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Mobile Batch Heat Treatment System for Treating HLB-Infected Citrus Trees

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Abstract. *Citrus production in Florida is devastated by citrus greening disease, also known as HLB. The HLB is a phloem-limited bacterial disease of citrus, and currently, there is no known cure for it. Previous research has shown that heat treatment slows down the progress of this disease and increases the production life of HLB-infected trees. The objective of this research was to develop a mobile heat treatment system using steam to heat treat individual small- to mid-sized HLB-infected citrus trees under field conditions. The mobile heat treatment system consisted of a tree-covering enclosure system attached to a citrus hauling truck, a portable steam generator, a water tank, a water supply pump, and an electric generator. The tree covering enclosure system was built in a reverse U-shape frame attached to the side of the truck and was hydraulically operated. The frame was covered by a relatively heat-resistant opaque plastic tarp to completely cover an area of about 14 m^3 in volume. The steam was supplied from a diesel-operated portable steaming generator, which was loaded on the back of the hauling truck. The inside temperature of the tree enclosure was monitored using four thermocouples and a data logger. More than 1600 trees of different varieties and ages were treated in more than 10 different locations. Trees were steamed at different temperatures and for different durations. It took about 25 to 30 s to hydraulically unfold the tent and cover the tree, fold it back, and move to the next tree. However, raising the air temperature within the tent to about 60°C took 60-90 s depending on the ambient temperature and wind speed. The treatment duration was between 0-6 min. The apparatus is simple in design and efficient for field use. However, the long-term effect of heat treatment is still under investigation.*

Keywords. *Citrus orchards, Heat treatment, Huanglongbing (HLB), Disease, Steam, Thermotherapy.*

Introduction

The citrus industry in Florida and several other citrus producing area in Brazil and China is suffering from citrus

greening disease, also known as HLB. HLB is a fatal disease to citrus trees with no known cure. HLB-infected trees have low production and low fruit quality and could die within about three to four years.

Several research projects are underway to control HLB or at least suppress its bacteria to prolong the production life of the infected trees. The research focuses on finding plants resistant to the disease (plant breeding), using agrochemicals to control the psyllid that transmits the disease, and some other techniques. Raising the temperature of infected-trees (heat treatment) could be a promising technique to control the HLB. Heat treatments (thermotherapy) have been used for plant disease control for a long time (Grant, 1957; Kunkel, 1936; Nyland & Goheen, 1969). However, most of these attempts were conducted under controlled environment in the laboratory.

In a controlled-growth chamber, Hoffman et al. (2013) exposed citrus seedlings infected with HLB to different heat treatments for a duration of 2-120 days. The qPCR results indicated a reduction in the level of HLB bacteria within the treated seedlings as compared with untreated ones. Based, on their results, exposing the seedlings to 40-42°C continuously for a minimum of 48 hours eliminated or significantly reduced the HLB bacteria in the treated citrus seedlings.

After trees have been infected, they will need to be treated under field conditions. This requires covering individual trees and raising their temperature. Some work has been done in which the tree is covered in the field with a plastic tarp, and the temperature under the plastic enclosure is raised by sunlight. Covering the HLB-infected citrus trees with clear plastic on a sunny day raised the inside air temperature to 55°C for at least 4 hours a day. These conditions resulted in healthier trees than non-treated ones (Ehsani, Corcuera, & Khot, 2013). The fruit and juice quality of the heat-treated trees was also improved. However, this method of thermotherapy is time-consuming and directly influenced by the weather conditions.

Thus, there is a need for a controllable and practical heat source to treat individual trees in the field in a short time. Higher temperatures could kill the bacteria that cause HLB as well as the hosts (infected trees). However, depending on the treatment temperature and duration, the treated tree might re-grow healthier. One advantage of heat treatment is that it is more environmentally friendly than using agrochemicals. The objective of this work was to develop a mobile system that uses steam to treat HLB-infected citrus trees.

Materials and Methods

Design Concepts

Using steam to treat HLB-infected citrus trees under field conditions requires an enclosure to cover the tree canopy and hold the steam for a certain amount of time. The high temperature of the steam, which could damage the tree if it exceeds some limits, requires a fast removal of the cover from the tree. Random distribution of the infected trees within each grove requires a movable heating-system and the ability to treat individual trees. In addition, the whole steaming system needs to be usable in different field conditions. Thus, the following concepts were considered during the system development:

- Simple and easy to operate by most growers
- Low initial cost
- Easily moves on the road and inside citrus fields
- Treats individual trees

A frame of four reverse U-shape square metal tubes was created and attached to the side of a citrus hauling truck. All the tubes are pivoted together from bottom to be stacked vertically to the truck side for transportation. However, their upper ends can be hydraulically moved away at different distances from the truck side to form a support frame that covers the tree canopy. The frame was covered by a relatively heat-resistant clear plastic tarp to create a canopy enclosure of about 14 m^3 in volume (Figure 1). The enclosure has a base of 2.9 m length × 2.8 m width with 2.3 m in its highest part. It takes about 25 - 30 s only to unfold the enclosure, fold it back, and move to the next tree. However, steaming time varies based on different temperatures and durations required for each treatment. During the transportation, the lower side of the frame was about 0.3 m above the ground while it was touching the ground for good sealing during the heating. Attaching the enclosure to a truck made it easy to move within groves, as infected trees were randomly located within each grove.

An external steaming machine (Steam-Flo, Sioux Corporation, USA) was loaded on the truck to provide the steam. A gas powered portable generator to operate the steamer and a 100-gallon water tank to supply water to the steamer were also loaded on the truck. Two electrical fans were also used inside the enclosure to improve the steam distribution around the canopy. A stopwatch was used to monitor the starting and ending time of each treatment and the duration of keeping the tree covered. The steam was transferred from the

steamer into the enclosure through a heat resistant hose with two outlets. After covering the infected tree, the steam was manually directed into the enclosure through a three-way ball valve. When the inside temperature reaches the targeted level, the steam will be diverted outside the enclosure and the tree will stay covered for the required duration. The steam might be redirected into the enclosure to maintain the inside temperature at the intended level. Then, the enclosure will be lifted and moved with the truck to the next tree.

Data Collection and Evaluation Variables

Until now, more than 1600 trees, visually diagnosed as HLB-infected, were treated by the heating system in more than 10 different locations in Florida. The trees were different in their varieties (tangerine and orange), ages (0.5-17 years), and the level of HLB infection (severe and low). The temperature inside the enclosure was measured at four locations (0.6 and 1.8 m heights at both sides of the tree) by thermocouples and data logger (12 Channels Temperature Recorder, Omega, Taiwan). The temperature was recorded continuously at 1-second intervals. The recorded temperature will be used to explain any changes in the plant reaction towards the steam. Pictures for the treated trees were taken before the treatment and after (at different periods of time). They will be used for visual comparisons and perhaps image processing to determine any changes in the canopy and foliage characteristics. Before that, visual changes on the plant such as killing the whole plant, some of its branches, or dropping the leaves and fruits were noticed periodically and used to modify the steaming temperature and duration. Leaf samples were taken before and after some random treatment for a PCR analysis to determine any changes in the HLB bacteria population. The yield also was sampled from some trees and juice quality was studied.

Figure 1. First prototype of a citrus canopy-steaming enclosure. A) before covering the tree and B) covered the tree.

Results and Discussion

Temperature Rise vs. Time

Air temperature under the enclosure was raised to different levels. It was also kept at those temperatures for certain periods of time (Figure 2). The figure shows that temperature changes over time look similar for different treatments. However, raising the temperature to higher temperatures took more time. Thus, the treated plants were kept under the heat stress for different durations. It took about 68 s and 145 s to raise the air temperature under the enclosure to the 55°C and 65°C, respectively. Higher temperature at short duration or lower temperature at longer duration might have similar effects on the plant and the bacteria causing the HLB. However, the higher the temperature at shorter duration could be more economical as it speeds up the work.

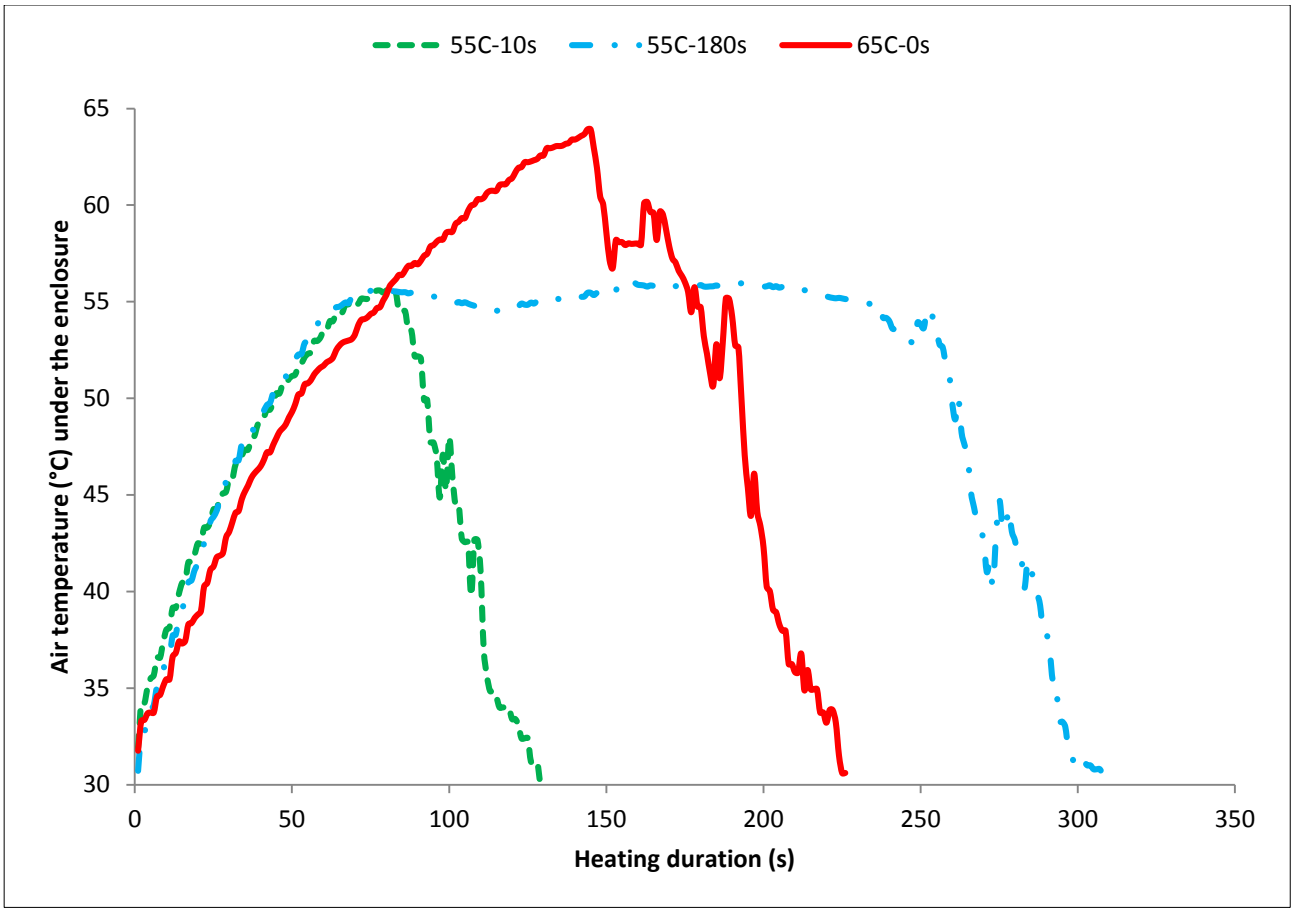

Figure 2. Heat rising under the enclosure for different temperatures and durations.

Operation Speed

The machine productivity, as tree per time unit, depends mainly on the steam-generator capacity, targeted temperature, and the duration to reach that temperature and keep the tree under it. Other factors such as the ability to move the enclosure between trees, operator efficiency, and water and fuel supply also affect machine productivity.

Within about 1-2 minutes, the steam was able to raise the air temperature within the enclosure to about 50-60°C. The enclosure also maintained the inside temperature to some extent after shutting the steam off. Only two people were able to run the whole system and able to treat about 10-20 trees per an hour. However, those numbers varied based on the targeted temperatures and durations.

Physical Effects

During the first attempts, a few trees were killed due to the high temperature of the steam. Other trees were not physically affected by the treatments due to the low temperature and durations. However, heating temperature and duration were adjusted to the level of dropping most of the leaves and leaving as much as possible of the fruits. At that level of steaming, most of the treated trees were able to grow back, produce new flushes, and grow more foliage (Figure 3). It was visually noticed that increasing the temperature is more effective on reducing the plant's physical damage than extending the heating time. However, choosing the best combination of the temperatures and durations are still under investigation.

Fruit Quality

The processing of fruit quality of the treated trees is still ongoing. However, initial results of some samples showed significant changes in some juice qualities due to different heating temperatures and durations. Figure 4 shows increase in the Brix of the juice as temperature increased. Longer heating durations resulted in higher Brix, but the change was less than that of higher temperature. The acidity of the juice was not affected by the heat treatments. However, the Brix/acid ratio increased significantly at higher temperature or longer duration. In all cases, fruit quality of the heated trees was not different from those of the untreated ones.

Figure 3. A citrus tree was steamed at 55°C for 4 min. A, B, C, and D are the images for the same tree before the treatment, at 2, 10, and 15 weeks after the treatment, respectively.

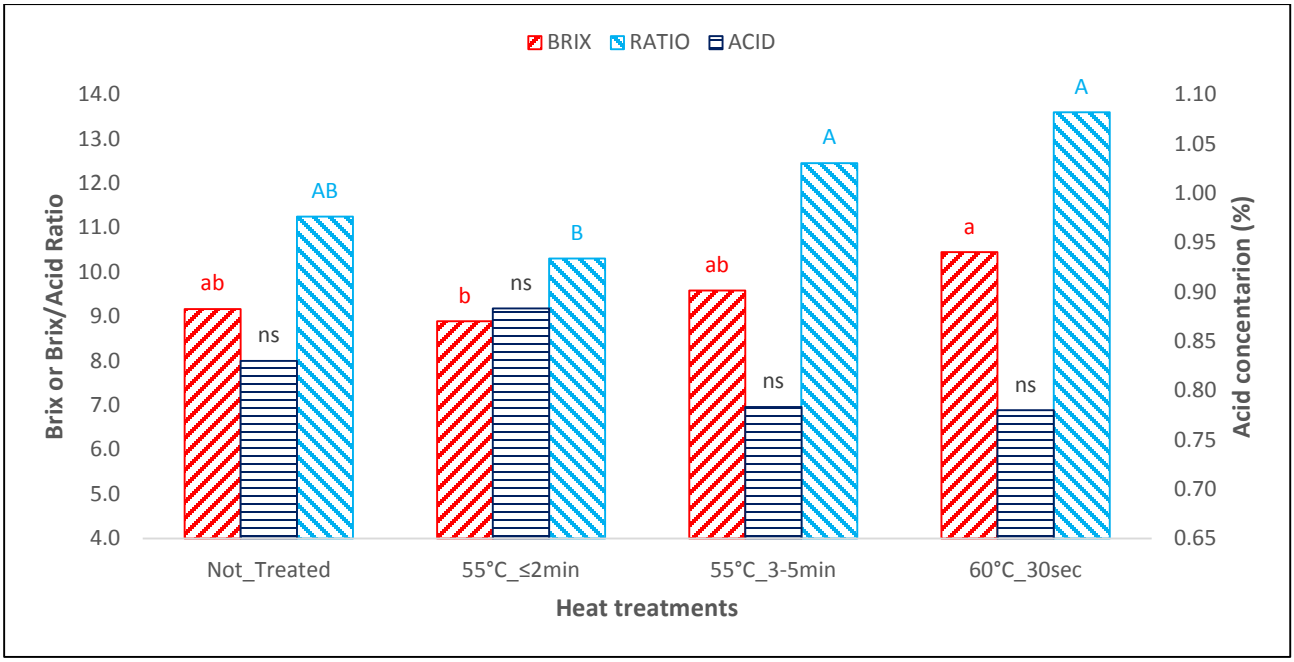

Figure 4. Total soluble solids (Brix), the acidity (acid), and the Brix/acid ratio of citrus juice as affected by heat treatment.

Conclusions

The developed prototype of heating system was able to efficiently cover small- to mid-size citrus trees, raise their surrounding air temperature to about 55-65°C within about 1-2 minutes. These treatments dropped most of the tree leaves and some fruits yet allowed the trees to regrow to some extent. The biological effects and best time-temperature setting for the steam treatments of HLB infected citrus trees are still under investigation. For future work, more data will be collected about the effect of steam on the HLB bacteria population, citrus production, and quality of the treated trees.

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