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Example of direct pest damage to fruit observed in the top layer of a harvest bin. Damage types visible (clockwise from bottom center) include forktailed bush katydid scar, citrus peelminer, putative limb rub and California red scale infestation.

A "Big Data" Approach for Pest Management in Mandarins

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Project Summary

Citrus production in California has changed dramatically in recent years, with a sharp increase in mandarin acreage. With the absence of research into insect pests in mandarins, our current integrated pest management (IPM) guidelines have been based largely on research done with oranges. We know these crops are different in many ways, but do not know which IPM practices to change for optimal production. Here we report the first results emerging from a "big data" approach to analyze pest control advisor (PCA) and grower records of citrus grove management in the San Joaquin Valley. We found differences in pest densities and fruit scarring between navel oranges and the commonly-grown mandarins. Tango and Afourer variety mandarins have notably low levels of fruit damage; specifically, damage from fork-tailed bush katydids, California red scale and citrus peelminer is absent, suggesting they may have natural resistance to these pests. This real-world data set provides our first look at pest effects in mandarins. More traditional field experiments are underway to determine why these pests cause less damage, and to tailor pest management recommendations accordingly.

Pest Management in Mandarins

Citrus in California's main growing region is plagued by early season insect and mite pests. Fork-tailed bush katydids, citrus thrips and caterpillars (mostly citrus cutworm), feed directly on young fruit, creating scars. This scarring, as well as heavy infestations of citrus peelminer or California red scale, can cause the fruit to be downgraded from "fresh" to "juice" quality at harvest, resulting in a nearly complete loss of value. Pests are successfully managed on navel oranges with a year-round IPM program built on decades of experience and field experiments (Ferguson and Grafton-Cardwell 2014). However, citrus production in California has changed substantially in recent years, with a sharp increase in mandarin acreage (2018 California Citrus Acreage Report, California Department of Food and Agriculture, California Agricultural Statistics Service). There are currently no specific IPM guidelines established for mandarins, so research is needed to develop these guidelines.

Why use grower data?

Re-building major components of the IPM program for mandarins would be costly and labor-intensive if the industry relied solely on traditional field studies. There are numerous mandarin varieties. They are attacked by many different pests and are grown under a broad range of growing conditions. In cases like this, an ecoinformatics[1] or "big data" approach can help to discover patterns and focus experiments (Rosenheim and Gatton 2017). By pooling the wealth of data collected by growers and PCAs as part of their normal management, we can learn about pest conditions in real commercial groves, at the scale and pace needed to keep guidelines accurate and relevant.

Citrusformatics Database

We constructed a large *"Citrusformatics"* database of pest management records from commercial growers in California's San Joaquin Valley. From this database, we analyzed a subset of 201 groves from six growers. These groves were each monitored for one to ten years between 2003 and 2012. We tested whether oranges and mandarins differ in (1) pest densities and (2) the resulting damage to fruit at harvest. Mandarin cultivars were grouped by citrus species: Tango and Afourer varieties (*C. reticulata*), clementines (*C. clementina*), Minneola tangelos (*C. tangelo*), and satsumas (*C. unshiu*). Navel oranges (*C. sinensis*) were used as the standard for comparison.

Pest densities are different on mandarins

Densities of fork-tailed bush katydids and citrus thrips were different for the mandarin group compared to oranges (**Figure 1**). Fork-tailed bush katydids were lower on Minneola tangelos, and citrus thrips were lower on Tango and Afourer mandarins. Average caterpillar and California red scale densities appeared lower on all mandarin varieties tested, but these effects were due more to differences among year and/or location than citrus species.

Lower relative densities of pests in these mandarins may be due to:

1. greater pesticide coverage;
2. pests having not yet moved into the newer mandarin fields (although we controlled statistically for differences in tree age, this could be a potential factor for pests such as scale insects that don't disperse very far and thus take a while to build up in young mandarin orchards);
3. mandarins being less suitable hosts for these pests or
4. increased effectiveness of natural enemies in mandarins than in navels.

Ongoing experimental work will test these hypotheses to help determine whether less-frequent monitoring and treatment is required for these pests.

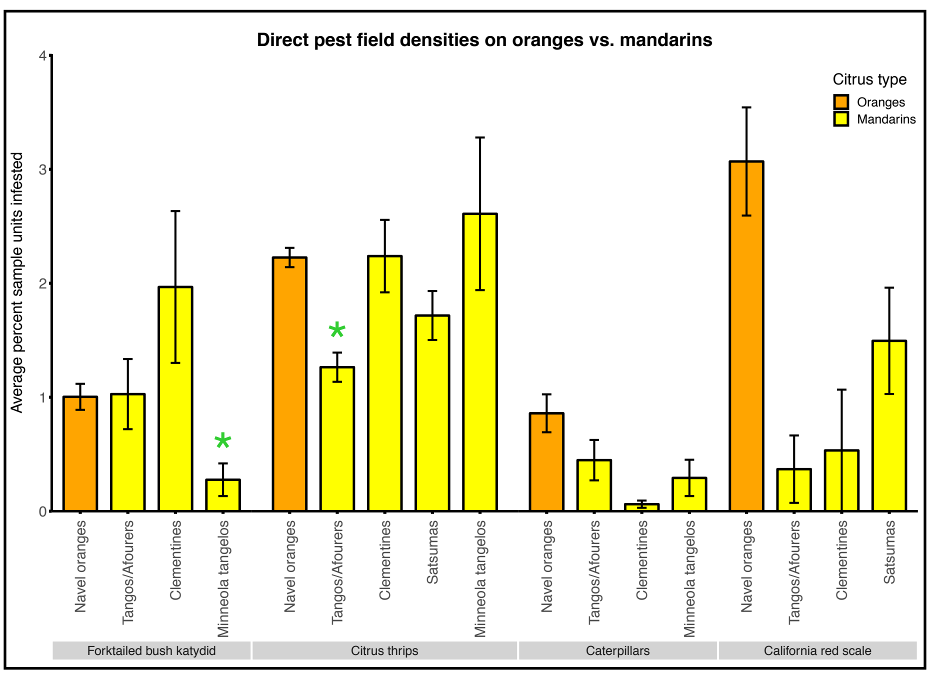

Figure 1. Field densities differ in mandarin species (yellow) compared to navel oranges (orange) for the main direct pests in commercial California citrus groves. A sample unit is made up of fruit, foliage or tree depending on the pest of interest. Green asterisks above bars indicate a significant difference from oranges.

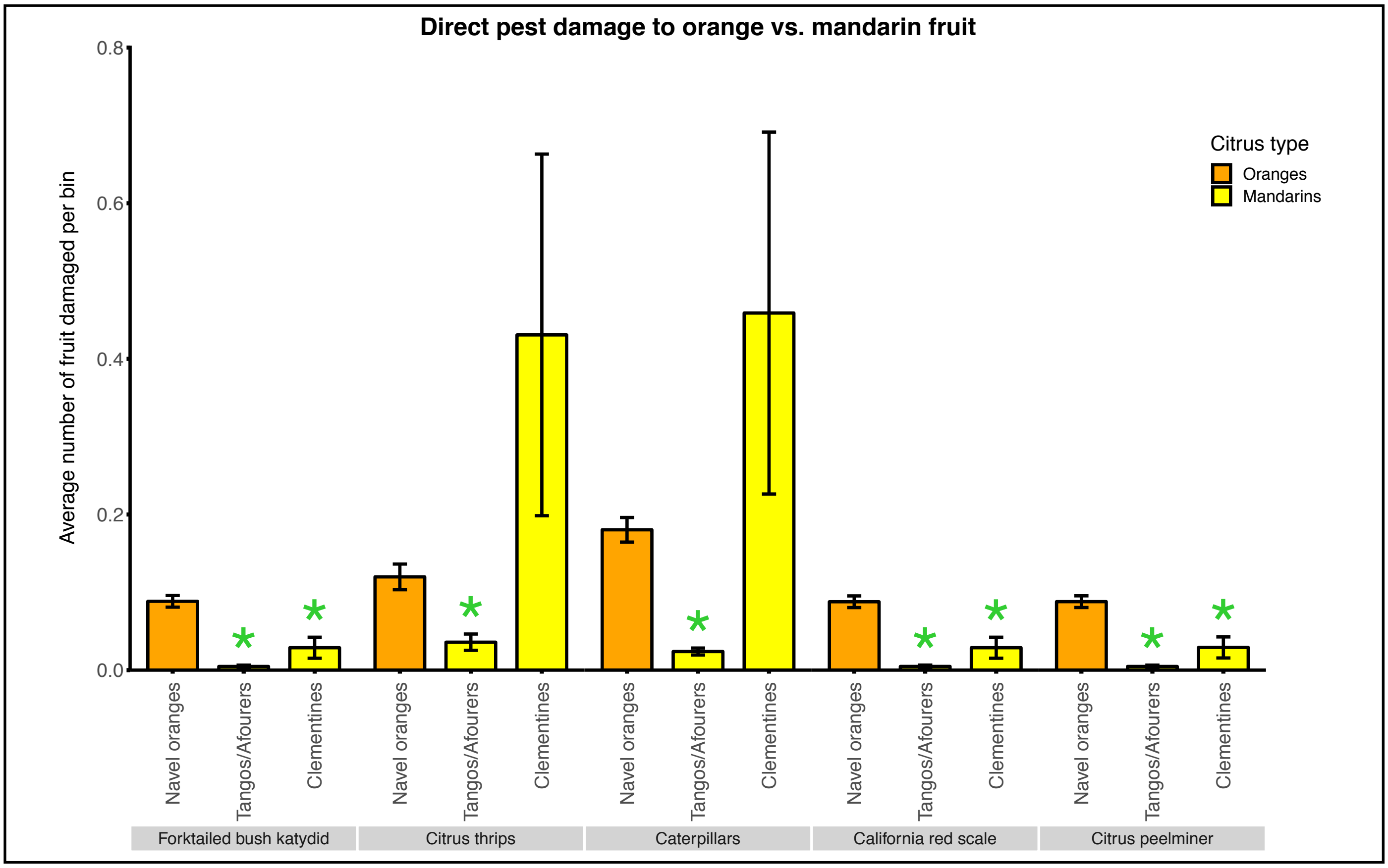

Figure 2. Direct damage to fruit (rind scarring or infestation) was lower in Tango and Afourer mandarins than in navel oranges, and variable in clementines. Green asterisks above bars indicate a significant difference from oranges.

Very Low Pest Damage in Mandarins

Damage levels were consistently lower in Tango and Afourer mandarins than in navel oranges across the full suite of direct pests, which damage the marketable part of a plant (**Figure 2**). These scarring densities also were lower than expected, given the relative pest field densities in Tango and Afourer mandarins compared to navel oranges. The remarkably low scarring by fork-tailed bush katydids and infestation by California red scale and citrus peelminer observed in Tango and Afourer mandarins raises the question of whether these are pests at all on these varieties. Our statistical model controlled for as many confounding factors as possible, but as these are observational correlations, caution should be taken in assigning citrus species as the reason underlying the observed differences. Controlled field experiments are ongoing to confirm what is driving these differences in Tango and Afourer mandarins.

There were fewer clementine orchards than those of other citrus species to compare, but damage from fork-tailed bush katydids, California red scale and citrus peelminer were lower than in navel oranges and lower than expected for fork-tailed bush katydids given their relative field densities.

Fruit damage levels were measured as the number of fruit with visible damage (rind scarring or infestation) per top layer of fruit in a harvest bin before transport to the packinghouse. Each pest creates damage with a characteristic appearance, allowing the specific pest to be identified (Grafton-Cardwell et al. 2003). It is inherently difficult to convert from number of fruit damaged per bin to percentage of fruit scarred. We took a conservative approach of assuming equal numbers of fruit sampled per bin for all varieties instead of assuming 100 oranges and 200 mandarins per top layer of a harvest bin, a common estimate by the consultants performing these damage surveys. This over-estimates the damage percentage for the smaller mandarins such as Tango and Afourer varieties, with the true values likely about half the value reported here.

The curious case of katydids

Tango and Afourer mandarins (and to a lesser extent, clementines) had very low scarring by fork-tailed bush katydids despite field densities similar to those seen in navel oranges. Ongoing field experiments are determining whether this is due to:

1. katydid feeding preference;
2. fruit recovery from damage;
3. katydid scarring looking different in mandarins, so that we're not recognizing it or
4. preferential abscission of damaged fruit.

In the case of the third hypothesis, the katydids still may be a pest. California red scale showed a similar trend, although there were fewer records to assess.

Conclusions

This analysis of commercial citrus production records provides our first overview of comparative pest densities and fruit damage in California mandarins, revealing a very different picture of pest effects than what usually is seen in navel oranges. This indicates that new IPM recommendations developed specifically for mandarins are needed. Most strikingly, Tango and Afourer mandarins appear to be partially to fully resistant to the entire suite of pests that attack young fruit. Fork-tailed bush katydids, California red scale and citrus peelminer may not be pests of these mandarin fruit at all.

These results also demonstrate the utility of a big data approach using records from cooperating PCAs and growers to provide timely and accurate information for pest control. The continued maintenance of the *Citrusformatics* database created for this study will provide historical perspective as California adapts to the invasion of the Asian citrus psyllid vector of *'Candidatus* Liberibacter asiaticus,' the bacterium associated with huanglongbing (Grafton-Cardwell 2015). This work provides a foundation for understanding pest dynamics in mandarins at the scale of commercial production and is the first step in our larger project combining big data and field experiments. The updated IPM guidelines resulting from this project will help growers make pesticide decisions to preserve a quality mandarin harvest while avoiding unnecessary or ineffective pesticide applications.

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Glossary

[1]**Ecoinformatics:** A data mining method of research where researchers collect and analyze a large volume of data pooled from multiple sources, often covering a larger scale and timeframe than could be assessed using traditional field experiments.

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