EDITORIAL

Citrus Greening Disease (Huanglongbing) in the Southwestern USA

Citrus greening disease (CG), also known as Huanglongbing (HLB), is generally acknowledged as the most destructive citrus disease known, eclipsing the worst citrus tristeza virus outbreaks in the early 20th century. This article will describe CG and its vector and describe its effects on citrus trees and the citrus industry in the United States. Comparisons of disease spread in tropical and sub-tropical areas such as Florida with spread in the Mediterranean and desert climactic zones, which are similar to those found in the Middle East and North Africa (MENA), will be made. Additionally, successful methods used to slow the spread of the disease in the USA will be presented, and some suggestions will be made that may slow the movement of CG into the MENA and reduce its impact upon arrival.

Description and Characterization of the Disease and its Vector

The term "citrus greening" originated in South Africa a, where it likely referred to the abnormal green color of the fruits at harvest. However, the correct name of the disease is "Huanglongbing", which is translated as "yellow shoot disease", referring to the yellowing of branches and entire sections of the affected trees. The CG pathogen is a gram-negative bacterium that exists in the phloem. It occurs in two strains: *Liberibacter africanus* causing African CG, and *Liberibacter asiaticus* causing Asian. Even though the strains are both well-characterized, they are unculturable, thus they were renamed *Candidatus* liberibacter africanus (Claf) and *Candidatus* liberibacter asiaticus (Clas). Claf is transmitted by the African citrus psyllid *Trioza erytreae* (Del Guerico), while Clas is transmitted by the Asian citrus psyllid (ACP) Diaphorina citri (Kuwayama).

Effect of Temperature on Claf and Clas

Claf appears to be heat-sensitive; symptoms disappeared at 27 to 32 ˚C in a greenhouse study, and the pathogen is found in cooler areas of southern and eastern Africa, as well as the islands of the Indian Ocean. *Trioza erytreae* has been found in all these areas, including coastal Spain, Portugal, and Madeira. Clas is more heat-tolerant; symptoms become visible above 25 ˚C. The author observed symptoms in Punjab, India, in November, where mean daily maximum temperatures reach 27˚C and record high temperatures can reach 35˚C. Clas is widely distributed across China, India, Pakistan, Indonesia, the Philippines, South America (excluding the western Andes), Central America, Mexico, the Caribbean, and the United States. The ACP vector is found in all these countries and has recently been found in Kenya, Tanzania and Benin. Both strains have been reported in Saudi Arabia, Yemen and Reunion Island, where Claf is found in the cooler highlands, while Clas has been found in warmer coastal areas. Since only Clas has been found in the United States, the remainder of this article focuses only on it and its ACP vector.

Symptoms of CG in Citrus Trees

Virtually all citrus species have some susceptibility to CG. CG enters a region as it is carried with the ACP, in infected trees or other host plants or through the use of infected citrus budwood. Nurseries and individuals can spread CG by propagating trees using infected budwood.

After 20 years of experience in Florida, lemons, grapefruit, pummelos, and sour oranges are less susceptible to disease than oranges, mandarins, and tangelos. Some limes, trifoliate orange and trifoliate orange hybrids are the most tolerant. Primary symptoms of CG in the tree include asymmetrical, blotchy mottling of leaves (which

varies by citrus type and is often the first symptom noticed), vein yellowing and corkiness, small leaves, sparse foliage, and root dieback. Fruit CG symptoms include small, lopsided fruit, aborted seeds, incomplete ripening, bitter or sour taste (low sugar to acid ratio) and drastically reduced production. Secondary symptoms include increased susceptibility to root diseases and pests, such as phytophthora, and chronic drought stress, leading to ethylene production and pre-harvest fruit drop. Generally, CG does not kill a tree but makes it economically worthless.

There has been considerable controversy regarding how Clas causes CG symptoms. There is a general consensus that symptoms are caused by phloem blockage, which limits the movement of nutrients and carbohydrates to the roots, leaves and fruit. Recently, a study suggested that CG is a pathogen-triggered immune response which leads to callose deposition in the phloem, and production of reactive oxygen species, which leads to the death of sieve and companion cells of the phloem. Control methods that reduce the formation of reactive oxygen species, such as the application of antioxidants or gibberellins, have been suggested.

Once in the tree, the bacteria moves throughout the tree, including the roots. One study in Florida, where the trees flush most of the year, showed that 43% of all tree leaves had detectable Clas after one year, and it took three years for the entire tree to become infected. Considering the slowness of movement of Clas in the tree, symptoms of CG are not immediately visible. Therefore, a tree may exhibit the disease several weeks or months before the pathogen is detected by inspection. Furthermore, it is likely that sampling at one location on the tree may not always detect disease because the Clas is unevenly distributed. At some point, much of the Clas in a tree may be in the roots, meaning that pruning a tree to eliminate CG is ineffective. Heat treatments have been found effective in slowing the spread of CG and reducing the bacterial titer of Clas. Brazilian citrus orchards in the northern periphery of the main citrus growing region are less at risk of the disease. Treatment of infected trees at CG spread in the tree can also be reduced through the injection of antibiotics, and there is some tolerance to CG in certain citrus varieties.

The ACP Vector

The ACP prefers to feed and reproduce on new flush; ACP are unable to transmit Clas on mature leaves. Visual symptoms of ACP feeding include the presence of adults and/or nymphs, twisted or notched leaves, evidence of waxy "tube-like" deposits produced by the nymphs, honeydew and/or sooty mold. In the absence of Clas, the damage caused by the ACP feeding is negligible.

ACP will survive temperatures as low as -6˚C for several hours, and optimal survival temperature is between 20 and 25˚C. In desert areas where the summer heat reduces flush, ACP populations are generally lowest during the summer and increase in the fall through spring. A recent study showed that when ACP populations were subjected to 3 and 6 hour thermal cycles of 28, 37, 40 and 43˚C, longer cycles and increased temperatures reduced adult emergence. At 43˚C, there was no emergence at all as the entire population of ACP died. However, the beneficial effect of high temperatures causing ACP population decreases should not cause citrus growers to become complacent. If CG is in the area, it is vitally important to reduce ACP populations, especially in the cooler months of the year. ACP populations can be reduced through the use of contact or systemic insecticides, through the introduction of parasites and parasitoids and through repellants.

Discoveries of infected ACP almost always precede discoveries of infected trees. ACP's can jump from one tree to another, can fly up to 2 km, can be carried on strong winds perhaps up to 480 km and can "hitchhike" on vehicles. An infected psyllid means there is an infected tree somewhere nearby, but it may be very difficult to find that tree. We have noted that when ACP is spreading, it is almost always found along the side of the orchard that faces the prevailing wind or along transportation corridors.

Citrus Greening and the Asian Citrus Psyllid in the United States

In the United States, the ACP was first found in Florida, California and Arizona in 1998, 2008 and 2009, respectively. Clas was first detected in those states in 2005, 2012 and 2025. ACP and Clas are now found in all citrus growing states except Hawaii, where only the vector is found. In Florida, California and Arizona, the presence of the ACP, presence of Clas, tree phenology, the environment and degree of regulatory oversight have led to quite different outcomes in the fight against CG.

Florida

The Köppen climate zones encompassing the Florida citrus industry include tropical rainforest (Af), tropical monsoon (Am), tropical savannah(Aw) and humid subtropical (Cfa) None of these climates occur in the MENA. Citrus growing in Florida is the most damaged by CG. Although the ACP was first discovered in 1998, it was likely widespread before that time, but was considered

to be inconsequential because Clas was not found in the state, Clas was found in a garden south of Miami in 2005, likely blown in with ACP on hurricane winds or was smuggled in. The disease moved quickly and could not be contained by phytosanitary regulations. Within five years virtually the entire industry was affected. Florida's tropical climate ensures continual tree flush in the spring, summer and fall months. Abandoned orchards harbor the disease and the insect. Insecticide resistance is growing. As a result, Florida citrus production has dropped from 300 million boxes to under 20 million boxes from 2003 to 2023. Some of the drop is due to freezes, hurricanes and urbanization, but the majority is due to CG. Losses to the economy have been in the billions of dollars. Thousands of jobs have been lost as orchards are abandoned, converted to other crops or urbanized, processing plants are closed and agricultural support industries become smaller. Hundreds of millions of dollars have been spent on research, and there are some new plantings of tolerant citrus from breeding programs and a "clean" budwood program. Growers are injecting trees with oxytetracycline to lower the disease titer, and new management strategies that reduce the impact of stress, root loss and fruit drop are implemented. The viability of the Florida citrus industry is still in question. The question is: "Will the cure come before the patient is dead?"

California Coastal and Interior

In California there are about 105,000 ha of citrus. The industry is growing slowly. The main part of the citrus industry is encompassed by the hot summer mediterranean (Csa) and warm summer mediterranean (Csb) Köppen climate zones. These zones in the MENA include the coastal regions of Türkiye, Syria, Lebanon, Israel, Palestine, Tunisia, Algeria and Morocco, and the northern regions of Syria and Iraq. The citrus industry in California has not been significantly impacted by CG because of the environment, strong phytosanitary regulations and diligence on the part of the growers and the government. Most California citrus trees grow in areas where the summer temperatures can reach 40C, rainfall is limited except in the winter and spring, and shoot flush is limited to the spring and fall. ACP was first found in California in 2008, and it is regularly found in the urban and rural areas of Southern California but is not as often encountered in the San Joaquin (Central) Valley, California's main citrus growing region. This is probably because there are mountains separating the two regions. Growers in California have organized themselves into "Citrus Health Management Areas" where insecticide sprays are applied at coordinated times to reduce ACP populations across large areas. Parasites and parasitoids are reared to help control the ACP populations. The USDA and the California Department of Food and Agriculture monitor traps for ACP and submit hundreds of samples for Clas detection annually.

Since CG was discovered in one Los Angeles garden in 2012, it has been confined mostly to the urban areas of that region. There are four GC quarantine areas in the Los Angeles area, where citrus plants or fruits may not be moved out or through without a permit. From 2012 to 2024, about 9,400 infected citrus trees, out of an estimated 6,000,000, have been positively identified with Clas and removed using the authority of governmental agencies. No Clas has been found in the San Joaquin Valley, but growers and authorities are vigilant. California has its own "clean" budwood program, and there are regulations on treatments needed to move citrus plants and fruits throughout the state to minimize the spread of the ACP and the Clas. California authorities and growers have learned from the experiences of Florida and have been fairly successful in minimizing the impact of CG.

Arizona and California Desert

Arizona citrus is mostly grown in the Köppen hot desert climate zone (BWh) which extends westward into California and includes the desert industry in that state. Similar areas in the MENA would include Eastern Syria, middle and southern Iraq, all of the GCC countries, most of Yemen, Egypt and Libya, southern Tunisia, and the Algerian and Moroccan Sahara. There are a few urban areas in the hot semi-arid zone (BSh) where citrus can be found. Similar areas in MENA include northern Syria and Iraq, small areas in coastal Libya and the river valleys of southwestern Morocco. The size of the desert industry in both states is about 5,000 ha and is shrinking due to shortage of water. The citrus industry and urban citrus in the deserts of Arizona and southern California have not been significantly affected by CG. Average summer maximum temperatures are above 40C from June to September. Rainfall is minimal and all citrus is irrigated. Trees flush only in the spring and fall. ACP was first found in Arizona in 2009, and most were originally found in transportation corridors coming from Mexico, indicating that the insect entered the desert region on the wind or on vehicle traffic. ACP levels are still low, but desert growers in both states have their respective Citrus Health Management Areas and conduct coordinated spraying. Networks of traps are monitored and many samples submitted.

Clas was first discovered in Arizona in January 2025 in the city of Nogales (Köppen Zone BSh) at the Mexican border (Figures 1,2 and 3). This city

is about 400 km from the main citrus growing area of the state. The trees are old and appear to have been infected several years ago, with the symptoms only becoming noticeable this year. Trapping and sampling have been increased and a quarantine zone established. Inspectors are going "door-to-door", speaking with residents and collecting samples. Currently there are 17 positive trees in 11 gardens in a small part of the city. All these trees will be removed within the next month. Homeowners whose trees are removed will receive a replacement deciduous tree free of charge. Arizona benefits from the experiences of Florida and California and because of this and its climate has generally escaped impact from the disease.

Figure 1. First tree infected with CG disease, Nogales, AZ 2025.

Figure 2. Leaf symptoms of CG disease, Nogales, AZ

Implications and Suggestions for MENA

Based on our experience in the United States, Clas is most likely to enter MENA countries by the introduction of infected trees or budwood either to commercial nurseries or to individuals. There is a smaller chance that the disease could arrive in infected ACP via the wind or by 'hitchhiking" on vehicles.

Areas in the Mediterranean climates (Köppen zones CSa and CSb) and hot semi-arid climate (Köppen zone BSh) are most likely to see introduction first. Movement of the disease into an area will not be

as fast as it was in Florida because the environment is not as favorable for ACP survival and the trees do not flush continuously. Disease entry may be slowed further if any or all of the steps listed below are taken:

Before CG arrives:

1. It is likely that the first find of CG will be in a garden rather than in a commercial orchard. As the disease gets closer, there should be organized communication with private citizens, nursery owners and growers. This communication should inform them of the threat of the disease to their own trees and to the industry and encourage them to report anything unusual.
2. Government and University employees, growers and nursery workers should be trained to recognize the disease. A plan should be developed to determine everyone's roles and responsibilities when confronting the disease. What shall be done if there is a positive find?
3. Quarantine regulations restricting entry of citrus and citrus relatives from other countries should be established and rigorously enforced, especially at airports and at national borders. Dogs can be trained to smell ACP and Clas and should be used.
4. Governmental authorities should be given the authority in advance to remove trees that are infected and replace them with alternatives if requested by the owner of the infected tree.
5. It is best to have a "clean" budwood program established so that infected trees are not propagated by nurseries.
6. Nurseries should be enclosed with screenhouse or greenhouse to exclude ACP and only disease-free budwood should be allowed to propagate trees.
7. Growers should create Citrus Health Management Areas to coordinate spraying if ACP is in the area.
8. Plans to import, rear and release the ACP's natural enemies should be made.
9. Authorities should be sampling for Clas in ACP and trees before their arrival. Urban areas around airports, transportation corridors, citrus nurseries and where there are already citrus trees in gardens should be prioritized. Citrus orchards should be sampled, especially those closest to an ACP or Clas quarantine zone.

After Clas is discovered

1. Survey and sample collection for Clas in trees and in ACP should be extensive and ongoing.
2. Infected trees should be removed as soon as possible, chipped and buried.
3. Trees surrounding the infected trees should be sprayed with insecticide and given systemic insecticide as soon as possible. Treated zones should be as large as practically possible.
4. A quarantine zone should be established. It should be as large as practically possible.
5. Citrus trees, leaves, roots, fruit and prunings should not be removed from th
6. e quarantine zone. Transport of harvested citrus fruit out of the quarantine zone should only be allowed if the fruit is washed and if all leaves are removed. Transport of harvested fruit through a quarantine zone should be prohibited, or if that is not practical, those fruit should be washed then covered while passing through the quarantine zone.

Measures taken now to reduce or eliminate the impact of CG disease will improve the chance of a successful and profitable citrus industry in MENA nations far into the future. Good luck!

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