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MAGAZINE — WINTER 2023

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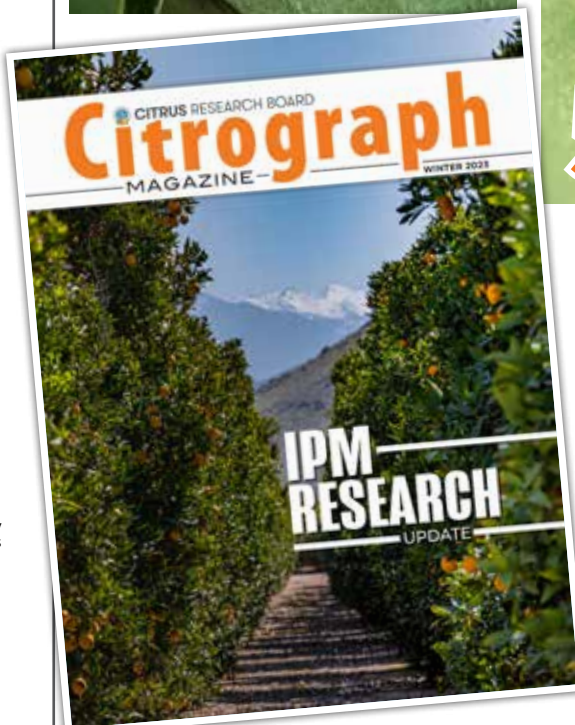
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**On the Cover:** Welcome to the winter 2023 issue of *Citrograph*. We hope you enjoy reading this edition of the magazine, which focuses on integrated pest management (IPM), including a look at current CRB-funded research into this important area. Our editorial and production teams sincerely wish each of you a very healthy, happy and successful new year.





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**THE MISSION OF THE CITRUS RESEARCH BOARD**  
 Ensure a sustainable California citrus industry for the benefit of growers by prioritizing, investing in and promoting sound science.

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## JANUARY 26 CITRUS RESEARCH BOARD (CRB) MEETING.

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# From the PRESIDENT'S DESK

Marcy L. Martin

Marcy L. Martin

October marked the beginning of the Citrus Research Board's (CRB's) fiscal year, and for many California citrus growers, the new season commenced. Mother Nature ultimately dictates the timing of all activities that may follow; regardless, the CRB's efforts carry forward. With the budget finalized, the crop estimate decided upon and the portfolio of research projects approved, we are prepared for the coming year.

With this new year, we welcome the slate of elected officers for the 2022-23 fiscal year with Justin Brown of Citricove Orchards in District 1 returning for another term as Chairman. Mark McBroom from Bloom to Box Crop Care Inc. in District 3 will serve as Vice Chairman, and John C. Gless III of Gless Ranch in District 2 will serve as Secretary/Treasurer. We are certain this slate of officers will confidently guide the CRB through the next year, and we will support them in their efforts.

The CRB calendar is nearing completion and includes committee meetings and events that will take us through the entire season. Board and committee members were notified of their research committee appointments in late November, and January marks the first research committee meetings of the season. Our committee makeup includes Board members, staff and subject experts. While all Board members participate within many committees, we encourage growers interested in one or two subject areas to reach out to us if you would like to participate. These are our core committees:

- » New Varieties Research
- » Vectored Diseases Research
- » Production & Post-harvest Technology Research
- » Pest Management Research
- » Citrus Clonal Protection Program Committee

By January, the Research Priority Screening Committee (RSPC) will review and approve the Request for Proposals (RFP) for selecting 2023-24 projects. March is the month we invite pre-proposals for full proposal consideration.

The CRB's scope of research priorities align with the mandate under our marketing order, but growers and the Board determine the critical areas and allocate funding based on these criteria. This *Citrograph* edition emphasizes Integrated Pest Management (IPM) as an integral component of farming. I want to highlight two continuing projects the CRB's Board selected.



## Jay Rosenheim, Ph.D. (earwig work)

Jay Rosenheim with the University of California, Davis currently is working on a project to determine the damage caused by European earwigs and identify effective management options for citrus growers, as information to date about earwig damage potential, monitoring and management is lacking. Rosenheim has been investigating the type of damage earwigs are causing in citrus, including when citrus is most vulnerable to this damage. His research identified that sweet oranges and clementines are susceptible to severe damage by earwigs, but true mandarins like 'Tango' are naturally resistant. Furthermore, fruit is only vulnerable when very small and typically before four weeks after petal fall. This information will allow growers to differentiate between earwig damage and damage caused by other pests. For management practices, Rosenheim has been investigating the use of trunk barriers and insecticide applications, which not only have an effect on earwigs, but also on other citrus pests like Fuller rose beetle and ants. Rosenheim will continue exploring management options to provide growers with a complete integrated pest management program for European earwigs. More information from this research project can be found on page 56.

## Sandipa Gautam, Ph.D. (mealybug work)

Sandipa Gautam with the University of California-Agriculture and Natural Resources is working within the more extensive Citrus IPM Program supported by the CRB to address increasing reports of mealybug infestation throughout the Central Valley. Citrus mealybug can be a significant issue as an infestation can reduce tree vigor, cause fruit contamination and fruit drop and ultimately lead to reduced fruit quality. Gautam's early response to this issue will focus on determining the seasonal ecology of mealybugs in the Valley to optimize pest monitoring and treatment thresholds. In collaboration with Jacob Wenger, Ph.D., at California State University-Fresno, Gautam will identify the peak times and placement of lure traps for citrus mealybug males to improve monitoring windows for this pest. Preliminary pesticide trials are underway to identify products with the greatest efficacy and residuality in reducing mealybug populations. More information from this research project can be found on page 32.

Beginning in late January and continuing throughout the year, the CRB will support or host several grower events. The University of California, Riverside will host Citrus Day in early spring. The CRB will host its annual Grower Educational Webinar series in early summer; and this year, we plan to host a Post-harvest Conference in late summer. Please visit [www.citrusresearch.org](http://www.citrusresearch.org) for scheduled dates and registration information.

As the new year begins, we invite you to utilize the resources that the CRB has available for you. Our website hosts a collection of reports from each of our core research areas, plus past issues of *Citrograph*, each with a wealth of valuable information, while our various grower events provide educational opportunities throughout the year with the latest updates from our researchers. We wish all growers a healthy and joyous new year, and we look forward to working with you to advance California's citrus industry. 🍊

***Marcy L. Martin serves as the president of the Citrus Research Board, based in Visalia, California. She also is the executive editor of Citrograph. For more information, please contact [marcy@citrusresearch.org](mailto:marcy@citrusresearch.org)***



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2022-23 RESEARCH AGENDA APPROVED AT

# CRB ANNUAL BOARD MEETING

Caitlin Stanton



JUSTIN  
BROWN



MARK  
MCBROOM



JOHN  
GLESS III



The Citrus Research Board (CRB) met on September 20, 2022, to approve the annual budget and refine the 2022-23 research agenda. Board members and guests traveled from around the state to the Lindcove Research and Extension Center in Exeter, California, to attend the meeting. Joining the Board members were representatives from California Citrus Mutual (CCM), the California Citrus Quality Council (CCQC) and the California Department of Food and Agriculture (CDFA).

**“This yearly meeting of the Board is imperative to reaffirm support for the crucial research projects being funded within our priority areas”**

CRB President Marcy L. Martin

During the meeting, each committee chair provided an update on their group’s activities. They shared an impressive slate of research projects and informed attendees about current developments at the BSL-3 Laboratory, the Citrus Clonal Protection Program and the California-focused Citrus Research and Field Trials (CA-CRaFT) Program. New projects, as well as continuing projects, were approved in the New Varieties Research, Vecteded Diseases Research, Production and Post-harvest Technology Research, and Pest Management Research committees. Additional information on the FY2022-23 new and continuing projects will be shared in the upcoming summer issue of *Citrograph*.

The Finance Committee provided an update on the CRB’s financial position. The Board remains committed to ensuring that fiscal responsibility is one of the organization’s key principles. An overview of the CRB’s financial position also will be shared in the summer issue. A discussion of the FY2022-23 budget yielded key decisions such as a commitment to hosting a Post-harvest Conference in 2023 and organizing the rescheduled International Research Conference on Huanglongbing (IRC HLB) for 2024.


The Board voted to increase the current assessment rate of \$0.03/carton to \$0.032/carton, with a total estimate of \$6,000,000. More than 66 percent of this funding will be spent on core research programs that will benefit growers

with field-level applications. This rate has been sent to the California Department of Food and Agriculture Secretary for approval.

Executing vital research projects, maintaining an appropriate budget and communicating these activities to the growers remain the primary focus as the CRB mission is carried out.

The CRB staff looks forward to working with the Board and its various committees to continue the mission of the organization as we strive to maintain a sustainable citrus industry established on sound science. 🌱

**Caitlin Stanton is the communications coordinator with the Citrus Research Board and also serves as the editorial assistant on *Citrograph*. For more information, please contact [events@citrusresearch.org](mailto:events@citrusresearch.org)**



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# CITRUS CONFERENCE

## CALIFORNIA CITRUS CONFERENCE Highlights Important Research

Caitlin Stanton

Joining the 2022 California Citrus Conference from the University of Maryland, Anne Simon, Ph.D., shared how RNA therapeutics could be helpful for disease control in citrus.







**M**any citrus industry members gathered together for the California Citrus Conference on October 19, 2022, in Visalia, California. Nearly 350 attendees arrived at the Visalia Convention Center to listen to notable industry updates and gain insight from a slate of Citrus Research Board (CRB)-funded researchers and agricultural experts. The one-day conference provided a needed opportunity for essential citrus research to be shared through several talks and more than 20 scientific posters.

Casey Creamer of California Citrus Mutual (CCM) opened the conference with an overview of their current advocacy work and how research can play a role in affecting change. CCM has worked closely with the CRB during the past year to develop proactive strategies to address neonicotinoid and imidacloprid regulations so that these pesticides can continue to be available for citrus growers. Creamer shared that the Farm Bill has been an additional topic of interest as CCM has relied on the CRB to integrate crucial research into the push for more citrus-related funding. In addition, CCM has engaged various members of Congress to initiate funding for the expansion of the U.S. Department of Agriculture (USDA) citrus breeding program into the USDA Agricultural Research Service facility in Parlier, California, with funding still to come. Creamer added that there are still many issues to solve, but CCM has made substantial differences by focusing on the aforementioned areas.

“I don’t know what is next—nobody does. There are a lot of issues in front of us, but I can tell you, **we will roll up our sleeves and work together to make the best of any situation that comes before us**”

Casey Creamer

CRB Chief Research Scientist Melinda Klein, Ph.D., provided an update on the California-focused Citrus Research and Field Trials (CA-CRaFT) program. The program is working with growers to test and demonstrate different ACP mitigations for California commercial citrus growers in those areas with endemic ACP populations. Applications currently are being reviewed, and late submissions may be accepted as time and space permit. Visit [www.citrusresearch.org/growers-application](http://www.citrusresearch.org/growers-application) for more information.

Joining the conference from the USDA’s Horticultural Research Laboratory in Fort Pierce, Florida, Kim Bowman, Ph.D., shared an overview of new rootstocks for use in California. There are seven rootstocks that are available for use now, with 350 other hybrid rootstocks currently in trials that aim to address the ongoing huanglongbing (HLB) devastation to Florida’s citrus industry. A number of USDA rootstocks have been cleaned by the Citrus

Clonal Protection Program (CCPP), and additional, new, promising additions are being submitted to the CCPP on a regular basis. These rootstocks have shown exceptional performance with sweet oranges in Florida, including some quality results with mandarins and lemons.

Sonia Rios of Bayer Crop Science provided a look at weed management in citrus, with insight into herbicide choices for different weed situations. Herbicide resistance has become an issue over the last several decades, with broadleaves such as horseweed, fleabane and palmer amaranth, and grasses such as ryegrass, annual bluegrass and junglerice confirmed as resistant in California citrus orchards. In addition, resistance is suspected in lambsquarters, alkaliweed, threespike goosegrass, feather fingergrass, windmillgrass, sprangletop and witchgrass. Rios recommends managing resistance by creating a preventive program of field scouting and weed identification, as well as implementing tank mixes, sequences and rotations of key treatments. Prevention is the most important step in controlling weeds, but care should be taken to control weeds as they will often arrive unnoticed and can cause further problems if left untreated.

Peter Larbi, Ph.D., of the University of California, Agriculture and Natural Resources (UCANR), shared an overview of how citrus producers can minimize spray drift potential with on-target canopy deposition. To achieve the most effective spray application, the sprayer should be well-adjusted to target the canopy of the tree so that the spray is accurately spread throughout the tree without excessive drift. Larbi added that an effective spray has more considerations beyond applying the desired gallons per acre. UCANR has an airblast spray advisor web application that can help growers determine the best spray by inputting tree characteristics, orchard conditions, weather and application parameters. This helpful tool can be found at [www.ucanr.edu/sites/Airblast\\_Spray\\_Advisor/](http://www.ucanr.edu/sites/Airblast_Spray_Advisor/).

RNA therapeutics could be the future of disease control in citrus, according to Anne Simon, Ph.D., a professor at the University of Maryland. Simon's talk gave a summary of current research efforts going on in her lab on the use of short interfering (si) RNAs (a class of double-stranded RNA that can interfere with the expression of other genes) to control citrus diseases. By introducing and distributing these molecules in citrus trees through the citrus yellow vein-associated virus (CYVaV) key genes in specific pathogens can be targeted and silenced to limit disease development by the pathogens. While current work is testing the effects of these small RNA molecules in reducing levels of citrus tristeza virus, this work has potential broader applications to other citrus diseases. Simon added that additional work is being done to determine how to best use the CYVaV vector to deliver anti-bacterial peptides.

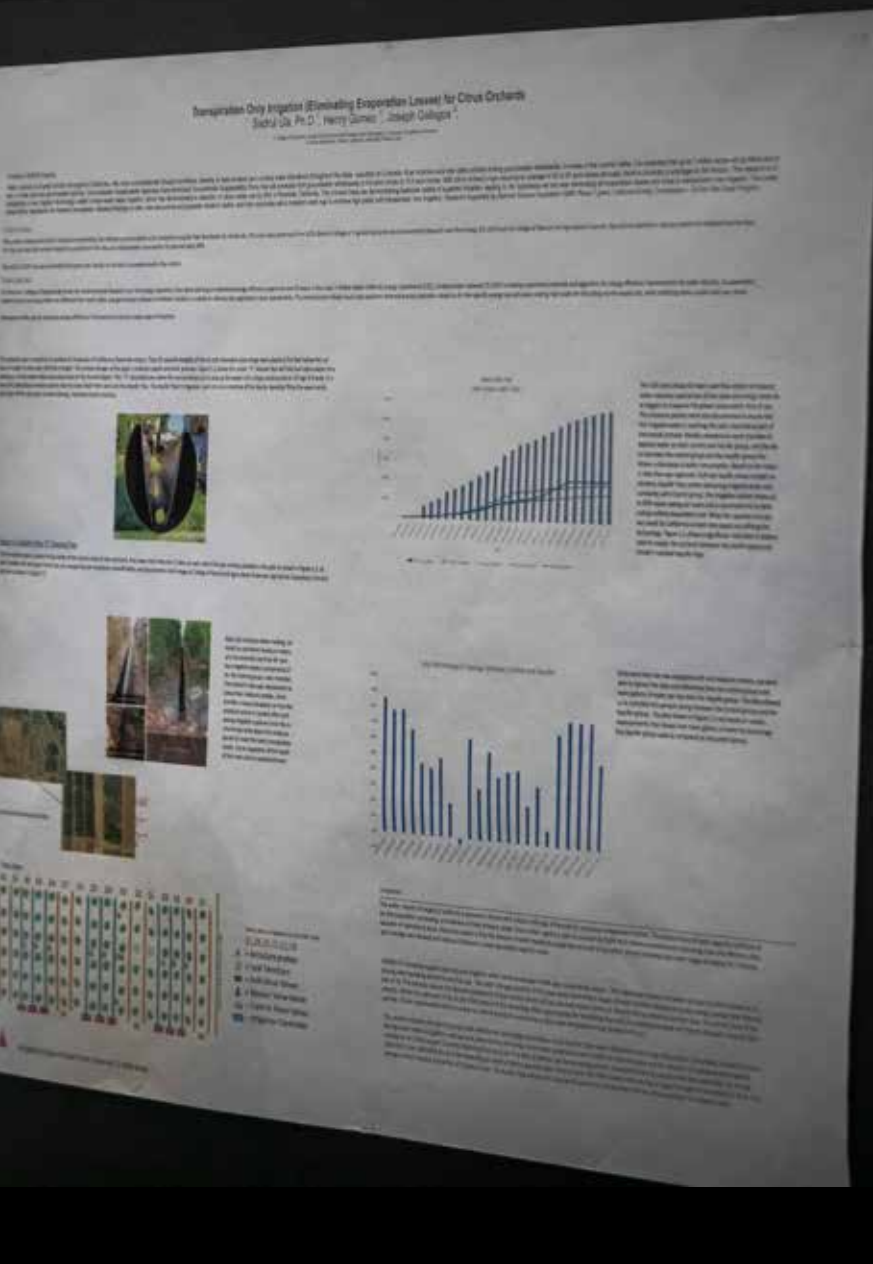


**An attendee of the 2022 California Citrus Conference viewed a research poster during scientific poster touring.**



**More than 300 citrus industry members attended the 2022 California Citrus Conference held at the Visalia Convention Center.**





Between sessions, growers had the opportunity to visit with researchers during scientific poster touring. Researchers from around the country shared applicable studies ranging from breeding HLB-tolerant citrus hybrids to results of mealybug and Asian citrus psyllid (ACP) field trials. More than 20 posters were on display, providing growers and researchers alike the opportunity to discuss some of the citrus industry's most innovative research.

To begin the afternoon sessions, Deputy Agricultural Commissioner/Sealer Amanda Zito from the Fresno County Department of Agriculture presented an update on pesticide laws and regulations. There are several significant upcoming changes regarding pollinator protections, medical supervision, carbon monoxide pest control devices, neonicotinoids and licensing adjustments. Regarding pollinator protections, the time of bee inactivity has been updated to include inactivity when the temperature is below 50°F. If bees are in the field, label restrictions apply. New regulations of carbon monoxide pest control devices have been developed to direct how these tools can be used to eradicate vertebrate pests, including specification of use at certain distances from structures. Neonicotinoid regulations likely will be updated soon to include application method and rate restrictions, application timing restrictions and seasonal application rate caps. Lastly, Zito provided an update on new licensing requirements including expanded competencies for the private applicator certificate that will result in a new examination for all current license holders.



**Reza Ehsani, Ph.D., University of California, Merced, provided a hopeful future for the use of robotic harvesting in the citrus industry.**



**Members of the citrus industry gathered during the 2022 California Citrus Conference.**



**Members of the citrus industry gathered during the 2022 California Citrus Conference.**

Sandipa Gautam, Ph.D., area citrus Integrated Pest Management (IPM) advisor for the UC IPM Statewide Program, shared an update on citrus IPM research in the San Joaquin Valley (SJV). Gautam covered citrus thrips resistance to insecticides, detailing a recent trial that found four products that work well to control thrips scarring: Exirel®, Beleaf 50 SG®, Plinazolin SC® and Plinazolin® DC. Citrus mealybug also has been of concern recently in the SJV and affects all citrus fruit. A recent study at the Lindcove Research and



Amanda Zito of the Fresno County Department of Agriculture presented an update of pesticide laws and regulations.

Extension Center found mealybug throughout tree canopies and at almost all parts of the growing season and as many as six generations in a year. To control these populations, Gautam stated that it is important to complete multiple applications.

Labor is a considerable aspect of citrus production that eventually may be aided by robotic harvesting, shared Reza Ehsani, Ph.D., of the University of California, Merced. There are many challenges to overcome before robotic harvesting of citrus can be achieved, including apparatus design to accommodate tree shapes and grove geography, as well as determining the correct technology for picking fruit from the tree. While robotic harvesting may have significant challenges, work is ongoing, and developments are being made to address the global need for mechanization with the goal of reducing costs and increasing outputs.

In addition to labor, water remains one of the most important issues in California's citrus industry. Daniel Cozad of the Central Valley Salinity Coalition stated that the Central Valley Salinity Alternatives for Long-term Sustainability (CV-SALTS) program is working to sustain reliable and high-quality water supplies for all in the SJV, including agricultural producers. The CV-SALTS program aims to provide safe drinking water, reduce nitrate and salt impacts and restore groundwater quality. Salt accumulation is an issue in the SJV and directly affects the quality of production areas. Nitrate control is an additional part of the CV-SALTS program, as nitrates can cause health effects when found in drinking water. To address the discovery of nitrates in SJV water, Sarah Rutherford of the Kaweah Water Foundation stated they are conducting a domestic well-testing program to determine where nitrates are being found and to provide safe drinking water to those in areas with affected water. The CV-SALTS program will continue to cultivate discussions regarding water use and quality to improve water availability for all SJV residents.

Jason Bills of Aerobotics shared that growing fruit is a complex and challenging practice that requires new

technologies to adapt to changing needs. Incorporating precision farming software into traditional farm management can elevate production practices by reducing labor, increasing available information and monitoring on a larger scale. Imagery allows growers to collect data to track grove health, yield, volume and more. Over time, these data provide growers with a wealth of information that will allow decisions to be made through a new lens and can ultimately improve the quality of fruit, health of trees and viability of groves.

To round out the conference, Jay Rosenheim, Ph.D., of the University of California, Davis provided an overview of IPM guidelines for mandarins, specifically spring pests. Mandarins make up a healthy percentage of California's citrus production, although they do come with their own IPM challenges that must be addressed, as many of the current guidelines for other varieties of citrus may not apply. Mandarins are naturally resistant to both katydids and European earwigs, which can attack young fruit and result in heavy scarring. The damage that these pests inflict also may be mistaken for the damage of other pests. With this research concluded, Rosenheim and his team are working to update the UC IPM Pest Management Guidelines for mandarins.

For those who missed the conference, select talks are available to view on [www.citrusresearch.org](http://www.citrusresearch.org). The CRB would like to thank all of the speakers and researchers who presented at the conference, as well as the industry members who attended. Please stay tuned for more upcoming events and opportunities to learn about "the best of the best" in citrus research. 🍊

***Caitlin Stanton is the communications coordinator with the Citrus Research Board and also serves as the editorial assistant on Citrograph. For more information, please contact [events@citrusresearch.org](mailto:events@citrusresearch.org)***





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Chet Roistacher picked fruit from the original Parent navel orange tree in Riverside, California in 2014.



Roistacher conducted training in Tucuman, Argentina, in 2005.



In 1961, Roistacher planted the first Citrus Clonal Protection Program Foundation block tree at the Lindcove Research and Extension Center.

# IN MEMORIAM: CHET ROISTACHER

Robert R. Krueger, John Bash and Georgios Vidalakis

Chester “Chet” Roistacher died September 29, 2022, at the age of 98 years. Chet was a staff member of the University of California, Riverside (UCR) Department of Plant Pathology starting in 1949. During his time at UCR, Chet was instrumental in the development of the Citrus Variety Improvement Program, which later evolved into the Citrus Clonal Protection Program (CCPP). The CCPP has the mission of producing and distributing “clean/sanitized” budwood to the California citrus industry. Chet was involved in the development of many citrus sanitation techniques such as the use of a sterilized substrate for the production of citrus rootstocks and indicators, sterilization of citrus seeds, biological indexing for citrus disease diagnosis and thermotherapy and shoot-tip grafting for pathogen elimination. The techniques developed and used at the CCPP remain global standards.

Chet also was involved in the 1960s efforts to create a marketing order to support research, quality and the production of citrus nursery stock free from viruses and mutations. This marketing order is the Citrus

Research Board (CRB), arguably one of the most impactful programs in research and development for the California citrus industry.

After his retirement in 1986, Chet traveled and lectured extensively on citrus pathology, contributing toward the establishment of many citrus quarantine and sanitation programs around the world. He conducted a short course in citrus



pathology for 26 years in Bari, Italy, aimed at students from the Mediterranean and Arab countries. Chet was an author on over 200 publications, including the "Handbook for Detection and Diagnosis of Graft-Transmissible Pathogens of Citrus," the standard reference in this area. In recognition of his contributions, Chet was bestowed an Honorary Doctorate Degree by the University of Pretoria, South Africa, in 1999.

Chet was an early member and eventual Fellow of the International Organization of Citrus Virologists (IOCV), of which he was Chair from 1989 to 1992 and Secretary from 1992 to 2007.

Away from work, Chet was an avid musician who especially enjoyed playing classic American folk music on his mandolin. Other enjoyments included fishing and spending time with his family in the Sierra Nevada and local San Jacinto Mountains, where Chet's ashes were scattered near his beloved cabin.

He was preceded in death by his wife Jeanne Roistacher and his son Mark Roistacher, and is survived by his four daughters – Robin Kinzer, Sandy Roistacher, Leslee Menke

and Dawn Frier – seven grandchildren and two great grandchildren.

Although it has been decades since he had an active role in the CCPP, Chet's unbounded energy and enthusiasm are still felt. His engaging presence, positive influence and thorough knowledge of graft-transmissible citrus diseases and their impacts are still missed. 🙏

**Robert R. Krueger, Ph.D., is the research leader at the U.S. Department of Agriculture-Agricultural Research Service National Clonal Germplasm Repository for Citrus and Dates in Riverside, California. John Bash is a retired staff research associate and manager of the Citrus Clonal Protection Program (CCPP) at the Department of Plant Pathology and Microbiology at the University of California, Riverside (UCR). Georgios Vidalakis, Ph.D., is a professor and University of California (UC) extension specialist in Plant Pathology at the UCR Department of Microbiology and Plant Pathology and also serves as the director of the CCPP. For more information, please contact [vidalg@ucr.edu](mailto:vidalg@ucr.edu)**

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Area-wide treatments help to further boost our industry's efforts in the fight against ACP.





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# BEFORE IT'S TOO LATE

Kevin Ball

As the threat of huanglongbing (HLB) continues to loom over California citrus, it's no secret to industry members that the best way to prevent HLB from infecting our groves is to limit populations of the Asian citrus psyllid (ACP), which can spread the bacteria associated with this deadly plant disease. But while actions like area-wide or coordinated grower treatments continue to be important to further boost our industry's efforts in the fight against growing ACP populations, we must do everything we can to best prepare ourselves and our industry in the event that HLB – or other dangerous pests and diseases – make their way into our groves. And, while we may not want to think about a day where our commercial operations may become impacted by deadly diseases such as HLB, it's best that we prepare now and be well equipped to act swiftly to handle the unthinkable.

The Citrus Pest and Disease Prevention Program (CPDPP) has been working to keep its foot on the accelerator in the ongoing fight against invasive pests and diseases and best provide the industry with the resources needed. As part of these efforts, the CPDPP recently worked to develop a response guide that clearly lays out the actions to be taken should a plant sample be confirmed positive for 'Candidatus Liberibacter asiaticus' (CLAs) – the bacterium that causes HLB – after being collected from a commercial citrus grove. And while, as of November, HLB had not yet been confirmed in a commercial grove, resources like the response guide will ensure that a comprehensive and science-based response to such a detection occurs seamlessly. The response guide currently is available on [CitrusInsider.org](http://CitrusInsider.org), where industry members can download the guidelines, as well as a handful of other helpful resources on the matter.

HLB isn't the only deadly plant disease for which the California Department of Food and Agriculture (CDFA) staff surveys. The CDFA staff also administers a multi-pest survey throughout areas of California – in both residential properties and commercial operations – to accurately assess major pest and disease threats to California's citrus trees.

Through the multi-pest survey, the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) confirmed positive identifications of citrus yellow vein clearing virus (CYVCV) on a residential property in the city of Tulare after being detected by the CDFA in the spring of 2022. As a result of this detection, the CDFA and APHIS have been conducting ongoing survey activities for CYVCV in Tulare, Fresno and Kings counties on residential and commercial properties. These learnings – coupled with the CDFA's



**A California Department of Fruit and Agriculture official surveying and collecting Asian citrus psyllids.**

robust pest prevention system that focuses on exclusion and monitoring, as well as the CDFA and USDA's experience responding to other vectored disease threats – are critical in developing an appropriate regulatory response. Along with surveys like the multi-pest survey implemented throughout California, which includes surveying for the ACP and HLB, it allows CDFA staff to be fully equipped with the proper resources to identify dangerous pests and diseases that may be looming in backyard citrus trees and potentially in our groves.

The cost to proactively manage threats to our California citrus – including the increased spike in ACP populations this past year – is far less than what the potential costs would be if diseases like HLB spread into our commercial groves. As we look to the impacts that our colleagues in Florida and Texas have had to endure over the last several years, California growers must take proactive measures to not only protect their groves from a similar fate, but to protect the future of California citrus.

The CPDPP has been dedicated to improving efficiencies to ensure we are maximizing the dollars entrusted to the program in keeping HLB out of our commercial operations. As part of the industry's comprehensive efforts, several measures have been set in motion across California to protect the state's coveted crop, including the development of a Science Advisory Panel, increased utilization of biocontrol to suppress ACP populations, and swift action in the state of a crisis. The program continues to rely on citrus growers and other stakeholders in our continual pursuit of identifying ways we can improve. Let's work together to best prepare ourselves and protect our beloved citrus crop for generations to come. 🍊

**Kevin Ball is the outreach subcommittee chair for the Citrus Pest and Disease Prevention Committee. For additional information, please contact [kevin.ball@aglandca.com](mailto:kevin.ball@aglandca.com)**





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# INDUSTRY VIEWS: **THOUGHTS ON IPMI**

McCall Machado





*This issue of Citrograph is focused on integrated pest management (IPM). We recently asked several citrus industry members for their insight on current IPM issues in California.*



**BRYAN HARDEN**  
Director of Pest Management,  
Booth Ranches  
Tulare County

**What pests are you currently seeing the most and what steps are you taking to combat them?**

The past couple of years have been a challenge with thrips. Chemical control has been inconsistent. Years like these make clear the importance of monitoring each block twice a week. This allows us to catch a product failure before significant scarring occurs and to re-treat if necessary.

I'm extremely concerned with citrus mealybug; I feel this will be one of the top three pests of citrus within the next five years. We are trying many different products, looking for something that will keep the pressure low. We also are releasing anagyrus wasps to see what kind of control we can achieve.

**What improvements would you like to see in IPM to better support the industry?**

There is little to no information available for citrus mealybug. Everything at this point is trial and error looking for control measures. In my opinion, more focus needs to be placed on this pest. As an industry, more effort needs to be made to help understand the basics, such as degree days before crawler emergence. Knowing this will go a long way to help contain mealybug. Once established, it could be that control isn't an option; the goal then will switch to just trying to contain it.

*Photo courtesy of Sandipa Gautam, Ph.D.*





**JOSH  
PLUMLEE**

**Crop Consultant, PCA/CCA  
Nutrien Ag Solutions,  
Lindsay Branch  
Tulare County**

**What pests are you currently seeing the most and what steps are you taking to combat them?**

There were three primary pests that dominated my 2022 season: citrus thrips, California red scale (CRS), and citrus mealybug. Thrips populations were high for many growers in Kern, Tulare and Fresno counties. Reduced pesticide efficacy and supply chain issues added to the challenge. Ultimately, I found that combining chemistries provided the best opportunity for extended control. The challenge then became doing so in an economical manner for the grower. It was a difficult thrips season for many, and without new chemistries, it isn't likely to get any easier in the years to come.

The California red scale populations are increasing as degree days continue to accumulate. I've seen the most success in controlling these populations in programs that utilize mating disruption and thorough monitoring for breakout populations. If scale is detected on the fruit, a spray with a systemic or contact product could be warranted, depending on the severity and timing.

While citrus mealybug is not as widespread as citrus thrips and CRS, it has become increasingly concerning. It's a relatively new pest that likely is becoming established as a result of chlorpyrifos being removed from the California market. Previous chlorpyrifos use probably kept the pest from becoming established. We're still determining which current products on the market will be most effective at controlling this pest.

**What improvements would you like to see in IPM to better support the industry?**

PCAs and growers need the proper tools to practice IPM. As products are regulated out of the market, the remaining products see more use, rotation cycles are shortened and, ultimately, opportunities for pests to develop resistance are increased. We need manufacturers to develop citrus pest-specific products that will fit in an IPM program and bring them to the California market. We also need the California Department of Pesticide Regulation (DPR) to be much more efficient in the review/approval process. The current rate of product approval by DPR is directly inhibiting our ability to develop and operate within an IPM program. 🙏

*(Editor's Note: Please see page 32 for an update on citrus mealybug IPM.)*

**McCall Machado is the communications and event coordinator for the Citrus Research Board. For more information, please contact [mccall@citrusresearch.org](mailto:mccall@citrusresearch.org)**

*Photo courtesy of Sandipa Gautam, Ph.D.*



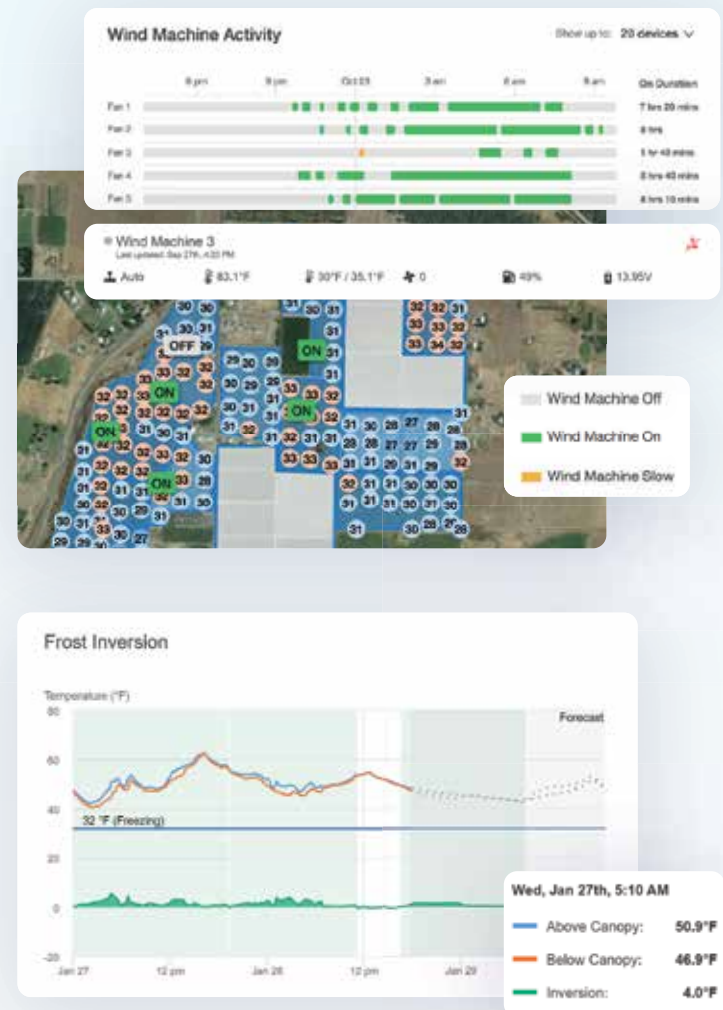
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# CORE IPM RESEARCH UPDATE

## Working Toward Citrus Mealybug IPM

Sandipa Gautam

**D**uring the last two years, citrus mealybug increasingly has been reported infesting lemons, navels, grapefruit and mandarins in the San Joaquin Valley. Citrus mealybug is a small, (about three millimeters long) soft-bodied insect with a distinctly segmented body covered with mealy wax. Mealybugs feed by extracting plant sap, thereby reducing tree vigor, reducing yield and contaminating fruit. They mostly are found under dense foliage or between fruit clusters.

**Figure 1. Citrus mealybug infestation - a cluster of mandarins showing mealy wax (white substance on fruit surface) and sooty mold (black substance on fruit surface). Note: light infestation - a fruit was lifted to show hidden infestation where fruits were touching in a cluster.**



Citrus mealybug has been present in the California citrus system for more than 50 years, but historically has not been a pest of concern in the San Joaquin Valley (Ebeling 1959; Grafton-Cardwell et al. 2020). Heavy mealybug infestations first were observed by some pest control advisors (PCAs) in Fresno and Tulare counties in 2019-20. In 2021-22, extensive infestations (**Figures 1 and 4**) were found by pest control advisors (PCAs) over a larger acreage that included Kern, Kings, Tulare, Fresno and Madera counties.

In the past, mealybug populations in citrus growing regions have been kept in check by natural enemies (Ebeling 1959). However, that ecological balance seems to be shifting. Though the factors that may have contributed to the increase of citrus mealybug are not well understood, there are three plausible reasons:

- » **a) loss or reduced use of insecticides** – loss of chlorpyrifos, reduced use of systemic neonicotinoids and lack of effective ant control products may have helped mealybug populations to develop over time,
- » **b) decline in natural enemies** – by the use of broad-spectrum insecticides or weather conditions affecting mealybug natural enemies and
- » **c) hidden nature** (between fruit clusters or under thick canopy leaves) of citrus mealybug infestations that can be overlooked.

It is likely that one or more of these factors are helping mealybugs survive better while natural enemies are affected. Without natural enemies, citrus mealybug can be destructive and hard to control because of its high reproductive rate, clumped distribution and overlapping generations (Ebeling 1959).

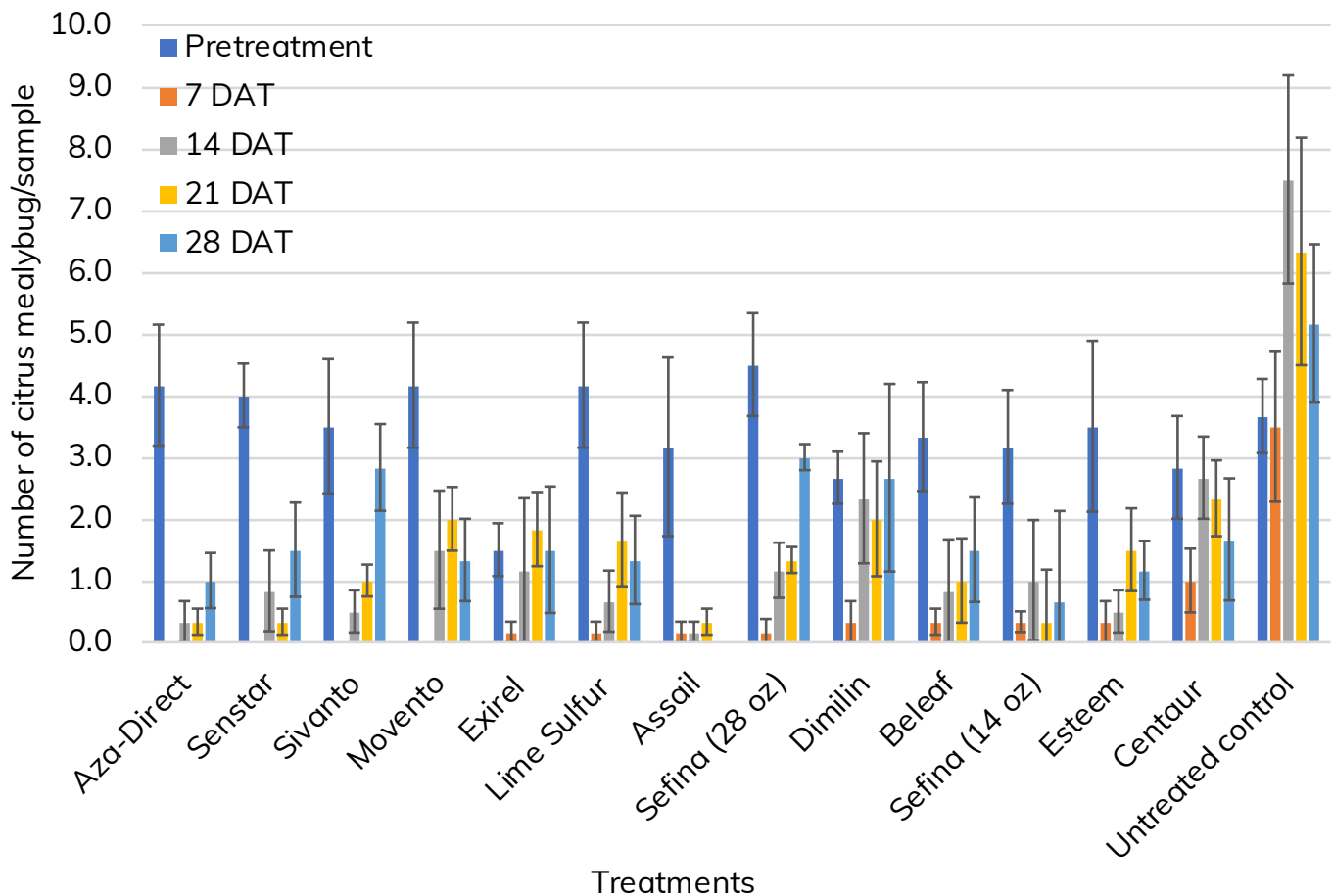
Mealybug management in citrus is challenging because little is known about the general biology, how to best scout or monitor for this pest, seasonal effects on the life cycle and appropriate management practices



**Figure 2. A staff member wrapping double sticky tape around a tree trunk to monitor the movement of citrus mealybug within the tree canopy.**

(tools and timing) for optimal control. In 2022-23, Fresno State University Associate Professor Jacob Wenger, Ph.D., and I will be leading research to address questions that will generate much needed information for integrated management of citrus mealybug. The following objectives will be addressed:

- » **Biology** – studying developmental biology of the citrus mealybug to determine upper and lower thresholds for optimal development under different environmental conditions.
- » **Scouting/monitoring** – investigating the use of pheromone monitoring traps against citrus mealybug and determining appropriate trap densities. Seasonal phenology will cover some aspects of scouting by reporting mealybug populations on trunk/branches, leaves and fruit throughout the season.
- » **Seasonal phenology<sup>1</sup>** – describing the movement of citrus mealybug in citrus orchards, determining the number of generations in one season and exploring degree day units required for key developmental events, e.g., male flight, crawler emergence.
- » **Management** – testing the efficacies of registered chemicals and biocontrol methods to provide management tools for growers and PCAs in the 2023 season.



**Figure 3. Efficacy of insecticide treatments to reduce citrus mealybug populations up to four weeks. Results are ordered by the most effective treatment on day 7 (left to right). Products with label recommendations for low volume insecticide applications were applied at 125 gallons per acre (gpa) while the remaining products were applied at 750 gpa. DAT = Day after treatment.**

## Preliminary Studies in 2021-22

In February 2022, my team and I initiated a preliminary trial to understand where mealybug populations were present within the tree and to follow their movement in the tree canopy throughout the season. This is an ongoing study. Thirteen trees with known infestation continue to be monitored since 2021 (Figure 2). We are using two methods – namely, visual monitoring of five sooty mold-infested leaves per tree and ten fruit per tree (when present) and using sticky tape on trunks and inner branches and counting the number caught on tapes to monitor movement. Sooty mold is a fungal disease that grows on leaves/fruit surfaces covered by honeydew. As mealybugs produce honeydew while feeding, the presence of sooty mold on the leaf/fruit surface can be an indicator of mealybug infestation. The number of mealybugs on each sample (leaf/fruit/sticky tape) have been counted.

## What Have We Found?

- » **February-March** – While population pressure early in the season was low, citrus mealybugs were present on leaves with sooty mold, usually hidden underneath

the dense canopy. Populations mostly consisted of dying females (a potential carry-over source from the previous season), egg sacs and early immatures. Signs of mealybug infestation, including the presence of white mealy wax and egg sacs, were seen on leaves/trunks even though live mealybugs were not present.

- » **April-June** – Mealybug crawlers were on the move. Crawlers/adult females and egg sacs were observed on inner canopy branches. Egg sacs/dead females also were observed on the trunk.
- » **July-August** – Most populations were found on fruit, although they also were present on leaves. Overlapping generations (live adults and immatures from two or more generations) were observed.

Given these observations, 2023 field trials to study seasonal phenology will be optimized to monitor populations in different orchards with known populations, using male trap cards, leaf sampling and fruit sampling.

Another critical research need for citrus mealybug management is the evaluation of new pesticides – determining which treatments work best and when to apply. We conducted a field trial on a 10-acre block of 12-year-old spring navel oranges in Ivanhoe, California, in March-





**Figure 4. Ants attending mealybug colonies. Note bleached feeding spots and overlapping generations showing adults and immatures.**

April 2022 with applications made on March 29. Rates and volumes followed manufacturer recommendations (125 or 750 gallons per acre [gpa]) and grower standards of crop production. Products with label recommendations for low volume insecticide applications were applied at 125 gpa, while the remaining products were applied at 750 gpa. All applications included a 0.5 percent oil and Exit® or Nu film 17®, except Lime sulfur UltraTM. Pre-treatment and week one

data were collected by counting the number of mealybugs on five leaves with signs of sooty mold per tree. Fruit was not inspected as the block was previously harvested.

All products tested reduced citrus mealybug populations compared to the control treatment, but did not eliminate them (**Figure 3**) despite low population pressure. All treatments reduced populations in week one, but

populations started increasing in week two. Observations revealed that pesticide coverage is critical, and surviving populations consisted mostly of crawlers, suggesting new hatches. Another critical observation in this trial was that the citrus mealybug population moved into the tree canopy from the outer canopy leaves starting the second week of April. For this, we updated week two through four post-treatment data collection method to a one-minute timed search on the tree trunk and inner canopy branches.

From this past year's research, we have identified three key factors for addressing the use of insecticides for citrus mealybug management. In 2023, insecticide trials will be optimized to address these issues.

- 1. Early-season and mid-season control.** During early season, mealybug infestations are present on outer canopy leaves and appear in the canopy in late March/early April. This population is the first generation of the season from overwintering eggs or from surviving females laying egg sacs; therefore, early populations are uniformly distributed and on the leaves. In mid-season, mealybugs move into the inner canopy and onto the fruit.
- 2. Thorough insecticide coverage is critical.** As mealybugs move into the tree canopy, they can be present everywhere on the tree including twigs, branches, trunk, leaves and fruit, thorough coverage is important. Use no less than 750-1,000 gallons per acre. Open the tree canopy by pruning, especially skirt pruning and hedging trees.
- 3. Multiple applications with different active ingredient.** Eggs protected within the egg sacs are not likely killed with insecticides. A second insecticide application within seven to ten days after the first application, targeting new hatch, may be necessary.

## Other Focus Areas

We have found ants foraging on mealybug colonies, especially on fruit (**Figure 4**). Research also will explore identifying different ant species tending mealybug colonies and combining ant control methods with mealybug management.

Mealybug samples collected from citrus orchards in Tulare and Fresno counties have shown signs of parasitism. Natural enemy populations also will be identified and their activity explored as a tool for integrated management of citrus mealybug. 🐜

### CRB Research Project #5500-501

## Glossary

**Phenology:** The study of the field ecology of an insect in relation to biotic and abiotic factors.

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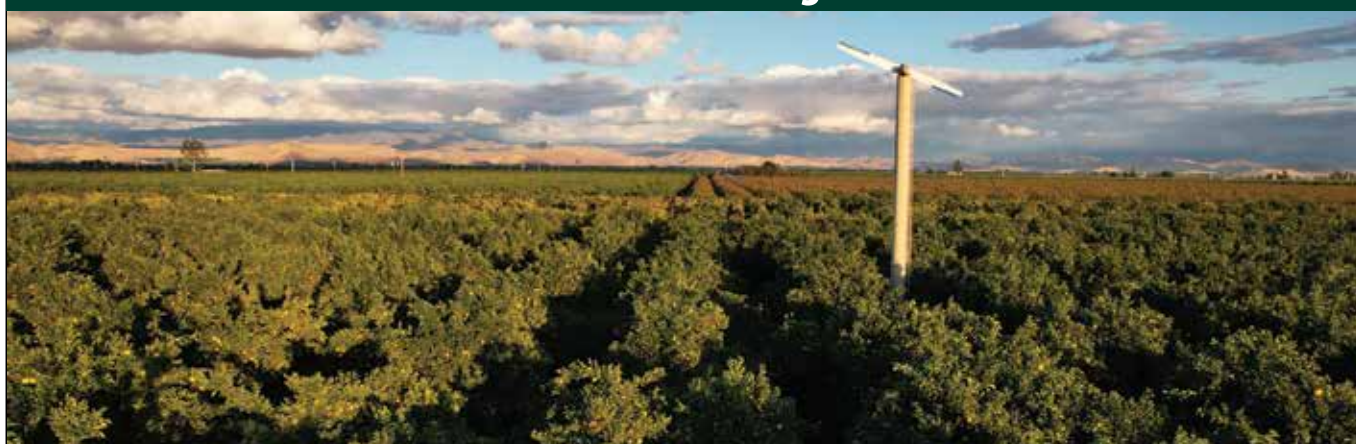
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*Sandipa Gautam, Ph.D., is an assistant University of California Cooperative Extension Integrated Pest Management advisor at the Lindcove Research and Extension Center, Exeter California. For additional information, please contact [sangautam@ucanr.edu](mailto:sangautam@ucanr.edu)*



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# University Research Confirms CheckMate® CRS Mating Disruption Reduces Pest Damage

Leading University experts recently published results from research conducted from 2015 to 2019 in commercial citrus orchards in central California (Grafton-Cardwell et al. 2021). Through these studies, the researchers demonstrated that CheckMate® CRS can be extremely effective at reducing California Red Scale (CRS) pest populations and damage.

The research concluded with several key findings demonstrating how truly effective mating disruption can be at reducing the impact of CRS:

- *Mating disruption using CheckMate® CRS was effective in reducing California Red Scale populations in every generation and can potentially reduce or even eliminate pesticide applications altogether, depending on pest density.*

- *Significant trap suppression, population and damage reductions were observed in blocks treated with CheckMate® CRS dispensers.*

- *In CheckMate® CRS treated blocks, cumulative male trap capture was reduced by an average of 90%, twig and leaf infestations by 95%, and highly scale-infested fruit by 75%.*

- *The percentage of highly infested fruit was less than 0.5% in 9 of the 10 mating disruption blocks in 2018 and 2019.*



Keeping CRS populations under control is imperative for growers looking to produce high-quality, cosmetically appealing fruit. CRS affects the marketability of citrus fruit and can be difficult to manage with conventional pesticides alone. Growers and PCAs can't control certain factors that drive pest populations such as weather, but they can minimize CRS damage by using CheckMate® CRS.

CheckMate® CRS is Suterra's season-long mating disruption dispenser solution for control of California red scale (CRS) in citrus and other crops where CRS is present. This product utilizes Suterra's proprietary technology for continuous release throughout the season. Easy to deploy, the dispensers penetrate inside the canopy and are compatible with all integrated pest management (IPM) tools and are suitable for organic production.

PCAs are encouraged to take advantage of the most effective tools available to them to remain competitive in today's market. CheckMate® CRS dispensers are proven to be effective and are the most trusted CRS mating disruption solution in the industry.

"After the product is up, it works year-long so **I can sleep at night knowing something is out there working.**"

**Brandon Koch**

PCA | [Wonderful Citrus](#)

## Case Study: Wonderful Citrus

Wonderful Citrus is famous for delivering nutritious, premium fresh fruit including Halo mandarins, Wonderful seedless lemons, and Red Scarlett grapefruit. The Halo mandarin brand is a favorite of parents and children for being a delicious, easy snack. The visual appeal of the fruit must be colorful and immaculate, which makes the cosmetic damage caused by California red scale (CRS) a massive economic problem. "The pests for us are cosmetic for you as the consumer. You want a clean piece of fruit. You want something that looks good because we all eat with our eyes first and then we taste," explains Brandon Koch, PCA at Wonderful Citrus.

"We've not had to go back and do re-applications with other pesticides, and our chemical usage and our chemical procurement has dropped exponentially over the years... We started with probably 3,000 acres out of a certain region that we sprayed. We've gone down to roughly 4-600 acres now that we're spraying," says Brandon Koch. "I would recommend Suterra to anyone in California and around the world."

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# PARTICLE FILMS REDUCE PSYLLIDS ON CALIFORNIA LEMONS

Christopher Vincent and Monique Rivera





## Project Summary

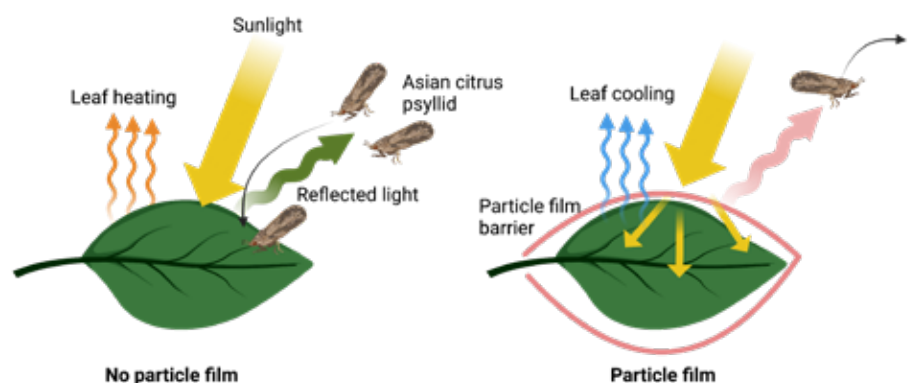
Citrus growers need viable options to manage Asian citrus psyllids (ACP). Tools that can prevent psyllids from feeding rather than killing them after they have fed may be more effective in preventing the spread of huanglongbing (HLB). Particle films are a type of non-insecticidal tool that have shown promise against ACP in Florida. This project tested two colors of particle films on young lemons in Ventura and Riverside counties. When these films were applied over two growing seasons from May-October of 2020 and 2021, they reduced psyllid populations significantly. A red-dyed (“pink”) film was highly effective, reducing psyllids by more than 80 percent on average. All the products tested are commercially available.

## What Are Particle Films?

Particle films are suspensions of tiny particles that form a thin layer over the leaf surface after they are sprayed and dry. Most particle film material is kaolin clay because it is found in naturally small particles with a reflective white color. These films can be useful since they reflect light, which can camouflage the leaf from some insects and improve the environment around the leaf to keep it cool and reduce stress (Pierre et al. 2021; Jifon and Syvertsen 2003).

**Figure 1** illustrates the effects of particle films on citrus leaves and ACP.

In Florida, we tested particle films applied to a new sweet orange planting. We found that the natural white kaolin, sold as Surround WP™, was effective in reducing ACP populations. However, when the kaolin included a red dye, giving it a pink color, psyllid suppression was improved and delayed the spread of ‘*Candidatus Liberibacter asiaticus*’ (CLAs), the bacterium associated with HLB (Pierre et al. 2021). We wanted to test these same products on lemons in California. Because of lower rainfall in California, the products could be effective with fewer applications; however, lemons pose a challenge as they flush throughout the year.



**Figure 1.** How particle films work in citrus. Without particle films, sunlight heats leaves inducing light and temperature stress. At the same time, green and other visible light is reflected by the leaf, and psyllids can detect citrus and arrive to feed. With particle films, sunlight strikes the particle film and is scattered. Less light reaches the leaf, allowing it to remain cool. Meanwhile, the reflected light does not have the colors of a citrus leaf, and psyllids go elsewhere looking for citrus plants. *Figure created with BioRender.*

## Testing Particle Films in California Lemons

We began three replicated trials in different groves of young, non-bearing lemons – two in Ventura County and one in Riverside County. We applied either Surround WP, Surround with a red dye or an untreated control. Our treatments were:

- » **White:** The white Surround treatment was applied at six percent weight by volume. At this rate, 100 gallons per acre would apply 50 lbs. of Surround per acre.
- » **Pink:** The pink treatment was the same Surround product mixed with a red mulch colorant, Colorback™. Because the mulch colorant changes the film color, shades leaves more and adheres longer, we applied this at a lower rate: 4.2 percent weight by volume, equivalent to 35 lbs. per acre at 100 gallons per acre. We also added 2.5 fluid oz. Colorback per lb. Surround, approximately 0.7 percent by volume.
- » **Untreated control:** One treatment was an untreated control. All blocks were treated according to each grower's practices. Other pesticide sprays continued, but the trees were not treated for psyllids.

The result was the eye-catching field in **Figure 2**. We treated each time more than one-third of the canopy was covered in new flush, which equated to two times each growing season, once in May and once in July or August. We counted the number of ACP every two weeks from May through

December 2020 and May through October 2021. Each time, we counted in three different ways:

1. tapping the branches with a pencil 20 times and counting how many psyllids dropped out onto a sheet of paper,
2. inspecting the tree for resting adults and counting them and
3. inspecting the tree for nymphs and counting those.

Every six months we also measured changes in trunk girth and canopy volume with measuring tape and measuring sticks.

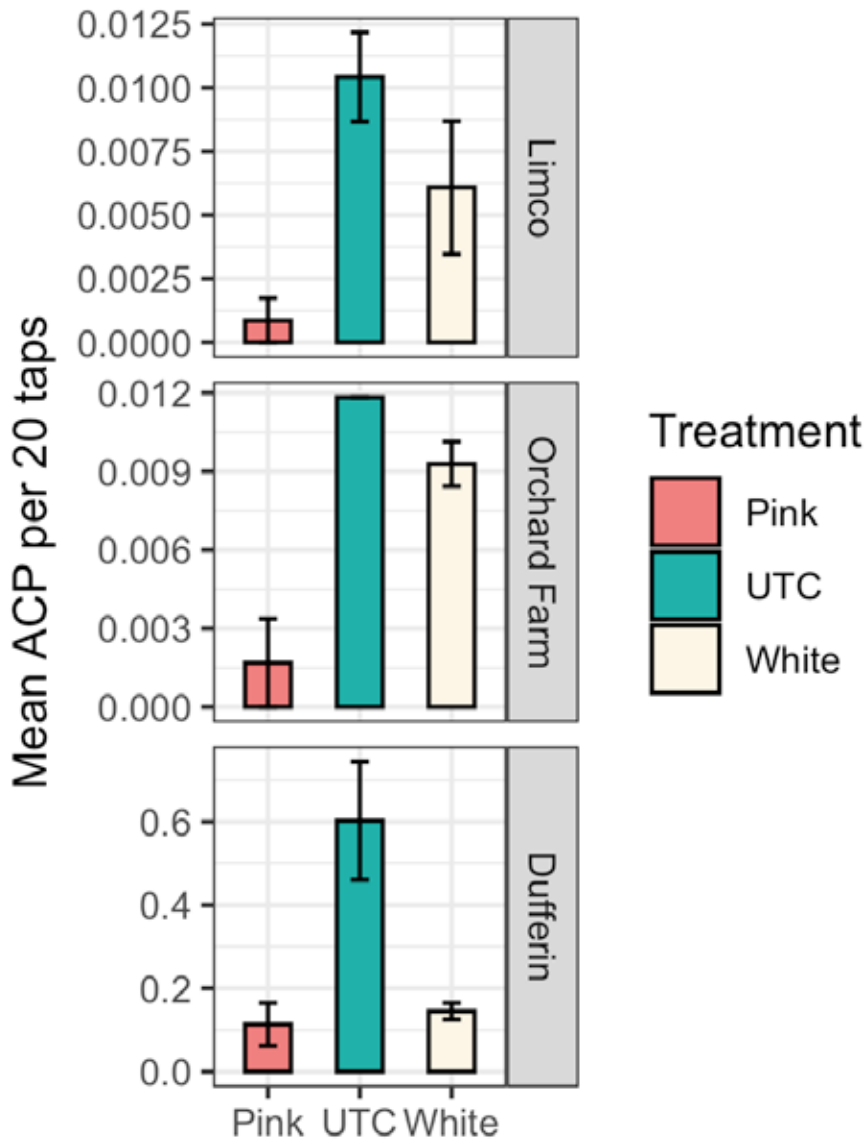
## Particle Films Effective Against ACP

We found that particle films reduced psyllid adults and nymphs. **Figure 3** shows the results for tap samples, but the pattern was the same for the visual counts of both nymphs and adults. Although the white film was effective, pink film was much more effective with more than 80 percent reductions in most cases. This appears to be the result of a longer residual effect of the pink treatment. Typically, the white treatment was equally effective for two months after application but began to lose its efficacy as it either sloughed off the leaves or was covered by new flush. The pink treatment continued to be effective for an additional month. This longer residuality may come from pink being



**Figure 2. Aerial photograph of white and pink (red-dyed) kaolin particle film treatments on a first-year lemon planting in Ventura County, California.**





**Figure 3. Sum of bi-weekly tap counts of Asian citrus psyllids (ACP) on lemons (*Citrus x limon*) in Ventura (Limco and Orchard Farm) and Riverside counties (Dufferin), in California during approximately one year of treatments with pink (red-dyed) or white kaolin particle films or no particle film (UTC) over the entire period of the study.**

more effective, but it also may be because the colorant, which includes a strong adhesive, typically lasts longer on the leaf. These results were consistent with our earlier field study in Florida. However, the California results were achieved with just three applications per year.

## Particle Films May Enhance California Lemon Growth

We expected to see improvements in tree growth in response to both particle film treatments. Previous research in Florida showed that growth increased with regular particle film treatments (Hall et al. 2007; Jifon and Syvertsen 2003; Pierre et al. 2021). We have measured how particle films help keep leaves cool on warm days and how moderately warm temperatures can reduce photosynthesis (Guha et al. 2021).

### Treatment



We observed larger canopies of pink-treated trees in two groves by the end of the study and of white-treated trees in one grove. However, they were inconsistent among sites and represent too short a period to draw confident conclusions about the treatment effects on growth of lemons in California.

## Product Availability

Both Surround and Colorback are commercially available and are approved for use in conventional production. Surround is Organic Materials Review Institute approved for use in organic production. Unfortunately, Colorback is not approved for organic production.

## Recommendations on Applications

We recommend applying at high pressures to achieve a fine droplet size and even distribution on leaves. It is possible to over-apply and cause excessive shading. Accordingly, we suggest waiting to reapply until enough new flush has emerged that at least one-third of the outside of the canopy consists of uncovered leaves. If rain or wind causes the product to wash off or slough off, one could consider an application at a reduced rate. Kaolin does not adhere well to new, expanding leaves, so it is best to apply after a flush rather than trying to keep the young leaves covered.

## Conclusions

Surround particle films with pink colorant effectively reduce ACP populations in California lemons. These films may also improve the growth of lemons in California. Surround particle films are commercially available, but the colorant we tested is only approved for use in conventional, not organic, production. 🍌

**CRB Research Project #5500-221**

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# THE ASIAN CITRUS PSYLLID UNDER CALIFORNIA CONDITIONS

*How California Climate Influences the  
Behavior and Growth of ACP*

Carlos Andres Antolínez, Xavier Martini  
and Monique J. Rivera

Wind vane trap deployed in the field used to capture ACP when flying in different directions. One side of the trap always faces in the direction of the oncoming wind, and the opposite side is always facing against the oncoming wind, allowing capture of insects traveling downwind, upwind or perpendicular to the wind direction.





## Project Summary

*Information is lacking on the effects of California's climate on Asian citrus psyllid (ACP). Our goal was to identify how California's climatic conditions influence ACP flight, survival and potential for acclimation and spread throughout the state. Specifically, we determined how windspeed, atmospheric pressure, extreme temperatures and humidity affect dispersal, development and survival of ACP. We found that exposure to temperatures of 105°F or above slowed ACP development, decreased population and decreased ACP flight ability. ACP survived freezing temperatures and acclimatized to colder temperatures over time. Strong winds increased ACP dispersal and determined the direction of ACP movement. Lastly, ACP dispersal decreased when atmospheric pressure declined.*

## Background and Significance to California Growers

Huanglongbing (HLB) and ACP, the vector of the HLB-associated bacterium '*Candidatus Liberibacter asiaticus*' (CLAs), continue to threaten California citrus growers since HLB first was detected in southern California in 2012. Fortunately, HLB and ACP have spread more slowly in California compared to Florida and Texas, and HLB finds have been limited to residential areas in the Los Angeles basin. The reason for the slow spread of HLB and ACP in California is unknown, but could be attributable to differences in control practices or climatic conditions. This project focused on climatic conditions since California citrus is grown across more diverse and variable climates compared to Florida and Texas.

Climatic conditions vary within California's citrus regions. Differences include variation in atmospheric pressures due to elevation, humidity, levels of high heat in summer or freezing temperatures in winter, and exposure to high-speed winds such as the Santa Ana winds. Because CLAs spread is primarily driven by the movement of its vector, understanding how California citrus-specific climatic conditions affect ACP biology and dispersal is of paramount importance for risk assessment across the state. To assess the effect of climate, we built and used multiple custom apparatuses to simulate heat, wind and atmospheric pressure under laboratory conditions. We evaluated conditions common to California citrus grown in coastal regions (Escondido and Ventura) or inland areas (Calipatria, Indio and Riverside).

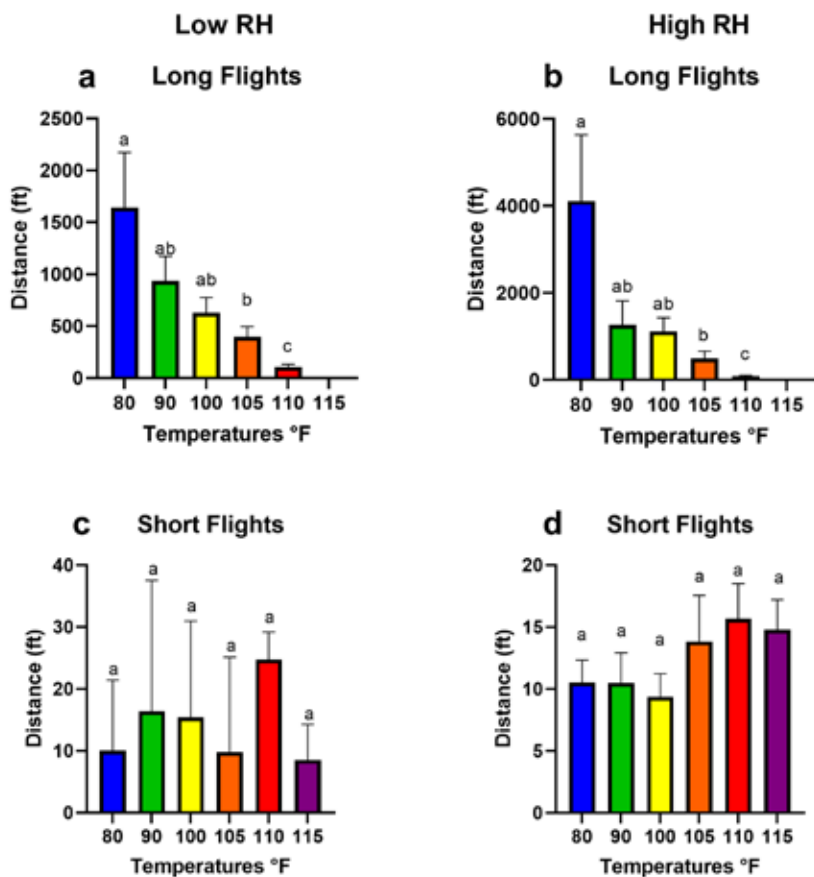
## What We Did

We quantified ACP flight distance using a customized temperature-controlled flight mill inside an experimental arena. ACP were attached to a fiber optic cable, and turn arounds in the flight mill were counted over time. We evaluated the ACP's propensity to fly under atmospheric pressure changes using a pressure chamber equipped with a remote-controlled opening box. In two separate growth chamber experiments, we evaluated ACP survival and acclimation at low and freezing temperatures, in addition to how high heat and humidity affect survival and developmental time. We addressed the effect of wind on ACP dispersal using a high-speed wind tunnel at the University of California, Riverside.

## Results

### 1. Relationship of temperature and humidity to ACP flight

ACP performed two types of flights, short flights (less than 40 feet) and long flights (40 feet or more). High temperatures gradually decreased the capacity to disperse for long distances with a more pronounced decline at temperatures above 105°F at low humidity (on average 30 percent) and high humidity (on average 83 percent) (**Figures 1A, B**). Distance dispersed was not affected by temperature during short flights at low or high relative humidity (**Figures 1C, D**). Based on these results, long distance dispersal of ACP is expected to decrease in areas where temperatures regularly exceed 105°F.



**Figure 1.** Mean (and standard error) distance flown in feet (ft) by Asian citrus psyllids at different temperatures and relative humidity (RH) for long flights (less than 40 feet) and short flights (40 feet or more). (A) Long flights at low humidity. (B) Long flights at high humidity. (C) Short flights at low humidity. (D) Short flights at high humidity. Different letters represent statistically significant differences between temperatures according to two-way analysis of variance (ANOVA).

## 2. How atmospheric pressure impacts ACP flight

Twenty ACP in a box equipped with a system that allows it to be opened remotely were placed in a chamber in which air pressure could be manipulated (Figure 2). Two hours after the air pressure was changed, the box was opened remotely, and the ACP were allowed to fly outside the box. A young citrus flush was placed above the box. The numbers of ACP that landed and fed on the citrus leaf flush were counted during two hours.

Psyllids were more active, and more ACP left the box to feed on the citrus flush when air pressure increased. Conversely, when pressure decreased, psyllids tended to be less mobile and fewer were found on the citrus flush (Figure 3).

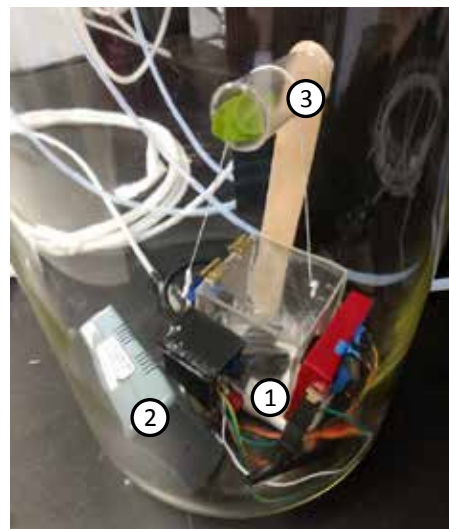
## 3. Cold tolerance and high-heat tolerance of ACP

**3.1 Cold tolerance:** We investigated adult ACP survival under two exposure times (six and ten hours) at freezing temperatures (30°F, 27°F, 25°F) compared to 72°F (control temperature). This experiment was repeated four times. Freezing temperatures significantly affected ACP survival compared to the control temperature (Figure 4A). However, only temperatures of 25°F killed more than 50 percent of the individuals, suggesting some degree of cold tolerance. Different exposure times did not cause significant differences in ACP survival except for 10 hours at 30°F, where fewer insects survived when compared to the same temperature for six hours (Figure 4A). Sex did not affect survival, and color morph

survival was only significantly different at 27° where green-blue morph survivorship was higher (Figure 4B, C).

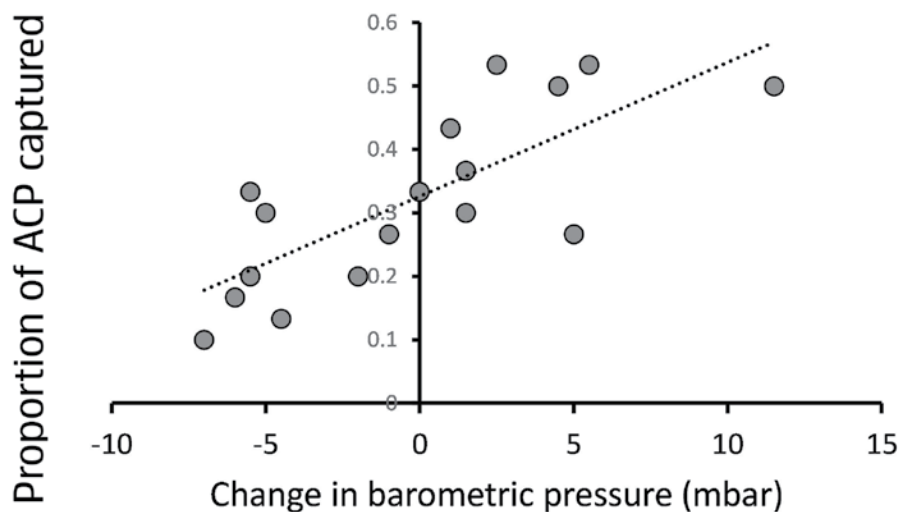
In a second experiment, we evaluated the ACP's ability to acclimate to cold and sub-freezing conditions. We subjected one group of insects to gradually decreasing temperatures (temperature decreased from 75°F to 42°F by 3°F three times a week), another group to intermittent cold periods (42°F for ten hours per day), for one- or two-week acclimation treatments. Each of these acclimation treatments was compared to ACP maintained at 75°F (control). This control group was different for each treatment. Finally, we exposed ACP from the different treatments to 25°F for a period of ten hours with mortality assessed immediately after. Gradual and intermittent acclimation treatments increased ACP survivorship compared to the control (Figure 5A, B). However, survival was higher when ACP were acclimated gradually compared to that for intermittent periods of acclimation for one or two weeks (Figure 5A, B).

**3.2 High heat tolerance:** We reared ACP (from eggs to adults) under daily



**Figure 2.** Pressure chamber design within a glass jar. A remote-controlled box (1) where Asian citrus psyllids (ACP) are kept during pressure changes. Pressure changes are measured with a digital barometric sensor (2). Once the target pressure is reached, the box is opened without opening the pressure chamber, and ACP are allowed to reach the leaf target above the box (3) for two hours.





**Figure 3. Proportion of Asian citrus psyllids (ACP) captured on the citrus flush placed in the pressure chamber following air pressure changes.**

cycles that ramped up from 71°F to the maximum temperature for three or six hours and then back to 71°F using temperature-controlled growth chambers. The maximum temperatures tested were 82°F, 100°F, 105°F and 110°F. ACP were heat tolerant up to 100°F when maximum daily temperatures were maintained for three or six hours (Figure 6). However, temperatures equal to or above 105°F significantly decreased the number of insects that reached the adult stage (Figure 6). The effect of heat exposure time was significant only for the 105°F treatment when longer exposure times (six hours vs. three hours) significantly decreased the number of emerged adults (Figure 6). High temperatures also affected the duration of the ACP life cycle. Generally, higher temperatures (105°F or greater) and longer exposure times resulted in slower ACP development and fewer adults (Figure 7).

#### 4. ACP dispersal under continuous strong winds

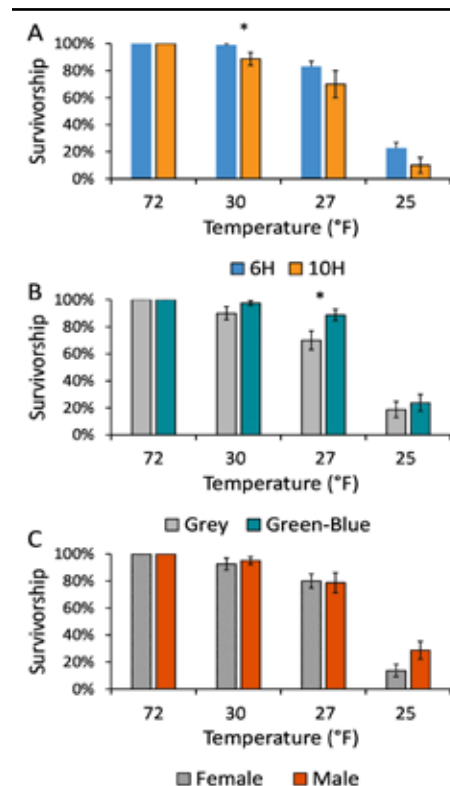
In the wind tunnel experiment, we evaluated the number of ACP that migrated from a source plant to a receptor plant located 11.31 inches away (controlled dispersion) or from the source plant into uncontrolled flight with no attachment or landing on a plant (uncontrolled dispersion). We tested controlled and uncontrolled dispersion under the following wind speeds (0, 5, 15, 22, 30, 40 and 60 mph). ACP showed a marked tendency to remain on the source plant (Figure 8A) at wind speeds below 30 mph. Wind speed did not influence plant-to-plant movement (Figure 8B). However, wind speeds above 30 mph were able to dislodge psyllids from the plant and thus induce uncontrolled dispersal (Figure 8C).

## Concluding remarks

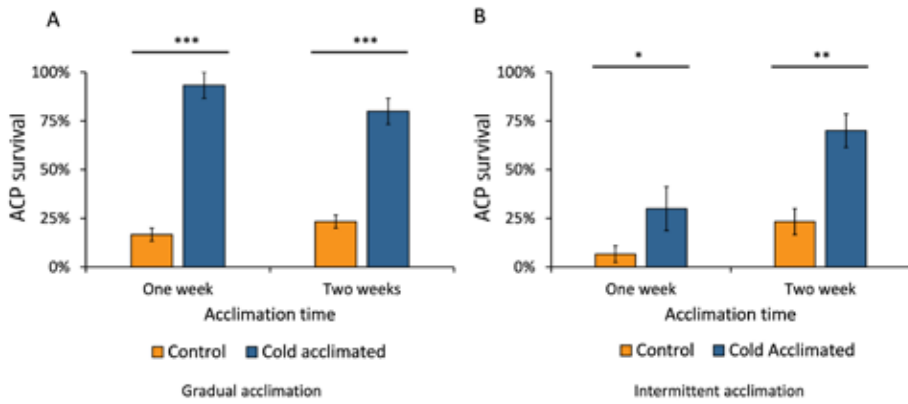
We conclude that ACP can survive and disperse in high temperatures that occur across California. However, if local temperatures exceed the ACP's upper heat tolerance limit of 105°F, ACP dispersal capacity likely declines significantly. This could explain the current distribution of ACP in California, where more abundant ACP populations are established in moderate climates such as those close to the coast (e.g., in Ventura and Pauma Valley), while low populations are found in areas with higher temperatures (Imperial Valley, San Joaquin Valley and the Coachella Valley).

We demonstrated that ACP can survive freezing temperatures and that gradual acclimation to freezing temperatures further increases survival. Our findings suggest that a gradual decrease in temperatures during fall favors the ACP's capacity to overwinter and increase populations in the following spring. ACP populations should be significantly lower in areas prone to sudden freezing periods, not allowing ACP to acclimate.

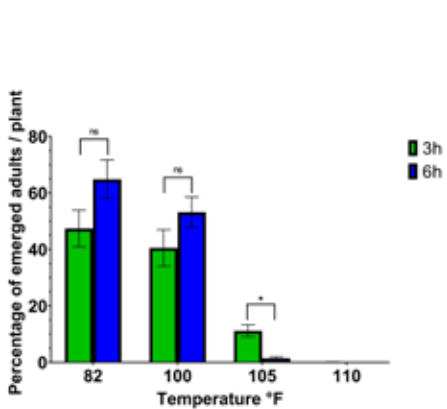
Wind was determined to induce involuntary ACP dispersal. Since wind speed increases the probability of long-distance dispersal, we highly recommend monitoring wind direction over time to estimate the risk of ACP migration between citrus groves and where first invasions may occur. Atmospheric pressure is an important factor for dispersion since pressure



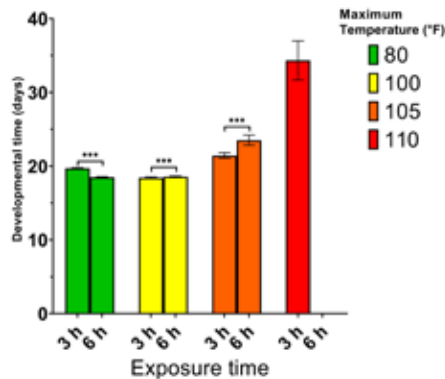
**Figure 4. Survival (average and standard error) of Asian citrus psyllids exposed to 72°F, 30°F, 27°F and 25°F related to (A) exposure time (six hours or ten hours), (B) color morph (grey or green-blue) and (C) sex. Asterisks (\*) indicate significant differences between treatments according to generalized linear model (GLM) with binomial distribution.**



**Figure 5.** Survival (average and standard error) of Asian citrus psyllid (ACP) exposed to (A) 25°F for ten hours after gradual cold acclimation or (B) after intermittent cold acclimation. Asterisks (\*) indicate statistically significant differences between treatments according to generalized linear model with binomial distribution: \* P < 0.05, \*\* P < 0.01, \*\*\*P < 0.001.



**Figure 6.** Percentage of adults that emerged per plant when Asian citrus psyllids were subjected to daily periods of three (green bars) or six (blue bars) hours (h) at different maximum temperatures. Significant differences between exposure times (\* P < 0.05) and non-significant (ns) differences between exposure times are according to the Mann-Whitney U test followed by Bonferroni correction.



**Figure 7.** Average developmental period (and standard error) of Asian citrus psyllids (ACP) subjected to daily periods of three or six hours at different maximum temperatures. Asterisks over the columns for the same temperature signify statistically significant differences between exposure times (\*\*\*P < 0.001) according to Mann-Whitney U test followed by Bonferroni correction. No ACP developed when exposed to daily periods of six hours at 110°F.

changes significantly affected the propensity to engage in flight. Our findings suggest that ACP prefers to engage in flight under high pressures typical of low elevations or stable environmental conditions. 🌍

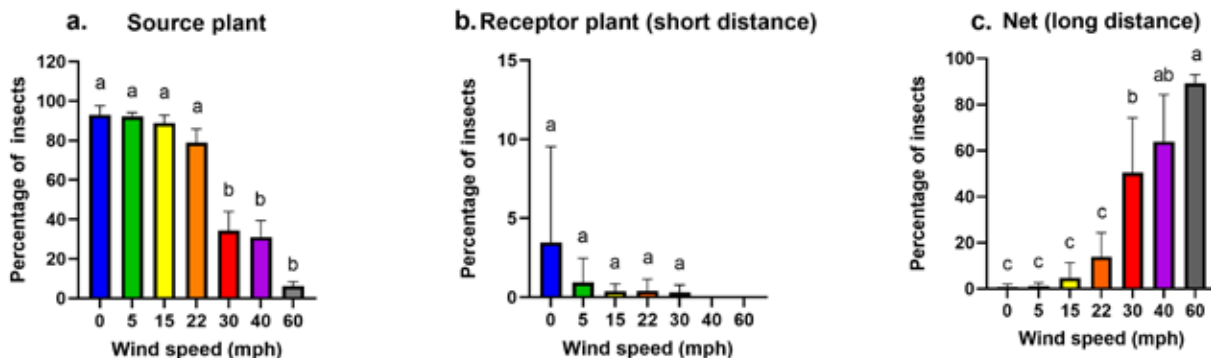
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**Figure 8.** Mean percentage (and standard error) of Asian citrus psyllid (ACP) captured at different positions in the wind tunnel after two hours of continuous wind. (A) Percentage of ACP remaining on the source plant, (B) percentage of ACP on the receptor plant, (C) percentage of ACP in the net. Different letters between wind treatments represent statistically significant differences according to analysis of variance (ANOVA) on ranks.



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# RESIDENT PREDATORS:

ALLIES IN A WAR WITH ACP

Raju Pandey

ACP colonies are attended by Argentine ants, *Linepithema humile*, for honeydew and provide a safeguard against their natural enemies such as predators and parasitoids.



## Introduction

When the Asian citrus psyllid (ACP), an efficient vector of the fatal bacterial disease huanglongbing (HLB), was detected in California in 2008, the state responded by implementing an eradication program in urban areas. However, the cost of these efforts and increased ACP detections outside these areas led the state to reassess this approach several years after its implementation (Hoddle and Pandey 2014). As ACP populations grew and expanded throughout the state, the management strategy shifted from ACP eradication to suppression. With the significant amount of residential and non-commercial citrus present across California, biocontrol options were pursued to provide some landscape level ACP control to reduce overall psyllid pressures where other tools (i.e., pesticides) may not be routinely applied. The Citrus Pest and Disease Prevention Program (CPDPP), in conjunction with the Citrus Research Board (CRB), University of California, Riverside (UCR), California Department of Food and Agriculture (CDFA) and the United States Department of Agriculture (USDA), lead a program that releases parasitoids in residential areas of southern California.

There are several biological control methods that can be applied to further ACP control efforts within the state, both in commercial production and residential areas at this time. These methods include classical biological control (introduction of new, natural enemies to an invaded area), conservation of existing natural enemies (supporting the populations of natural enemies already present) and augmentative biological control (the rearing and release of additional natural enemies to an area). Natural enemies are further classified here as either parasitoids (insects that develop within or on the pest) or predators (insects that feed on the pest) (Stoner nd). Following review of these approaches and natural enemies, opportunities for growers to take advantage of these options will be discussed.

## Classical Biological Control Efforts

To establish classical biological control options for ACP in California, two highly specific ACP parasitoids (*Tamarixia radiata* and *Diaphorencyrtus aligarhensis*) collected in Pakistan – the native range of ACP – were widely released in California (Hoddle and Morgan 2022). Since 2011, more than 23 million *T. radiata* were released in the state throughout various areas including HLB quarantine areas, along borders and trade routes and in locations with newly established ACP. Additionally, between 2014 and 2018, more than 700,000 *D. aligarhensis* were released in the state. Although *T. radiata* has become established widely across southern California residential areas (Hoddle and Morgan 2022), *D. aligarhensis* was not found to establish as readily as *T. radiata*, nor did it exhibit parasitism levels similar to *T. radiata*, so production was suspended in 2019 (Milosavljević et al. 2022). It is important to note that most of these parasitoid releases have

occurred in residential areas. *T. radiata* remains unavailable for commercial use in California. Additional information regarding the classical biological control of ACP in California can be found at [www.biocontrol.ucr.edu](http://www.biocontrol.ucr.edu).

## Existing Natural Predators

ACP biocontrol in California, led by the CPDPP, has largely focused on production and distribution of *T. radiata*. However, other predatory arthropods of ACP are present in California, and efforts have been made to study the impacts of native, natural enemies of ACP present in the state. These predators are important when considering management of ACP, particularly in commercial citrus orchards, as these predators are already established and not dependent solely on ACP as a food source. Arthropods collected through intensive field surveys at commercial orchards were analyzed



**Egg, larva and adult *Diomus pumilio*, a highly effective psyllid predator. It was imported from Australia in the 1970s to control the Acacia psyllid. Both larvae and adult feed on eggs and nymphs of ACP. Photos courtesy of Iris Chien, former graduate student, University of California, Riverside.**



Green lacewing, *Chrysoperla comanche*, larvae feeding on an ACP nymph.

for the presence of ACP DNA in their guts. The results showed that predatory arthropods such as lady beetles, lacewings and spiders were consuming ACP in southern California (Goldmann 2017). The most common species of predators identified by this survey included spiders (*Sassacus vitis*, *Anyphaena pacifica*, *Hibana incursa*, *Trachelas pacificus* and *Theridion* spp.), coccinellid beetles (*Diomus pumilio* and *Rhyzobius lophanthae*) and green lacewings (*Chrysoperla comanche*).

Additional studies found syrphid larvae, predatory mites, green lacewing larvae, thrips and the introduced parasitoid, *Tamarixia radiata*, were the dominant natural enemy groups visiting immature ACP colonies. Spiders rarely attacked immature ACP, but syrphid and green lacewing larvae and *T. radiata* visits to the sentinel colonies<sup>1</sup> resulted in ACP attacks

(Kistner et al 2017). The association between predatory Phytoseiid and whirling mites with ACP are limited to observational reports of their visits to the ACP nymph colonies (Kistner et al. 2017). The *Anystis* spp. remain most active during cooler winter months and disappear during hot summer months (R. Pandey, personal observation). They were observed in 2022 feeding on ACP eggs and nymphs.

To determine the impact of these predators on ACP colonies, exclusion studies were performed by creating barriers (applying sticky materials around stems limiting the access of walking insects, covering the pest colonies with cages, etc.) to exclude these predators from one set of plants, and psyllid numbers were compared to other plants lacking the barriers. Based on several studies in both commercial (Goldmann and Stouthamer 2015; Goldmann 2017) and residential





Whirligig mite, *Anystis* spp., is a fast-running predatory mite that feeds on ACP eggs and nymphs.

areas (Kistner and Hoddle 2015) of California, ACP survival was reduced when generalist predators were able to access ACP. Similar results have been reported for generalist predators from Florida, as well. Michaud (2004) reported a 120-fold higher survival of ACP colonies without access to predators when compared with colonies exposed to predators. Qureshi and Stansly (2009) found five to 27 times higher net reproductive rates for ACP when predators were excluded.

## Conservation of Natural Predators

Beyond the identification of native predator species of ACP, it is important to promote the survival and persistence of these predators through several methods of conservation. For example, spider abundance can be increased by providing a diverse continuous habitat, use of organic manure, adoption of botanicals and biological pest control methods (Rajeswaran et al. 2005). Among the important ACP predators identified, spiders and syrphids rarely are available for augmentative releases through mass rearing because of their complex biology and behavior. Spiders are mostly cannibalistic, which would require them to be reared individually; and syrphids require plant nectar and insect hosts, such as aphids, for larval development. Syrphid fly activities were higher during spring and fall when floral sources were available through naturally occurring flowering weeds such as scarlet pimpernel, sow thistle, wild mustard, sweet clover, stinking chamomile and prickly lettuce. Providing additional floral resources in the orchard by planting flowering cover crops such as alyssum was found to increase syrphid fly activities (Irvin et al. 2022). Additional conservation efforts, particularly in commercial citrus orchards, can include selective application timing and selection of softer pesticides (Goldmann and Stouthamer 2015).

In addition to altering cultural practices and providing floral resources for native predators, ant control remains an important component for ACP management. The presence of ants in an agricultural field usually increases the abundance of honeydew-producing pests and decreases efficacy of natural enemies (Anjos et al. 2022). ACP, a honeydew producing pest, is associated most commonly with the Argentine ant, *Linepithema humile*, in California (Kistner et al. 2016; Goldmann 2017). A study conducted

in three urban sites by continuous video recording of ACP colonies on sentinel plants<sup>2</sup> showed Argentine ants, as the most common arthropod, which usually fends off the ACP natural enemies, visiting ACP colonies. When ant access to ACP colonies was restricted, natural enemy abundance and attack rates increased, particularly those of syrphids and *T. radiata*. Syrphids and lacewing larvae combined killed up to 93 percent of ACP nymphs when syrphid flies belonging to *Allograpta* spp. outnumbered lacewing larvae by two to one (Kistner et al. 2016). This highlights the importance of effective ant management for improved control of ACP.

## Augmentative Biological Control

When biological control agents can be mass produced economically, releases can be made to augment naturally occurring populations. The generalist predators *R. lophanthae* and *C. comanche* have shown great promise both in the laboratory and field cage studies (Gómez-Marco et al. 2022) *R. lophanthae* is commercially available; however, *C. comanche*, the only green lacewing species collected from citrus orchards, is not widely available commercially at the moment, but currently is being produced by Rincon Vitova Insectaries Inc. for field experiments in state.

The brown lacewing, *Symphorobius barberi*, has been shown to suppress ACP in some cases; however, success with this predator has varied (Khan et al. 2020; Gómez-Marco et al. 2022).

*D. pumilio*, a coccinellid beetle, is a specialist predator that feeds on psyllid eggs and early instar nymphs. Though it was imported in 1970 from Australia for the control of acacia psyllid, very little information is available on its biology and behavior (Dreistadt and Hagen 1994). Small scale production of *D. pumilio* is in progress as part of a study on ACP suppression through augmentative releases in Hemet, California. Preliminary results suggest it is an effective ACP predator with great potential (Gómez-Marco et al. 2022; *R. Pandey unpublished data*).

## Conclusions

The California citrus industry continues to invest significant resources in protecting its commercial orchards from the devastating effects of HLB. The suppression of ACP, particularly in residential areas of southern California, remains a critical component to the overall efforts in state. In addition to the use of insecticide treatments, biological control methods can be used as an additional mitigation for ACP.

## What Can Growers Do?

- » The most important thing a grower can do is to continue applying insecticides (conventional or organic) following regional or county spray guidelines. The use of biocontrol options alone is not as effective in reducing psyllid populations as insecticide application.
- » Selective use of broad-spectrum insecticides (i.e., spot treatments or when natural enemies are not present) can help minimize the impact on native predator species.
- » Control of ants (particularly Argentine ants) should be considered as ants will protect ACP from predators, thereby reducing the impacts of these predators.
- » Growers may consider purchasing commercially available predator species (i.e., purple scale predator [*R. lophanthae*]) or may consider planting floral resources appropriate for regional predator species as part of their efforts to manage ACP.
- » Additional information can be found on the UC IPM website (<https://www2.ipm.ucanr.edu/agriculture/citrus/asian-citrus-psyllid/>).

## Glossary

**<sup>1</sup>Sentinel colonies:** Laboratory-reared Asian citrus psyllid nymph colonies on a plant used for monitoring activities of natural enemies in fields.

**<sup>2</sup>Sentinel plants:** Plants that are monitored for the presence of species of interest in the field.

## Acknowledgement

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# EUROPEAN EARWIGS IN CITRUS

*Signs of Damage and  
Control Options*

Hanna M. Kahl, Emma Cluff, Tobias G. Mueller,  
Elizabeth E. Grafton-Cardwell and  
Jay A. Rosenheim



## Project Summary

*Although it has been suggested that earwigs are capable of damaging citrus fruit, very little research has been conducted to characterize this damage. In this project, our experiments investigated the nature of earwig damage to the fruit of sweet oranges, clementines and 'true mandarins.' We also tested the efficacy of bifenthrin treatments to tree trunks and barriers of sticky materials for reducing the numbers of earwigs, Fuller rose beetles and ants in citrus tree canopies. We found that earwigs chew holes into young orange and clementine fruit, which develop into large scars as the fruit matures. True mandarins, in contrast, are largely naturally resistant to earwig attack. Earwigs are early season pests; they move into the canopy in early spring and stop feeding on fruit at around four weeks post-petal fall. Sticky barriers and bifenthrin trunk treatments successfully reduced movement of earwigs, Fuller rose beetles and ants into tree canopies. Sticky barriers reduced fruit scarring and the proportion of fruit infested with Fuller rose beetle eggs.*



## Introduction

The role of European earwigs in citrus has been enigmatic. Earwigs are nocturnal, so it is difficult to observe their behavior. Previous research conducted in Europe has identified earwigs as effective predators of aphids in citrus (Piñol et al. 2009), and earwigs have been reported to feed on California red scale (Romeu-Dalmau et al. 2012). However, growers and pest control advisors have observed that earwigs also consume citrus leaves, flowers and fruit (Kallsen 2006). If earwigs chew extensively on fruit, it is plausible that the resulting damage could lead to fruit scarring and downgrading of the fruit at the packinghouse, with significant loss of fruit value and, in turn, profit loss for citrus growers. Yet, little was known previously about earwig damage to citrus fruit, and there had been no comparisons made between earwig damage and that of more well-known chewing herbivores of citrus, such as fork-tailed bush katydids.

We also know very little about earwig movement. Earwigs dig nests in the ground during the winter, and older nymphs and adults are thought to move into the trees in the spring by crawling, as the winged adults are rarely observed to fly. However, the timing of earwig invasion of the citrus canopy has not been studied. We also explored whether citrus species vary in their susceptibility to earwig damage, as has been observed with other citrus herbivores (Cass et al. 2019; Mueller et al. 2019).

Through this research, we:

1. characterized earwig damage to citrus fruit,
2. assessed differences in earwig damage on various citrus species,
3. identified the period of time during which fruit are vulnerable to earwig damage and
4. identified whether treatments to citrus tree trunks can be used to manage earwigs, Fuller rose beetles and ants.

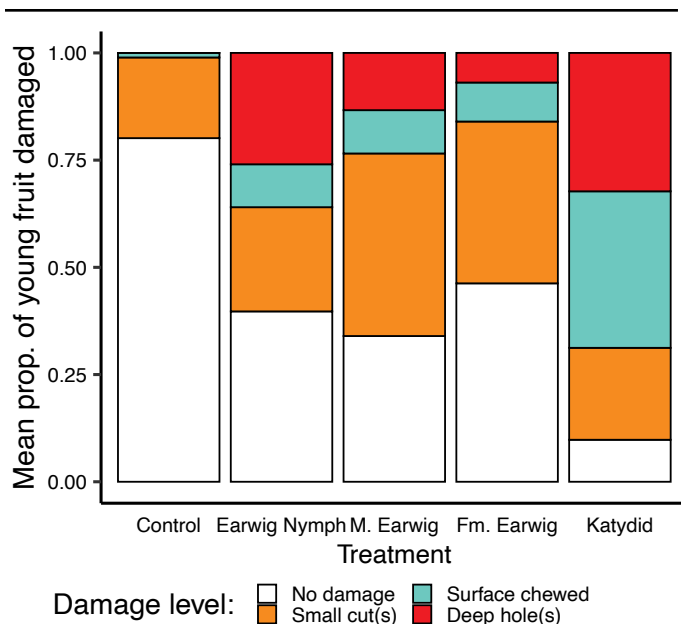
## Earwig Damage to Citrus

We conducted field experiments caging European earwigs (2nd to 4th instar nymphs and adults) and fork-tailed bush katydid nymphs onto citrus branch terminals containing young developing fruit at the University of California Lindcove Research and Extension Center (LREC) in May 2019. First, we found that earwig nymphs and adults could chew deep holes into young sweet orange (*Citrus sinensis* cv. 'Washington') fruit or chew the surface of the fruit extensively (**Figure 1A, B, Figure 2**; Kahl et al. 2021). The damage caused by earwig feeding was variable in appearance and easily could be mistaken for damage caused by katydid feeding. We suspect that earwig damage commonly may be misdiagnosed as katydid damage (**Figure 1C, D**). Whereas earwigs readily chewed

A young navel orange fruit damaged by a European earwig.



Figure 1. Examples of initial damage on young sweet orange fruit by earwigs. (A) surface chewed by earwigs. (B) Deep holes and small cuts chewed by earwigs. The arrows point at examples of small cuts. (C) Surface chewed by katydids. (D) Deep hole chewed by katydids. Credit: Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al., Characterizing herbivory by European earwigs (Dermaptera: Forficulidae) on navel orange fruit with comparison to forktailed bush katydid (Orthoptera: Tettigoniidae) herbivory, *Journal of Economic Entomology*, 2021, 114(4):1722-1732, by permission of Oxford University Press.

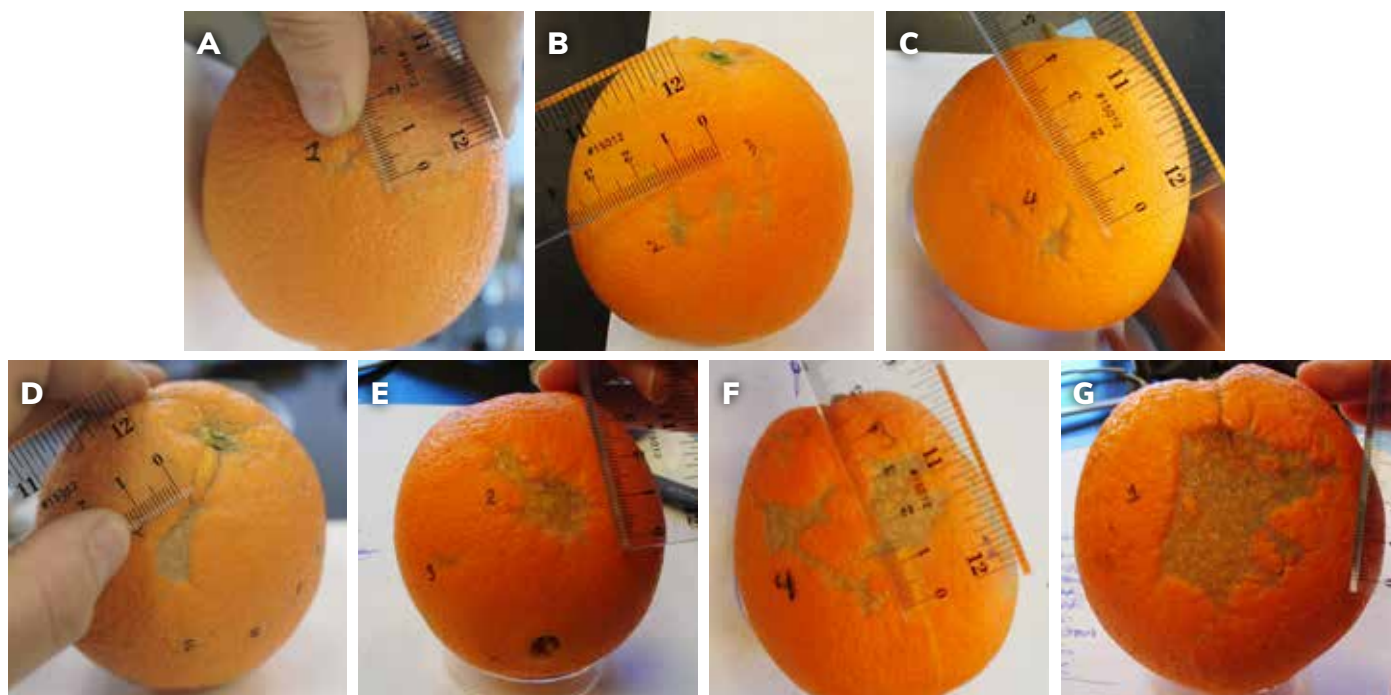


**Figure 2. Mean proportion of fruit that had each damage level (no damage, small cut[s], surface chewed and deep hole[s]) across insect treatments (control, earwig nymph, male [M.] earwig adult, female [Fm.] earwig adult and katydid nymph). Credit: Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al., Characterizing herbivory by European earwigs (Dermaptera: Forficulidae) on navel orange fruit with comparison to forktailed bush katydid (Orthoptera: Tettigoniidae) herbivory, *Journal of Economic Entomology*, 2021, 114(4):1722-1732, by permission of Oxford University Press.**

on sweet orange fruit when fruit were small, earwigs stopped chewing holes into sweet orange fruit at around four weeks post-petal fall (Kahl et al. 2021).

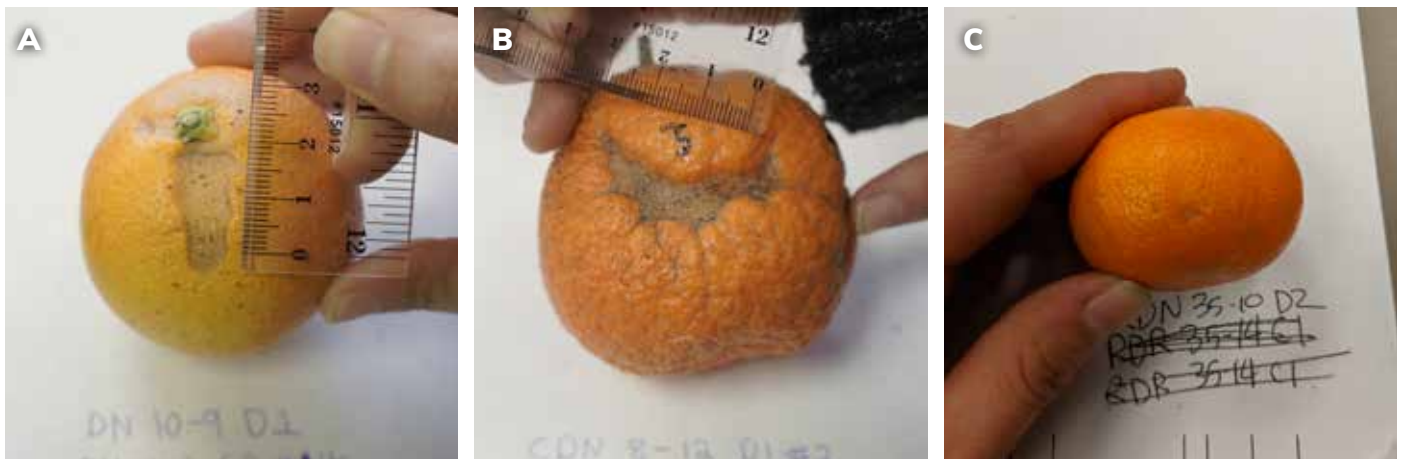
Many young citrus fruit abscise naturally; but for fruit that did not abscise, earwig damage developed into large scars as the fruit matured. The scars caused by earwig feeding varied in size and shape, but they often were irregular-shaped with some jagged edges (Figure 3A-E). The scars on the mature fruit that resulted from early season earwig damage looked similar to scars on the fruit caused by katydids (Figure 3F-G; Kahl et al. 2021). Many of the fruit seriously damaged by earwigs would be downgraded at the packinghouse, losing most or all of their value.

We also discovered that earwig damage varied across citrus species. Earwigs caused serious damage in sweet oranges and clementines (*C. clementina* cv. 'de Nules' and 'Fina Sodea'), but true mandarins (*C. reticulata* cv. 'Tango') showed nearly complete resistance to extensive earwig feeding (Figure 4; Kahl et al. 2022). True mandarin fruit exposed to earwigs rarely received more than small cuts. It seems that earwigs may avoid feeding on true mandarin fruit after taking small "tastes." Previous research established that fork-tailed bush katydids also cause intensive damage to sweet orange and clementine fruit, but almost no discernable damage to true mandarin fruit (Cass et al. 2019).



**Figure 3. Examples of scars on sweet orange fruit at harvest that were caused by (A-E) earwigs and (F-G) fork-tailed bush katydids. Credit: Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al., Characterizing herbivory by European earwigs (Dermaptera: Forficulidae) on navel orange fruit with comparison to forktailed bush katydid (Orthoptera: Tettigoniidae) herbivory, *Journal of Economic Entomology*, 2021, 114(4):1722-1732 by permission of Oxford University Press.**





**Figure 4. Examples of earwig damage at harvest on (A) sweet orange, (B) clementine and (C) true mandarins. Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al., Herbivory by European earwigs (*Forficula auricularia*; Dermaptera: Forficulidae) on citrus species commonly cultivated in California. *Journal of Economic Entomology*, 2022, 115(3):852-862, by permission of Oxford University Press.**

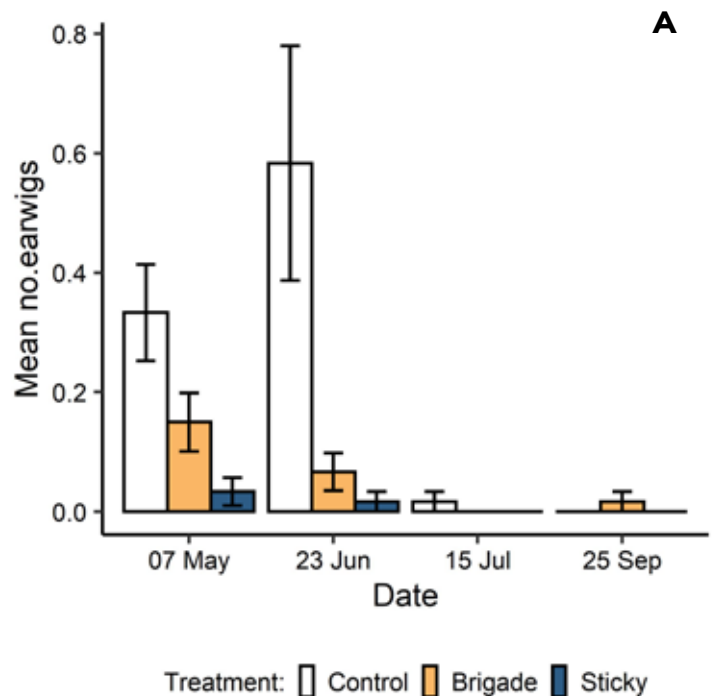
## Influence of Trunk Barriers

We tested the efficacy of barriers placed on citrus tree trunks to block the movement of earwigs, Fuller rose beetles and ants into citrus canopies. At the LREC, we skirt-pruned 90 experimental sweet orange (cv. 'Washington') trees and weeded under the trees, making the trunk the only way to access the canopy on March 25, 2020. On March 31, 2020, we established three treatments:

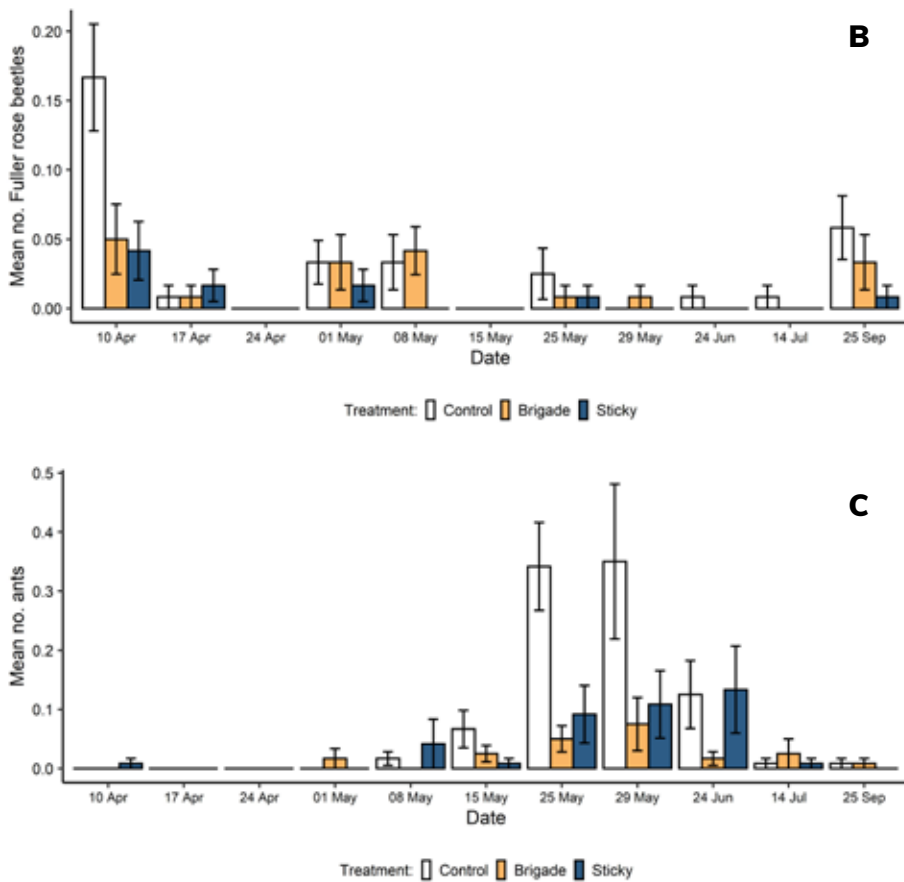
1. trees were left without barriers (control),
2. a roughly 18-centimeter wide sticky barrier (Sticky Stuff Coating, Olson Products Inc., Medina, Ohio) was added to the trunk of each tree and
3. an insecticide (bifenthrin, Brigade®, FMC Corporation) was sprayed on the soil and the trunk of each tree.

Foliage beating was used to sample Fuller rose beetles and ants, and earwigs were sampled by placing cardboard roll traps in the tree canopies. We also used video cameras to monitor arthropods climbing tree trunks and the efficacy of sticky barriers.

We found that both chemical and sticky barriers reduced densities of earwigs (**Figure 5A**), Fuller rose beetles (**Figure 5B**) and ants (**Figure 5C**) in the tree canopies, particularly from April to June. If applied to an entire block rather than to individual trees as in our study, bifenthrin may show greater efficacy than



**Figure 5. Mean numbers of (A) European earwigs (means  $\pm$  standard error [SE]) from cardboard rolls across dates, (B) Fuller rose beetles from foliage beat samples (means  $\pm$  SE), and (C) ants from foliage beat samples (means  $\pm$  SE). Means were calculated by averaging first by tree and then by treatment per each date. Standard errors were calculated from mean counts by tree, date and treatment. Treatments were applied on March 31, 2020. Sampling timing and frequency differed with the different sampling methods (cardboard rolls used in graph A and foliage beat samples used in B and C). See next page for figures B and C.**



Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al. 2021. Characterizing herbivory by European earwigs (Dermaptera: Forficulidae) on navel orange fruit with comparison to forktailed bush katydid (Orthoptera: Tettigoniidae) herbivory. *Journal of Economic Entomology* 114(4):1722–1732.

Kahl H.M.; Mueller, T.G.; Cass, B.N.; et al. 2022. Herbivory by European earwigs (*Forficula auricularia*; Dermaptera: Forficulidae) on citrus species commonly cultivated in California. *Journal of Economic Entomology* 115(3):852–862.

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it did in our study. Video monitoring confirmed that both earwigs and Fuller rose beetles were unable to cross sticky barriers. Sticky barriers reduced the incidence of scarred fruit at harvest and decreased the proportion of harvested fruit infested with Fuller rose beetle eggs.

## Conclusions

This research highlights that earwigs can cause serious damage to sweet orange and clementine fruit, but that true mandarins (cv. 'Tango') are naturally resistant. Earwig damage easily can be mistaken for damage caused by katydids. This suggests that monitoring and management of earwigs, when needed, should be considered in citrus pest management planning. Future work will focus on developing sampling methods that easily can be adapted by pest control advisors and an economic density threshold for earwigs.

These results also suggest that chemical or sticky trunk barriers, particularly sticky barriers, show promise for reducing the densities of pests such as earwigs, Fuller rose beetles and ants that access the tree canopy by crawling. However, applying sticky barriers is very time-intensive and painstaking. Future work identifying better ways to better apply sticky barriers to tree trunks is needed. 🌱

CRB Research Project #5500-220

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# MORE FRUIT, LESS DROP, EARLIER SIZING



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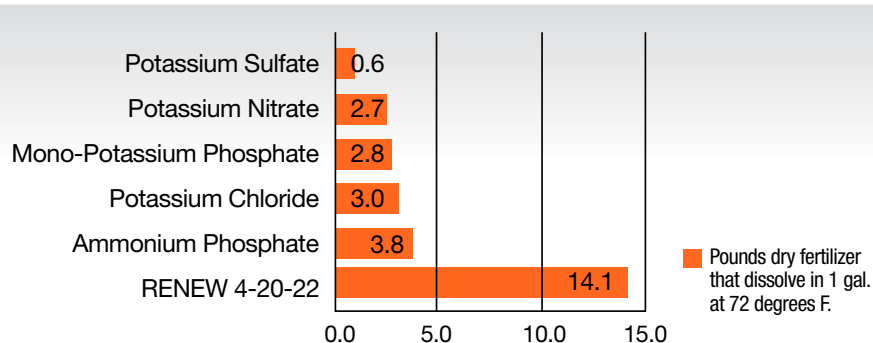
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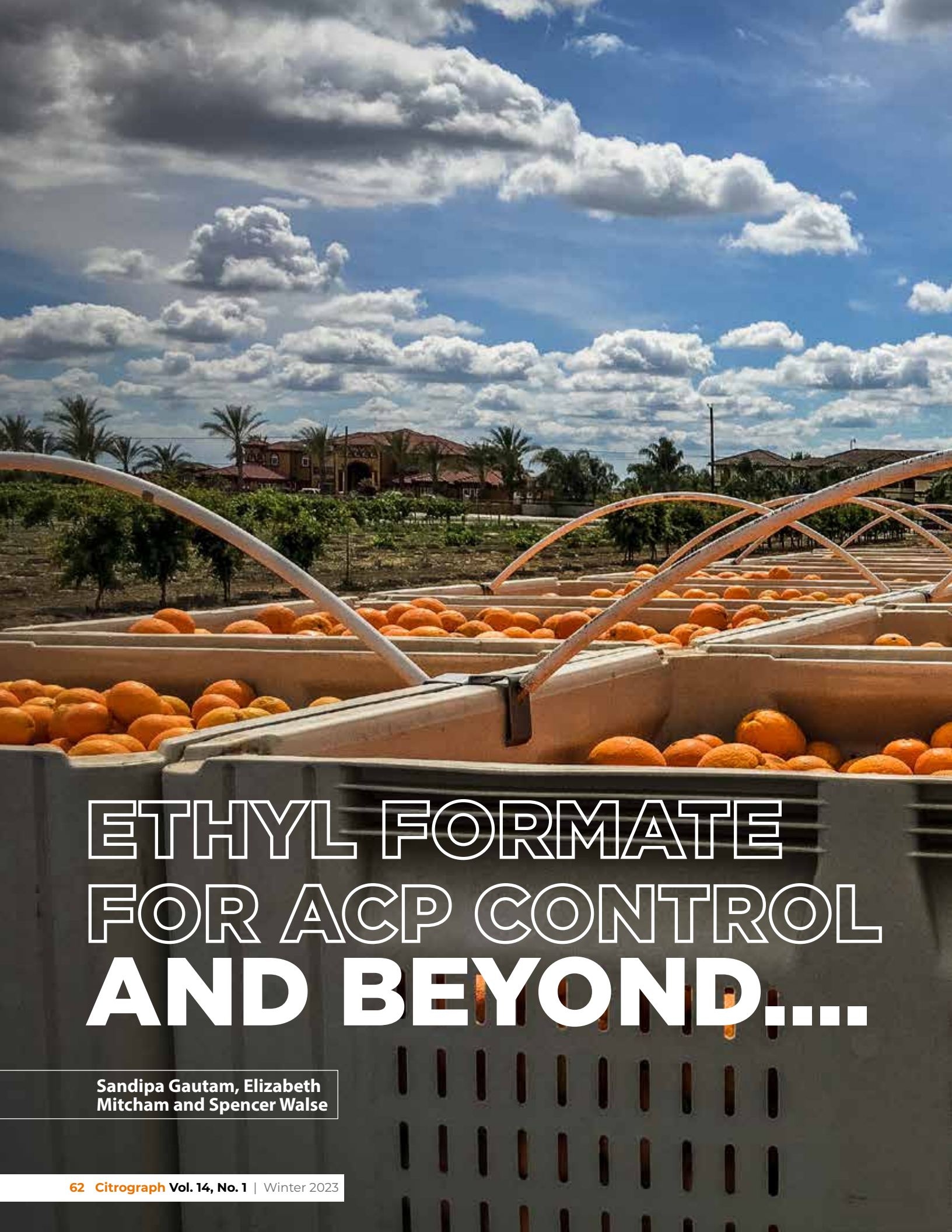
*RENEW* is a clear, pH balanced nutritional containing low biuret urea to foster enhanced leaf absorption. *RENEW* contains no sodium or chlorides for safe compatible applications without rind stain. *RENEW* can be tank mixed with most pesticides, including fungicidal copper (maintain pH >6.2).

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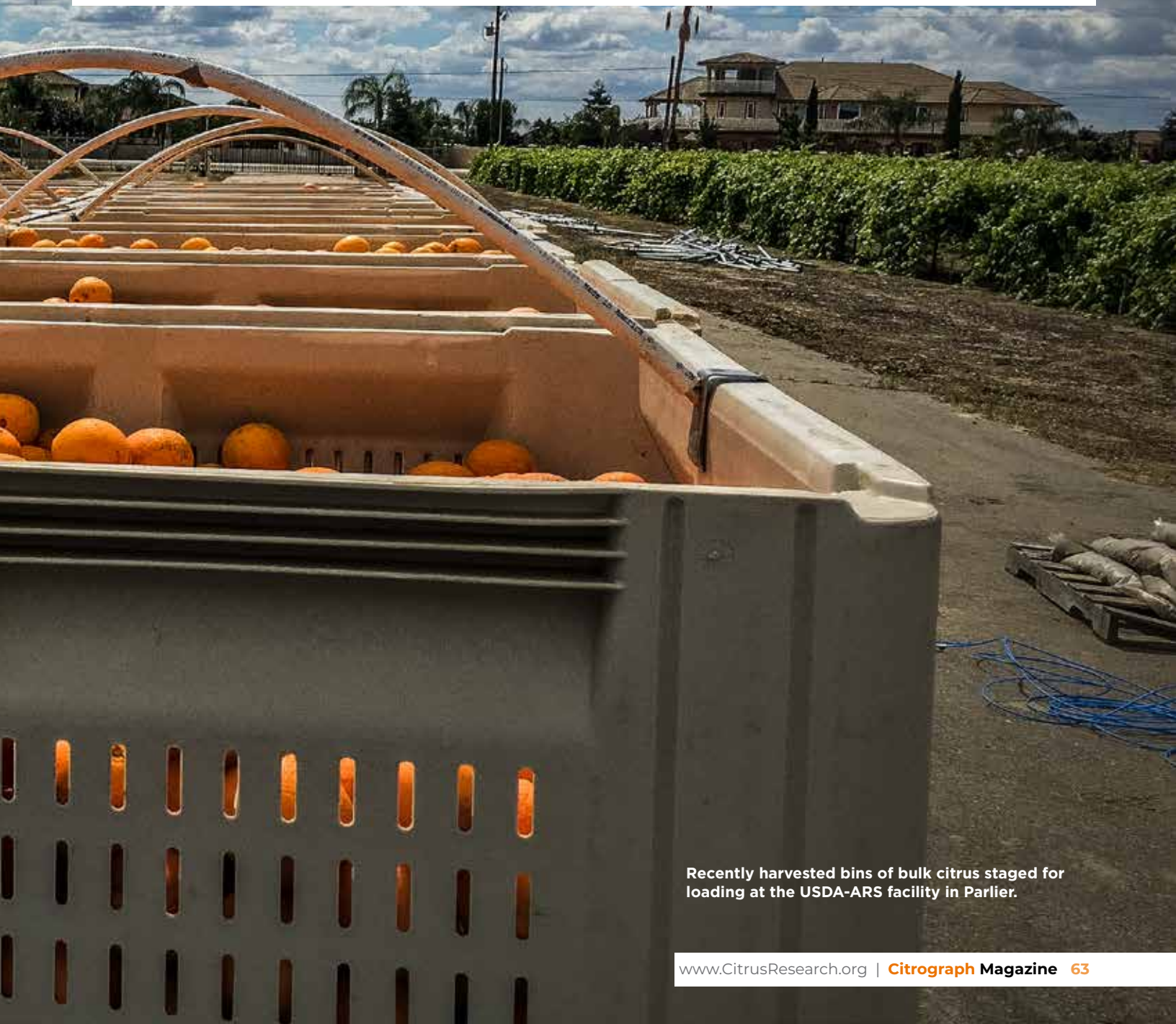
# ETHYL FORMATE FOR ACP CONTROL AND BEYOND....

Sandipa Gautam, Elizabeth  
Mitcham and Spencer Walse



## Project Summary

For more than 12 years, the California citrus industry has been looking for ways to keep Asian citrus psyllid (ACP) out of groves, transportation routes to packinghouses and marketing channels. To address the latter two critical needs, a team of researchers have worked tirelessly to optimize, validate and register the fumigant, eFUME™, a commercialized formulation of ethyl formate diluted in carbon dioxide. Although each grower and packer have many considerations, and pest control strategies rarely are embraced universally, eFUME treatment can be a strategic alternative to “field-packing” and/or “spray and move” for satisfying the California Department of Food and Agriculture (CDFA) quarantine. Moreover, its use can be parlayed into satisfying phytosanitary requirements for export. eFUME offers key advantages: 1) it is safe to humans and the environment – an “organic” certification will be pursued, 2) it does not require any additional handling or wetting of the fruit, which is known to decrease quality and 3) it is highly effective against ACP and other key insect pests without the potential drawbacks of conventional (residual) insecticides such as spray variability, restricted entry intervals (REIs), maximum residue level (MRL) exceedances and narrowed Integrated Pest Management (IPM) options. Research history and efforts are summarized, treatment options are outlined and the critical need for technology transfer events to further harness industry input is discussed.



Recently harvested bins of bulk citrus staged for loading at the USDA-ARS facility in Parlier.



**Recently harvested bins of bulk citrus easily can be tarped in preparation for fumigation with eFUME, a commercialized fumigant formulation of ethyl formate diluted in carbon dioxide.**

In 2009, the Citrus Research Board (CRB) and the California Citrus Quality Council (CCQC) approached the U.S. Department of Agriculture-Agricultural Research Service-San Joaquin Valley Agricultural Science Center (USDA-ARS-SJVASC) to evaluate Asian citrus psyllid (ACP) removal during “standard” packline events (Walse et al. 2014). The objective was to defuse concerns from Australia and New Zealand about the security of California exports. Both countries were tracking the spread of ACP northward from Mexico, as evidenced by just a few documented findings in the south of District 2. Packline events effectively removed ACP, a finding that ensured continued export from packinghouses. Perhaps more importantly, this initial packline work was quickly recognized by the USDA-Animal and Plant Health

Inspection Service (APHIS) and the CDFA to eventually serve as the technical basis for “field-packing” becoming an approved means to move fruit across quarantine boundaries.

With the spread of ACP throughout Districts 2 and 3, the “spray and move” program evolved. It eventually was coupled to netting trailer loads of bulk citrus and still serves as the principal means for compliance with CDFA quarantines (CDFA 2022). In 2015, California Citrus Mutual (CCM) united researchers from USDA-ARS-SJVASC and University of California, Riverside to more securely prohibit ACP spread via the trucking of bulk citrus, particularly loads heading to District 1 packinghouses from the infested groves, and to relieve frustrations of juggling harvest(s) around “spray and

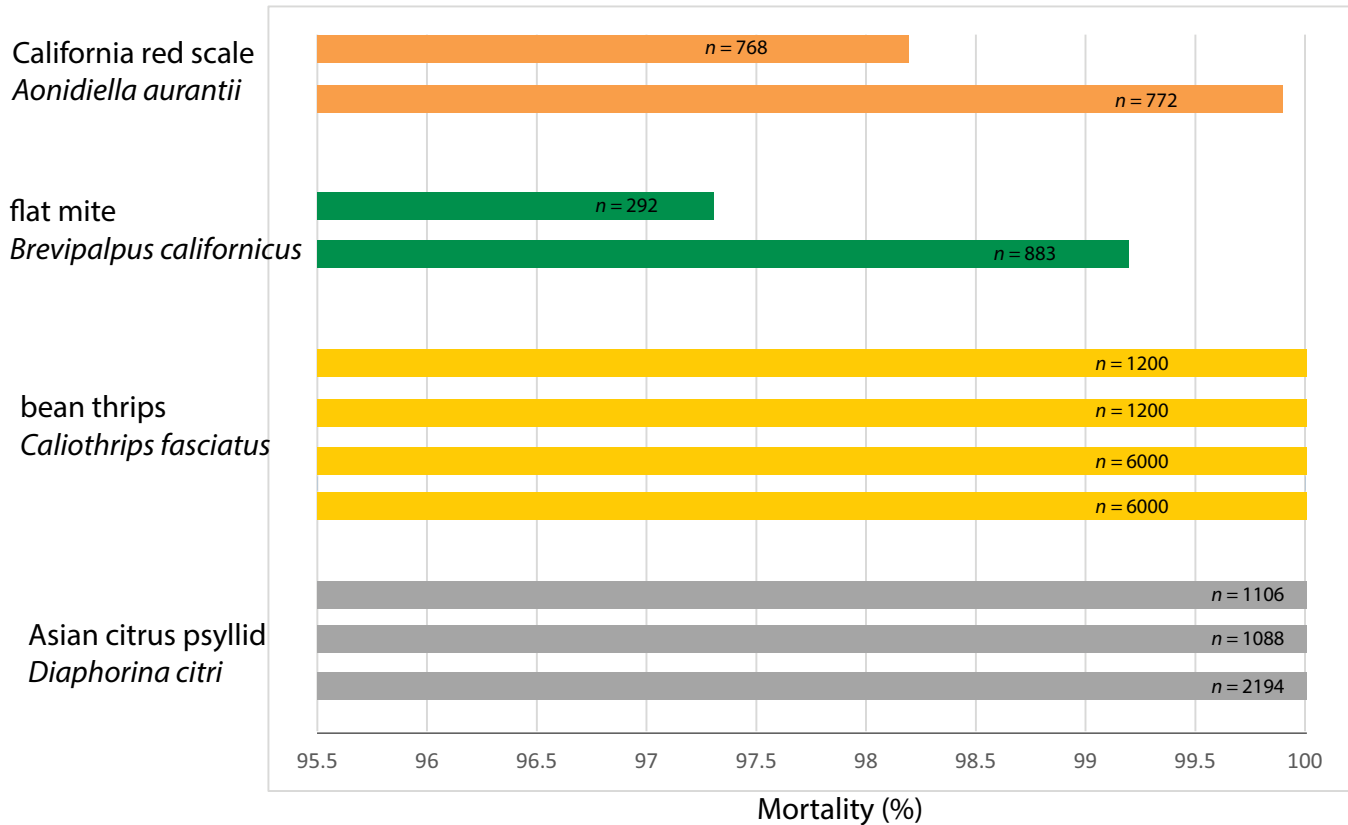
move” REI and weather compliance issues, particularly in groves already stressed by intensive, ACP insecticide regimes. The request from industry was to eliminate ACP on bulk fruit in bins near the grove with negligible disruption to picking, binning and trailer loading. The research yielded a “quick-drying” post-harvest fogging treatment with EverGreen® Pro 60-6 (USEPA Reg. No. 1021-1770), ultimately approved by the California Department of Pesticide Regulation (CDPR) Section 18 Quarantine Exemption No. 18-07 (Wilcox 2018; Corbett et al. 2018). The emergency exemption originally was scheduled to expire in spring 2021, but it was withdrawn in 2019 because the CDPR did not record a single reported use. The lack of implementation was attributed to the prohibitive costs of the tenting structure and fogging





The application of eFUME requires a generator, which powers the volatizer that ensures cylinderized fumigant is expelled uniformly under the enclosure until the correct mass is applied, shown here during trials involving “curtain-side” (A) and “step deck” (B) trailers.

## Efficacy of the ethyl formate applied to bulk fruit in bins per the “Special Citrus Use”



**Figure 1.** The “Special Citrus Use” involving the treatment of bulk citrus in bins serves as an opportunity to simultaneously address the domestic need for ACP control and the export requirements to control mites, thrips and red scale for Australia, New Zealand and Korea.

equipment. Accordingly, the research team refocused on finding a cheaper, less infrastructurally cumbersome option.

CRB- and CCQC-funded research, conducted at the University of California, Davis during the period 2010 to 2016, evaluated the efficacy of various ethyl formate formulations toward key insect pests (Bikoba et al. 2019, Pupin et al. 2013), including ACP (Gautam et al. 2019). Ethyl formate is a colorless liquid with a pleasant, banana-like odor and a boiling point of 54°C. Ethyl formate and its break-down products, ethanol and formic acid, occur naturally in citrus fruit and are listed by the US Food and Drug Administration (FDA) as generally recognized as safe (GRAS)<sup>1</sup>. Having a flash point of 2.3 V/V% in air, the use of ethyl formate has long been accompanied by dilution in carbon dioxide carrier gas for the purpose of fire suppression and to act as a propellant – such is the case for eFUME. Carbon dioxide affects insects in many ways as reviewed by Nicolas (1989), and the impact of carbon dioxide carrier gas on the toxicity of eFUME, as well as fruit quality, was a major focus of the cited investigations. A “Post-harvest Use” involving the treatment of packed, palletized fruit in a manner analogous to phytosanitary fumigations with methyl bromide was initially targeted. Importantly,

understanding eFUME use in this scenario – and particularly its lack of impact on fruit quality – coincidentally prepared the California citrus industry for Korea’s 2021 decision to conduct fumigations on arrival with ethyl formate instead of methyl bromide.

A “Special Citrus Use” involving the treatment of bulk citrus in bins served as an opportunity to simultaneously address the domestic need for ACP control, as described above, and the export requirements to control mites, thrips and red scale for Australia, New Zealand and Korea (Figure 1). The “Special Citrus Use” is essentially a novel application approach, which affords several strategic advantages relative to fumigations that occur after packing and/or cooling. First, ethyl formate is far more toxic when applied to fruit at field temperature – before insects are cooled along with the fruit, which means that a much lower level of fumigant is used to obtain the required mortality (Bond 1984). Second, the breakdown of ethyl formate, once sorbed into fruit, into non-toxic ethanol and formic acid residues, occurs more quickly when the fruit is at field temperature. Note that residues are masked by naturally occurring levels of ethanol and formic acid already in the fruit. The “Special Citrus Use” is all about the





**Photo 3. Users may prefer to conduct eFUME fumigations using more “permanent” enclosures, such as a tent placed at a location where many loads will transit.**

balance between efficacy and using the citrus to “scrub” the fumigant so that there are no unnecessary emissions. Readers familiar with the “total utilization” of sulfur dioxide will recognize that we adapted this fumigation technique from the table grape industry. Bins of bulk citrus, staged for loading onto a trailer or already on a trailer, are tarped and then eFUME is applied at a level to control ACP, thrips, mites and red scale in about an hour. The USDA-ARS-SJVASC has prepared guidelines to best gauge application rates and how they change as a function of citrus type, season and temperature. Once the hour has passed, and the eFUME levels have dropped to near zero in the enclosure, the tarp can be removed – and all the insects residing on the surface of the fruit – less the eggs of the pesky Fuller’s rose beetle – are D.O.A. (to the packinghouse)!

Despite its demonstrated success in addressing citrus needs, as well as its global potential as a methyl bromide alternative for fresh fruit disinfestations, it wasn’t until 2018 that Draslovka Services, LTD stepped forward to pursue the FIFRA<sup>2</sup> and State registrations of eFUME. Both the “Post-harvest” and

“Special Citrus” uses of eFUME are nearing the end of USEPA evaluation, with a registration review decision expected in February 2023. After USEPA approval, the CDPR could issue another Section 18 Quarantine Exemption to address ACP control before the formal California registration is finalized; but with near certainty, it won’t be granted again unless the industry actually intends to use eFUME. Toward this end, now is the time to transfer this technology to industry, gather feedback on all facets of the potential use pattern and strategically optimize eFUME for the California citrus industry – growers and packers alike. Industry outreach events spearheaded by the CCQC in April 2022 allowed Draslovka Services, LTD to meet many in the citrus industry, and the roll-out of eFUME to interested parties is underway. Importantly, contracting a fumigation service provider will not be required to conduct an eFUME treatment, the appropriate CDPR licensing (QAL or QAC) will suffice.

No one is required to use eFUME, but in today’s world, where the California citrus industry depends financially on exports and the plant protection products used for security are

constantly being assaulted by nonsensical consumers and regulators, it is critical to understand that eFUME is a valuable tool for our future. eFUME leaves no detectable residues, it controls nearly every insect without having to spray broad-spectrum insecticide over acres, and it eliminates the need for workers to pick recently treated fruit. Simply put, ethyl formate is worth considering for ACP control and beyond.... 🌍

## CRB Research Project #5500-218

### Glossary

**<sup>1</sup>GRAS:** Acronym for Generally Recognized As Safe. Under sections 201(s) and 409 of the Federal Food, Drug and Cosmetic Act.

**<sup>2</sup>Federal, Insecticide, Fungicide and Rodenticide Act (FIFRA):** The Federal statute that governs the registration, distribution, sale and use of pesticides in the United States.

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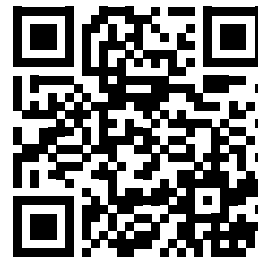
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