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Large controlled atmosphere rooms open (left) and closed (right) for cold storage phosphine fumigations.

Post-harvest Fumigation: Opportunities and Challenges

Breaking trade barriers for California citrus exports

Spencer Walse

Project Summary

The over-arching goal of this research is to develop post-harvest treatments to facilitate movement of California citrus through international trade and marketing channels. Particular attention is paid to the expansion and retention of export markets. This research critically supports compliance with domestic and international regulations related to the protection and distribution of fresh citrus, as well as human and environmental health concerns associated with the use of agrochemicals. Efforts to develop post-harvest fumigation as a tool to maintain the global prominence of California citrus are briefly outlined in this report.

With the ever-increasing demand in domestic and international markets for food quality, safety and security, there also is the critical need to control horticultural crop pests in the safest and most economical ways possible. Whenever horticultural crops traverse political boundaries, pest-related trade barriers can ensue. Frequently, but not always, these barriers can be lowered or removed when sound scientific evidence is provided. The Crop Protection and Quality Research Unit (CPQRU) of the US Department of Agriculture – Agricultural Research Service (USDA-ARS) San Joaquin Valley Agricultural Sciences Center in Parlier, California, has a team of scientists dedicated to addressing horticultural crop export issues, with particular attention given to post-harvest pest control strategies that enhance the competitiveness of American agriculture.

The CPQRU research team comprises three principle investigators who conduct post-harvest citrus research: Spencer Walse, Ph.D., Chang-Lin Xiao, Ph.D., and David Obenland, Ph.D. The team focuses on trade barrier issues, with the major goals of (1) retaining and expanding domestic and/or international markets for US growers and (2) protecting US growers from the agricultural, ecological and economic threat posed by horticultural crop pests. With a research scope that encompasses a variety of key technical and regulatory issues, including Maximum Residue Levels (MRL)[1], pesticide registrations, food safety and IPM strategies, arguably the greatest effort goes to the development of novel theories and treatments for post-harvest insect pest control.

Relative to treatments applied during production, post-harvest opportunities allow for greater synchronization of the treatment with the logistical and infrastructural constraints that funnel into the marketing channel. While efforts continue across the gamut of post-harvest possibilities (e.g., cold-treatments, heat-treatments, irradiation, controlled-atmosphere, fogging, etc.), fumigation is an invaluable treatment option.

Post-harvest fumigation is a critical element of the $3 billion per year California citrus industry. Post-harvest fumigation provides a biological safeguard against pests and, in many cases, is the only available tool for governments, regulators and industry to guarantee pest-free security and food safety. One fumigant, methyl bromide (MeBr), has dominated post-harvest applications in California and beyond. It quickly penetrates commodity loads and has, in general, non-discriminating efficacy against insect and microbiological pests (Bond 1984). As such, MeBr has been used successfully for quarantine[2] and pre-shipment[3] (QPS) disinfestations over the last four decades. Its routine use has left the California citrus industry, producers and port facilities alike, with infrastructural capabilities that are almost exclusively geared toward post-harvest chambers designed specifically for MeBr use.

Many dynamics are involved with the continued use of MeBr by the specialty crop industry as a whole, several of which are currently relevant to the California citrus industry. Methyl bromide use is regulated via international legislation under the Montreal Protocol[4]. The Protocol (Article 2H) *recognizes that QPS methyl bromide is an important remaining use of this ozone-depleting substance that is not controlled*, a clear acknowledgment by the international community that MeBr is critically important and will continue as the "tool of first choice" due to its internationally accepted efficacy and regulatory status. However, (decision XI/13) urges *Parties to implement procedures to monitor the QPS uses of methyl bromide by commodity, and* (decision VII/5) urges *Parties to refrain from using methyl bromide and to use non-ozone-depleting technologies*. This "urging of the Parties" away from QPS MeBr use creates myriad challenges for regulatory, agricultural and industry entities with a stake in post-harvest chamber fumigation, a technology that literally evolved around QPS MeBr use. The situation is further complicated by the fact that continued QPS uses are at the discretion of the importing nation per Food and Agriculture Organization (FAO) standards (ISPM, 2007).

One example is South Korea, one of the key export markets for California citrus, valued at approximately $200 million annually. A true testament to successful negotiations by citrus industry leaders and the US government in the 1980s, the on-arrival QPS MeBr fumigation in South Korea caused minimal disruption to export marketing, resulted in optimal fruit quality and negated the expense of building chambers in California packinghouses. In this light, it was a nearly ideal post-harvest treatment for the California industry. All indications suggest, however, that the use of QPS MeBr for this export is on borrowed time, as it appears South Korea is poised to remove this treatment option, likely due to logistical, regulatory and political pressure on their end.

The following summarizes efforts made by Walse of the CPQRU research team, as well as key University of California, citrus organizations (Citrus Research Board [CRB], California Citrus Quality Council and California Citrus Mutual) and industry collaborators, toward the development of post-harvest MeBr alternatives for the California citrus industry.

Since the US government became a signatory of the Montreal Protocol in 1988, researchers and industry near and far have been working diligently to develop technically and economically viable post-harvest alternatives to MeBr. Foremost, any alternatives must have a domestic food tolerance[5], which can cost a registrant more than $1 million and take five years for the US Environmental Protection Agency (EPA) review, with no guaranteed approval. Secondarily, the alternatives must have MRLs in the target market, which essentially means the process must repeat itself in the foreign regulatory realm.

Table 1. Treatment durations required to control key citrus insect pests with phosphine fumigation conducted on packed, palletized fruit at 40°F.

species	*target life stage*	*market*	*duration (hour)*	*efficacy (% kill)*
bean thrips	adults	Australia	12	> 99
California red scale	all	Korea	24	> 99
Asian citrus psyllid	adults	domestic	36	> 99
Fullers rose beetle	eggs	Korea	48	>95

Only a single post-harvest MeBr alternative, phosphine, can be used to treat citrus in the US. Owing to the pioneering work of Fransiskus Horn, Ph.D., in the late 1990s, phosphine is now used across the globe to treat fresh fruit at cold-storage temperature, and MRLs of 10 parts per billion (ppb) are established in nearly all key exports markets for California citrus, with the notable exception of Australia and New Zealand. MRLs of 10 ppb, consistent with "no detection" per international food standards of Codex Alimentarius, are essentially a regulatory formality because they "acknowledge" a treatment that would otherwise be undetected during residue analysis. The rapid off-gassing of phosphine from fresh fruit, including citrus, during the EPA mandated 48-hour lag (under cold-storage) between fumigation aeration and consumption, enables compliance with such a low food tolerance and ensures that chances of non-compliance in a foreign market are essentially nil. Moreover, the rapid off-gassing of phosphine during aeration minimizes worker exposure concerns, relative to MeBr, which takes more than 20 times longer to off-gas from a given type of fruit. Another advantage of phosphine is that it generally enhances the quality of waxed, packed, palletized fruit. Recently, a CRB-sponsored project began to thoroughly benchmark the quality of phosphine-treated citrus relative to that treated with MeBr, in order to better ascertain the potential use of phosphine for export to Korea.

Figure 1. Due to treatment durations that are long, relative to those for methyl bromide, cold-storage phosphine fumigations can be conducted in large controlled-atmosphere rooms, maintained under cold-storage conditions, as a means to minimize disruptions to export throughput.

There are key features, however, that differentiate phosphine and MeBr. Whereas MeBr works on the timescale of two to four hours at treatment temperatures above 40°F, phosphine is

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Figure 2. Phosphine fumigations can also be conducted in methyl bromide chambers (top left), modified reefer containers (bottom left), or even under tarpaulins (top right).

typically used for 12 to 72 hours at "cold-storage" temperatures spanning about 31 to 45°F (**Table 1**). For extremely difficult-to-control insect pests, such as internal feeding Tephritid fruit fly larvae (e.g. Mexican fruit fly, Medfly), treatment temperature can be increased up to nearly 70°F for 48 hours (Williams et al. 2000). The need to treat for such a long period of time, relative to MeBr treatments, requires compensatory scaling of fumigation structures to accommodate packinghouse throughput requirements, particularly for several of the larger export markets. Chile fresh fruit packers and shippers have overcome this logistical complication, primarily by conducting phosphine fumigation in large controlled-atmosphere rooms (**Figure 1**) or banks of modified reefer containers (**Figure 2**). The CRB has funded commercial-scale research with phosphine as a proof of concept for industry and USDA-Animal and Plant Health Inspection Service (APHIS) regulators. A 48-hour treatment with a dose of 1.5 milligrams per liter phosphine at 40°F controlled 95 percent of more than 7,000 Fuller rose beetle eggs buried throughout 88 pallets of navels packed for export to Korea. Whether used as a stand-alone post-harvest fumigation or as a final mitigation step as part of a systems-approach, phosphine is a viable tool for the California citrus industry, and its use is expected to increase.

Two other fumigants, ethyl formate and propylene oxide, are currently being investigated for insecticidal efficacy, residue characteristics and impact on fruit quality. While it is unlikely that two-hour fumigations with ethyl formate and propylene oxide will provide control of Fuller rose beetle and Tephritid fruit flies at doses that do not harm fruit, both ethyl formate and propylene oxide are highly effective against external feeding insects, including mites, psyllids and thrips.

If any citrus packers wish to learn more about post-harvest treatments, including fumigation, please reach out to Spencer Walse of the CPQRU research team. We are always willing to conduct fumigations in Parlier, California, so that packers have an opportunity to observe the treatment and evaluate fruit quality on their own terms/criterion – drop the fruit off, we will treat it and then return it for evaluation.

CRB Research Project #5400-149

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Glossary

[1]**Maximum Residue Levels (MRL):** The highest level of a pesticide residue that is legally tolerated in or on food or feed when pesticides are applied correctly per label instructions.

[2]**Quarantine disinfestation:** Treatments to prevent the introduction, establishment and/or spread of quarantine pests (including plant pathogens).

[3]**Pre-shipment disinfestation:** Treatments applied directly preceding and in relation to export to meet the phytosanitary or sanitary requirements of the importing country.

[4]**Montreal Protocol:** International treaty designed to protect the ozone layer by phasing out the production of numerous substances responsible for ozone depletion. It has been ratified by 197 parties, including 196 states and the European Union, making it the first universally ratified treaty in United Nations history.

[5]**Food tolerance:** Limits on the amount of pesticides that may remain in or on foods marketed in the US (referred to as MRLs in many other countries); set by the EPA and enforced by USDA (meat and poultry) and FDA (other foods).

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