エチレン処理後の包装がカキ‘西条’（Diospyros kaki Thunb.）の熟柿化と裂果に及ぼす影響

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Effects of Packaging after Ethylene Treatment on Soft Ripening and Fruit Cracking in ‘Saijo’ Persimmons (Diospyros kaki Thunb.)

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After being stored for several weeks at 0°C, ‘Saijo’ persimmons were treated with 100 ppm ethylene in sealed containers for 48 hours at 20°C. Immediately after the ethylene treatment, the fruit were packaged in perforated polyethylene film bags and perforated containers and then kept for 4 days at 20°C. Packaging of the individual fruit in the perforated bags that had a perforation area of 39.3 mm² per persimmon significantly decreased the fruit cracking ratio. Packaging of the persimmons in a container that had a perforation area of 42.5 mm² per persimmon or in a container that had a perforation area of 137.8 mm² per persimmon also significantly decreased the fruit cracking ratio. A relatively high calyx abscission ratio and the greatest weight loss were observed in the persimmons packaged in the container that had a perforation area of 137.8 mm² per persimmon. From a practical point of view, packaging persimmons in a container with a perforation area of 42.5 mm² per persimmon or individual packaging of the fruit in a perforated bag with a perforation area of 39.3 mm² per persimmon seems to be the most useful method for inhibiting fruit cracking during the soft ripening of ‘Saijo’ persimmons.

Key words : ethylene treatment, fruit cracking, perforated bag, ‘Saijo’ persimmon, soft-ripened persimmon

Fruit cracking is a serious problem that occurs when producing soft-ripened persimmons. Akaura et al.1) established a procedure for obtaining soft-ripened ‘Saijo’ persimmons by cold storage and ethylene treatment of the harvested fruit. After being stored for several weeks at 0°C, ‘Saijo’ persimmons were treated with 100 ppm ethylene in sealed containers for 48 hours at 20°C and then kept in perforated containers for 4 days at 20°C. A fruit cracking ratio of more than 30% was observed for the soft-ripened persimmons originating from persimmons stored for 8 weeks at 0°C after harvest. Akaura2) found that there was a correlation between the fruit cracking ratio and the length of cold storage of the harvested persimmons. He assumed that the prolonged contact of the stored fruit with moisture in the sealed polyethylene film bag induced an increase in turgor pressure of the fruit cell and caused the development of small cracks on the fruit peel. To date, effective measures to inhibit fruit cracking have not been found.

A polyethylene film bag has a larger perforation area per persimmon than the perforated container that has been conventionally used for storage of ethylene-treated persimmons. Increasing the perforation area would decrease the turgor pressure of the persimmon by accelerating the evaporation from the fruit, hence increasing the perforation area is expected to reduce the incidence of fruit cracking. Immediately after the ethylene treatment, the persimmons were packaged in stainless steel containers, individually packaged in perforated polyethylene film bags or individually vacuum packaged in polyethylene film bags. We examined the effects of perforation area per persimmon on fruit cracking in ‘Saijo’ persimmons.

Materials and Methods

1. Effects of packaging after ethylene treatment on the removal of astringency, coloring and fruit cracking in soft-ripened ‘Saijo’ persimmons

‘Saijo’ persimmons were harvested at commercial

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maturity late in October 2005 in Matsue, Japan. The persimmons were stored in accordance with the procedure described by AKAURA2). Eight persimmons were packaged in a 26 × 38 cm polyethylene film bag of 0.08 mm thickness and stored for 5 weeks at 0°C. Immediately after the end of storage, a 300-mm-long cut was made in each bag for ventilation. The bags containing the persimmons were left to stand at room temperature for 6 hours.

For ethylene treatment, persimmons were treated with 100 ppm ethylene at 20°C for 48 hours in a sealed plastic container (capacity of 9 ℓ, 12 persimmons per container). Ninety-six persimmons were treated with ethylene and a total of ninety persimmons were used for the packaging portion of this experiment.

After the ethylene treatment, thirty persimmons were each individually packaged in a 23 × 11.9 cm polyethylene film bag of 0.08 mm thickness that had two perforations of 5 mm in diameter (perforated bag). In each perforated polyethylene film bag, the persimmon was arranged so that the fruit apex was close to the perforations. Another thirty persimmons were each individually vacuum packaged in a 23 × 11.9 cm polyethylene film bag of 0.08 mm thickness (vacuum package). The remaining thirty persimmons were packaged in stainless steel containers. Six persimmons were transferred to a stainless steel container (265 × 153 × 84 mm) that had a polyethylene cover (390 cm² area) with a perforation of 5 mm in diameter.

The packaged persimmons were soft-ripened for 4 days at 20°C and fruit cracking was checked for the soft-ripened persimmons. Fig. 1 depicts the procedures used to obtain soft-ripened ‘Saijo’ persimmons in Experiment 1.

Removal of astringency in soft-ripened persimmons was checked by a sensory test employing two trained male adults. The peel color of the fruit was measured by comparison with the color chart (Kaki, Ministry of Agriculture, Forestry and Fisheries, Japan) and fruit cracking was checked. This experiment was carried out using five replicates, with 6 persimmons per replicate.

2. Effects of cold storage length prior to ethylene treatment on fruit cracking in soft-ripened ‘Saijo’ persimmons

‘Saijo’ persimmons were harvested at commercial maturity late in October 2006 in Matsue, Japan. Eight persimmons were packaged in a sealed polyethylene bag and stored for 4 or 6 weeks at 0°C. After storage, the persimmons were treated with ethylene as described above for Experiment 1. Sixty persimmons were used for each storage period.

After the ethylene treatment, thirty persimmons were each packaged individually in a 23 × 11.9 cm polyethylene film bag of 0.08 mm thickness that had two perforations of 5 mm in diameter. In the perforated polyethylene film bag, the persimmon was arranged so that the fruit apex was close to the perforations. Six persimmons were transferred to a stainless steel container (265 × 153 × 84 mm) that had a polyethylene cover (390 cm² area) with a perforation of 5 mm in diameter.

The packaged persimmons were soft-ripened for 4 days at 20°C and fruit cracking was checked for the soft-ripened persimmons. Fig. 1 depicts the procedures used to obtain soft-ripened ‘Saijo’ persimmons in Experiment 2. This experiment was carried out using five replicates, with 6 persimmons per replicate.

![Fig. 1 Diagram of procedures used to obtain soft-ripened ‘Saijo’ persimmons in Experiments 1 and 2](image)
3. Effects of number of perforations on fruit cracking in soft-ripened 'Saijo' persimmons packaged in containers

'Saijo' persimmons were harvested at commercial maturity late in October 2007 in Matsue, Japan. Eight persimmons were packaged in a sealed polyethylene bag and stored for 6 weeks at 0°C. After storage, the persimmons were treated with ethylene as in Experiment 1. Sixty persimmons were used in this experiment.

After the treatments, six persimmons were transferred to a stainless steel container (265 x 153 x 84 mm) that had a polyethylene cover with one or thirteen perforations (container φ 5 x 1 and container φ 5 x 13, respectively). The diameter of each perforation was 5 mm and the area of the polyethylene cover was 390 cm².

The packaged persimmons were kept at 20°C for 4 days and fruit cracking was checked for the soft-ripened persimmons. This experiment was carried out using five replicates, with 6 persimmons per replicate. Figure 2 depicts the procedures used to obtain soft-ripened 'Saijo' persimmons in Experiment 3.

4. Effects of perforation area of packaging container on fruit cracking, calyx abscission and weight loss in soft-ripened 'Saijo' persimmons

'Saijo' persimmons were harvested at commercial maturity late in October 2008 in Matsue, Japan. Eight persimmons were packaged in a sealed polyethylene bag and stored for 6 weeks at 0°C. After storage, persimmons were treated with ethylene as described in Experiment 1. One hundred and twenty persimmons were used in this experiment.

After the treatments, thirty persimmons were packaged individually in 23 x 11.9 cm polyethylene film bags of 0.08 mm thickness that had two perforations of 5 mm in diameter (perforated bag). In each perforated polyethylene film bag, the persimmon was arranged so that the fruit apex was close to the perforations. Another thirty persimmons were packaged in the stainless steel containers that had polyethylene covers with one perforation of 5 mm in diameter (container φ 5 x 1). Another thirty persimmons were packaged in the stainless steel containers that had polyethylene covers with thirteen perforations of 5 mm in diameter (container φ 5 x 13). The remaining thirty persimmons were packaged in the stainless steel containers that had polyethylene covers with thirteen perforations of 9 mm in diameter (container φ 9 x 13). The area of the polyethylene cover was 390 cm².

The packaged persimmons were kept at 20°C for 4 days, and fruit cracking and the abscission of the calyx were checked for the soft-ripened persimmons. The relative humidity in the containers was measured one day after the end of the ethylene treatment using a hygrometer (Sato, Inc. SK-140 TRH). Because the perforated bags each containing a persimmon did not have sufficient empty space for inserting a sensor probe for humidity, the humidity was not measured. This experiment was carried out using five replicates, with 6 persimmons per replicate. Figure 2 depicts the procedure used to obtain soft-ripened 'Saijo' persimmons in Experiment 4.

Results

1. Effects of packaging after ethylene treatment on removal of astringency, coloring and fruit cracking in soft-ripened 'Saijo' persimmons

Astringency was removed in the persimmons packaged in the perforated containers and in the perforated bags. On the other hand, astringency was not removed in every individually vacuum-packaged persimmon. The color chart value was significantly lower in the vacuum-packaged persimmons. The fruit cracking ratio of the persimmons packaged in the perforated bags was significantly lower than that of the persimmons packaged in the perforated containers (Table 1, Fig. 1).

2. Effects of length of cold storage prior to ethylene treatment on fruit cracking in soft-ripened 'Saijo' persimmons

Compared with the fruit cracking ratios of the persimmons packaged in the perforated containers, those of the fruit individually packaged in the perforated bags were significantly lower for the persimmons stored at 0°C both for 4 and 6 weeks prior to the ethylene treatment. The fruit cracking ratio decreased from 20.0% to 6.7% for the persimmons stored for 4 weeks and from 36.7% to 13.3% for 6 weeks (Table 2, Fig. 1). Taken together with the result obtained in Experiment 1, packaging of the ethylene treated fruit in the perforated bags inhibited fruit cracking regardless of the length of cold storage prior to the ethylene treatment.
Table 1 Effects of packaging after ethylene treatment on removal of astringency, coloring and fruit cracking in soft-ripened 'Saijo' persimmons

<table>
<thead>
<tr>
<th>Packaging</th>
<th>Astringent fruit (%)</th>
<th>Coloring</th>
<th>Fruit cracking ratio (%)</th>
<th>Perforation area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>5 x 1³</td>
<td>0</td>
<td>23.3 a²</td>
<td>3.3</td>
</tr>
<tr>
<td>Perforated bag³</td>
<td>0</td>
<td>6.8 a</td>
<td>3.3 b</td>
<td>30.3</td>
</tr>
<tr>
<td>Vacuum package³</td>
<td>100</td>
<td>4.3 b</td>
<td>20.0 ab</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Z : After being stored for 5 weeks at 0°C, the persimmons were treated with 100 ppm ethylene for 48 hours at 20°C and subsequently packaged. The packaged fruit were then kept for 4 days at 20°C. Removal of stringency, coloring and fruit cracking were examined 6 days after the beginning of ethylene treatment.

Y : Coloring of the peel is represented by color a chart value.

X : Fruit cracking ratio is expressed as the number of cracked fruit divided by the total number of fruit in a replicate.

W : Perforation area per persimmon in bag or container

V : Six persimmons were packaged in containers that had a polyethylene cover with a perforation.

U : Different characters indicate that the means are significantly different among packaging at the 1% level with the Tukey-Kramer test.

T : Each persimmon was individually packaged in perforated polyethylene film bag that had two perforations of 5 mm in diameter near the fruit apex.

S : Each persimmon was individually vacuum packaged in a polyethylene film bag.

Table 2 Effects of cold storage length prior to ethylene treatment on fruit cracking in soft-ripened 'Saijo' persimmons

<table>
<thead>
<tr>
<th>Packaging</th>
<th>Perforation area (mm²)</th>
<th>4 weeks</th>
<th>6 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perforated container³</td>
<td>3.3</td>
<td>20.0% ³</td>
<td>36.7% ³</td>
</tr>
<tr>
<td>Perforated bag³</td>
<td>39.3</td>
<td>6.7%</td>
<td>13.3%</td>
</tr>
</tbody>
</table>

Z : Persimmons were treated with 100 ppm ethylene for 48 hours at 20°C and subsequently packaged. The packaged fruit were then kept for 4 days at 20°C. Fruit cracking was examined 6 days after the beginning of the ethylene treatment.

Y : Perforation area per persimmon in bag or container.

X : Six persimmons were packaged in a container that had a polyethylene cover with a perforation of 5 mm in diameter.

W : Fruit cracking ratio was expressed as the number of cracked fruit divided by the total number of fruit in a replicate.

V : Indicates that the means are significantly different between storage lengths at the 5% level by the t-test.

U : Each persimmon was individually packaged in a polyethylene film bag that had two perforations of 5 mm in diameter near the fruit apex.

T : ns indicates that the means are not significantly different between storage lengths by the t-test.

S : Indicates that the means are significantly different between types of packaging at 5% level by the t-test.

3. Effects of number of perforations on fruit cracking in soft-ripened 'Saijo' persimmons packaged in containers

The fruit cracking ratios of the persimmons packaged in the φ 5 x 1 containers and the φ 5 x 13 containers were 28.7% and 6.7%, respectively (Table 3, Fig. 2). The fruit cracking ratio was significantly lower in the persimmons packaged in the φ 5 x 13 containers.

4. Effects of perforation area of packaging container on fruit cracking, calyx abscission and weight loss in soft-ripened 'Saijo' persimmons

The fruit cracking ratios of the persimmons packaged in the φ 5 x 13 containers, the φ 9 x 13 containers and the perforated bags were significantly lower than that of the persimmons packaged in the φ 5 x 1 containers. There was no significant difference in the calyx abscission among the packaging in stainless containers and the packaging in perforated bags. However, the calyx abscission ratio in the φ 9 x 13 container was relatively high. The greatest weight loss was observed in the persimmons packaged in the φ 9 x 13 container (Table 4, Fig. 2).

Discussion

AKAURA and ITAMURA² reported that packaging the soft-ripened 'Saijo' persimmons individually in polyethylene film bags extended the storage life of the persimmons up to 20 days at 5°C. The soft-ripened persimmons were either packaged in the perforated bag or vacuum packaged individually 4 days after the ethylene treatment. Soft-ripened persimmons need to be handled carefully during the packaging operation because the very soft peel of
Table 3 Effects of number of perforations on fruit cracking in soft-ripened 'Saijo' persimmons packaged in containers

<table>
<thead>
<tr>
<th>number of perforation</th>
<th>fruit cracking ratio (%)</th>
<th>perforation area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 perforation</td>
<td>28.7</td>
<td>3.3</td>
</tr>
<tr>
<td>13 perforations</td>
<td>6.7</td>
<td>42.5</td>
</tr>
</tbody>
</table>

*: Indicates that the means are significantly different at the 5% level by the t-test.

Z: After being stored for 6 weeks at 0°C, the persimmons were treated with 100 ppm ethylene for 48 hours at 20°C and subsequently six persimmons were packaged in the containers that had polyethylene covers with one perforation and 13 perforations of 5 mm in diameter. The packaged fruit were then kept for 4 days at 20°C. Fruit cracking was examined 6 days after the beginning of the ethylene treatment.

Y: Fruit cracking ratio was expressed as the number of cracked fruit divided by the total number of fruit in a replicate.

X: Perforation area per persimmon in bag or container.

W: Indicates that the means are significantly different at the 5% level by the t-test.

Table 4 Effects of perforation area of packaging container on fruit cracking, calyx abscission and weight loss in soft-ripened 'Saijo' persimmons

<table>
<thead>
<tr>
<th>packaging</th>
<th>fruit cracking ratio (%)</th>
<th>calyx abscission (%)</th>
<th>weight loss (%)</th>
<th>humidity (%)</th>
<th>perforation area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>container 5 × 1</td>
<td>23.3 a</td>
<td>16.7 ns</td>
<td>0.33 b</td>
<td>76.8 a</td>
<td>3.3</td>
</tr>
<tr>
<td>container 5 × 13</td>
<td>3.3 b</td>
<td>20.0 ns</td>
<td>2.44 b</td>
<td>68.1 b</td>
<td>42.5</td>
</tr>
<tr>
<td>container 9 × 13</td>
<td>0.0 b</td>
<td>43.3 ns</td>
<td>3.77 a</td>
<td>57.0 c</td>
<td>137.8</td>
</tr>
<tr>
<td>perforated bag</td>
<td>13.3 b</td>
<td>16.7 ns</td>
<td>0.91 b</td>
<td>93.9</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Z: After being stored for 6 weeks at 0°C, the persimmons were treated with 100 ppm ethylene for 48 hours at 20°C and subsequently packaged. The packaged fruit were then kept for 4 days at 20°C. Fruit cracking was examined 6 days after the beginning of the ethylene treatment.

Y: Fruit cracking ratio was expressed as the number of cracked fruit divided by the total number of fruit in a replicate.

X: Relative humidity in the containers was measured one day after the end of the ethylene treatment.

W: Perforation area per persimmon in bag or container.

V: See Fig. 3.

U: Different characters indicate that the means are significantly different at the 5% level with the Tukey-Kramer test.

T: ns indicates that the means are not significantly different.

S: Different characters indicate that the means are significantly different at the 5% level with the Tukey-Kramer test.

R: Different characters indicate that the means are significantly different at the 1% level with the Tukey-Kramer test.

Q, P, O: See Fig. 3.
the fruit is easily damaged. Commencing the packaging operation immediately after the ethylene treatment was expected to reduce the risk of damage to the peel. Effects of the two types of individual packaging on the soft ripening process and fruit cracking were examined in Experiment 1.

The vacuum packaging of the individual persimmons immediately after the ethylene treatment inhibited the removal of astringency and the coloring of the soft-ripened persimmons. Vacuum packaging does not seem to be a suitable method for making soft-ripened persimmons. Packaging of the individual persimmons in a perforated polyethylene film bag immediately after the ethylene treatment did not affect the removal of astringency and coloring. Compared with packaging of the 6 persimmons in a perforated container, which was the conventional method adopted by Akaura et al., packaging of the individual persimmons in a perforated bag markedly reduced fruit cracking. A similar tendency was observed in Experiment 2 conducted in a different year (Table 2). Irrespective of the length of the cold storage period prior to the ethylene treatment, packaging of the individual persimmons in a perforated bag significantly inhibited fruit cracking compared with packaging 6 persimmons in perforated containers. From the practical point of view, packaging of individual persimmons in a perforated bag immediately after ethylene treatment effectively increases the yield of soft-ripened persimmons.

The perforation areas per persimmon in the polyethylene film bag and the perforated container were 39.3 and 3.3 mL, respectively. The larger the perforation area of a container is, the lower the humidity should be in the container containing the persimmons. The decrease in the fruit cracking ratio of the persimmons individually packaged in the perforated bags might be attributed to the lower humidity in the bags. By varying the perforation areas of the container, the effect of the perforation area per persimmon on fruit cracking was investigated in Experiments 3 and 4.

The perforation areas per persimmon in the φ 5 × 1 and the φ 5 × 13 containers were 3.3 and 42.5 mL, respectively. The relative humidities in the φ 5 × 1 and the φ 5 × 13 containers were 76.8 and 68.1%, respectively. By increasing the number of perforations, the fruit cracking ratios significantly decreased from 28.7% to 6.7% and from 23.3% to 3.3%, respectively (Tables 3 and 4). Packaging of the persimmons in the φ 9 × 13 containers markedly reduced the incidence of fruit cracking but induced severe calyx abscission. From the practical point of view, packaging of 6 persimmons in a φ 5 × 13 container, i.e., packaging of the persimmons in a container that has a perforation area of 42.5 mL is useful for inhibition of fruit cracking. Packaging of the persimmons in a container that has a perforation area of more than 42.5 mL is not recommended because it induces calyx abscission and weight loss that impairs the commercial value of the soft-ripened persimmons.

Low humidity in the package resulted in weight loss of the packaged persimmons. The weight loss of the detached persimmons could be mainly attributed to the water loss from the fruit. The water loss caused a decrease in the fruit turgor pressure. Yamamoto et al. described that the occurrence of cracking in growing ‘Satonishiki’ cherry was thought to be closely related to the high turgor pressure of the fruit and humid air. Watanabe et al. suggested that an increase in fruit cracking of tomato under a low vapor pressure deficit, i.e., a high humidity environment, was attributed to an increase in water flow into the fruit, which resulted in fruit swelling. Although we could not find evidence that a decrease in the incidence of fruit cracking of the detached persimmons was caused by low turgor pressure, the turgor pressure of the detached fruit seemed to play some role in fruit cracking.

Ohta et al. reported that incidence of fruit cracking of cherry tomatoes grown on hydroponic culture decreased in a low humidity environment. They described that low humidity induced an increase in the peel toughness of the fruit. Akaura et al. reported that persimmons rapidly soften after ethylene treatment and peel toughness decreases as the fruit ripen. Peel toughness was not affected by humidity conditions in persimmons treated with ethylene after harvest.

In this study, fruit cracking ratios of 6.7% (Table 3) and 3.3% (Table 4) were obtained for the persimmons packaged in the φ 5 × 13 containers which were stored at 0°C for 6 weeks prior to the ethylene treatment. If a fruit cracking ratio of lower than 10% is acceptable from a practical point of view, then the storage period of soft-ripened ‘Saijo’ persimmons at 0°C could be extended up to 6 weeks.
repacking packaged in the perforated bags do not need operation of soft-ripened persimmons obtained 4 days after the ethylene treatment is that the fruit peel is not very soft by then. Packing prior to soft ripening seems effective in preventing damage to the fruit. The packing operation of soft-ripened persimmons obtained 4 days after the ethylene treatment needs much more careful handling because the soft peel of the fruit is easily damaged. The soft-ripened persimmons packaged in the perforated bags do not need repacking, but the bags containing the cracked fruit might be wasted.

Fig. 3 Recommended procedures for obtaining soft-ripened persimmons effectively

This extended period of available supply is 3 weeks longer than that proposed by AKAURA and ITAMURA, who recommended storage for 3 weeks at 0°C.

Fig. 3 shows the recommended procedures for preparing the soft-ripened persimmons for storage and shipment. The advantage of individual packaging of the persimmons immediately after the ethylene treatment is that the fruit peel is not very soft by then. Packing prior to soft ripening seems effective in preventing damage to the fruit. The packing operation of soft-ripened persimmons obtained 4 days after the ethylene treatment needs much more careful handling because the soft peel of the fruit is easily damaged. The soft-ripened persimmons packaged in the perforated bags do not need repacking, but the bags containing the cracked fruit might be wasted.

References