EFFICACY OF TEMPERATURE TREATMENTS FOR INSECT
DISINFESTATION OF DRIED FRUITS AND NUTS - ENGINEERING
DESIGN

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ABSTRACT
Pilot scale tests demonstrated that dried prunes in standard storage bins could be
successfully disinfested in a forced air heating chamber. Heating times of less
than 24 hours produced small amounts of weight loss and acceptable fruit
quality. Fruit temperature was lower for a longer time in storage with night air
ventilation compared with a conventional non ventilated design. A ventilated
storage in Yuba City, CA could protect fruit from reinfestation from November
through March. Night ventilation can cause fruit moisture increases.

BACKGROUND
Laboratory testing has shown that navel orangeworm and Indianmeal moth, can
be killed if they are exposed to temperatures above 113°F for several hours.
They are not active at temperatures below about 50°F and can be killed if they
are kept below this temperature for a prolonged period. Time for low
temperature disinfestation depends on temperature. About 60 days are required
to kill the pests if they are held near 50°F, 24 days at 41°F and 14 days at 34°F.
Product temperature management could serve as a practical, non chemical
method of controlling insects.

OBJECTIVE
Using a pilot scale storage chamber, determine how dried prune temperature
and quality are affected by forced air heating for insect disinfestation and night
air ventilated storage.

PROCEDURE
We modified a 20' marine container to disinfest and store pallet bins of dried
prunes. A chamber, illustrated in figure 1, was built in the container and fitted
with a fan and heating system. Resistance heaters with a 3.9 kVA capacity were
used for heating air to about 140°F. The fan had a capacity to move air past the
bin walls at speeds greater than 500 fpm. The chamber held a maximum of three
4' x 4' x 4' pallet bins. We used standard, uncovered plywood storage bins with
no side or bottom vents. During heating, the chamber was sealed and air
recirculated inside. After the heating cycle was complete, the chamber was
opened and ducting changed to pull outside air past the bins when ever outside
air was 5°F cooler than the fruit temperature. The first test was conducted at
Davis, CA all others were at Yuba City, CA.
Figure 1. Schematic diagram of chamber for heating and storing three bins of fruit.

Fruit temperature distribution in the center bin was determined by installing 53 thermocouples throughout the bin. Air temperatures outside and inside the chamber were also measured. Moisture samples were collected at the beginning and end of heating and storage tests. Fruit quality was evaluated by Sunsweet Growers, Inc, Yuba City, CA.

Caged insects were placed in the center of bins to determine efficacy of the high temperature disinfestation treatments.

RESULTS
Four heating tests were conducted during the year and are summarized in table 1 and temperature plots are in figures 7, 8, 9 and 10. The first test conducted at Davis had only one bin in the chamber and the coolest fruit in the bin reached 104°F in 16 hours. (We compare heating times based on reaching 104°F rather than 113°F because some of the tests did not reach this level.) The other tests required considerably longer to reach disinfestation temperature. The first Yuba City test required 5 days to reach temperature. The long time was partially caused by the a problem in the air temperature control which allowed the air to reach only 131°F for the first 24 hours. The long heating time caused the top fruit in the bin to dry to below 13% moisture. Average air speed past the bin was 100 fpm which was much lower than the first test. In the second Yuba City test, air speed was increased to 260 fpm. However in this test it was apparent that the heating capacity was inadequate because the air temperature did not reach 140°F until after 30 hours of heating. In spite of this, the heating time was reduced to 54 hours. Figure 2 shows the temperature distribution in the center of the bin at 60 hours when the heaters were turned off. The large temperature gradient implies that most of the moisture loss was from the surface fruit. The heating capacity was increased for the last test and only two bins were placed in the chamber. The air temperature reached the set point within a few hours and air speed averaged 390 fpm, but the heating time was actually longer than the previous test. This may have been caused by unusually high fruit moisture at the beginning of the test and the large amount of drying that occurred during heating.
Table 1. Summary of 1992 high temperature prune disinfestation tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Bins in chamber</th>
<th>Average air speed past bin (fpm)</th>
<th>Heating capacity (kVA)</th>
<th>Initial moisture (% wb)</th>
<th>Final moisture (% wb)</th>
<th>Time to heat to 40°C (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis.1</td>
<td>1</td>
<td>530</td>
<td>3.9</td>
<td>na</td>
<td>na</td>
<td>16</td>
</tr>
<tr>
<td>Yuba City.1</td>
<td>3</td>
<td>100</td>
<td>3.9</td>
<td>17</td>
<td>&lt;13</td>
<td>120</td>
</tr>
<tr>
<td>Yuba City.2</td>
<td>3</td>
<td>260</td>
<td>3.9</td>
<td>18</td>
<td>17</td>
<td>54</td>
</tr>
<tr>
<td>Yuba City.3</td>
<td>2</td>
<td>390</td>
<td>5.6</td>
<td>24.5</td>
<td>15-16</td>
<td>70</td>
</tr>
</tbody>
</table>

1 Temperature of coolest point in the bin.

The caged Indian meal moth eggs, larvae and pupae were killed in all of the tests. Driedfruit beetle larvae and adults were placed in the center of a bin in the third test and were killed during high temperature disinfestation. Minimum fruit temperatures in the test bins ranged from 104°F to 118°F. Although the top fruit in the bin lost some moisture, the fruit quality was good after each test.

With an air speed of about 500 fpm past the bins and fruit moistures close to a typical storage level of 18% to 20%, it appears that high temperature disinfestation can be accomplished within 24 hours of heating with 140°F air. Slightly higher air temperatures could probably be used to increase the minimum fruit temperatures to 113°F. Fast heating appears to minimize fruit drying, causing potentially only a few points of loss.

Two long term storage tests with night air cooling were conducted. Moisture data is summarized in table 2 and temperature data in figures 11 and 12. In the first test, fruit temperature dropped below 50°F during the fourth week of storage and fruit should have been protected from reinfestation or fruit loss after this. The second test began in mid December when the outside air temperatures were low. Fruit dropped below 10°C during the first week of storage and remained there for almost two months.

Table 2. Summary of night air ventilated prune storage tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Number of bins in chamber</th>
<th>Initial moisture (% wb)</th>
<th>Final moisture (% wb)</th>
<th>Test period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuba City.1</td>
<td>3</td>
<td>14</td>
<td>19</td>
<td>11Nov. 91 - 12Dec. 92</td>
</tr>
<tr>
<td>Yuba City.2</td>
<td>3</td>
<td>17</td>
<td>19, 24.5</td>
<td>13 Dec. 91 - 25 Mar.92</td>
</tr>
</tbody>
</table>

1 Both tests were conducted after an initial high temperature disinfestation test so the initial moistures are low.
2 Sample for test 1 was on the top of the bin, test 2 is a center and a top moisture
We found that after four to five weeks the weekly average fruit temperature was equal to the weekly average air temperature. Figures 3 and 4 show the difference between air and fruit temperature. In the second test, the fruit reached the weekly average air temperature in four weeks and stayed at this level for the rest of the test.

We compared the performance of the night air ventilated storage with prune temperature data for fruit stored in a non insulated, non ventilated warehouse in figure 5. Figure 6 shows the difference between air and fruit temperature for the warehouse. Fruit temperature was about 13°F warmer than outside air for the first 20 weeks in conventional storage and cooled to a minimum of about 50°F. It did not reach ambient temperature until May (forty weeks of storage), when outside air temperature had risen considerably above the winter minimums. Based on the air temperature data in figure 5, night air ventilated storage should be capable of dropping fruit temperature below 50°F in early November. This temperature is reached when warehouses are normally fumigated, so night air ventilation may protect fruit from damage as effectively as chemical fumigation. Storage temperature is then below 50°F long enough to disinfect the fruit. Fruit should be protected from reinestation until March. The test chamber had a very high surface area for outside heat gain considering the small amount of fruit. In a large storage, the mass of fruit may not warm as quickly in the spring, allowing insect-protected storage below 50°F into April.

The fruit was in good condition after both storage periods. However, night air cooling caused moisture content increases in the fruit. In the second test, 16 weeks of storage increased moisture from about 18% (the moisture of the center fruit just before the high temperature heating test) to 19%. Surface fruit rose from 17% to 24.5% during the storage test. Fruit moisture rise could be lessened by reducing ventilation after fruit has reached an acceptably low temperature during the winter.

DISCUSSION
The high temperature disinestation tests showed that cycle times less than 24 hours are needed to minimize fruit moisture loss. This will require air speeds of about 500 fpm past four sides of bins. A special air distribution system will be needed and bins must be stacked in lanes with a 4" to 6" free space between lanes. This type of air flow system is used in grape cold storages although air speeds are typically 100 to 200 fpm. The heated air has a high moisture content and the heat treatment room must be insulated to minimize condensation on walls and ceiling.

These requirements imply that high temperature fumigation might be most inexpensively done as a batch operation in specially modified rooms. Bins are stacked tightly in conventional storage and warehouse owners may not want to devote space to aisles between lanes and to an air distribution system. It would be less expensive to insulate and install a relatively small heating and air
distribution system in a small room rather than modify a large warehouse. Batch operation will, however, require the fruit to be handled twice. A third handling would be needed if fruit remaining in the late spring or summer required an additional disinfection.

High temperature disinfection and night air ventilated storage can both cause non uniformity in prune moisture. Moisture loss in disinfection can be minimized by keeping disinfection times short. Night air ventilation will add moisture back to the fruit and this could be a problem if humidity in the storage room is allowed to remain high for a long time. Reducing ventilation during the coldest months should reduce moisture gain while still not allowing prunes temperature to rise above 50°F. Air cooled by night-time radiant cooling may be an inexpensive alternative to mechanical refrigeration which will allow low temperature storage without fruit moisture increases.

CONCLUSIONS
Prunes in standard storage bins can be effectively disinfested by heating them with 140°F air for about 24 hours. Heating times can be minimized by forcing air 500 fpm past four sides of the bin. Fruit quality appears to be unaffected by the process, although moisture of fruit in the tops of bins is slightly reduced.

Night air ventilated storage keeps fruit cooler for a longer period than conventional non ventilated storage. Fruit can be kept below 50°F from November through March, protecting it from reinfestation and even disinfesting it. Night air ventilation adds moisture to the fruit but does appear to affect fruit quality.
Figure 2. Prune temperatures (°C) for Yuba City-2 after 60 hours of heating. Temperatures are in a horizontal plane at the two foot depth.
Figure 3. Night air ventilation storage, temperature difference between average prune and average ambient temperature (CIMIS - Colusa).

Figure 4. Night air ventilation storage, temperature difference between average prune and average ambient temperature (CIMIS - Colusa).
Figure 5. Prune and air temperature in a conventional uninsulated warehouse.

Figure 6. Conventional unventilated prune storage, temperature difference between average prune temperature and average ambient temperature (CIMIS - Colusa)
Figure 7. High temperature disinfestation of prunes in a pallet bin, Davis-1.

Figure 8. High temperature disinfestation of prunes in a pallet bin, Yuba City-1.
Figure 9. High temperature disinfestation of prunes in a pallet bin, Yuba City-2.

Figure 10. High temperature disinfestation of prunes in a pallet bin, Yuba City-3.