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A Review of Citrus Diseases and Pathogens in Texas

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ABSTRACT

Citrus is host to at least 90 fungal, oomycete, nematode, bacterial, viral, viroid, and algal pathogens, causing many diseases, some of which have ravaged citrus industries in many countries. Some of these diseases have been in Texas for several decades (eg. greasy spot, psorosis, melanose), while others are recent introductions (eg. Huanglongbing). Some pathogens have been identified that have not caused losses because sensitive rootstocks are not used. Citrus canker was the first disease recorded in Texas in 1911, and was eradicated in the 1940s, but recently returned, while psorosis, widespread in the 1940's, declined through the use of pathogen-free budwood. There are also a number of serious diseases that that have not been detected in Texas (eg. leprosis, black spot, variegated chlorosis), and continuous surveys and laboratory analyses are conducted to detect any as early as possible and appropriate actions can be taken. A state-mandated citrus budwood program requires all citrus nursery propagation to be conducted in insect-resistant structures using certified pathogen budwood. This paper reviews the history, research, economic impact, and current situation of citrus diseases in Texas.

Additional index words: canker, Huanglongbing, *Phytophthora*, fungal pathogens, nematodes, viruses and viroids

While the first reported planting of a citrus orchard in Texas was in 1883 at Laguna Seca, north of Edinburg in the Lower Rio Grande Valley (LRGV) (Waibel, 1953), citrus had been grown in in the Valley prior to this; gardens were reported near present-day Brownsville where vegetables and fruits, including oranges and lemons, were grown in the late 1840s (Johnson, 2001). The first commercial grapefruit orchard was planted in 1904 (Friend, undated). Along the Upper Gulf Coast, oranges and satsumas imported from Japan were grown commercially from the 1890's (Waibel, 1953) until the outbreak of citrus canker in 1911, which caused significant losses (Dopson, 1964). Commercial citrus production in Texas is now limited to the LRGV, although citrus is still found in the Upper Gulf Coast area primarily in dooryards, with a few small orchards (da Graça and Sauls, 2000).

There are several records of other citrus diseases in the LRGV in the 1920's and 1930's including cotton root rot, psorosis, gummosis, stem-end rot, melanose, greasy spot, and foot rot (Anon., 1929; Anon., 1930; Bach, 1931a; Bach, 1931b; Taubenhaus, 1930). Scaly bark (psorosis) was reported to be widespread in the 1940's (Fawcett, 1948), leading to the launch of a voluntary psorosis-free budwood program (Sleeth, 1961). Psorosis is now rarely encountered, most likely due to tree-killing freezes and the use of psorosis-free budwood (Skaria, 2004).

Other pathogens and diseases have been identified in Texas over time, including Huanglongbing (HLB also known as citrus greening) and sweet orange scab. Some viruses and viroids have been detected in Texas through various assays, but these diseases have not been recorded recently since they are not widespread. Current budwood varieties are tested for viruses and viroids; thus, keeping the citrus industry ahead of these diseases in Texas.

The following is a comprehensive review of citrus diseases and pathogens in Texas, including description of the symptoms, history, prevalence, and economic impact where recorded. Some pathogens, while present, have not thus far not caused significant losses, but are included to provide as complete a picture as possible. This provides a record of the past, the current situation including new research findings, and the roles provided by researchers, growers and regulators to protect the Texas citrus industry from severe losses. The review begins with the first disease reported, citrus canker, and is followed by one of the recent detections, HLB – both are caused by bacteria and both pose a significant risk to the Texas citrus industry, and grouping them together is appropriate. We have maintained the organization by pathogen type for the rest of the review. Thus, the bacterial section is followed by diseases caused by fungi, oomyctes, and nematodes, and finally viruses and viroids.

BACTERIAL PATHOGENS

Citrus Canker. Citrus canker symptoms in Texas were first observed in 1911 on satsuma trees in the Upper Gulf Coast area imported from Japan (Stevens, 1915). A survey showed that it had quickly spread in the area (Berger, 1914), and an eradication program was launched. The last infected tree was destroyed in Corpus Christi in 1943 (Dopson, 1964). Surveys conducted in the LRGV and the Upper Gulf Coast from 1999 to 2005 did not identify the disease (Skaria and da Graça, 2012). In 2015, canker symptoms were discovered in the LRGV in dooryard Mexican lime; investigations found that this was caused by a strain named A^{w}, which has a very limited host range (da Graça et al., 2017). The Asiatic strain, which has a wide host range, was detected in dooryard citrus in Houston and neighboring areas in 2016 and has since spread to two neighboring counties (Perez et al., 2021). The causal bacterium, *Xanthomonas citri* subsp. *citri* is spread by wind-blown rain and causes lesions on leaves, stems and fruit. They appear as tiny, slightly raised blister-like lesions, turning tan then brown with a water-soaked margin, often with a yellow halo (Fig. 1) (Gottwald et al., 2002). The lesion center becomes raised and corky. Citrus leafminer (*Phyllocnistis citrella*), activity causes coalescence of lesions along the mines, greatly increasing the damage (Gottwald and Graham, 2000). This pest was first detected in Texas in 1994 (French et al., 1994).

On-going surveys for citrus canker are conducted by the Texas A&M University-Kingsville, the Texas Department of Agriculture (TDA), and USDA-APHIS-PPQ, in both the LRGV and the Upper Gulf Coast, and any infected trees are removed by TDA (Perez et al., 2021).

A B C D

Figure 1. Asiatic Citrus Canker symptoms on grapefruit leaves (A) and sweet orange fruit (B). Citrus canker strain A^{w} with limited host specificity on Mexican lime on the stem (C) and leaves (D).

Citrus Huanglongbing (HLB) (also known as Citrus Greening). The first confirmed case of HLB in Texas was in a commercial Valencia tree in the LRGV in January 2012 (Kunta et al., 2012; da Graça et al., 2015). Later, an HLB finding in a semi-open nursery facility demonstrated vulnerability of the plants produced in open-field facilities to HLB (Alabi et al., 2014). TDA initiated enforcement of new regulations requiring citrus nurseries to produce and maintain trees only in insect-resistant enclosed facilities. Since then, surveys and sampling have been ongoing, and the disease is now spread throughout the LRGV (Sétamou et al., 2020), and has been detected in dooryard citrus in neighboring counties as well as in Houston. The disease is associated with the bacterium *Ca.* Liberibacter asiaticus (CLas), and is transmitted by the Asian citrus psyllid, *Diaphorina citri* (Bové et al., 2006). *D. citri* was first detected in the LRGV of Texas in 2001 (French et al., 2001), and by 2008 had become established throughout the south Texas including Houston and San Antonio (da Graça et al. 2008). The symptoms of HLB include blotchy mottle on the leaves resulting in a general yellow appearance of branches, lopsided fruit that remain green at the flower end (Fig. 2). Affected fruit also has a bitter taste, and trees decline gradually which can result in death, especially of young trees.

A

B

Figure 2. Upper panel: (A) Typical HLB symptoms observed in canopy and leaves and (B) fruit of an infected sweet orange tree. (A) Foliage with asymmetric blotchy mottle, and yellow lateral veins and midrib and (B) lopsided fruit with color inversion, brown staining in the vascular tissue of the fruit columella, and aborted brownish-black seeds.

Aerial plant parts including peduncle, columella, and leaf midrib and petiole had consistently higher CLas concentrations while young shoots, leaf blade, and especially leaf margins had the lowest concentrations in both sweet orange and grapefruit trees in Texas (Kunta et al., 2014). The CLas distribution was found to be uniform in the roots (Louzada et al., 2016) and fibrous roots offer better diagnostic samples for earlier or pre-symptomatic and consistent CLas detection (Park et al., 2018a; Braswell et al., 2020). Kunta et al. (2017) reported a draft whole genome sequence of CLas strain TX 2351 from *D. citri*. A variant of a related species associated with HLB in Brazil, *Ca.* L. americanus, has been detected in a few psyllids in Texas, but thus far not in any citrus trees (da Graça and Kunta, 2015).

HLB was first detected in Florida where it has caused significant economic losses (Singerman et al., 2018). A similar scenario was anticipated in Texas, and a risk assessment of exotic arthropod diseases ranked it as posing the highest risk (da Graça et al., 2007). However, an analysis of the incidence of CLas in trees and psyllids over 10 years showed a slower development of the disease epidemic and a subsequent reduced economic impact, possibly due in part to local environmental conditions (Sétamou et al., 2020) and management practices (Sétamou, 2020).

All citrus propagation in Texas is required by law to be undertaken in insect-proof screenhouse using certified pathogen-free budwood (da Graça et al., 2020). HLB-mitigation in the LRGV is managed through a voluntary area-wide management (AWM) program for vector control timed to have maximum control, together with surveys for the psyllid vector and HLB symptoms (Sétamou, 2020). However, Zapata et al. (2022) created an economic model to compare grapefruit production in Texas under AWM versus no control, and although AWM was the preferential choice, substantial losses could still be expected.

OOMYCETE AND FUNGAL PATHOGENS

***Phytophthora* Diseases**. Three species of the oomycete *Phytophthora* are known to infect citrus, namely *P. nicotianae, P. citrophthora*, and *P. palmivora* (Graham & Menge, 2000), but only *P. nicotianae* has been confirmed in Texas (Kunta et al., 2007b; Chaudhary et al., 2020). The symptoms include foot rot, root rot, trunk gummosis, and brown rot of fruit (Fig. 3). The first reports of these symptoms in Texas were by Bach (1931a) and Taubenhaus (1932). Recent surveys have confirmed that *Phytophthora* is present throughout the LRGV, with foot rot symptoms occurring in 97% of orchards surveyed between 2015 and 2017 (Chaudhary et al., 2020). Infection results in a slow decline of trees, which can be hastened by additional biotic and abiotic stress. Infection of roots has reported to be enhanced by damage caused by root weevils (Skaria and French, 2001).

A resistant sour orange plant that survived 18 months post-inoculation was obtained in a study exposing four citrus genotypes to high amounts on *P. nicotianae* to screen for tolerance (Kunta et al., 2020). Recent metagenomic analysis revealed that there are reduced beneficial microorganism associations in the roots of foot rot-affected trees (Yang and Ancona, 2021). An isolate of the fungus *Trichoderma* sp. from a citrus orchard in Texas has shown strong antagonistic action against *Phytophthora* which may provide a level of biocontrol (Gurung at al., 2017).

A B

Figure 3: (A) Foot rot, gummosis, and root rot symptoms of a grapefruit tree infected by *Phytophthora nicotianae*. (B) brown rot of grapefruit.

Melanose and Greasy Spot. Both melanose and greasy spot are endemic in the LRGV and were reported in the 1930s by Taubenhaus (1930, 1931) and Bach (1931a). While melanose was not reported to be severe at first (Taubenhaus, 1931), a high incidence occurred after the severe 1949 freeze (Godfrey, 1950). Similarly, a high surge in melanose was observed in many orchards in the LRGV after severe freeze in February 2021 (Kunta, personal observations).

Melanose is caused by *Diaporthe citri* (anamorph *Phomopsis citri*), and the symptoms include small, brown sunken spots impregnated with gum (Whiteside et al., 1977). A periderm below the dead cells develops causing the spots to rise giving a rough appearance and feel to the leaves. The fruits can also be infected; in young fruit this can result in cracks called "mudcake melanoses" (Fig. 4). As noted in the Introduction, melanose is endemic, but mostly causes economic problems after severe freezes.

Figure 4. Small brown corky pustules on the grapefruit leaves, and mudcake and tear-staining symptoms of melanose on citrus fruit.

Greasy spot is caused by *Zasmidium citri-griseum* (=*Mycosphaerella citri*). Grapefruit is particularly susceptible. Leaf symptoms first appear as a yellow mottle on the upper surface (Fig. 5). A matching orange to yellowish blister appears on the undersurface. The affected areas later become dark with a greasy appearance, and leaves drop from the tree. The fungus causes rind blotch on the fruit (Fig.5). Accurate assessment of the disease in the field is essential to estimate yield losses and to implement disease management strategies. A quantitative visual scale with representative images of different levels of disease severity on a scorecard was developed for field assessments of greasy spot in grapefruit orchards (Schneider et al., 2013). Although it was noted in Florida that greasy spot does not cause severe economic losses (Timmer et al., 1980), grapefruit is particularly susceptible and since it comprises 70% of Texas citrus production and the industry is primarily fresh fruit orientated, symptomatic fruit are rejected in the packinghouses, and severe leaf drop will likely reduce tree vigor.

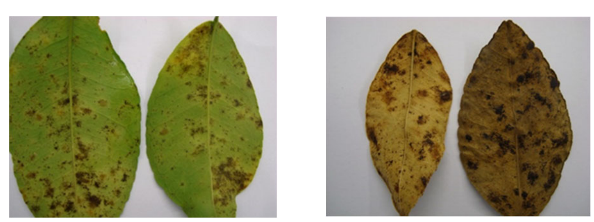


Figure 5. Dark brown to black spots with greasy appearance on grapefruit leaves infected by *Zasmidium citri-griseum*.

Fungal root rots. In addition to *Phytophthora*, there are several fungal root rots known in Texas. Cotton root rot was reported as a problem in young citrus trees in 1929 (Anon., 1929). The fungus, *Phymatotrichum omnivora*, is widespread in LRGV soils, but is not a problem in mature trees.

A *Fusarium* sp. was isolated from infected feeder roots, and it was suggested that this may have been the cause, since this fungus can cause dry root rot in citrus (Fig. 6). A recent study proved that *F. solani* is the cause of dry root rot in Texas (Kunta et al., 2015). Since then, sudden tree death due to Fusarium infection has been observed in many orchards (Kunta et al., 2018).

Figure 6. Sweet orange tree infected by *Fusarium solani* showing dry rot, wilting, and sudden death displaying patchy, black discoloration and decaying roots and reddish-purple discoloration in the wood at the base of the sour orange rootstock.

Ganoderma is also an endemic fungus but is not a serious problem unless trees are subjected to environmental stress (Skaria and Farrald, 1989). After the 1989 freeze, a number of young citrus trees died suddenly (Skaria, 1990). Based on ribosomal DNA sequences, *Ganoderma* infecting citrus trees in the LRGV was reported to be a unique taxon within the *G. lucidum* complex (Kunta et al., 2010). It is common to see infected citrus trees in Texas with fruiting bodies (conks or brackets) that are produced around the tree trunk by rhizomorphs of the fungus (Fig. 7A). Under favorable environmental conditions, air-borne basidiospores are released from these fruiting bodies enabling the spread of the disease.

Armillaria root rot, commonly found causing oak root rot worldwide, can infect citrus; the fungus was recently observed in declining citrus trees in south Texas (Kunta et al., 2017). Trees showed initial leaf and twig dieback, premature leaf drop, dried and dead branches, sometimes the fruit still hanging on the tree which eventually dried up, and later death of the whole tree or in some trees sudden wilt and total collapse of the tree was observed. Although it appears as sudden death since initially no apparent symptoms were seen above the ground, the disease is well established in the larger roots and crown, destroying the whole root system. White mycelial mats were observed underneath the bark of infected roots and crown area and spreading into the wood (Fig. 7B) and very rarely honey-colored sporocarps appeared near the base of the tree trunk (Fig. 7C). The roots were rotten, wet, spongy, with brown to black bark which peels off easily, and with strong mushroom odor, all of which are typical symptoms of root rot caused by *Armillaria* spp. (Fig. 7D). It is not currently causing any significant economic losses.

A B C D

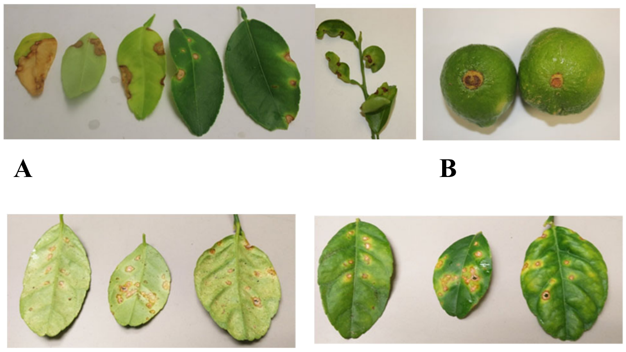
Figure 7.(A) Basidiocarps (fruiting bodies) of *Ganoderma* on a grapefruit tree. B-D: *Armillaria* sp., (B) *Armillaria* sp. white mycelial mats between wood and rotting bark, (C) clusters of honey-colored sporocarps of *Armillaria* near the base of the tree trunk, and (D) completely destroyed structural roots that emitted a characteristic mushroom odor.

Alternaria Brown Spot. *Alternaria alternata* causes brown spot of mandarins and hybrids (Fig. 8). Grapefruit can also become affected, but it is not a common commercial problem (Timmer at al., 2000a). Latent infections of *Alternaria* in grapefruit are common in Texas (Okamura and Davis, 1987). It does not currently cause significant economic losses.

A B C

Figure 8. (A&B) Black rot symptoms caused by *Alternaria* in sweet orange fruit and (C) Alternaria brown spots on grapefruit leaves (leaf symptom photo credit: Marissa Gonzalez).

Anthracnose. Timmer (1978) identified anthracnose on Mexican lime in Texas caused by *Colletotrichum acutatum*. Ruiz et al. (2014) confirmed the limited host range of the fungus and conducted molecular characterization. Persian lime was shown not to be a host, but a tree of this species in Corpus Christi was found to have similar symptoms (Fig. 9). The responsible fungus was identified as *C. queenslandicum*, a species not previously reported on citrus anywhere, and never found on other hosts in Texas (Kunta et al., 2018). No further infected trees have been observed. Mexican limes are not grown commercially in the LRGV, but there are now some Persian lime orchards. Currently, anthracnose is not a problem in Texas, but could potentially become one in the future.



A B

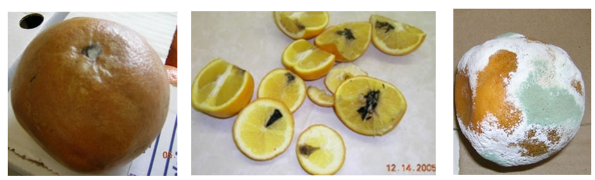
C D

Figure 9. Mexican lime (A) leaves and fruit (B) showing lime anthracnose disease symptoms of necrotic spots. Misshapen small fruit with large deep and depressed necrotic cankers. Persian lime leaves (C) abaxial and (D) adaxial showing typical anthracnose symptoms caused by *Colletotrichum queenslandicum.*

Scab. Sour orange scab, caused by *Elsinöe fawcettii*, has been present in Texas for several years (Timmer, 1974). The symptoms appear on leaves and fruit as raised lesions (Fig. 10). Kunta et al. (2013a) isolated *E. australis*, the causal organism of sweet orange scab (SOS), from citrus in the Gulf Coast region as well as the LRGV, often associated in orange and grapefruit with what is called late season wind scar damage (Fig. 10). Since affected fruit are not suitable for the fresh market, wind scarring can cause economic losses. California declared SOS an actionable quarantine pest in 2010, which would have had a serious financial impact on the Texas citrus industry, which sends 25% of its fruit to California, but in early 2011 USDA-APHIS determined it was safe to import fruit from Texas (Santa Ana, 2011). Fungicide applications for greasy spot are also effective against these fungi, as are post-harvest treatments in packingsheds (Kunta, unpublished data).

Figure 10. (Upper panel) Citrus fruit and leaf with raised lesion symptoms of common scab and (lower panel) flattened off-white pustules to large, coalesced lesions and "late-season windscar"–like lesions on sweet orange fruit and relatively large and coalesced on the margins of the upper side of the Satsuma mandarin leaves.

Post-harvest fungal diseases. Stem-end rot (*Diplodia natalensis*) and Phomopsis stem-end rot (*Diaporthe citri*) are the common post-harvest citrus diseases in Texas. *Alternaria citri* infection also leads to stem-end rot in fruit stored for longer durations, especially in navel sweet orange (Fig. 11) (Skaria, 2002). Anthracnose (*Colletotrichum gloeosporiodes*) is a post-harvest disease mainly of grapefruit and navel oranges. Air quality, maintenance of appropriate levels of ethylene, temperature and relative humidity in the packinghouse de-greening facilities are important to control these problems (Brown, 1986; Skaria and Thomas, 2005). Green mold (*Penicillium digitatum*) and blue mold (*P. italicum*) are also common post-harvest problems in Texas. Skaria et al. (2003) reported that fruit damage due to packinghouse handling practices enhances incidence of green mold (Fig. 10). During the periods of prolonged wet seasons, sour rot (*Galactomyces citri-aurantii* and mixed infections with *Penicillium* spp.) affects particularly over-mature fruits in packinghouses (Fig. 11) (Timmer et al., 2000b).



A B C

Figure 11. Post-harvest citrus fruit diseases. A: *Diplodia* stem-end rot on grapefruit, B: *Alternaria* rot on sweet orange, C: *Penicillium digitatum* green mold on grapefruit.

NEMATODES

The citrus nematode, *Tylenchulus semipenetrans*, was first reported in south Texas in 1950 (Godfrey and Waibel, 1950). Subsequent surveys determined it was present in 90% of the orchards (Heald, 1970), and was responsible for significant economic losses (Timmer and Davis, 1982). The feeding of nematodes on the roots can result in canopy thinning and defoliation (Fig. 12). A membrane filter technique was developed to screen soil samples collected from citrus orchards under different irrigation systems such as flood, drip, and microsprinker (Skaria et al., 2005). Nematode populations were highest around drips. Gene expression studies in sour orange and C-22 Bitters citrandarin rootstock plants inoculated with citrus nematode revealed that a gene supporting nematode resistance in citrus which might be related to the CTV resistance gene (Reddy et al., 2010). This study shed light on the need for further investigations to understand interaction mechanisms between citrus nematode and rootstock plants. The application of systemic nematicides has been shown to significantly reduce nematode populations in mature trees (Laughlin and Ancona, 2019).

Figure 12. (Left) Citrus nematode juveniles extracted using Baermann funnel and stained with acid fuchsin, (right) grapefruit tree showing slow decline symptoms of canopy thinning and defoliated branches.

VIRUSES AND VIROIDS

Psorosis. The only widespread viral disease observed in Texas was psorosis (Fawcett, 1948), recognized by the characteristic bark scaling symptoms (Fig. 13). This was the first citrus disease demonstrated by Fawcett (1934) to be graft transmitted and likely a virus, although the responsible virus, *Citrus psorosis virus* (CPsV), was not characterized until 1988 (Derrick et al., 1988). The use of virus-free budwood, along with tree loss due to freezes, has resulted in the disappearance of this disease (Skaria, 2004). Analysis of the incidence of symptoms in one of the last infected orchards in the LRGV suggested movement through the soil (Gottwald et al., 2005), the presence of the virus in spores of the fungus *Olpidium* isolated from these trees suggested this may be the vector since it transmits related viruses in lettuce and tulips (Palle et al., 2005). Citrus ringspot virus was recorded in Texas by Timmer et al. (1974); this was later proven to be a strain of CPsV (da Graça et al., 1991). No further detections have occurred in Texas.

Figure 13. Bark scaling symptom of psorosis on a grapefruit branch.

Tristeza. *Citrus tristeza virus* (CTV) was first detected by Olson and Sleeth (1954) in Meyer lemon, a symptomless host, through biological indexing on Mexican lime. Olson (1955, 1956) then tested trees which had originated from outside Texas and detected CTV in several. Only one sweet orange tree on sour orange rootstock, the major rootstock in South Texas, was reported to have thin foliage, dieback, and honeycombing of the sour orange bark (Olson, 1955). Davis et al. (1984), using an enzyme-linked immunosorbent assay, were unable to detect CTV in commercial orchards, but did find the virus in some noncommercial varieties. Severe strains of CTV can cause quick decline in trees on sour orange, but, apart from one symptomatic tree tested by Olson (1955), none has been observed because CTV incidence is very low, native aphid species are poor vectors (Dean and Olson, 1956; Smith and Farrald, 1988). The efficient vector, the brown citrus aphid (*Toxoptera citricida*) has not been recorded in Texas, Many CTV strains found are mild, although, Herron et al. (2005) identified severe strains in a greenhouse collection of historic field isolates, and recent molecular analysis of Upper Coast samples has shown that they include strains which can potentially cause decline on sour orange, stem pitting in grapefruit and able to overcome resistance in trifoliate orange (Park et al., 2021). CTV is now rarely found in the LRGV but is more widely present in the Upper Gulf Coast region (Solís-Gracia et al., 2001; Park et al., 2021).

Tatterleaf. Citrus tatterleaf virus (*Apple stem-grooving virus*) (CTLV) was first detected by biological indexing in symptomless Meyer lemon (Timmer, 1974). CTLV causes the tatterleaf symptoms (Fig. 14) in trifoliate orange and some of its hybrids, and when used as rootstocks a bud-union incompatibility develops. CTLV does not cause symptoms in sour orange. Some sweet orange trees on Swingle citrumelo rootstock which showed bud union incompatibility tested positive for CTLV (M. Skaria, 1994 - unpublished data). A low rate of seed transmission of CTLV was reported in Eureka lemon (Tanner et al., 2011). Since a reliable and sensitive CTLV detection assay was lacking for routine diagnostic tests, Park et al. (2018b) developed a reverse transcription-quantitative PCR assay that showed 98% amplification efficiency and 100% detection rate.

Figure 14. Troyer citrange (*Citrus sinensis* 'Washington' sweet orange x *Poncirus trifoliata*) infected with citrus tatterleaf virus showing deformed leaves with irregular chlorotic spots.

Citrus virus A. Citrus virus A (CiVA), which is possibly associated with concave gum, cristacortis and impietratura, was recently detected in young plants in a shadehouse in Texas through next-generation sequencing (Park et al., 2022). These plants had oak-leaf patterns (Fig. 15) which have been associated with the three diseases listed, but none of these diseases has been recorded in Texas. The source of CiVA remains unknown.

Table 1. List of citrus diseases and pathogens detected in Texas.

Disease	**Pathogen**
Citrus canker	*Xanthomonas citri* subsp. *Citri*
Citrus greening (Huanglongbing)	*Ca.* Liberibacter asiaticus
Foot rot; Fibrous root rot; Gummosis; Brown rot of fruit; Damping-off in seed-beds	*Phytophthora nicotianae*
Melanose; Phomopsis Stem-end rot	*Diaporthe citri (*anamorph *Phomopsis citri)*
Greasy spot	*Mycosphaerella citri*
Cotton root rot	*Phymatotrichum omnivore*
Ganoderma root rot/heart rot/wood rot	*Ganoderma lucidum*
Dry root rot	*Fusarium solani*
Armillaria root rot	*Armillaria mellea*
Alternaria brown spot; Black rot	*Alternaria alternata*
Lime anthracnose	*Colletotrichum acutatum*
Sweet orange scab	*Elsinöe australis*
Sour orange scab	*Elsinöe fawcettii*
Persian lime anthracnose	*Colletotrichum queendslandicum*
Green mold and blue mold	*Penicillium digitatum; P. italicum*
Slow decline (nematode)	*Tylenchulus semipenetrans*
Psorosis (scaly bark)	*Citrus psorosis virus*
Tristeza (quick decline; stem pitting)	*Citrus tristeza virus*
Exocortis	*Citrus exocortis viroid*
Cachexia (Xyloporosis)	*Hop stunt viroid*
Tatterleaf	*Apple stem grooving virus*
Citrus dwarfing, gum pocket, bark cracking	*Citrus dwarfing viroid; Citrus bark cracking viroid; Citrus viroid V*
Oak leaf pattern	Citrus virus A

Figure 15. Oak leaf pattern on symptomatic Madam Vinous sweet orange leaves associated with Citrus virus A.

Viroids. Several viroids have been detected in Texas. Initially, detection of *Citrus exocortis viroid* (CEVd) and citrus cachexia viroid (*Hop stunt viroid*) (CCaVd/HSVd) (Olson, 1954) was done through biological indexing. Later, using molecular techniques, additional viroids have been reported, namely *Citrus dwarfing viroid* (CDVd) (Miao et al., 1996; Kunta et al., 2007), Citrus viroid IV (*Citrus bark cracking viroid*) (Kunta et al., 2007) and Citrus viroid V (Kunta et al., 2013). CEVd, CCaVd and CDVd mostly affect rootstocks of trifoliate and mandarin background which are not widely used in Texas, so disease symptoms in orchard trees have not occurred. The remaining viroids have not been associated with any disease symptoms.

The establishment of the state-mandated citrus budwood certification program in 1996 (Skaria et al., 1998; da Graça et al., 2020), established in response to the detection of CTV in the LRGV (Skaria, 1993), has undoubtedly reduced the incidence of viruses and viroids in Texas citrus.

CONCLUSIONS

Table 1 contains a list of the diseases and pathogens which have been reported in Texas. Some pathogens have been present since shortly after the establishment of commercial production, while others have arrived subsequently. Yet, Texas citriculture has not suffered the devastating epidemics that have occurred elsewhere (for example: CTV quick decline in Brazil and Argentina, HLB in several countries in Asia and Africa, and Florida, and canker in Florida). Canker was detected in Texas over 100 years ago, and subsequently eradicated, but has now returned. Several fungal diseases occur but can be managed by timely fungicide applications. Since some cause symptoms on fruit, control is paramount because Texas citrus mainly targets the fresh fruit market, and successful control can be costly.

There are several serious pathogens of citrus, which have not been recorded in Texas. These include citrus leprosis, caused by viruses belonging to two unrelated genera, *Cilevirus* and *Dichorhavirus* (Zhou et al., 2020), citrus variegated chlorosis (CVC) caused by a sharpshooter-vectored xylem-limited bacterium, *Xylella fastidiosa* (Baretta & Leite Jr., 2000), and citrus black spot (CBS) caused by the fungus *Guignardia citricarpa* (Kotzé, 2000). Leprosis is present in several countries in South America and in Mexico (Zhou et al., 2020), CVC is present in South America (Rossetti, 2000), and CBS appeared in Florida in 2010 (Schubert et al., 2012). All of these could potentially cause losses to the Texas citrus industry, and continuous surveys statewide are on-going for early detection and eradication. The risk assessment of arthropod-vectored diseases conducted in 2007 ranked leprosis and CVC third and fourth, after HLB and tristeza (da Graça et al., 2007).

Pathogens which are spread via infected budwood are now mostly not a threat since all citrus nursery production must be based on certified pathogen-free budwood and trees must be propagated in insect-resistant structures since some pathogens have arthropod vectors. Such a program has been in existence in Texas for over 20 years (da Graça et al., 2020).

Texas is the home of the dark red grapefruit varieties which constitute approximately 70% of citrus production in the state. The environment conditions are ideal for high quality grapefruit, but unfortunately grapefruit is particularly susceptible to several diseases, namely CTV stem-pitting, greasy spot, canker and *Phytophthora*. The high fruit quality is also due in part to the use of sour orange rootstock, which means that if severe CTV strains become established, death from quick decline will occur. Fortunately, native aphids are poor vectors of CTV, and their populations have declined in recent years, possibly as a result of spray programs against the Asian citrus psyllid (M. Sétamou, pers. comm).

HLB is perhaps the most serious disease to have become established, but coordinated efforts by Texas growers, regulators and scientists, will hopefully maintain production while research into long-term management is on-going.

Following the introduction of HLB, Texas established on-going surveys conducted by USDA-APHIS, TDA, Texas A&M University-Kingsville Citrus Center and the Texas Pest and Disease Management Corporation. The presence of canker was discovered relatively soon after its introduction, and continuing surveys and eradication programs have protected the commercial industry thus far. The commercial citrus industry in Texas is over a century old, and these surveys, together with collaborative research, should ensure that it will remain viable for the future.

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