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Combatting Huanglongbing in Organic Systems

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Abstract— *Huanglongbing (HLB), also commonly known as Citrus Greening Disease, is a wide-spread citrus disease that has devastated the citrus industry. While substantial research has been conducted investigating HLB control methods, the majority of this research is focused on techniques that are not compliant with organic regulations. Management of the HLB vector, the Asian citrus psyllid in conventional citrus is based largely on intensive use of synthetic insecticides, which are banned from use under organic management. Research specifically targeted at investigating control of Huanglongbing in organic systems are rare. However, some studies on conventional groves have included methods that potentially could be incorporated into organic protocols. This review examines research from multiple citrus systems to distill the techniques that could be used under organic certification to help control HLB. Examination of available literature, unpublished research data and grower observations have produced evidence that Citrus Greening may be managed and marketable fruit produced. Strict disease prevention, diligent scouting, ACP control, nutritional support of healthy and infected trees, implementation of biological controls and the planting of cultivars considered tolerant or resistant to HLB may be combined to give organic growers as good a chance as any to produce marketable fruit. The inherent restrictions of organic production may force growers to utilize the very techniques that create a sustainable growing system that puts tree health first; that alone may carry the organic citrus grower past the conventional grower in weathering the storm.*

Keywords— ***Asian citrus psyllid, Citrus, Citrus greening disease, Huanglongbing, Organic.***

I. INTRODUCTION

Huanglongbing (HLB), also commonly known as Citrus Greening Disease, is a wide-spread bacterial citrus disease caused by three identified *Ca*. Liberibacter pathogen species: asiaticus, africanus and americanus. It is vectored by two citrus psyllids: the Asian citrus psyllid (ACP) and the African citrus psyllid, *Trioza erytreae* [1-4]. In the US, the pest of concern is the Asian citrus psyllid which vectors the bacterial pathogen *Candidatus* Liberibacter asiaticus (Clas).

Upon infection in the field, trees have a latency period of six months to two years before visible symptoms of the disease appear. Because there are no practical methods available for growers to diagnose asymptomatic trees, they often serve as hidden bacterial reservoirs for feeding psyllids [5, 6]. Once symptoms emerge, trees often deteriorate rapidly. Roots are damaged, and phloem become blocked, inhibiting the flow of nutrients through the tree [5]. Initial symptoms include yellow-splotchy leaves, similar to signs of nutrient deficiency, and eventually progress to include green, bitter fruit and extensive branch die-off [5-7]. Trees typically decline and become unproductive within four to five years after becoming infected.

The US organic sector as a whole is a $43 billion industry with an annual growth rate of ten to eleven percent [8]. Citrus is an important and stable part of the mix, primarily because families demand organic citrus and expect a steady supply. The US organic citrus industry has an estimated value of $86.6 million, as reported by the National Agricultural Statistical Service [9]. However, this number does not include Arizona or Texas, both of which have an organic citrus presence. While organic citrus represents 1.5 percent of citrus acreage in the United States, it accounts for three percent of the dollar value [10]**.** In other words, organic citrus production is providing a significantly greater economic return per acre planted than non-organic citrus. Organic citrus is also increasingly becoming an important export commodity, with 25.6 million dollars of citrus exported in 2015 [11].

Huanglongbing has caused significant damage to the citrus industry since it was first discovered in Florida citrus groves in 2005. An economic impact analysis covering 2006 through 2011, estimated that Florida, the primary producer of juice oranges, saw total cumulative production decrease by 23%, revenue declined by 16%, and almost 50% of total jobs in the citrus industry were lost [12]. In 2011 it was estimated that 50 – 75% of all Florida orange trees were infected with Huanglongbing [13]. In addition to Florida, Huanglongbing has been found in Louisiana, Georgia, South Carolina, and Texas as well as California, the number one producer of citrus for the fresh fruit market [14-16]. Furthermore, Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, South Carolina and Texas are currently under federal quarantine for the vector of Huanglongbing, the Asian citrus psyllid.

Current methods to reduce the infection of trees by Huanglongbing rely primarily on monitoring, identification and removal of symptomatic citrus trees, in combination with vector population control. However, the majority of research investigating Huanglongbing control methods are focused on techniques that are not available to organic farmers. Management of the Asian citrus psyllid in conventional citrus is based largely on intensive use of synthetic insecticides such as such as imidacloprid, chlorpyrifos, and dimethoate, as well as new insecticides such as cyantraniliprole [17-22]. Studies have investigated the development and use of synthetic pesticides [18, 20], agricultural antibiotics [23, 24], and development of genetically engineered citrus varieties [25].

Research specifically targeted at investigating control of Huanglongbing in organic systems are rare. However, some studies on conventional groves have included methods that potentially could be incorporated into organic protocols. This review examines research from multiple citrus systems to distill the techniques that could be used under organic certification to help control HLB. We summarize published research from conventional systems, research examining the efficacy of organic approved insecticides conducted in a laboratory settings or in conventional citrus groves, organic farmer and researcher experiences, and current educational materials for organic growers, to provide a cohesive guidance for organic citrus growers on HLB management.

II. ORGANIC ACP MANAGEMENT AND CONTROL

To create an efficient ACP control program, first a grower must understand certain vector-pathogen interactions involved in the acquisition, persistence and transmission of Clas by ACP. Psyllids are more attracted to infected trees until they have fed on them; then they prefer feeding on uninfected trees [1]. This behavior is concerning if resets of uninfected trees are being planted near infected trees. Uninfected adult ACP can acquire the Clas bacteria in less than an hour of feeding, yet only 40% test positive for Clas after 35 days. Nymphs aquire the pathogen more readily, and adults resulting from Clas positive nymphs are markedly better at transmission [1, 26]. This is important to understand when one is considering at what life stage the ACP should be targeted for control and how it should be done. It may take up to 25 days for an adult ACP to be able to transmit Clas since the bacteria need to move through the insect's body and into the salivary glands; nymphs can transmit as soon as they become adults [1]. It is clear that targeting adults is important to decrease transmission of Clas and breeding populations of ACP. Controlling nymphs has a twofold impact – reduced acquisition of Clas and reduction of breeding populations.

2.1 Biological Control of ACP

Biological control of ACP includes the use of parasitoids, predators and pathogens that consume or destroy ACP nymphs and/or adults thus reducing populations. Conservation of wild predators as well as augmentation with commercially available biological control agents will have a synergistic effect for growers looking to utilize predation and parasitoidism as a control measure for ACP.

The use of insect predators of ACP has been shown to significantly reduce ACP populations. For example, predaceous arthropods such as lady beetles, lacewings, and spiders are known to consume ACP [27]. Lady beetles alone are highly voracious feeders and one of the most important predators of ACP [18, 27-33]. There are over 6,000 species of lady beetles worldwide and over 105 species in Florida, 106 in Texas and the southwest, and around 200 species in California, making them highly accessible to growers from the wild, though not all prey on ACP [34-36] (Appendix I).

Lady beetles undergo complete metamorphosis during the four stages in their life cycle. During the larval stage, lady beetles are strictly carnivorous predators feasting on ACP nymphs; as adults they are omnivorous able to feed on ACP as well as nectar and honeydew to sustain themselves. Lady beetles can produce several generations per year and adults generally hibernate in winter. In addition to ACP suppression from both larvae and adults, different species feed on various scale insects, mealy bugs, mites, whiteflies and aphids [34].

A study in central Florida showed that when predators such as lady beetles were excluded from citrus branches infested with ACP, the duration of infestation was doubled and the chances of ACP reaching adulthood increased by 120-fold. It was also shown that survival of the parasitoid wasp, *T. radiata*, increased as well due to the fact that they parasitize ACP nymphs. However, in environments that included ladybeetles and other predators, *T. radiate* was relatively ineffective due to competition with local predators. Unfortunately, to date there is no prescription to balance natural enemies [31].

Certain lady beetle species are commercially available for purchase online (Appendix I). The wild species in each region can be encouraged to populate citrus groves by providing alternative food sources from nectar and insect produced sugars such as honeydew. Providing

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alternative food source is an important component of successfully establishing wild or artificially released natural enemies as described in the next section on *T. radiate* [34-36].

The parasitoid wasp, *Tamarixia radiata*, is a tiny wasp that has co-evolved with the Asian citrus psyllid in China and surrounding regions [19]. The female wasp lays her eggs under a fourth or fifth instar ACP nymph. Once hatched, the wasp larva consumes the nymph, attach the shell to the plant tissue and pupate inside. Female wasps may also feed on nymphs and can destroy up to 500 ACP [37]. Though *T. radiata* can establish well in citrus producing climates, mass releases are suggested to maintain and augment populations. Also, studies have shown that the adult wasp may require a sugar source to meet the nutritional needs. Intercropping citrus groves with plants that provide extrafloral nectaries (nectar produced in locations on a plant other than the flower) could support wasp establishment. Suggested plants include Cowpea and Snap bean, both nitrogen fixers that perform well as ground cover and green manure [38].

A second parasitoid wasp, *Diaphorencyrtus aligarhensis*, has been imported and released in Florida [39]; unfortunately, establishment has been unsuccessful. Further evaluation of different species and identification of alternate food sources to sustain the population are needed to utilize the biocontrol potential to our advantage.

Consulting local agencies and extension offices will assist growers in scheduling releases of any beneficial insect in a manner that best suits their individual circumstances.

Isaria fumosorosea Wize (*Ifr*) and associated species are entomopathogenic fungi that are available as commercially formulated products such as PFR-97 20% WDG® (Certis USA). The fungal spores infect target hosts by breaching the insect exoskeleton, entering the body and causing death [40]. Destruction of natural enemies in addition to the target ACP would need to be considered when planning an application. This fungus is known to target insects, even specific species of insects and do not attack plants [40].

A project was conducted in 2013 to develop a system of inoculating ACP with an acutely virulent strain of *Ifr* in the field. The greenhouse study investigated the ACP attractant SPLAT™ (Specialized Pheromone and Lure Application Technology, ISCA Technologies, Inc.) coated with spores from pulverized cotton burrs and blastospores of the *Ifr* fungal pathogen. These substances were added to a bright yellow material with pleated surfaces; the color and shape encouraged ACP to land and walk along the edges while picking up the pathogen which is then carried back to the citrus canopy to infect another ACP. The auto disseminator or dispenser worked well showing 55% of available adults infected within 24 hrs. and 27-35% tree feeding nymphs becoming infected after exposure to adults that had visited the dispenser. Fungal blastospores are negatively impacted by direct sunlight and the dispenser loses effectiveness over time; further evaluation is required to overcome this limitation [41]. Still, this project shows great promise of a tool for a new bio control method for Asian citrus psyllid suppression in organic systems [1].

It was also considered that releasing *Ifr* 'dusted' Clas negative adult ACP might be an efficient means of infecting the wild ACP population. Fungus infected ACP do not feed, so there would be negligible chance of increasing the spread of HLB from them. The study showed some encouraging results and it was considered that this approach may help control psyllid in organic systems, abandoned groves and residential areas due to its effectiveness, safety and environmental friendly approach [40].

Another fungus available for organic application is *Beauveria bassiana*, the active ingredient in the commercially available product Mycotrol ESO® (BioWorks, Inc.) Its mode of action (MoA) is similar to that of *I. fumosorosea*. Reports from farmers show that this product works better than the bacterial products listed below [42].

Chromobacterium subtsugae strain PRAA4-1T (Grandevo® WDG, Marrone Bio Innovations) is a microbial insecticide product containing bacteria that control ACP. According to the manufacturer the multipart MoA includes combinations of insect repellent property, oral toxicity, reduced egg hatch, and reduced pest reproduction. Grandevo® WDG is also gentle on beneficial insects. A field study showed this product able to reduce ACP nymph and adult populations for more than three weeks when applied with FL-435-66 oil [43]. This control method is mentioned in the chemical control section as well.

2.2 Cultural/Mechanical Control of ACP

Cultural control includes any changes to the growing environment or ecosystem and that causes disruption of feeding or breeding of the pest in question; examples include changes in soil pH or use of banker plants. Mechanical control includes activities that are physically destructive to the pest such as soil discing or vacuuming greenhouse plants. These two Integrated Pest Management (IPM) strategies overlap occasionally so they have been presented together.

Since Clas can be transmitted by a single psyllid during a single feeding, most growers dream of completely blocking it out to keep their valuable crops from being exposed to even a single ACP. Citrus Under Protective Screen (CUPS) Production Systems have been developed to address this by preventing the Asian citrus

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psyllid access to the tree. The installation of CUPS can provide protection from ACP and HLB, although insecticides are sometimes used in combination with CUPS [44]. CUPS support normal tree growth, encourages higher yields of premium-quality fruit and reduces fruit drop while allowing for uncomplicated irrigation and fertilizer application in the high-density plantings (1300 trees/acre). The method will be effective if implemented correctly but can be expensive. Putting citrus under screen houses can initially cost up to $1 per square foot and the high-density polyethylene screen may need to be replaced every 7-10 years at up to $0.5 per square foot. There are other negative implications; mites and thrips may enter through the screen and beneficial insects are excluded; greasy spot and other fungal diseases may establish more easily in the more humid atmosphere and extreme weather in the form of tornado or hurricane can dismantle the screen structures. However, it is possible to release beneficial insects into the structure where they will be protected and this may be a practical and useful technique to manage pests. The screen structures can be insured against natural disaster damage, and there are options for treating trees exposed to the elements resulting in potential inoculation with Clas [45-47]. There are methods of treating trees infected with Clas on an individual basis and they will be discussed in the Clas control section.

Citrus grown under screen protection can either be in the ground or in pots. There are benefits to both growing situations with in ground producing a fuller canopy faster but potted trees producing better juice quality. They each produce about the same number of boxes when established. CUPS structures must have the strictest of sanitation standards including decontamination of personnel and equipment entering the structure, regular scouting for pests and pathogens and appropriate pesticide applications. Drip fertigation and planting media augmentation provide nutritional supplementation as desired.

Growing citrus in completely enclosed screen houses has the benefit of reducing frequency of insecticide sprays and excessive nutrition to combat HLB [48]. This reduction in costs could help offset the cost of installation over time.

There are a number of construction companies that specialize in CUPS or similar structure installation[45-47]. It is imperative that state and local building zoning and codes must be followed. It is advisable to check with various agricultural insurance companies to acquire coverage for these structures.

Metallized reflective mulch (MRM) is a highly reflective film that is applied to planting beds [49, 50]. It can provide better tree growth due to increased soil water retention, decreased weed pressure and a reduction in ACP populations and thus the incidence of HLB [49]. MRM is installed by a tractor attachment that unrolls the material, cuts a furrow and tucks the edges around the bed. It is important that the bed be well prepared by weed and grass removal, multiple disc and roto tilling, then leveling, rolling and packing. The trees are then planted by cutting a 1ft by 1 ft. "X" in the MRM and carefully using an auger to dig holes as usual. One-inch poly tubing is run over the mulch for irrigation and fertilization; two drippers are installed per tree. At the time of installation in 2013, the cost was about $600 per acre [51]. The compost used costs about $120/acre/yr. In one trial, Ray Ruby grapefruit trees were exposed to two mulch treatments (organic compost and MRM) and bare ground as the control. The trees planted in MRM grew15% more than the trees in compost mulch and about 20% more than trees in bare ground [52]. In addition to deterring ACP from colonizing young trees, the amplified growth with MRM use could be due to increased photosynthetic light available to trees by reflection, water and nutrients drip irrigation/fertigation conservation and weed control. Farmers who use MRM recommend a grove planting design that uses 8ft wide MRM under trees (particularly around the border), providing habitat/refuges for beneficial insects both outside and within the citrus planting/block/grove to provide biological control for ACP that do enter the area [52]. The farm itself should include a multi-level plan for pest and pathogen control including water quality testing with careful irrigation management, compost use, scouting and careful, conservative application of chemical control.

The Photonic Fence (PF) is a laser system that identifies, tracks and kills flying insects. At this time, this technology is not available to growers and is still in the experimental stages but in future this could protect citrus groves from ACP very efficiently. The Photonic Fence is an optical system able to monitor a boundary for motion, evaluate and identify specific species of insect by wing beat frequency and, if the movement matches the identification profile in the database, destroy the insect with a single laser pulse [53]. This type of technology will be useful in protecting resets or new grove plantings.

2.3 Organic Compliant Chemical Control of ACP

Chemical control methods are numerous and varied, but many materials currently used for ACP control that are compliant with organic standards are untested. Here, only chemicals and combinations of chemicals that have been found to have some success will be presented for consideration. The Organic Materials Review Institute (OMRI) produces an online publication that enables interested parties to search for products and confirm approval with ease [54].

Combining insecticides with 435 horticultural oil has repeatedly been shown to improve ACP control, particularly adults, producing higher mortality for longer periods of time [18, 43, 55]. As stated previously in the Bio control section, Grandevo (*Chromobacterium subtsugae)* mixed with oil provides excellent adult psyllid and nymph control for up to three weeks. Products such as M-Pede (potassium salts of fatty acids), Sil-Matrix (potassium silicate), Entrust SC (spinosad), and Grandevo, when applied alone, provided an average of only two weeks of control at a rate consistent with standard synthetic insecticides which are not approved for organic application [18]. The important take away message from these studies and publications is that:

1. Insecticides approved for organic production use can work almost as well as standard synthetic insecticides but provide control for a shorter period.
2. OMRI approved insecticides should be applied in rotation and diligently in response to insect scouting and sampling counts that meet action thresholds; this could mean every 2 weeks.
3. OMRI approved horticultural oils not only provided strong control (80% adult mortality in some studies) when used alone but can increase adult ACP mortality to 97% when combined with other products such as M-Pede or Grandevo.

SucraShield (Natural Forces, LLC) or sucrose octanoate, is a synthetic version of natural sugar esters found in the leaves of the wild tobacco species *Nicotiana gossei*. Lab and field trials showed a >90% control of ACP nymphs and adults when treated with a 2% formulated product and a thorough coverage [56].

III. BACTERIAL MANAGEMENT AND CONTROL

3.1 Biostimulants for tree health

The term biostimulant can be generally applied to any substance beneficial to plants while not being a nutrient, pesticide or soil amendment. Through the application of such substances it is reported that plant growth (particularly root growth) is improved, tolerance to biotic and abiotic stresses is better and nutrient uptake is increased [57]. Common Classes of biostimulants include humic acids, microbial inoculants, protein hydrolysates and amino acids, and seaweeds.

In nature, humic acid is a byproduct of microbial metabolism during the decomposition of organic matter. Products containing humic acids have been shown to significantly increase dry weight of plant tissue, increase soil fertility and improve uptake of macro and micro nutrients by roots.

Microbial inoculants are marketed as biofertilizers that contain living microorganisms such as free-living bacteria named plant growth promoting bacteria and rhizobacteria (PGPB and PGPR), fungi, and arbuscular mycorrhizal fungi (AMF). These substances, when applied to plant tissue, seed or soil promote growth by increasing nutrient supply, root biomass and nutrient uptake [57].

Protein hydrolysates and amino acids come from a variety of sources including the recycling and processing of plant and animals waste products. These products have been shown to be safe in conventional as well as organic farming systems [58]. It has been shown that plants readily take up amino acid and peptides through foliar application or root uptake. In the plant these substances act as a plant growth stimulator and enhance tolerance to biotic and abiotic stresses such as disease, pest feeding, drought, nutrient stress and more. It is believed that this Class of biostimulants may decrease plant toxicity by heavy metals through chelation [57].

Seaweed extracts have long been used in farming systems for their ability to increase utilization of mineral nutrients by plants, improve soil structure and aeration and promote root growth while also increasing crop yield, flower set, fruit production, and tolerance to stresses. It is believed that the biostimulant effects come from plant growth hormones and related low molecular weight compounds contained in seaweed products. Some researchers maintain that some larger molecules such as polysaccharides and polyphenols may also be biochemically important as allelochemicals and for enhancing stress resistance. Brown seaweeds such as *Asophyllum nodosum, Fucus, laminaria, Sargassum* and *Turbinaria* spp. are most commonly used to produce commercially available product which, when applied in low dilution concentration such as 1: 1,000, produce beneficial plant growth and health responses [57].

Biostimulants are regulated and the EPA requires companies to label biostimulant products as either biopesticides or biofertilizers, though the product neither of these. Biostimulant products currently lack a specific regulatory path that would enable developers to register products according to their intended use, benefits, and safety [59].

3.2 Impacts of Micronutrients

Improved micronutrient nutrition can be a key part of combating HLB, as research has found that providing a constant elevated supply of micronutrients can help restore root function, tree health and productivity [60]. In addition to causing micronutrient deficiencies in leaves, HLB can cause severe micronutrient deficiencies in the roots of infected trees. Impacted nutrients include calcium, magnesium, iron, zinc, manganese, boron, sulfur and copper [61]. This may be a cause of one of the primary symptoms of HLB, feeder root loss [62]. Indeed, large doses of micronutrients significantly reduce feeder root loss, with a triple dose of manganese as the most effective treatment for maximizing feeder root density. Additionally, large doses of manganese and boron might reduce Clas bacterial titers, as applications of high quality Controlled-Release Fertilizer (CRF) supplemented with extra manganese and boron to HLB impacted field trees have been found to significantly improve tree health and productivity [63]. Current research is examining the optimum levels of each nutrient required for maximum tree health and productivity in an HLB endemic environment, as well as the most economically viable methods for supplying the nutrition [60].

3.3 Potential Bactericide Therapies

The use of nanoparticles (NPs) as an alternative to traditional antibiotics is well on the way to becoming the treatment of the future for bacterial infection and disease. Simply put, NPs are particles between 1-100 nanometers (1 nanometer equals 1 billionth of a meter) in size and often have a surrounding interfacial layer of ions and organic or inorganic molecules that greatly affects the particle properties[64]. Though the antibacterial mechanisms are not well understood, it is generally accepted that the bacterial cell is destroyed due to oxidative stress induction, metal ion release and certain non-oxidative mechanisms. These mechanisms create disruption of the bacterial cell membrane, generating ROS (reactive oxygen species), penetration of the bacterial cell membrane and induction of intracellular antibacterial effects including interactions with DNA and proteins [65]. These reactions result in bacterial cell death. Since these mechanisms often occur simultaneously, the bacteria would require multiple simultaneous gene mutations to attain resistance to NPs [65].

Copper products, such as Magna-Bon CS 2005, are used in citrus production for their antibacterial properties to treat a variety of microbial infections including citrus canker. Metal oxide nanoparticles (MeO-NPs) are the focus of many research projects studying potential bacteria destroyers [66]. MeO-NPs such as zinc oxide (Zinkicide ™) are being carefully evaluated by scientists hoping to be able to provide a bactericide that growers can apply to existing HLB infected trees and be used to prophylactically protect new resets. Zinkicide™ is designed to release Zn in a sustainable manner; it is thought to travel through the leaf cuticle into the mesophyll and on to the phloem where Clas resides [67]. This is a promising technology for the future.

The use of nanoparticles in the treatment of disease for both plant and animal species is well on the way to becoming common place. Still, for these products to be available to organic farmers it will take grower participation with careful monitoring of the status of these treatments and a proactive approach to getting the products approved for organic application, if possible.

Extreme environmental stresses can kill any living organism and it is reasonable to consider that a citrus tree exposed to extreme stresses such as drought, nutrient stress and heat would become a most inhospitable environment for Clas bacteria to live and thrive. For example, an experiment conducted by USDA and University of Florida researchers found that trees that were intermittently exposed to nutrient and drought stress exhibited a Clas titer equal to that of non-inoculated controls. These trees also later presented a growth rate that *surpassed* the non-stressed trees [68].

Therapies such as this should be utilized for emergency treatment only. For example, if a valuable tree was exposed to ACP accidentally a grower could try to discourage bacterial establishment and proliferation by creating an environment inside the tree that Clas may not be able to survive in.

Thermotherapy (heat treatment) has attracted attention as a possible cure for huanglongbing in organic citrus. It has been shown that thermotherapy can extend the life of the tree by slowing down the progression of HLB, however thermotherapy may also be damaging to the tree itself.

While thermotherapy is compliant with organic standards, aquiring the equipment may be costly or difficult to access. In the field it is possible to treat small to medium sized infected trees with a retractable tree covering enclosure, portable steam generator and a truck and tractor. The apparatus moves along the row treating tree after tree [69]. Under controlled lab conditions, Clas was significantly reduced or eliminated entirely with a continuous exposure to 40-42ºC temperatures for a minimum of 48 hours [70].

These are just a few examples of past research and the effort continues. A mobile trailer unit for treating potted citrus is being investigated which would pair nicely with CUPS systems in areas like Florida where extreme weather like hurricanes could expose trees to ACP occasionally. It is clear from the laboratory research that thermotherapy can kill Clas, now it is a matter of field trials and practical application.

3.4 Commercially Available Varieties/Breeding

The discovery, production and commercial availability of HLB tolerant and resistant rootstock and scion varieties may be the *silver bullet* organic growers need to be able to put HLB behind them. A tolerant variety acquires the disease yet continues to produce fruit while resistant varieties are inhospitable hosts to the Clas bacterium and infection rate is low or nonexistent.

At this time scientists and breeders are reluctant to suggest rootstock or scion varieties to a grower looking for reliable relief from HLB. Field trials are being conducted and cultivars are on the verge of release, but there is no perfect variety for every situation. During a presentation at the 2018 Florida Citrus Show, a USDA scion breeder stated that they had 14,000 new hybrids in field trials with another 7,000 on the way [71]. Though progress has been made, there is no variety that can be recommended with absolute certainty of resistance or tolerance to HLB. There are many factors to consider when choosing a variety for resets or a new planting. State, local and individual site characteristics have a great influence on how a tree will perform. Data suggests that climate, soil characteristics, and pest and pathogen pressure all have an influence on how a variety will respond to HLB [72].

There is also variability of the pathogen itself. There are hundreds of 'isolates' or bacterial populations with genetic diversity within the three strains of Candidatus *liberibacter* (Candidatus *liberibacter* asiaticus, africanus and americanus, although the latter two are irrelevant for U.S. growers) [73]. It is not fully understood how isolate variation may impact the tree response and impact of the disease. The recommendation is that a grower access their state and local grower's groups, nurseries, University Extension agents and USDA scientists for advice as to what they should plant and where. Every grove is different and it takes the intimate knowledge of the farming area for a recommendation on variety to be made with confidence.

Clearly, there are scion varieties that perform better under HLB pressure than others. For example, data suggests that varietal pedigrees that include citron (*Citrus medica*) may be more tolerant to HLB than many others while distant citrus relatives such as Orange Jasmine (*Murraya paniculata*) and the Curry Tree (*Bergera koenigii*) are highly resistant [72]. *Poncirus trifoliata* and its hybrids have been shown to be among the most resistant citrus to HLB, as rootstocks, however, the resistance does not benefit the scien when used as a rootstock [74]. Rootstocks have a significant influence on the productivity and disease resistance of citrus trees [75].

The breeders of citrus are working to produce scion and rootstock cultivars that tolerate or resist HLB and there are some very promising data being collected. It is only a matter of time until these new releases are provided to growers to plant in their commercial groves; it is unfortunate that the process is a slow one.

IV. CONCLUSION

Huanglongbing is one of the most researched plant diseases at this time. Hundreds of millions of dollars have been spent on research and every journal article includes the phrase '*and there is no cure'*. Despite this plethora of research, there is still a dearth of information on methods that are compliant with organic cultivation. This means that if current research provides a solution that uses a banned substance or method (such as synthetic pesticides or bioengineering) it will not be available for use by organic growers. This paper attempts to provide information that organic citrus growers can use immediately to help slow the spread of HLB while research continues on controlling this devastating disease. It is the recommendation of the authors that future research include additional organic-compliant options such as Integrated Pest Management (IPM) techniques, as they may provide long-term solutions that are at a lower risk for ACP development of resistance.

Additionally, regionally specific information on ACP control is critical. The ACP control methods addressed in this investigation are only a few of what may be available or used in any specific area of the country. It is paramount that a grower applies many control practices simultaneously to get the most effect from each. IPM acts synergistically; the results of the combined efforts will be better than the sum of each part added individually.

Organic growers should prioritize selecting HLB tolerant or resistant varieties when planting or resetting, even if it means a variety shift from previous plantings. Growers should reset or plant the oldest tree available from nursery stock, and encourage nurseries to adjust to keeping trees under protection longer- the longer in the nursery, the longer in the field.

Moving trees under protective screen enclosures is one of the safest strategies available to organic growers; the trees can be grown in pots as referred to in this document. If a breach of biosecurity occurs, an emergency treatment plan should be utilized such as thermotherapy or abiotic stresses to clear as much bacteria from the trees as possible immediately.

Organic farmers should also support the health of the tree as much as possible. Getting leaf tissue analyzed for nutrient concentrations will allow for adjustments to the fertilization program to address any deficiencies.

In areas where groves are not inundated with HLB (e.g. Florida), farmers can send tissue samples to extension offices for HLB testing. A positive result should result in the tree being culled immediately. Any tree with blotchy mottle should be tested for HLB.

Unfortunately, organic citrus growers will have to learn to live with HLB until available varieties are unaffected by the disease. Just as conventional farmers have benefitted from practices that are integral to organic farming such as crop rotation, cover cropping, integrated pest management, etc., the organic grower community could benefit from accessing conventional citrus grower functions, conferences and meetings. While most research is geared toward conventional production of citrus, this does not mean that the organic community should not participate. There are many breeding programs and therapies being investigated that should interest organic growers. The citrus industry worldwide is evolving in an effort to combat HLB; growers of organic citrus are doing the same. Over time, they will succeed and resume producing abundant, fresh and healthy organic citrus for their consumers.

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Appendix I: Known predators, pathogens, and parasitoids of Asian citrus psyllid

Common Name	**Scientific Name**	**Mode of Control & target life stage**	**Availability**
Lady beetle	*Curinus Coeruleus*	predator	wild
Lady beetle	*Olla v. nigrum* Mulsant	predator	wild
Lady beetle	*Rodolia carinalis* Mulsant	predator	wild
Lady beetle	*Harmonia axyridis* (Pallas)	predator	wild
Lady beetle	*Cycloneda sanguinea* (L.)	predator	wild
Lady beetle	*Adalia bipunctata*	predator	Avail online
Lady beetle	*Hippodamia convergens*	predator	Avail online
Lady beetle	*Coelophora inaequalis* (Fabricius)	predator	wild
Lady beetle	*Cryptolaemus montrouzeri* Mulsant	predator	Avail online
Lady beetle	*Azya obigera* Mulsant	predator	wild
Lady beetle	*Brachiacantha dentipes* (Fabricius)	predator	wild
Lady beetle	*Exochomus childerni* (Mulsant)	predator	wild
Lady beetle	*Chilocorus stigma* (Say)	predator	wild
Lady beetle	*Coleomegilla maculate* Mulsant	predator	wild
Spiders	*various species*	predator	wild
Green lacewing	*Chrysoperla carnea*	predator, nymph and adult	Avail online
Brown lacewing	*Family Hermerobiidae*	predator, nymph and adult	Avail online
Predatory mite	*Amblyseius swirskii*	predator, eggs and nymphs	Avail online
Parasitoid wasp	*Diaphorencyrtus aligarhensis*	parasitoid of nymphs, predator of adults	Failed to establish, needs further research
Parasitoid wasp	*Tamarixia radiata*	parasitoid of nymphs, predator of adults	Avail online
Pathogenic fungi	*Isaria fumosorosea* Wize	pathogen of nymphs and adults.	PFR-97 20% WDG®
Pathogenic fungi	*Hirsutella citriformis* Speare	pathogen of nymphs and adults	
Pathogenic fungi	*Lecanicillium lecanii* Zimm	pathogen of nymphs and adults	
Pathogenic fungi	*Beauveria bassiana* (Bals.) Vuill.	pathogen of nymphs and adults	Mycotrol ESO®
Pathogenic fungi	*Cladosporium* sp. nr. *oxysporum*	pathogen of nymphs and adults	
Pathogenic fungi	*Acrostalagmus aphidum* Oudem.	Pathogen of nymphs and adults	
Pathogenic fungi	*Paecilomyces javanicus*	Pathogen of nymphs and adults	
Pathogenic fungi	*Capnodium citri* Berk. & Desm.	Pathogen of nymphs and adults	