Systems-based strategies for postharvest insect control: Mortality and removal of light brown apple moth, codling moth, brown marmorated stink bug, and other insect pests in California apples during packing and export

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Executive Summary.

An overall metric of treatment efficacy was developed, via combining the individual contributions from preharvest and postharvest processes, to evaluate systems-based strategies for insect control in fresh commodities, including apples. Systems-based strategies have potential overcome trade barriers for export of apples and will reduce the amount of chemical used to control an insect pest.

Background.

The detection and elimination of insect pests is necessary to ensure the safe movement of agricultural commodities from infested to non-infested areas through marketing channels. All treatments are subject to both regulatory and market-driven concerns, including commodity value. A treatment that is acceptable today may not be acceptable in the future. Over the last 20 years a framework based on biology was developed to assess and mitigate the risk posed by insects. This “systems approach” (Jang et al. 2006; Jang 1996; Jang and Moffitt 1994; Vail et al. 1993; Moffit 1990) was developed largely to support risk-assessments and mitigations that could occur in a broader based “system” of activities that cumulatively meet the quarantine requirements of the importing country. This approach provides both a framework for harmonizing risk assessment and mitigation, as well as a forum for oversight when disagreements exist (FAO 2011). We have expanded on this work via a toxicological-based approach where each event of protection, beginning in the field and ending at the point of sale, can be combined into a quantitative metric of insect control in order to meet the requirements of quarantine security.

Results and Discussion.

Research was conducted to quantify the control of key apple pests in various segments of the “system”, which includes production, packing, and shipping. Approaches for quantifying the cumulative effect of multiple events in a system on pest control (or risk associated with no control) have been limited to those instances when low prevalence of the pest in the field has been quantified. The proposed research provides a means for such quantification when low prevalence does not exist, as events are considered retrospectively from the final postharvest treatment event.

Using the general rule for the multiplication of probabilities (Rosenthal 1978; Finney 1948) on combining results (probabilities) of independent events, data from respective events were combined to quantify the cumulative effect of consecutive events on the “systemic” joint probabilities of control. For each event, the observed likelihood (expressed as a percentage) of finding a live insect, the theoretical percentage of mortality calculated at the 95% level of confidence (LOC) by the method of Couey and Chew (1986), and the associated probability, $P(E_x)$, could be tabulated. The Probit values at the 95% LOC and the confidence interval associated with Probit 9 treatment efficacy were calculated for each event as described in Liquido and Griffin (2010). In the case where one event, E_1, had no effect on the probability of the other(s), the joint probability of mortality associated with multiple treatment events, $P(E_{1} + E_{2} + En)$, was calculated from the multiplication of the simple probability of each event (Finney, 1948):

$$P(E_{1} + E_{2} + En) = 1 - (1 - P(E_1))(1 - P(E_2))(1 - P(En)) \text{ (Eq.1).}$$

Given equation 1, the special multiplication rule for independent events, the probability of insect mortality following the joint occurrence of two or more treatment events was calculated for any combination of events to meet (or supersede) control efficacies > 99.9968%, a statistical benchmark of phytosanitary treatment efficacy (Follet and Neven 2006; Couey and Chew 1986). An alternative approach to calculating the joint probability of multiple treatments, $P(E_b|E_a)$, involves multiplying the simple probability of the first event times the conditional probability of the second event, E_b, given the first,

$$E_a : P(E_b|E_a) = \frac{P(E_a \text{ and } E_b)}{P(E_a)} \text{ (Eq. 2).}$$

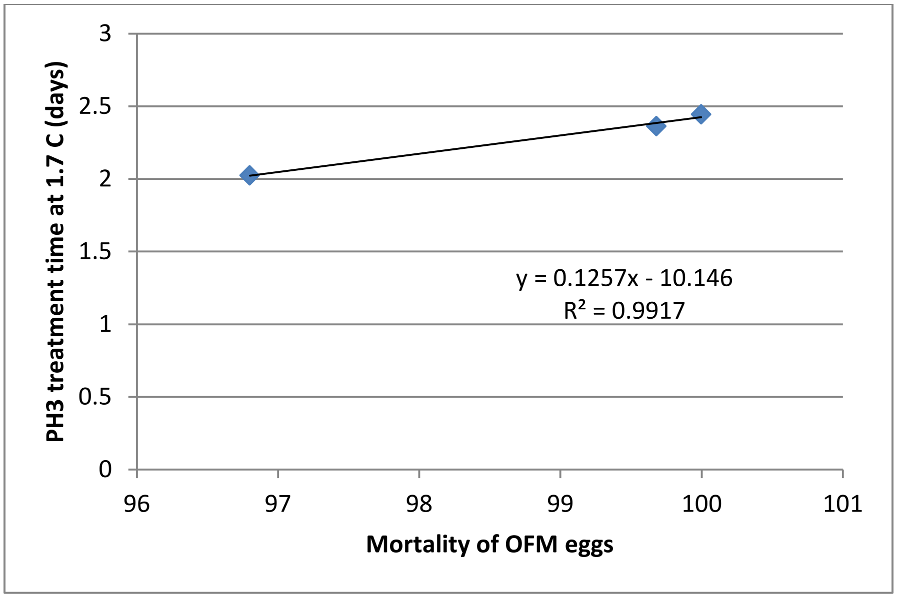
It is critical to note that even greater mortality is expected if a pair or series of events was evaluated conditionally (equation 2) versus independently (equation 1), because treatment survivors often are not fully healthy and are more susceptible to the subsequent treatment (Finney 1948).

Last year (Walse 2013 final report), we applied these models to the control of brown marmorated stink bug (BMSB) control on apples. Results can be used to support APHIS risk assessments and negotiations with foreign governments regarding BMSB-related phytosanitary issues. The research should enable The California apple industry to retain key export markets without a need for fumigation if BMSB is detected in production areas. Several series of postharvest events typically employed by California industry are highlighted and yield removal/mortality efficacies > 99.9968%, a statistical benchmark of phytosanitary treatment efficacy. This research can be provided to regulators and trading partners to quantify the reduction in risk/threat of BMSB as apples move from production areas through packing operations toward export markets.

Last year we also developed a mathematical model that predicted fumigations at 1.7 ± 0.5 °C ($\bar{x} \pm s$) with 1.5 mgL^{-1} (1000ppmv) required ~3 d treatment times for "quarantine" control of OFM eggs (i.e., ≥ 99.9986% mortality) per the equation:

$$\ln(y + 0.01) = 3.67 + 2.2x_1 - 2.6x_1^2 - 1.15x_2 - 0.26x_2^2 + 1.35x_1x_2 \quad \text{(Eq. 3)}$$

which is graphically depicted below.



Importantly, a 2-d treatment under these conditions is needed to control OFM larvae (Walse 2014 final fumigation report). If we are able to confirm 96.8% mortality of 10,000 OFM eggs following a 2-d fumigation at 1.7 ± 0.5 °C ($\bar{x} \pm s$) with 1.5 mgL^{-1} (1000ppmv) PH_3, as the equation 3 predicts, than we can use equation 1 or 2 above to estimate the probability of removing OFM eggs during packing that is needed to demonstrate that industry achieves Probit 9-level control (99.9986% mortality). Of course this will only be necessary should the egg life stage ever occur, or be considered to occur, in the marketing channel. If we assume that 300,000 boxes annually are shipped to export partners concerned with OFM, industry only needs to demonstrate that < 300 or < 310 OFM eggs enter the export marketing channel annually based on solving equation1 or 2, respectively.

County inspections for OFM support this assumption. Moreover, research was conducted to record the occurrence of OFM eggs entering a packing line to estimate the number of OFM eggs, given a two-leaf box tolerance (3.5g leaf per box), which are shipped in the 300,000 export boxes. For the past three years we have collected 750 lbs/year (wet weight) (340 kg) of leaf litter grated from packing lines, inspected the litter for OFM eggs, and incubated the litter under optimal rearing conditions for OFM. We have recorded two eggs, only one of which successfully hatched into a neonate, which translates into 0.002 OFM eggs/kg leaf. Based on the above logic, 2.1 OFM eggs can be expected in the 300,000 export boxes, more than 100-fold lower than what is needed to prove that OFM eggs could be controlled at a Probit-9 level of security following a postharvest fumigation with 1.5 mgL^{-1} (1000ppmv) PH_3 for 2 d at 1.7 ± 0.5 °C ($\bar{x} \pm s$).

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