, agricultural engineering, economics, and social sciences. Collaborative efforts between researchers, growers, the public, social scientists, economists, and policymakers are vital to developing, adapting, and implementing effective HLB management strategies and for reducing any consumer resistance to citrus produced using new technologies (e.g., gene editing with CRISPR).

In addition to education and outreach campaigns, conducting targeted training programs for local agricultural workers, first responders, extension officers, professional pest managers, insecticide applicators, regulators, and scientists is crucial. These programs should focus on vector-HLB identification, monitoring, reporting, continuing education programs, and the most up-to-date and agreed-upon management practices. Training sessions should include hands-on workshops, field demonstrations, conferences, and the most current scientific knowledge to equip targeted end users with the skills to effectively identify and manage pathogen dispersing vectors and HLB. Enhancing the expertise and preparedness of those on the front lines can improve overall responses to HLB threats, thereby ensuring coordinated region-wide implementation of best practices in managing this devastating disease.

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4 Epilogue

Throughout this review, the difficulties in managing HLB and its vectors, along with the current management possibilities and ongoing efforts to address this threat, have been highlighted. Unfortunately, the Mediterranean region is not exempt from this threat, and if the HLB situation is not rapidly and urgently addressed in the early stages of this dual vector invasion, catastrophic impacts on the citrus industry may result. By implementing a forward-looking anticipatory plan, the Mediterranean region could build a resilient defense against the threat of HLB, ensuring the sustainability and prosperity of its citrus industry. While this review emphasizes vector management strategies due to the journal's scope, it is important to recognize that resistant/tolerant citrus material, early plant screening, and nursery certification are equally critical elements of HLB management in affected regions. When complemented by vector management, these components form a holistic approach to combating HLB. Enhanced surveillance, strict quarantine protocols, public awareness, robust international cooperation, research, and long-term stable financial support for these multi-disciplinary efforts will be critical for protecting the Mediterranean from the devastating impacts of HLB.

References

Aidoo, O. F., Ablormeti, F. K., Ninsin, K. D., Antwi-Agyakwa, A. K., Osei-Owusu, J., Heve, W. K., … Sétamou, M. (2023). First report on the presence of huanglongbing vectors (*Diaphorina citri* and *Trioza erytreae*) in Ghana. *Scientific Reports, 13*(1), 11366. https://doi.org/10.1038/s41598-023-37625-9

Aidoo, O. F., Tanga, C. M., Mohamed, S. A., Khamis, F. M., Opisa, S., Rasowo, B. A., … Borgemeister, C. (2021). The African citrus triozid *Trioza erytreae* Del Guercio (Hemiptera: Triozidae): temporal dynamics and susceptibility to entomopathogenic fungi in East Africa. *International Journal of Tropical Insect Science, 41*(1), 563–573. https://doi.org/10.1007/s42690-020-00241-5

Ajene, I. J., Khamis, F., Ballo, S., Pietersen, G., van Asch, B., Seid, N., … Mohamed, S. (2020a). Detection of Asian citrus psyllid (Hemiptera: Psyllidae) in Ethiopia: A new haplotype and its implication to the proliferation of huanglongbing. *Journal of Economic Entomology, 113*(4), 1640–1647. https://doi.org/10.1093/jee/toaa113

Ajene, I. J., Khamis, F. M., van Asch, B., Pietersen, G., Rasowo, B. A., Ombura, F. L., … Ekesi, S. (2020b). Microbiome diversity in *Diaphorina citri* populations from Kenya and Tanzania shows links to China. *PLoS One, 15*(6), e0235348. https://doi.org/10.1371/journal.pone.0235348

Ajene, I. J., Khamis, F. M., van Asch, B., Pietersen, G., Seid, N., Rwomushana, I., … Ekesi, S. (2020c). Distribution of *Candidatus* Liberibacter species in Eastern Africa, and the First Report of *Candidatus* Liberibacter asiaticus in Kenya. *Scientific Reports, 10*(1), 3919. https://doi.org/10.1038/s41598-020-60712-0

Ajene, I. J., Khamis, F. M., van Asch, B., Pietersen, G., Seid, N., Wairimu, A. W., … Ekesi, S. (2022). Genetic diversity of *Diaphorina citri* (Hemiptera: Liviidae) unravels phylogeographic structure and invasion history of eastern African populations. *Ecology and Evolution, 12*(7). https://doi.org/10.1002/ece3.9090

Ajene, I. J., Khamis, F., Mohammed, S., Rasowo, B., Ombura, F. L., Pietersen, G., … Ekesi, S. (2019). First report of field population of *Trioza erytreae* carrying the huanglongbing-associated pathogen, '*Candidatus* Liberibacter *asiaticus*', in Ethiopia. *Plant Disease, 103*(7), 1766–1766. https://doi.org/10.1094/PDIS-01-19-0238-PDN

Amaral, F. S. de A., Miranda, M. P., Timossi, M. do C., Eduardo, W. I., & Omoto, C. (2023). Resistência comprovada. *Revista Cultivar, 142*, 13–17.

Antolínez, C. A., Byrne, F. J., Wasantwisut, S., Rohula, T., Aziz, K. L. G.-A., & Rivera, M. J. (2023). Assessment of renewable compounds as biopesticides for Asian citrus psyllid, *Diaphorina citri* (Kuwayama) (Hemiptera: Psyllidae). *Journal of Pest Science, 96*(2), 663–670. https://doi.org/10.1007/s10340-022-01542-z

Antwi-Agyakwa, A. K., Fombong, A. T., Deletre, E., Ekesi, S., Yusuf, A. A., Pirk, C., & Torto, B. (2019). Lemon terpenes influence behavior of the African citrus triozid *Trioza erytreae* (Hemiptera: Triozidae). *Journal of Chemical Ecology, 45*(11–12), 934–945. https://doi.org/10.1007/s10886-019-01123-y

Arredondo, B. H. (2013). Control biológico: componente de las áreas regionales de control del PAC. In *Memorias de la Reunión Nacional de Sanidad Vegetal* (pp. 16–19).

Ávila, C. A., & Genao, K. V. (2018). *Dinámica poblacional de Diaphorina citri (Hemiptera: Liviidae) en naranja, mandarina y limón y exploración de controladores biológicos en el Valle del Yeguare, Honduras. Thesis in Spanish*. Escuela Agrícola Panamericana.

Barret, A. (2024). Data from the website Ministry of Industry, Commerce, Agriculture and Fisheries (MICAF). https://miic.gov.jm

Bassanezi, R. B., Lopes, S. A., de Miranda, M. P., Wulff, N. A., Volpe, H. X. L., & Ayres, A. J. (2020). Overview of citrus huanglongbing spread and management strategies in Brazil. *Tropical Plant Pathology, 45*(3), 251–264. https://doi.org/10.1007/s40858-020-00343-y

Beattie, G. A. C. (2020). Management of the Asian citrus psyllid in Asia. In *Asian citrus psyllid: biology, ecology and management of the Huanglongbing vector* (pp. 179–209). CABI; https://doi.org/10.1079/9781786394088.0179

Beattie, G. A. C., & Holford, P. (2022). Can *Oecophylla smaragdina* be used to suppress incidence of CVPD in citrus orchards in Indonesia? *IOP Conference Series. Earth and Environmental Science, 1018*(1), 012030. https://doi.org/10.1088/1755-1315/1018/1/012030

Blaustein, R. A., Lorca, G. L., & Teplitski, M. (2018). Challenges for managing *Candidatus* Liberibacter spp. (Huanglongbing disease pathogen): Current control measures and future directions. *Phytopathology, 108*(4), 424–435. https://doi.org/10.1094/PHYTO-07-17-0260-RVW

Bové, J. M. (2006). Huanglongbing: A destructive newly emerging, century-old disease of citrus. *Journal of Plant Pathology, 88*(1), 7–37.

Bové, J. M. (2014). Huanglongbing or yellow shoot, a disease of Gondwanan origin: Will it destroy citrus worldwide? *Phytoparasitica, 42*(5), 579–583. https://doi.org/10.1007/s12600-014-0415-4

Bové, J. M., Bonnet, P., Garnier, M., & Aubert, B. (1980). Penicillin and tetracycline treatments of greening disease-affected citrus plants in the glasshouse, and the bacterial nature of the prokaryote associated with greening. *Eighth IOCV Conference; International Organization of Citrus Virologists,* 102–107.

Buitendag, C. H., & Van Broembsen, L. A. (1993). Living with citrus greening in south Africa. *International Organization of Citrus Virologists Conference Proceedings (1957–2010), 12*(12). https://doi.org/10.5070/C58WQ051RR

Caicedo, J. D., Rivera-Vargas, L. I., Segarra, A. E., & Davis, R. E. (2015). Detection and molecular characterisation of a group 16SrIX phytoplasma infecting citrus (*Citrus sinensis* and *C. limon*), coffee (*Coffea arabica*), periwinkle (*Catharanthus roseus*), and tabebuia (*Tabebuia heterophylla*) in Puerto Rico. *Australasian Plant Disease Notes, Australasian Plant Pathology Society, 10*(1), 28. https://doi.org/10.1007/s13314-015-0178-x

Catling, H. D. (1996). Pesticide use on citrus in southeast Asia. *Proceedings of the VIII International Society for Citriculture Congress, Sun City, South Africa*, 12–17.

Chen, X. D., Stockton, D., Gossett, H., Qureshi, J. A., Ibanez, F., Pelz-Stelinski, K. S., & Stelinski, L. L. (2022). Comparisons of economic thresholds for Asian citrus psyllid management suggest a revised approach to reduce management costs and improve yield. *Frontiers in Sustainable Food Systems, 6*. https://doi.org/10.3389/fsufs.2022.948278

Cidasc (2022). *Nota técnica DEDEV Nº 03/2022. Nº 03/2022*. https://www.cidasc.sc.gov.br/defesasanitariavegetal/files/2022/10/Nota_tecnica_DEDEV_03-2022_HLB.pdf

Cifuentes-Arenas, J. C., Beattie, G. A. C., Peña, L., & Lopes, S. A. (2019). *Murraya paniculata* and *Swinglea glutinosa* as short-term transient hosts of '*Candidatus* Liberibacter asiaticus' and implications for the spread of huanglongbing. *Phytopathology, 109*(12), 2064–2073. https://doi.org/10.1094/PHYTO-06-19-0216-R

Cocuzza, G. E. M., Urbaneja, A., Hernández-Suárez, E., Siverio, F., Di Silvestro, S., Tena, A., & Carmelo, R. (2017). A review on *Trioza erytreae* (African citrus psyllid), now in mainland Europe, and its potential risk as vector of huanglongbing (HLB) in citrus. *Journal of Pest Science, 90*(1), 1–17. https://doi.org/10.1007/s10340-016-0804-1

Coletta-Filho, H. D., Targon, M. L. P. N., Takita, M. A., De Negri, J. D., Pompeu, J., Machado, M. A., … Muller, G. W. (2004). First report of the causal agent of huanglongbing ("*Candidatus* Liberibacter asiaticus") in Brazil. *Plant Disease, 88*(12), 1382–1382. https://doi.org/10.1094/PDIS.2004.88.12.1382C

Cortez, M. E., López A., Hernández, L. M., Fú, A., & Loera, J. (2010). *Control químico de* Diaphorina citri *Kuwayama en cítricos dulces, en México. Selección de insecticidas y época de aplicación. Folleto técnico No. 35 INIFAP-SAGARPA*. https://studylib.es/doc/4440904/control-qu%C3%ADmico-de-diaphorina-citri--kuwayama

Costa Lima, A. (1936). *Terceiro catálogo de insetos que vivem nas plantas do Brasil*. Rio de Janeiro: Directoria Da Estatística Da Producção.

CRI (2023a). *South African Action Plan for Huanglongbing and Asian Citrus Psyllid – preparedness, early detection and rapid response. Citrus Research International*. https://www.citrusres.com/public-downloads/

CRI (2023b). *HLB Safe System for the production of citrus trees in nurseries. Citrus Research International*. https://www.citrusres.com/public-downloads

da Graça, J. V., Cook, G., Ajene, I. J., Grout, T. G., Pietersen, G., Roberts, R., … Maree, H. J. (2022). A review of the

‘*Candidatus* Liberibacter africanus’ citrus pathosystem in Africa. *Phytopathology, 112*(1), 44–54. https://doi.org/10.1094/PHYTO-07-21-0296-FI

da Graça, J. V., Douhan, G. W., Halbert, S. E., Keremane, M. L., Lee, R. F., Vidalakis, G., & Zhao, H. (2016). Huanglongbing: An overview of a complex pathosystem ravaging the world’s citrus. *Journal of Integrative Plant Biology, 58*(4), 373–387. https://doi.org/10.1111/jipb.12437

da Graça, J. V., Kunta, M., Sétamou, M., Rascoe, J., Li, W., Nakhla, M. K., … Bartels, D. W. (2015). Huanglongbing in Texas: Report on the first detections in commercial citrus. *Journal of Citrus Pathology, 2*(1). https://doi.org/10.5070/C421027939

DALRRD (2021). *Control Measures relating to Asian citrus psyllid* (Diaphorina citri) *and Citrus greening: Asian and American strains* (Candidatus *Liberibacter asiaticus and* Candidatus *Liberibacter americanus*). Department of Agriculture, Land Reform and Rural Development, Government Gazette 44258.

Díaz-Padilla, G., López-Arroyo, J. I., Sánchez-Cohen, I., Guajardo-Panes, R. A., Mora-Aguilera, G., & Quijano-Carranza, J. A. (2018). Áreas de abundancia potencial en México del vector del Huanglongbing, *Diaphorina citri* (Hemiptera: Liviidae). *Revista Mexicana de Ciencias Agrícolas, 5*(7), 1137–1153. https://doi.org/10.29312/remexca.v5i7.836

Ellis, J., Lázaro. E., Duarte, B., Magalhães, T., Duarte, A., Benhadi-Marín, J., Pereira, J. A., Vicent, A., Parnell, S., & Cunniffe, N. J. (2024). Developing epidemiological preparedness for a plant disease invasion: modelling citrus huánglóngbìng in the European Union. *BioRxiv* https://doi.org/10.1101/2024.06.04.597414

EPPO Global Database (2022). First report of Diaphorina citri in Israel. EPPO Reporting Service No. 02 Num. Article: 2022/032. https://gd.eppo.int/reporting/article-7262

EPPO Global Database (2023). *First report of* Diaphorina citri *in Cyprus*. EPPO Reporting Service No. 08 Num. Article: 2023/178. https://gd.eppo.int/reporting/article-7660

FAO (2011). *Support OIRSA member countries to control Huanglongbing*. TCP/RLA/3311(D). https://coin.fao.org/coin-static/cms/media/14/13499161922150/prodoc_tcp_rla_hlb.pdf

Folimonova, S. Y., Robertson, C. J., Garnsey, S. M., Gowda, S., & Dawson, W. O. (2009). Examination of the responses of different genotypes of citrus to huanglongbing (citrus greening) under different conditions. *Phytopathology, 99*(12), 1346–1354. https://doi.org/10.1094/PHYTO-99-12-1346

French, J. V., Khalke, C. J., & da Graça, J. V. (2001). First record of the Asian citrus psylla, Diaphorina citri Kuwayama (Homoptera: Psyllidae) in Texas. *Yaredai Zhiwu Kexue, 53*, 14–15.

Fundecitrus (2023). *Levantamento da incidência das doenças dos citros: greening, CVC e cancro cítrico / Fundo de Defesa da Citricultura. Araraquara, SP: Fundecitrus, 2023. 77 p*.

Gaire, S., Albrecht, U., Batuman, O., Qureshi, J., Zekri, M., & Alferez, F. (2022). Individual protective covers (IPCs) to prevent Asian citrus psyllid and *Candidatus* Liberibacter asiaticus from establishing in newly planted citrus trees. *Crop Protection (Guildford, Surrey), 152*, 105862. https://doi.org/10.1016/j.cropro.2021.105862

Gasparoto, M. C. de G., Primiano, I. V., Bassanezi, R. B., Lourenço, S. A., Montesino, L. H., Wulff, N. A., … Amorim, L. (2022). Prevalent transmission of ‘*Candidatus* Liberibacter asiaticus’ over ‘*Ca*. Liberibacter americanus’ in a long-term controlled environment. *Phytopathology, 112*(1), 180–188. https://doi.org/10.1094/PHYTO-06-21-0239-FI

Godefroid, M. (2024). ¿Cuál es el riesgo que el psílido africano de los cítricos Trioza erytreae se establezca en la península ibérica? *Phytoma España, 359*, 37–40.

Gómez-Correa, J. C., Robledo-Buriticá, J., Parra-Fuentes, M., Brochero-Bustamante, C. E., Guzmán-Sánchez, L. F., & Pérez-Artiles, L. (2021). Caracterización del sistema productivo de cítricos, con énfasis en la enfermedad huanglongbing, en Ponedera, Atlántico. *Temas Agrarios, 26*(2), 145–156. https://doi.org/10.21897/rta.v26i2.2889

Gottwald, T. R. (2010). Current epidemiological understanding of citrus huanglongbing. *Annual Review of Phytopathology, 48*(1), 119–139. https://doi.org/10.1146/annurev-phyto-073009-114418

Grafton-Cardwell, E. E., Stelinski, L. L., & Stansly, P. A. (2013). Biology and management of Asian citrus psyllid, vector of the huanglongbing pathogens. *Annual Review of Entomology, 58*(1), 413–432. https://doi.org/10.1146/annurev-ento-120811-153542

Graham, J., Gottwald, T., & Setamou, M. (2020). Status of huanglongbing (HLB) outbreaks in Florida, California and Texas. *Tropical Plant Pathology, 45*(3), 265–278. https://doi.org/10.1007/s40858-020-00335-y

Guo, J., Cen, Y. J., Wang, Z. R., Duan, H. F., Xia, Y. L., & Gao, J. Y. (2012). A Study on the morphology, biology, and occurrence of *Cacopsylla citrisuga. Journal of South China Agricultural University, 33*(4), 475–479.

Halbert, S., & Nuñez, C. A. (2009). Distribution of the Asian citrus psyllid, *Diaphorina citri* Kuwayama (Rhynchota: Psyllidae) in the Caribbean basin. *The Florida Entomologist, 97*, 401–402. https://doi.org/10.1653/0015-4040(2004)087[0401:DOTACP]2.0.CO;2

Hernández-Morales, L. M., García-Pérez, E., Cortés-Flores, J. I., Villegas-Monter, Á., & Mora-Aguilera, J. A. (2021). Fertilización integral en árboles de naranjo ‘Marrs’ en producción con síntomas de virus de la tristeza de los cítricos (VTC) y huanglongbing (HLB). *Revista Fitotecnia Mexicana, 44*(1), 59. https://doi.org/10.35196/rfm.2021.1.59

Hoddle, M. S. (2024). A new paradigm: Proactive biological control of invasive insect pests. *BioControl, 69*(3), 321–334. https://doi.org/10.1007/s10526-023-10206-5

Hoddle, M. S., & Pandey, R. (2014). Host range testing of *Tamarixia radiata*; (Hymenoptera: Eulophidae) sourced from the Punjab of Pakistan for classical biological control of *Diaphorina citri*; (Hemiptera: Liviidae: Euphyllurinae: Diaphorinini) in California. *Journal of Economic Entomology, 107*(1), 125–136. https://doi.org/10.1603/EC13318

Holford, P., Om, N., Donovan, N. J., Beattie, G. A. C., Subandiyah, S., Gunadi, R., & Poerwanto, M. E. (2022). High altitudes limit the incidence of huanglongbing and its vector, *Diaphorina citri*, in citrus orchards. *IOP Conference Series. Earth and Environmental Science, 1018*(1), 012019. https://doi.org/10.1088/1755-1315/1018/1/012019

Husain, M. A., & Nath, D. (1927). The citrus psylla (*Diaphorina citri*, Kuw.) [Psyllidae: Homoptera]. *Memoirs of department of Agriculture in India (Entomological Series), 10*, 5–27.

Irvin, N. A., Pierce, C., & Hoddle, M. S. (2021). Evaluating the potential of flowering plants for enhancing predatory hoverflies (Syrphidae) for biological control of *Diaphorina citri* (Liviidae) in California. *Biological Control, 157*, 104574. https://doi.org/10.1016/j.biocontrol.2021.104574

Khamis, F. M., Rwomushana, I., Ombura, L. O., Cook, G., Mohamed, S. A., Tanga, C. M., … Ekesi, S. (2017). DNA barcode reference library for the African citrus triozid, *Trioza erytreae* (Hemiptera: Triozidae): vector of African citrus greening. *Journal of Economic Entomology, 110*(6), 2637–2646. https://doi.org/10.1093/jee/tox283

Kistner, E. J., Amrich, R., Castillo, M., Strode, V., & Hoddle, M. S. (2016). Phenology of Asian citrus psyllid (Hemiptera: Liviidae), with special reference to biological control by *Tamarixia radiata*, in the residential landscape of southern California. *Journal of Economic Entomology, 109*(3), 1047–1057. https://doi.org/10.1093/jee/tow021

Leong, S. S., Leong, S. C. T., & Beattie, G. A. C. (2022). Integrated pest management strategies for Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) and huanglongbing in citrus for Sarawak, East Malaysia, Borneo. *Insects, 13*(10), 960. https://doi.org/10.3390/insects13100960

Lopes, S. A., Frare, G. F., Camargo, L. E. A., Wulff, N. A., Teixeira, D. C., Bassanezi, R. B., … Ayres, A. J. (2010). Liberibacters associated with orange jasmine in Brazil: Incidence in urban areas and relatedness to citrus liberibacters. *Plant Pathology, 59*(6), 1044–1053. https://doi.org/10.1111/j.1365-3059.2010.02349.x

Luis, M., Collazo, C., Llauger, R., Blanco, E., Peña, I., López, D., … Bové, J. M. (2009). Occurrence of citrus huanglongbing in Cuba and association of the disease with *Candidatus* Liberibacter asiaticus. *Journal of Plant Pathology, 91*(3), 709–712. Retrieved from http://www.jstor.org/stable/41998692

Luis-Pantoja, M., Paredes-Tomás, C., Uneau, Y., Myrie, W., Morillon, R., Satta, E., … Bertaccini, A. (2021). Identification of '*Candidatus* Phytoplasma' species in "huanglongbing" infected citrus orchards in the Caribbean. *European Journal of Plant Pathology, 160*(1), 185–198. https://doi.org/10.1007/s10658-021-02234-7

Ma, W., Pang, Z., Huang, X., Xu, J., Pandey, S. S., Li, J., … Wang, N. (2022). Citrus huanglongbing is a pathogen-triggered immune disease that can be mitigated with antioxidants and gibberellin. *Nature Communications, 13*(1), 529. https://doi.org/10.1038/s41467-022-28189-9

MAGRAMA (2023). *Plan de contingencia de Trioza erytreae (Del Guercio). Programa nacional para la aplicación de la normativa fitosanitaria*. https://www.mapa.gob.es/es/agricultura/temas/sanidad-vegetal/pnct_erytreae_mayo_2023_tcm30-136114.pdf

Manrakhan, A., Sibiya, X., Cook, G., De Bruyn, R., Kirkman, W., Carstens, E., … Gebeheyu, S. (2021). Trapping for asian citrus psyllid in southern Africa: Current status and the way forward. *SA Fruit Journal, 20*(1), 74–77.

McCalla, K. A., Milosavljević, I., & Hoddle, M. S. (2023). A low-toxicity baiting program precipitates collapse of Argentine ant and ant-associated hemipteran pest populations in commercial citrus. *Biological Control, 177*, 105105. https://doi.org/10.1016/j.biocontrol.2022.105105

Milosavljević, I., Morgan, D. J. W., Massie, R. E., & Hoddle, M. S. (2021). Density dependent mortality, climate, and Argentine ants affect population dynamics of an invasive citrus pest, *Diaphorina citri*, and its specialist parasitoid *Tamarixia radiata*, in Southern California, USA. *Biological Control, 159*, 104627. https://doi.org/10.1016/j.biocontrol.2021.104627

Mishra, R., Narayana, R., Ibanez, F., Achor, D., Shilts, T., El-Mohtar, C., … Bonning, B. C. (2023). Bacterial pesticidal protein Mpp51Aa1 delivered via transgenic citrus severely impacts the fecundity of Asian citrus psyllid, *Diaphorina citri. Applied and Environmental Microbiology, 89*(8). https://doi.org/10.1128/aem.00723-23

Molina, P., Hernández-Suárez, E., Rizza, R., Martínez-Ferrer, M. T., Campos-Rivela, J. M., Agustí, N., … Arenas-Arenas, F. J. (2022). Efficacy of selected insecticides for chemical control of the African citrus psyllid, *Trioza erytreae* (Psylloidea: Triozidae). *Agronomy (Basel), 12*(2), 441. https://doi.org/10.3390/agronomy12020441

Monzo, C., & Stansly, P. A. (2017). Economic injury levels for Asian citrus psyllid control in process oranges from mature trees with high incidence of huanglongbing. *PLoS One, 12*(4), e0175333. https://doi.org/10.1371/journal.pone.0175333

Mora-Aguilera, G., Robles-García, P., López-Arroyo, J. L., Flores-Sánchez, J., Acevedo-Sánchez, G., Domínguez-Monge, D., & González-Gómez, R. (2014). Situación actual y perspectivas del manejo del HLB de los cítricos. *Revista Mexicana de Fitopatología, 32*, 108–119.

Morales, P. G., Monteverde, E. E., & Cermeli, M. (2020). La citricultura venezolana en tiempos del huanglongbing. Visión actual y retos futuros. *Agronomía Tropical, 70*, 1–31. Retrieved from https://api.semanticscholar.org/CorpusID:234568290

Morán, F., Herrero-Cervera, M., Carvajal-Rojas, S., & Marco-Noales, E. (2023). Real-time on-site detection of the three '*Candidatus* Liberibacter' species associated with HLB disease: A rapid and validated method. *Frontiers in Plant Science, 14*. https://doi.org/10.3389/fpls.2023.1176513

National Academies of Sciences (2018). *A review of the citrus greening research and development efforts supported by the citrus research and development foundation*. National Academies Press Washington, DC. https://doi.org/10.17226/25026

OIRSA (2009). Plan de contingencia para la prevención y contención de Huanglongbing o Greening de los cítricos, en los países miembros OIRSA. https://www.oirsa.org/Contenido/Biblioteca/Huanglongbingplandecontingenciaoirsajulio2009.pdf

Om, N., Beattie, G. A. C., Donovan, N. J., Holford, P., & Agho, K. E. (2021). Incidence of psyllids and '*Candidatus* Liberibacter asiaticus' in mandarin orchards at different altitudes in Tsirang, Bhutan. *Tropical Plant Pathology, 46*(1), 81–97. https://doi.org/10.1007/s40858-020-00413-1

ONEI (2023). Anuario Estadístico de Cuba 2022. Edición 2023. Oficina Nacional de Estadística e Información, (ONEI). (Cuban Statistical Yearbook, Spanish). https://www.Onei.Gob.Cu/Anuario-Estadistico-de-Cuba-2022

Parajuli, S., Beattie, G. A. C., Holford, P., Yang, C., & Cen, Y. (2023). Susceptibility of *Diaphorina citri* to Irradiation with UV-A and UV-B and the Applicability of the Bunsen – Roscoe Reciprocity Law. *Insects, 14*(5), 445. https://doi.org/10.3390/insects14050445

Pérez-Hedo, M., Gallego-Giraldo, C., Forner-Giner, M. A., Ortells-Fabra, R., & Urbaneja, A. (2024). Plant volatile-triggered defense in citrus against biotic stressors. *Frontiers in Plant Science, 15*, 1425364. https://doi.org/10.3389/fpls.2024.1425364

Pérez-Otero, R., Mansilla, J. P., & Del Estal, P. (2015). Detección de la psila africana de los cítricos, *Trioza erytreae* (Del Guercio, 1918) (Hemiptera: Psylloidea: Triozidae), en la Península Ibérica. *Arquivos Entomolóxicos, 13*, 119–122. www.aegaweb.com/arquivos_entomoloxicos

Pérez-Rodríguez, J., Krüger, K., Pérez-Hedo, M., Ruíz-Rivero, O., Urbaneja, A., & Tena, A. (2019). Classical biological control of the African citrus psyllid *Trioza erytreae*, a major threat to the

European citrus industry. *Scientific Reports, 9*(1), 9440. https://doi.org/10.1038/s41598-019-45294-w

Pérez-Rodríguez, J., Suárez-Méndez, L., Urbaneja, A., Hernández-Suárez, E., & Tena, A. (2024). Implementation and assessment of the classical biological control program against the huanglongbing vector, *Trioza erytreae*, in the Canary islands. *Biological Control, 188*, 105431. https://doi.org/10.1016/j.biocontrol.2023.105431

PreHLB (2021). A simulation exercise to test the contingency plan for a hypothetical introduction of Huanglongbing in the peninsula. https://www.Prehlb.Eu/Simulation-Exercise-Huanglongbing/

Qureshi, J. A., Kostyk, B. C., & Stansly, P. A. (2014). Insecticidal suppression of Asian citrus psyllid *Diaphorina citri* (Hemiptera: Liviidae) vector of huanglongbing pathogens. *PLoS One, 9*(12), e112331. https://doi.org/10.1371/journal.pone.0112331

Rae, D. J., Liang, W. G., Watson, D. M., Beattie, G. A. C., & Huang, M. D. (1997). Evaluation of petroleum spray oils for control of the Asian citrus psylla, *Diaphorina citri* (Kuwayama) (Hemiptera: Psyllidae), in China. *International Journal of Pest Management, 43*(1), 71–75. https://doi.org/10.1080/096708797229013

Ramadugu, C., Keremane, M. L., Halbert, S. E., Duan, Y. P., Roose, M. L., Stover, E., & Lee, R. F. (2016). Long-term field evaluation reveals huanglongbing resistance in *Citrus* relatives. *Plant Disease, 100*(9), 1858–1869. https://doi.org/10.1094/PDIS-03-16-0271-RE

Rasowo, B. A., Copeland, R. S., Khamis, F. M., Aidoo, O. F., Ajene, I. J., Mohamed, S. A., … Borgemeister, C. (2021). Diversity and phylogenetic analysis of endosymbionts from *Trioza erytreae* (Del Guercio) and its parasitoids in Kenya. *Journal of Applied Entomology, 145*(1–2), 104–116. https://doi.org/10.1111/jen.12807

Rasowo, B. A., Khamis, F. M., Mohamed, S. A., Ajene, I. J., Aidoo, O. F., Ombura, L., … Borgemeister, C. (2019). African citrus greening disease in East Africa: Incidence, severity, and distribution patterns. *Journal of Economic Entomology, 112*(5), 2389–2397. https://doi.org/10.1093/jee/toz167

Reynaud, B., Turpin, P., Molinari, F. M., Grondin, M., Roque, S., Chiroleu, F., … Delatte, H. (2022). The African citrus psyllid *Trioza erytreae*: An efficient vector of *Candidatus* Liberibacter asiaticus. *Frontiers in Plant Science, 13*, 1089762. https://doi.org/10.3389/fpls.2022.1089762

Richard, K., Abdel-Rahman, E., Mohamed, S., Ekesi, S., Borgemeister, C., & Landmann, T. (2018). Importance of remotely-sensed vegetation variables for predicting the spatial distribution of African citrus triozid (*Trioza erytreae*) in Kenya. *ISPRS International Journal of Geo-Information, 7*(11), 429. https://doi.org/10.3390/ijgi7110429

Rodríguez-Aguilar, O., López-Collado, J., Vargas-Mendoza, M. de la C., Soto-Estrada, A., & Garcia-Avila, C. de J. (2024). Suitability area for *Candidatus* Liberibacter asiaticus under different climate change scenarios in Mexico. *Tropical and Subtropical Agroecosystems, 27*(1). https://doi.org/10.56369/tsaes.5207

Roldán, E. L., Stelinski, L. L., & Pelz-Stelinski, K. S. (2023). Foliar antibiotic treatment reduces *Candidatus* Liberibacter asiaticus acquisition by the Asian citrus psyllid, *Diaphorina citri* (Hemiptera: Liviidae), but does not reduce tree infection rate. *Journal of Economic Entomology, 116*(1), 78–89. https://doi.org/10.1093/jee/toac200

Ruíz-Rivero, O., Garcia-Lor, A., Rojas-Panadero, B., Franco, J. C., Khamis, F. M., Kruger, K., … Pérez-Hedo, M. (2021). Insights into the origin of the invasive populations of *Trioza erytreae* in Europe using microsatellite markers and mtDNA barcoding approaches. *Scientific Reports, 11*(1), 1–15. https://doi.org/10.1038/s41598-021-97824-0

Rwomushana, I., Khamis, F. M., Grout, T. G., Mohamed, S. A., Sétamou, M., Borgemeister, C., … Ekesi, S. (2017). Detection of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) in Kenya and potential implication for the spread of Huanglongbing disease in East Africa. *Biological Invasions, 19*(10), 2777–2787. https://doi.org/10.1007/s10530-017-1502-5

Sáenz-Pérez, C. A., Osorio-Hernández, E., Estrada-Drouaillet, B., Castro-Nava, S., Delgado-Martínez, R., López-Badillo, C. M., & Rodríguez-Herrera, R. (2020). Rootstock influence on growth and mineral content of *Citrus limon* and *Citrus sinensis* cv. Valencia inoculated with *Candidatus* Liberibacter Asiaticus. *Agronomy (Basel), 10*(10), 1564. https://doi.org/10.3390/agronomy10101564

Santiago-Rosario, L. Y., Faldyn, M. J., Martínez-Cález, E. L., & Rivera-Marchand, B. (2023). The invasion history of *Diaphorina citri* (Hemiptera: Liviidae) in Puerto Rico: past, present, and future perspectives. *Environmental Entomology, 52*(2), 259–269. https://doi.org/10.1093/ee/nvad012

Saponari, M., De Bac, G., Breithaupt, J., Loconsole, G., Yokomi, R. K., & Catalano, L. (2010). First report of '*Candidatus* Liberibacter asiaticus' associated with huanglongbing in sweet orange in Ethiopia. *Plant Disease, 94*(4), 482–482. https://doi.org/10.1094/PDIS-94-4-0482A

Sétamou, M. (2020a). Area-wide management of Asian citrus psyllid in Texas. In J. A. Qureshi & P. A. Stansly (Eds.), *Asian citrus psyllid: biology, ecology and management of the Huanglongbing vector* (pp. 234–249). CABI; https://doi.org/10.1079/9781786394088.0234

Sétamou, M., Alabi, O. J., Kunta, M., Dale, J., & da Graça, J. V. (2020b). Distribution of *Candidatus* Liberibacter asiaticus in citrus and the Asian citrus psyllid in Texas over a decade. *Plant Disease, 104*(4), 1118–1126. https://doi.org/10.1094/PDIS-08-19-1779-RE

Sétamou, M., Soto, Y. L., Tachin, M., & Alabi, O. J. (2023). Report on the first detection of Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) in the Republic of Benin, West Africa. *Scientific Reports, 13*(1), 801. https://doi.org/10.1038/s41598-023-28030-3

Shrestha, B., Martini, X., & Stelinski, L. L. (2021). Population fluctuations of *Diaphorina citri* and its natural enemies in response to various management practices in Florida. *The Florida Entomologist, 104*(3). https://doi.org/10.1653/024.104.0306

Singh, S., Livingston, T., Tang, L., & Vashisth, T. (2022). Effects of exogenous gibberellic acid in huanglongbing-affected sweet orange trees under Florida conditions – II. Fruit production and tree health. *HortScience, 57*(3), 353–359. https://doi.org/10.21273/HORTSCI16277-21

Sivager, G., Calvez, L., Bruyere, S., Boisne-Noc, R., Hufnagel, B., Cebrian-Torrejon, G., … Morillon, R. (2022). Better tolerance to huanglongbing is conferred by tetraploid Swingle citrumelo rootstock and is influenced by the ploidy of the scion. *Frontiers in Plant Science, 13*. https://doi.org/10.3389/fpls.2022.1030862

St. Vicent Times (2023). Citrus greening affecting fruits like orange, lime among others in SVG. https://www.Stvincenttimes.Com/Citrus-Greening-Affecting-Grown-in-St-Vincent/

Stelinski, L. L., Roldan, E., & Pelz-Stelinski, K. (2024). Integrating antibiotics into a broader management plan for HLB. *Citrus Industry Magazine, 105*(5), 6–9.

Teixeira, D. C., Ayres, J., Kitajima, E. W., Danet, L., Jagoueix-Eveillard, S., Saillard, C., & Bové, J. M. (2005b). First report of a huanglongbing-like disease of citrus in Sao Paulo state, Brazil and association of a new Liberibacter Species, " *Candidatus* Liberibacter americanus", with the disease. *Plant Disease, 89*(1), 107–107. https://doi.org/10.1094/PD-89-0107A

Teixeira, D. C., Luc Danet, J., Eveillard, S., Cristina Martins, E., Cintra de Jesus, W., Junior., Takao Yamamoto, P., … Bové, J. M. (2005a). Citrus huanglongbing in São Paulo State, Brazil: PCR detection of the '*Candidatus*' Liberibacter species associated with the disease. *Molecular and Cellular Probes, 19*(3), 173–179. https://doi.org/10.1016/j.mcp.2004.11.002

Teixeira, D. C., Luc Danet, J., Eveillard, S., Cristina Martins, E., Cintra de Jesus, W., Junior., Takao Yamamoto, P., … Bové, J. M. (2005b). Citrus huanglongbing in São Paulo State, Brazil: PCR detection of the '*Candidatus*' Liberibacter species associated with the disease. *Molecular and Cellular Probes, 19*(3), 173–179. https://doi.org/10.1016/j.mcp.2004.11.002

Tena, A., Urbaneja, A., Hernández-Suárez, E., Moure-Fernández, M., González-Freijo, A. B., Fraga-Vega, X. L., & Cuenca Valera, B. (2022). Introducción del parasitoide *Tamarixia dryi* en la península ibérica para el control de *Trioza erytreae*. *Phytoma España, 329*, 16–23.

Tiwari, S., Mann, R. S., Rogers, M. E., & Stelinski, L. L. (2011). Insecticide resistance in field populations of Asian citrus psyllid in Florida. *Pest Management Science, 67*(10), 1258–1268. https://doi.org/10.1002/ps.2181

Trinidad-Cruz, J. R., Rincón-Enríquez, G., Quiñones-Aguilar, E. E., Arce-Leal, Á. P., & Leyva-López, N. E. (2019). Inductores de resistencia vegetal en el control de *Candidatus* Liberibacter asiaticus en árboles de limón (*Citrus aurantifolia*) mexicano. *Revista Mexicana de Fitopatología*. *Revista Mexicana de Fitopatología, 37*(2). https://doi.org/10.18781/R.MEX.FIT.1901-1

Urbaneja, A., Grout, T. G., Gravena, S., Wu, F., Cen, Y., & Stansly, P. A. (2020). Citrus pests in a global world. In *The Genus Citrus* (pp. 333–348). Elsevier; https://doi.org/10.1016/B978-0-12-812163-4.00016-4

Urbaneja-Bernat, P., Hernández-Suárez, E., Tena, A., & Urbaneja, A. (2020). Preventive measures to limit the spread of *Trioza erytreae* (Del Guercio) (Hemiptera: Triozidae) in mainland Europe. *Journal of Applied Entomology, 144*(7), 553–559. https://doi.org/10.1111/jen.12771

Urbaneja-Bernat, P., Pérez-Rodríguez, J., Krüger, K., Catalán, J., Rizza, R., Hernández-Suárez, E., … Tena, A. (2019). Host range testing of *Tamarixia dryi* (Hymenoptera: Eulophidae) sourced from South Africa for classical biological control of *Trioza erytreae* (Hemiptera: Psyllidae) in Europe. *Biological Control, 135*, 110–116. https://doi.org/10.1016/j.biocontrol.2019.04.018

USDA (2023). Costa Rica: Citrus Annual. Costa Rica: Citrus Annual | USDA Foreign Agricultural Service. https://fas.usda.gov/data/costa-rica-citrus-annual-7

Wang, N. (2019). The citrus huanglongbing crisis and potential solutions. *Molecular Plant, 12*(5), 607–609. https://doi.org/10.1016/j.molp.2019.03.008

Wang, N. (2020). A perspective of citrus huanglongbing in the context of the Mediterranean Basin. *Journal of Plant Pathology, 102*(3), 635–640. https://doi.org/10.1007/s42161-020-00555-w

Wang, N., Sundin, G. W., La Fuente, L. D., Cubero, J., Tatineni, S., Brewer, M. T., … Munkvold, G. (2024). Key challenges in plant pathology in the next decade. *Phytopathology, 114*(5), 837–842. https://doi.org/10.1094/PHYTO-04-24-0137-KC

Yamamoto, P., Felippe, M., Garbim, L., Coelho, J., Ximenes, N., Martins, E., Leite, A. P. R., Sousa, M. C., Abrahao, D. P., & Braz, J. D. (2006). *Diaphorina citri* (Kuwayama) (Hemiptera: Psyllidae): Vector of the bacterium *Candidatus* Liberibacter americanus. *Proceedings of the Huanglongbing-Greening International Workshop*.

Yang, Y., Beattie, G. A. C., Spooner-Hart, R. N., Huang, M., Barchia, I., & Holford, P. (2013). Influences of leaf age and type, non-host volatiles, and mineral oil deposits on the incidence, distribution, and form of stylet tracks of *Diaphorina citri*. *Entomologia Experimentalis et Applicata, 147*(1), 33–49. https://doi.org/10.1111/eea.12046

Yuan, X., Chen, C., Bassanezi, R. B., Wu, F., Feng, Z., Shi, D., … Wang, N. (2021). Region-wide comprehensive implementation of roguing infected trees, tree replacement, and insecticide applications successfully controls citrus huanglongbing. *Phytopathology, 111*(8), 1361–1368. https://doi.org/10.1094/PHYTO-09-20-0436-R

Zapata-Contreras, Y. G., Osorio-Hernández, E., Silva-Espinosa, J. H., Delgado-Martínez, R., Rodríguez-Herrera, R., & Álvarez-Ramos, R. (2022). Situación actual, impacto económico y control del huanglongbing en Tamaulipas. *Ciencia Latina Revista Científica Multidisciplinar, 6*(1), 4242–4258. https://doi.org/10.37811/cl_rcm.v6i1.1797

Zhou, C. (2020). The status of citrus huanglongbing in China. *Tropical Plant Pathology, 45*(3), 279–284. https://doi.org/10.1007/s40858-020-00363-8

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