Efficacy of Temperature Treatments for Insect Disinfestation of Dried Fruits and Nuts

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Abstract

In order to determine the potential of various temperature treatments for disinfesting dried fruits and nuts of postharvest insect pests, high temperature/exposure response curves for navel orangeworm eggs and pupae and Diarimeal moth pupae were estimated. For navel orangeworm eggs, 99% mortality was achieved after exposure to 49°C for 14 minutes. For navel orangeworm pupae, 99% mortalities were produced after a 12 minute exposure to 49°C. Diarimeal moth pupae were less heat tolerant, similar mortalities were obtained after 13 minutes at only 46°C. Freezing points for various stages of the Diarimeal moth and navel orangeworm were also determined. Pupae had the lowest freezing points for both species, with freezing points of -24°C for Diarimeal moth and -22°C for navel orangeworm. Diapauing Diarimeal moth larvae also had low freezing points, averaging -23°C. The freezing points for non-diapauing larvae were highest, -15°C for Diarimeal moth and -10°C for laboratory-reared navel orangeworm. Wild-type NOW larvae had lower freezing points (-16°C) than laboratory-reared larvae, but freezing points for wild-type pupae (-22°C) were similar to those for laboratory-reared pupae. Age effected the response of both IMM and NOW eggs to sub-freezing temperatures. Eggs appear to be the most cold tolerant stage of both IMM and NOW, and the IMM is more tolerant than the NOW. Studies on the effect of high temperatures on product quality showed that the taste of prunes and raisins are only slightly effected by exposure to 50°C for 1 hour. Walnuts showed little change in taste for up to 9 months of storage, but an increase in rancidity was associated with heat treatments. Information on the engineering and economic aspects of both high and low temperature treatments was gathered and an analysis begun.

Objectives

The purpose of the study is the development of temperature treatments as alternatives to fumigation for insect disinfestation of postharvest dried fruits and nuts. In accomplishing this goal the following objectives have been set.

(a) Determine the temperature extremes and associated exposure times required to kill various stages of the Diarimeal moth (IMM), the navel orangeworm (NOW) and the dried fruit beetle (DFB).
(b) Compare control efficacy of different heat application methods against the above insects in infested raisins, prunes and walnuts.
(c) Evaluate the effect of the above treatments on product quality.
(d) Estimate and compare the costs and feasibility of the above treatments to currently used fumigants and other alternatives.
PROCEDURES

The mortality of pupae of the IMM, and eggs and pupae of the NOW exposed to temperatures ranging from 42 to 49°C for different times was determined. Treatments were applied in a water bath capable of maintaining constant temperatures with ±0.2°C accuracy. For IMM pupae, both direct hot water immersion and indirect immersion in small watertight cells were used to predict the efficacy of different heating methods. For NOW eggs and pupae, only direct immersion was used. Data were analyzed to plot thermal death rate curves and predict LT_{50}'s, LT_{95}'s and LT_{99}'s for each temperature.

Freezing points for IMM pupae, non-diapausing larvae and diapausing larvae and NOW pupae and larvae were determined by cooling test insects at constant rates in dewar flasks containing liquid nitrogen. Freezing events were observable as sudden increases in insect surface temperatures as detected by thermocouples. Mortality of different ages of IMM and NOW eggs exposed to sub-freezing temperatures, along with those of NOW larvae and pupae, was determined.

To determine the effect of high temperatures on product quality, prunes, raisins and walnuts were heated at 55°C for 1 hour. Walnuts were also heated at 40°C for 48 hours and 45°C for 4 hours. The heat treated samples and untreated controls were divided into subsamples, sealed in glass jars and stored at 20°C. Samples were removed every 2 months, processed and submitted to a duo-trio taste panel for flavor evaluation. Replicate samples were also evaluated for color and moisture.

Researchers have gathered much of the necessary information for analysis of the economic feasibility of temperature treatments for raisins, prunes and walnuts. A preliminary report on their findings has been prepared. Also, equipment that will be used to apply precise temperatures to infested commodities has been designed and built by project engineers.

RESULTS

Efficacy Studies:

Exposure times that would provide 50, 95 and 99% mortality (LT_{50}, LT_{95}, and LT_{99}) of IMM and NOW pupae at various temperatures were estimated using simple regression analysis, and are presented in Table 1. For both insects, a single degree change in temperature resulted in considerable differences in LT values. NOW pupae proved to be more heat resistant than IMM pupae. The LT_{99} for NOW at 46°C was nearly three times that for IMM. To obtain NOW LT_{99}'s that were comparable to those of IMM at 46°C, the temperature had to be raised to 49°C.

Tests using different heating methods against IMM pupae, showed that differences in heating rate account for differences in mortalities, because a slower heating rate increases the exposure times necessary for the desired mortality. For this reason, only direct immersion methods will be used for the remainder of these studies.
Simple regression analysis gave fairly accurate estimations of LT$_{50}$, LT$_{95}$, and LT$_{99}$ for NOW eggs, and are presented in Table 2. At lower temperatures, NOW eggs were fairly heat tolerant; 194 minutes were required to produce 99% mortality at 45°C. At 49°C, the same mortality is obtained at 14 minutes. Eggs proved much more heat tolerant than pupae at lower temperatures, but this difference decreased as temperatures increased, with eggs less tolerant than pupae at 49°C.

IMM larvae and pupae were capable of surviving exposure to temperatures well below 0°C without freezing (Table 3). IMM pupae proved most freeze resistant, the average temperature at which IMM pupae froze was -23.9°C. Diapausing larvae, the natural overwintering stage of the insect, had an average freezing point of -22.6°C. Non-diapausing larvae, with an average freezing point of only -15.2°C, were much less freeze tolerant than either diapausing larvae or pupae.

Laboratory-reared NOW larvae also had much higher freezing points (-9.7°C) than NOW pupae (-22.3°C). Freezing points for wild-type NOW larvae were much lower (-16.1°C) than for laboratory-reared larvae. Wild-type NOW pupae had freezing points very close to laboratory-reared pupae.

Effects of freezing temperatures on hatch of IMM eggs varied with the age of egg (Fig. 1). Eggs exposed to -16°C at 12 hour intervals and to -20°C at 6 hour intervals showed an increase in cold tolerance throughout the first 47 to 53 hours of egg development, followed by a rapid increase in susceptibility over the next 24 hours. A similar pattern has been identified in NCM eggs (Fig. 2), and additional work is planned to determine the most tolerant egg age for this insect. Preliminary work using -20°C as a treatment temperature for NOW eggs resulted in very high mortalities, indicating that NOW eggs are more susceptible than IMM eggs.

Mortality of NOW larvae and pupae exposed to -12, -16, -20 and -24°C showed that pupae were more cold tolerant than larvae (Table 4). This confirms predictions made from freezing point studies, which identified the pupal stage as the most cold tolerant. However, a comparison of Table 4 with Fig. 2 indicates that NOW eggs are even more cold tolerant.

Quality Studies:

Results from the quality studies showed that, after 9 months in storage, heat treatment did not cause accelerated darkening of raisins, prunes and walnuts. Taste panel results showed no discernable taste differences between treated and control raisins for up to 6 months in storage. At 9 months there was a flavor difference, with 20% of the panelists indicating an off flavor in the heated raisins. No taste differences were detected in prunes up to 9 months in storage. Treated walnuts showed no taste differences for up to 8 to 9 months in storage, when the study was stopped because of rancidity. Table 5 shows that the degree of the taste panel indicating rancidity seemed correlated to the severity of the treatment.
Economic and Engineering:

The economic analysis of high temperature disinfestations was begun, and will be based on the current cost of driers for products such as pistachio nuts, walnuts, and dried prunes. The complete financial analysis of high temperature disinfestation will probably be based on using these driers in their off season. These driers are idle for 10 to 11 months per year and would be available for use. Also, they will probably require very little modification in order to be used for disinfestation because they are already set up to handle the crops that we are considering.

Low temperature disinfestation costs will be based on forced air cooling and storage operations which are commonly used in California’s fresh fruit and vegetable industry. The off season for many of these facilities is six to nine months and we may assume that existing installations can be used for disinfestation in our financial analysis. We have collected some capital cost and energy use information for recently constructed facilities. The possibility of utilizing night air recirculation to reduce cooling costs is also being examined. Figs. 3, 4 and 5 give summaries of current and proposed insect control practices for prunes, walnuts and raisins, respectively.

CONCLUSIONS

The results from the efficacy tests indicate that temperatures as low as 46°C for as little as 13 minutes would effectively control IMM pupae. Both NOW eggs and pupae were more heat resistant; 49°C for 14 and 12 minutes would be needed to control eggs and pupae, respectively. When both insects are present, a treatment temperature of 50°C for 15 minutes should insure complete control. Before final recommendations can be made, the thermal death points for larval and adult stages of both NOW and IMM, along with eggs of the IMM and all stages of the DFB, need to be determined.

The freezing point determinations indicate that the pupal stage of the IMM and NOW is more freeze tolerant than the larval stage. Preliminary results from mortality studies with NOW confirm these findings. Cold tolerance of eggs of both IMM and NOW varied with age. The more resistant NOW egg ages were more cold tolerant than pupae. Early findings indicate that DFB may be the most cold tolerant of the three target insects.

Quality studies detected some off-flavors in heat-treated raisins after 9 months of storage. Heat-treated prunes showed no flavor differences after 9 months. Heat-treated walnuts showed no differences up to 9 months of storage, but increased rancidity was associated with severity of treatment. Low temperature methods may be more suitable for walnuts.

Preliminary engineering and economic studies indicate that modifications of existing dehydration procedures may provide the most economical heat disinfestation of candidate commodities. The use of existing low temperature facilities for disinfestation may also prove acceptable.
### Table 1. Lethal Times (in minutes) for IMM and NOW Pupae

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>IMM LT50</th>
<th>IMM LT95</th>
<th>IMM LT99</th>
<th>NOW LT50</th>
<th>NOW LT95</th>
<th>NOW LT99</th>
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<td>42</td>
<td>27.7</td>
<td>40.6</td>
<td>41.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>43</td>
<td>19.1</td>
<td>28.4</td>
<td>29.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>44</td>
<td>13.2</td>
<td>19.7</td>
<td>20.3</td>
<td>-</td>
<td>-</td>
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<tr>
<td>45</td>
<td>9.5</td>
<td>16.5</td>
<td>17.2</td>
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</tr>
<tr>
<td>46</td>
<td>7.4</td>
<td>12.4</td>
<td>12.9</td>
<td>24.0</td>
<td>35.6</td>
<td>36.6</td>
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<tr>
<td>47</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16.9</td>
<td>23.4</td>
<td>23.9</td>
</tr>
<tr>
<td>48</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10.8</td>
<td>17.1</td>
<td>17.7</td>
</tr>
<tr>
<td>49</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.2</td>
<td>11.3</td>
<td>11.6</td>
</tr>
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</table>

### Table 2. Lethal Times (in minutes) for NOW Eggs

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>LT50</th>
<th>LT95</th>
<th>LT99</th>
</tr>
</thead>
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<tr>
<td>45</td>
<td>143</td>
<td>189.9</td>
<td>194.1</td>
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<tr>
<td>46</td>
<td>57.4</td>
<td>106.9</td>
<td>111.3</td>
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<tr>
<td>47</td>
<td>31.4</td>
<td>57.8</td>
<td>60.2</td>
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<tr>
<td>48</td>
<td>11.1</td>
<td>28.1</td>
<td>29.6</td>
</tr>
<tr>
<td>49</td>
<td>5.0</td>
<td>10.9</td>
<td>14.2</td>
</tr>
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Table 3. Supercooling points for IMM and NOW larvae and pupae

<table>
<thead>
<tr>
<th>Insect and Stage</th>
<th>n</th>
<th>x +/- SE</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Non-diapausing IMM larvae</td>
<td>159</td>
<td>-15.2 +/- 0.2</td>
<td>-20.0</td>
<td>-8.0</td>
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<td>Diapausing IMM larvae</td>
<td>172</td>
<td>-22.6 +/- 0.2</td>
<td>-27.0</td>
<td>-12.0</td>
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<tr>
<td>IMM Pupae</td>
<td>184</td>
<td>-23.9 +/- 0.2</td>
<td>-28.0</td>
<td>-11.0</td>
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<tr>
<td>Laboratory-reared NOW larvae</td>
<td>55</td>
<td>-9.7 +/- 0.2</td>
<td>-14.0</td>
<td>-7.0</td>
</tr>
<tr>
<td>Wild-type NOW larvae</td>
<td>40</td>
<td>-16.1 +/- 0.5</td>
<td>-21.0</td>
<td>-9.0</td>
</tr>
<tr>
<td>Laboratory-reared NOW pupae</td>
<td>241</td>
<td>-22.3 +/- 0.5</td>
<td>-26.0</td>
<td>-9.0</td>
</tr>
<tr>
<td>Wild-type NOW pupae</td>
<td>40</td>
<td>-21.5 +/- 0.6</td>
<td>-27.0</td>
<td>-11.0</td>
</tr>
</tbody>
</table>
Table 4. Response of NOW Larvae and Pupae to Subfreezing Temperature

<table>
<thead>
<tr>
<th>TEMP (*C)</th>
<th>EXPOSURE (min)</th>
<th>% MORTALITY</th>
<th>Larvae</th>
<th>Pupae</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12</td>
<td>20</td>
<td>89.3</td>
<td>8.5</td>
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<td></td>
<td>40</td>
<td>85.8</td>
<td>18.8</td>
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<td></td>
<td>60</td>
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<td>32.6</td>
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<tr>
<td>-16</td>
<td>10</td>
<td>89.4</td>
<td>17.1</td>
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<td></td>
<td>25</td>
<td>98.3</td>
<td>74.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>100.0</td>
<td>98.3</td>
<td></td>
</tr>
<tr>
<td>-20</td>
<td>10</td>
<td>96.5</td>
<td>77.6</td>
<td></td>
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<tr>
<td></td>
<td>20</td>
<td>100.0</td>
<td>96.6</td>
<td></td>
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<tr>
<td></td>
<td>30</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>-24</td>
<td>5</td>
<td>96.5</td>
<td>56.8</td>
<td></td>
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<tr>
<td></td>
<td>10</td>
<td>100.0</td>
<td>84.5</td>
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<tr>
<td></td>
<td>15</td>
<td>100.0</td>
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Table 5. Percentage of Panel Indicating Samples Tasted Rancid

<table>
<thead>
<tr>
<th>STORAGE TIME</th>
<th>HEATED AT 40°C</th>
<th>HEATED AT 45°C</th>
<th>HEATED AT 55°C</th>
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<tbody>
<tr>
<td>0</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>8</td>
<td>15</td>
<td>20</td>
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<td>4</td>
<td>8</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
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<td>23</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
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<tr>
<td>9</td>
<td>-</td>
<td>55</td>
<td>60</td>
</tr>
</tbody>
</table>
Fig. 1  Effect of Age on IMM Egg Hatch after Exposure to $-16^\circ$ and $-20^\circ$C for 25 minutes

Fig. 2  Effect of Age on NOW Egg Hatch after Exposure to $-16^\circ$C for 30 minutes
Figure 3. Current and proposed insect control practices for prunes.
**WALNUTS**

**Current Insect Control Practices**

- hulled and washed
- 110°F drying air temperature for 2-48 hrs.
- MeBr fumigation at receiving and as needed later
- some nuts stored at 40-45°F, especially shelling stock
- some shelled nuts packaged in inert atmosphere
- inshell nuts are bleached in hypochlorite

**Alternative Insect Control Practices**

- reduce storage temperature to 28°F
- insulate roof and use night ventilation in unrefrigerated storage
- seal storage and use MA fumigation
- seal inshell nuts in nitrogen-flushed bag and disinfect in transit
- refrigerated storage of product or refrigerated transport
- MA packaging

<table>
<thead>
<tr>
<th>Level of infestation</th>
<th>Number of fumigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>X</td>
</tr>
<tr>
<td>low</td>
<td>X</td>
</tr>
<tr>
<td>high</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 4. Current and proposed insect control practices for walnuts.
SUNDRIED RAISINS

Process | Current Insect Control Practices | Alternative Insect Control Practices
---|---|---
Harvest |  |  
Sun Drying | - initial trash removal | - solar disinfect  
Farm Storage | - some PH3 fumigation |  
Long Term Storage | - sorting | - solar disinfect  
| | - monthly PH3 fumigation in paper covered stacks | - insulate roof and use night ventilation in storage rooms  
| | - MeBr fumigation in storage rooms or fumigators |  
Processing |  | - improve plant sanitation  
Nat. Cond | | - continuous flow hi- temp. disinfect during packing  
| | | - refrigerated storage of product  
| | | - MA packaging

<table>
<thead>
<tr>
<th>Level of infestation</th>
<th>Number of fumigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>_X</td>
</tr>
<tr>
<td>low</td>
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<tr>
<td>high</td>
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</table>

Figure 5. Current and proposed insect control practices for raisins.

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