Kiwifruit size influences softening rate during storage

Carlos H. Crisosto  David Garner  Katia Saez

Large (~101 grams), medium (~93 grams) and small (~81 grams) ‘Hayward’ kiwifruits were stored in either ethylene-free air or in a controlled atmosphere (CA) of 5% carbon dioxide (CO₂) and 2% oxygen (O₂) at 32°F for 16 weeks. Under both storage conditions, large fruit had a slower rate of softening than smaller fruit. Air-stored kiwifruit softened approximately 2.6 times faster than CA-stored fruit. Under air conditions, large, medium and small kiwifruit reached 5.0 lbf (the minimum pounds firmness required for packaging with minimal bruising) by 12, 10 and 8 weeks, respectively, while those stored under CA conditions softened to 5.0 lbf by 49, 30 and 20 weeks. Understanding the relationship between fruit size and the rate of softening under air and CA conditions will help cold storage managers safely monitor kiwifruit softening during bin storage.

Any technology that reduces the cost of repackaging kiwifruit will increase profit to the growers and packers. Traditionally, kiwifruit are picked, sorted, sized and packed immediately into containers of various sizes. Generally, after 2 to 3 months storage, kiwifruit are repackaged to remove fruit infected with fungus decay (Botrytis cineria), and to satisfy market conditions at the time. It is very difficult for packers to predict the container/size combination that will be required by buyers 2 to 3 months after harvest.

To eliminate repackaging costs, field-run kiwifruit can be stored in bins for up to 3 months before packaging in the final container. Short-term bin storage would reduce packaging pressure, cooling time, ethylene contamination and repackaging costs. However, it has been demonstrated (Mitchell 1990) that kiwifruit are more susceptible to vibration damage during packaging and/or transportation when they soften below 5.0 lbf (pounds firmness). For this reason, we investigated the relationship between fruit size, storage atmosphere and the rate of softening under both air-stored and controlled-atmosphere conditions.

Kiwifruit source

‘Hayward’ kiwifruit grown commercially in the Visalia area, were harvested at a late maturity (Nov. 11, 1996) into 18-inch-high plastic bins and immediately sized, graded and stored. Only small kiwifruit (~81 grams) were commercially bin-stored in air after a light brushing, sorting and grading. At the same time, kiwifruit samples of different sizes from the same lot were collected directly from the packingline after packaging (brushing, grading, sorting) and immediately transported to the F. Gordon Mitchell Postharvest Laboratory at the Kearney Agricultural Center in Parlier for the controlled-atmosphere (CA) experiment. Fruit quality evaluations included measurements of soluble solids concentration (SSC), acidity, firmness, water loss, decay and bruising. At harvest, kiwifruit had approximately 12.0 lbf (measured with an 8-mm penetrometer tip), 11% SSC and 1.9% titratable acidity (TA).

CA laboratory experiment

Since ethylene concentrations as low as 10 parts per billion induce rapid kiwifruit softening during cold storage, we investigated the rate of fruit softening under ethylene-free CA and air-storage conditions for small, medium and large fruit under controlled laboratory conditions, with a factorial design arranged in a split plot. Three replications of 10 fruit for each storage/size combination were withdrawn after 0, 2, 4, 6, 8, 10, 12, 14 and 16 weeks in storage. Upon arrival to the laboratory, kiwifruit were air-cooled to approximately 35°F within 6 hours.

The kiwifruit were then stored in 2.5-gallon jars under a continuous flow of either ethylene-free air or 5% CO₂ and 2% O₂ at 32°F. We established flow rates and gas mixtures using a mixing board with micrometering valves. Supply and exhaust gas composition were monitored using a gas chromatograph equipped with a thermal conductivity detector for O₂ and CO₂, and a gas chromatograph equipped with a flame ionization detector for ethylene (C₂H₄).

At each sampling date, fruit were warmed to ambient temperature (68°F) for evaluation of firmness and SSC. We removed the skin from opposite cheeks of each fruit and measured the firmness using a UC firmness tester with an 8-mm tip. Then, a longitudinal wedge (from stem end to calyx end) was removed from each fruit, pressed through cheesecloth, and the SSC of the juice measured with a temperature-compensated refractometer.

The data were subjected to analysis of variance (ANOVA), mean separation and regression analysis where appropriate using the statistical analysis software (SAS) program.
sampled from the bottom of the bin after dumping. Kiwifruit samples were immediately taken to the laboratory for firmness, SSC, bruising and decay evaluation.

**Interaction between size, storage**

**Controlled atmosphere experiment.** Because there was a significant interaction (P-value < 0.001) between storage atmosphere and kiwifruit size for changes in firmness during the 16-week storage period, firmness measurements are presented for individual treatments (storage size). Kiwifruit softening during the 16-week cold storage period was related to fruit size and storage atmosphere conditions (fig. 1). The increase in SSC during storage, however, was independent of the fruit size and the storage atmosphere conditions (data not shown). Regression equations significantly described firmness changes during storage (weeks) for each of the storage condition/size combinations (table 1).

Under both storage conditions, large fruit had a slower rate of softening than smaller kiwifruit. The rate of fruit softening described by the slope of the regression equations was always slower under CA than air conditions (table 1). Air-stored kiwifruit softened approximately 2.6 times faster than CA-stored fruit. After 16 weeks of CA storage, large, medium and small kiwifruit had firmnesses of 12.0, 9.0 and 9.0 lbf, respectively. Large, medium and small air-stored fruit all had firmnesses of approximately 3.0 lbf after this same period of time (fig. 1).

Because kiwifruit are more susceptible to vibration damage during packaging and/or transportation when they soften below 5.0 lbf, we ran our regression equations to predict the number of weeks to reach this firmness. Under air-storage conditions, large, medium and small kiwifruit from this orchard reached 5.0 lbf by 12, 10 and 8 weeks, respectively. In contrast, large, medium and small kiwifruit under CA storage conditions were estimated to reach 5.0 lbf by 49, 30 and 20 weeks, respectively. Thus,
the length of time the fruit could be
held safely in cold storage prior to
packaging was related to fruit size and
storage atmosphere.

**Bin cold storage.** During the stor-
age period, ethylene levels were al-
ways lower than 10 parts per billion
(ppb). For small fruit sampled from
the bottoms of the bins, fruit firmness
decreased from approximately 12.0 lbf
to 4.0 lbf after 10 weeks cold storage
(fig. 2). The greatest drop in fruit firm-
ness occurred within the first 4 weeks
of storage.

Using the regression equation (P-
value < 0.0001, \( r^2 = 0.75 \)) for the rela-
tionship between changes in firmness
versus weeks in air storage for the
bins, we predicted that after 7 weeks
our kiwifruit reached the critical firm-
ness level for packaging (5.0 lbf). The
kiwifruit lost approximately 0.6 lbf per
week during bin storage in air at 32°F.
The difference in time to reach 5.0 lbf
can be explained by the different stor-
age conditions in the commercial situ-
ation. Thus, this regression equation
can be used as a tool to predict the poten-
tial storage time under optimum condi-
tions (ethylene-free air at 32°F).
Firmness measurements should be
done during the storage period to de-
termine the end of the bin storage pe-
riod and a safe packaging date.

Exposed kiwifruit in the tops of the
bins (the worst-case scenario for fruit
damage) lost weight at a constant rate
during the cold-storage period (fig. 2).
The use of canvas covers over the tops of
the bins reduced the rate of water loss
by nearly half. In previous work, we
have observed kiwifruit shriveling
only after fruit water-loss values ex-
ceeded 4.0% of the initial fruit fresh
weight. Bruising incidence after pack-
aging varied from 1.0% to 4.1%. More
bruising occurred on the last two

**Softening-rate factors**

The rate of kiwifruit softening is re-
lated to kiwifruit size, storage atmos-
phere conditions and orchard factors.
In general, large kiwifruit had a
slower rate of softening than smaller
kiwifruit. Thus, large kiwifruit have
longer bin storage potential than me-
dium and small kiwifruit.

However, this bin storage period
may vary according to orchard influ-
ences. Ethylene-free, cold air storage is
a promising technique when there is a
short delay (less than 8 weeks) in
packaging. CA cold storage (5% CO2
and 2% O2) is a possibility for long-
term (more than 8 weeks) storage of
kiwifruit prior to packaging. Both
technologies are commercially fea-
sible. In both cases, we recommend
monitoring firmness changes during
storage to determine a safe packaging
time. A minimum of 5.0 lbf is sug-
gested as a critical level to prevent
bruising during packaging and do-


table 1. Regression equations showing the relationships between firmness and storage period
(weeks) for three sizes (45, 39, 36) of kiwifruit stored under air or controlled atmosphere conditions

<table>
<thead>
<tr>
<th>Parameter/treatment</th>
<th>Intercept</th>
<th>Slope</th>
<th>( r^2 )</th>
<th>P-value</th>
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<tr>
<td>Air 45</td>
<td>8.7</td>
<td>-0.44</td>
<td>0.68</td>
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<tr>
<td>Air 39</td>
<td>9.6</td>
<td>-0.50</td>
<td>0.79</td>
<td>0.0001</td>
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<tr>
<td>Air 36</td>
<td>10.7</td>
<td>-0.49</td>
<td>0.84</td>
<td>0.0001</td>
</tr>
<tr>
<td>Controlled atmosphere 45</td>
<td>9.4</td>
<td>-0.22</td>
<td>0.31</td>
<td>0.0024</td>
</tr>
<tr>
<td>Controlled atmosphere 39</td>
<td>10.7</td>
<td>-0.19</td>
<td>0.53</td>
<td>0.0001</td>
</tr>
<tr>
<td>Controlled atmosphere 36</td>
<td>11.4</td>
<td>-0.13</td>
<td>0.17</td>
<td>0.031</td>
</tr>
</tbody>
</table>

In commercial tests, kiwifruit were stored
in bins in air at 32°F. Covering the bins re-
duced the rate of water loss by nearly half.

C.H. Crisosto is Extension Postharvest
Physiologist, and D. Garner is Staff Re-
search Associate, Pomology Department,
UC Davis, located at Kearney Agricul-
tural Center, Parlier; and K. Saez is As-
sistant Professor with the Statistics and
Mathematics Department, University of
Concepcion, Concepcion, Chile.

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