Effects of storage temperature and wax coating on ethylene production, respiration and shelf-life in cherimoya fruit

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Summary

Respiration and ethylene production rates of cherimoya fruit were measured under various temperature regimes. The highest ethylene production was observed at 15°C and 20°C; it was restricted at 30°C and 35°C in ‘Libby’ fruit. The numbers of days required for fruit ripening at 15°C and 20°C were 9–11 days and 8 days, respectively. The optimum ripening temperature for cherimoya fruit ranged from 15 to 20°C. To determine the optimum storage period, fruit from five cultivars of cherimoya were initially stored at 10°C for 20 days and then ripened at 20°C. ‘Bay Ott’ and ‘Big Sister’ ripened normally, while ‘Chaffey’, ‘El Bumpo’ and ‘Mariella’ turned brown and their quality declined. It was found that ‘Bay Ott’ and ‘Big Sister’ were more resistant to chilling injury than other cherimoya cultivars. Coating the fruit with wax revealed that it reduced respiration and ethylene production of the fruit, and extended the shelf life by 5 days, with less weight loss and minimal browning.

Key Words: ethylene production, fruit storage, fruit wax, respiration, ripening temperature.

Introduction

Cherimoya (Annona cherimola Mill.) fruit has been imported into Japan from California in recent years; they are commercially grown in greenhouses in Wakayama Prefecture (Yamashita, 1995). There are studies on the post-harvest changes that occur with cherimoya fruit but there are many post-harvest problems that have to be solved on this fruit. Rapid softening of cherimoya during transportation and at retail stores is the biggest on-going problem. The fruit are often refrigerated to extend shelf life, but it is generally known that they do not ripen normally at below 5°C. Therefore, further studies of the post-harvest physiology of this fruit are needed.

Cherimoya is a climacteric fruit, i.e., the fruit produces ethylene and exhibits a rapid respiratory climacteric rise during ripening (Biale and Barcus, 1970). The ethylene climacteric peak in this fruit occurred 1–2 days after the first climacteric rise in respiration (Koshiyachinda and Young, 1975; Palma et al., 1993). Yonemoto et al. (1997) indicated that there was a difference in the maximum rate of ethylene production among 19 cherimoya cultivars, but no difference in the number of days to their ethylene peak.

Extended fruit storage has been considered problematic because of the high susceptibility to chilling injury (Fuster and Prestamo, 1980). However, Palma et al. (1993) reported that ‘Concha Lisa’ was able to be stored for 43 days in controlled atmosphere (CA) at 10°C in 5% O₂. Thompson (1998) also found it possible to extend by CA storage at 8°C–15°C. Even so, the high cost of CA storage for cherimoya is not feasible for small quantities of fruit produced. Without CA storage conditions, Alique et al. (1994) succeeded in ripening fruit of the cultivar ‘Fino de Jete’ at 20°C after a 12-day storage period at 8°C. Accordingly, low temperatures can effectively extend the storage period of some cultivars.

This study investigated three main aspects of post-harvest responses in cherimoya. First, fruit respiration and ethylene production rates were measured under various temperature regimes and storage periods to understand the physiological responses of these fruit under varying post-harvest conditions. Second, the number of days required for fruit ripening at the different temperatures was determined to show the optimum temperature regimes for long storage of cherimoya. Third, the post-harvest responses of wax-coated fruit...
Materials and Methods

Measurement of respiration and ethylene production rates and fruit qualities

The respiration (carbon dioxide production) and ethylene production rates were measured for individual fruit by a gas chromatographic system to determine their patterns during and after storage during ripening. Harvested fruit were placed individually in 0.03 mm thick polyethylene bags to prevent water loss during storage, and kept under the conditions described below. Air ventilation was ensured by leaving the upper portion of the bag open. Each fruit was sealed in a 4.1 liter acryl chamber and kept at the same temperatures as the storage conditions for one hour. Ethylene and carbon dioxide concentrations in the head space of the acryl chamber were measured by two gas chromatographs, GC-17A and GC-14BPB (Shimadzu Co. Ltd.) equipped with FID and TCD detector, respectively. Glass and stainless columns (2 m in length) filled with Porapak type-9 were used for ethylene and carbon dioxide, and the column temperatures were 70 °C and 50 °C, respectively. The measurements were recorded daily to determine the peak production rates of ethylene and carbon dioxide and the number of days to these peaks.

The fruit quality after storage was assessed by determining the percentage weight loss and the total soluble solid (TSS) of individual fruit with a refractometer; the eating quality, and tissue browning were then categorized. Individual fruit were weighed each time and the ethylene production rate was measured. The percentage weight loss was calculated from the weight loss during the storage period divided by the initial weight at harvest. Five persons independently categorized the taste of each fruit as poor, fair, good, or very good. The degree of tissue browning after storage was categorized visually as none, light, moderate, or severe. The degree of browning was categorized as light when less than 10%, moderate when it ranged between 10 to 50%, and severe when more than 50% of the surface of fruit exhibited browning.

Experiment 1. Optimum ripening temperatures and cultivar differences in ethylene production and respiration patterns

Respiration and ethylene production rates were determined for fruit stored at 15, 20, 25, 30, or 35 °C. Fifteen ‘Libby’ fruit, that were harvested on September 27, 128 days after pollination, were ripened at above temperatures immediately. To examine these parameters at lower temperature regimes, 12 ‘Big Sister’ (a late maturing cultivar) fruit were harvested on November 16, 160 days after pollination, and divided into four groups of three replicates. Each group was ripened at 10, 15, 20, and 25 °C. TSS and their eating quality was measured.

Experiment 2. Storage periods at 10 °C

Respiration and ethylene rates were measured on post-harvest fruit stored at 10 °C and ripened at 20 °C. Three ‘Bay Ott’ fruit, harvested on September 13, 120 days after pollination, were immediately stored at 10 °C for 10 days, and then ripened at 20 °C. Three comparable ‘Bay Ott’ fruit were stored at 20 °C, immediately after harvest, as a control. Browning of the peel, TSS, and eating quality of the fruit were assessed.

Four fruits each of ‘Bay Ott’, ‘Big Sister’, ‘Chaffey’, ‘El Bumpo’, and ‘Mariella’ that were harvested on October 8, 130, 140, 130, 125, and 130 days after pollination, respectively, were placed in lidded, corrugated cardboard boxes, and stored at 10 °C, with 60–70% RH for 20 days. The fruit were then placed individually in polyethylene bags and ripened at 20 °C for 4 days. The degree of peel and pulp browning after storage and at the completion of ripening were categorized; TSS and eating quality were then determined.

Experiment 3. Effects of wax coating on ripening

Of the 12 ‘El Bumpo’ fruit that were harvested on August 26, 148 days after pollination, six were dipped into either a 0 (water) or 100% concentration of water soluble fruit wax (Koto Fresh, KF-8000DX, Koto Co., Ltd.). The ingredients of this wax are carnauba wax, morpholine fatty acid salt, sellag gum lac, microcrystalline wax, sodium polyphosphate, and orange oil. The fruit were then fan-dried at room temperature (approx. 22 °C) for 15 minutes and stored at 25 °C. Their TSS, weight loss, eating quality, and tissue browning, were not determined. To seek the optimum wax concentrations, 18 fruit of ‘El Bumpo’ and ‘Libby’ were harvested on October 19, 140 days after pollination; Six each were dipped into a 0, 25, or 50% wax solution, fan-dried and ripened at room temperature. Their TSS, weight loss, eating quality, and tissue browning, were then assessed.

Results

Experiment 1. Optimum ripening temperatures and cultivar differences in ethylene production and respiration patterns

The highest ethylene production (338 μl·kg⁻¹·hr⁻¹) was observed at 15 °C and at 20 °C (355 μl·kg⁻¹·hr⁻¹) for ‘Libby’ and at 15 °C (94 μl·kg⁻¹·hr⁻¹) for ‘Big Sister’ (Fig. 1). Ethylene production was restricted at 30 °C (11 μl·kg⁻¹·hr⁻¹) and 35 °C (10 μl·kg⁻¹·hr⁻¹) for ‘Libby’ and was promoted at 15 °C for ‘Big Sister’. At lower temperatures, a longer period was required for fruit to reach the ethylene peak. The peak of ethylene production corresponded to softening of the fruit. The maximum rate of respiration was less affected by temperature. Although there was no significant difference in
Table 1. Effect of ripening temperatures on total soluble solid content (TSS) and eating quality of cherimoya ‘Libby’ and ‘Big Sister’.

<table>
<thead>
<tr>
<th>Ripening temperatures (°C)</th>
<th>TSS (Brix°)</th>
<th>Eating qualitya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Libby</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>16.9ab°</td>
<td>Very good</td>
</tr>
<tr>
<td>20</td>
<td>20.2a</td>
<td>Very good</td>
</tr>
<tr>
<td>25</td>
<td>17.0ab</td>
<td>Very good</td>
</tr>
<tr>
<td>30</td>
<td>14.5b</td>
<td>Poor</td>
</tr>
<tr>
<td>35</td>
<td>13.5b</td>
<td>Poor</td>
</tr>
<tr>
<td>Big Sister</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16.0a</td>
<td>Good</td>
</tr>
<tr>
<td>15</td>
<td>16.0a</td>
<td>Very good</td>
</tr>
<tr>
<td>20</td>
<td>16.5a</td>
<td>Very good</td>
</tr>
<tr>
<td>25</td>
<td>16.5a</td>
<td>Very good</td>
</tr>
</tbody>
</table>

a Eating qualities were evaluated into four levels; very good, good, fair and poor.

° Values followed by different letters within cultivars are significantly different at P<0.05 by Duncan’s multiple range test (n=3).

the storage period required to reach the respiration peak among different temperature treatments for ‘Big Sister’ (Fig. 1), at the lower temperatures, fruit tended to need more days to reach their carbon dioxide peaks. The TSS of 14.5 and 13.5 at 30 °C and 35 °C, respectively, are significantly lower than at lower temperatures for ‘Libby’ (Table 1). Ethylene production was slower and eating quality was poorer at these elevated temperatures.

**Experiment 2. Storage periods at 10 °C**

No ethylene was detected during 10–day storage at 10 °C for ‘Bay Ott’, but it became detectable 3 days after transfer to 20 °C, and peaked 3 days later (Fig. 2). The maximum rate was 772 μl·kg⁻¹·hr⁻¹. Similarly, fruit stored at 20 °C started to produce ethylene at day 1, and gradually increased until day 3. After day 4, there was a sharp increase in the ethylene production, peaking at day 6. The respiration rate (31–54 mg·kg⁻¹·hr⁻¹) was low during 10 days of storage at 10 °C, but increased 1 day after the fruit were transferred to 20 °C. No peel browning was observed and eating quality was very good for fruit in both storage conditions (Table 2).

No clear ethylene production and respiration peaks

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![Fig. 1](image-url) Time course changes in ethylene and carbon dioxide productions of cherimoya fruit at different storage temperatures. Left: ‘Libby’ stored between 15 °C – 35 °C. Right: ‘Big Sister’ stored between 10 °C – 25 °C. Vertical bars indicate SD (n=3).
were observed on fruit stored for 20 days at 10°C and ripened at 20°C, except for ‘Bay Ott’ (Fig. 3). Respiration and ethylene production rates remained at a low level for ‘Big Sister’.

Severe browning of pulp of ‘Chaffey’, ‘El Bumpo’ and ‘Mariella’ fruits (Table 3) occurred after ripening; their eating quality was poor.

**Experiment 3. Effects of wax coating on ripening**

Ethylene production and respiration peaks were significantly lower and the numbers of days to these peaks

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**Table 2.** Effect of storage at 10°C on total soluble solid content (TSS), browning of peel and eating quality of cherimoya fruit ‘Bay Ott’.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>TSS (Brix°)</th>
<th>Browning of peel at the end of ripening</th>
<th>Eating quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°C</td>
<td>17.7 ± 1.2°C</td>
<td>Non</td>
<td>Very good</td>
</tr>
<tr>
<td>10 - 20°C</td>
<td>19.9 ± 2.0°C</td>
<td>Non</td>
<td>Very good</td>
</tr>
</tbody>
</table>

² Evaluated into four levels; non, light, moderate, and severe.
³ Evaluated into four levels: very good, good, fair, and poor.
Values are average ± SD (n=3).
⁴ Fruits were harvested on September 13, and stored for 8 days at 20°C.
⁵ Fruits were harvested on September 13, stored for 10 days at 10°C, and then stored at 20°C for 9 days.

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**Fig. 2.** Time course changes in ethylene (close) and carbon dioxide (open) productions of cherimoya fruit ‘Bay Ott’ stored at 20°C for 8 days (control) and the fruit stored at 10°C for 10 days and then placed in 20°C storage for 9 days. Vertical bars indicate SD (n=3). Arrow head indicates the day of transfer to 20°C for ripening.

**Fig. 3.** Time course changes in ethylene and carbon dioxide productions of cherimoya fruits ‘Bay Ott’, ‘Big Sister’, ‘Chaffey’, ‘El Bumpo’ and ‘Mariella’ during the fruit at 20°C after 20 days of storage at 10°C. Vertical bars indicate SD (n=4).
Table 3. Effects of 20-day storage at 10 °C on total soluble solid content (TSS), browning of peel and pulp, and eating quality of five cherimoya cultivars.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>TSS (Brix\textsuperscript{a})</th>
<th>Browning of peel at the end of storage\textsuperscript{c}</th>
<th>Browning of peel at the end of ripening\textsuperscript{c}</th>
<th>Browning of pulp\textsuperscript{c}</th>
<th>Eating quality\textsuperscript{c}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bay Ott</td>
<td>24.9 ± 0.8\textsuperscript{x}</td>
<td>Light</td>
<td>Moderate</td>
<td>Light</td>
<td>Good</td>
</tr>
<tr>
<td>Big Sister</td>
<td>17.7 ± 0.2</td>
<td>Light</td>
<td>Moderate</td>
<td>Light</td>
<td>Good</td>
</tr>
<tr>
<td>Chaffey</td>
<td>20.1 ± 3.0</td>
<td>Severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Poor</td>
</tr>
<tr>
<td>El Bumpo</td>
<td>17.0 ± 1.5</td>
<td>Severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Poor</td>
</tr>
<tr>
<td>Mariella</td>
<td>15.0 ± 3.4</td>
<td>Light</td>
<td>Moderate</td>
<td>Severe</td>
<td>Poor</td>
</tr>
</tbody>
</table>

The fruits were harvested on Oct. 8, 1993 and then stored at 10 °C (60–70% relative humidity) for 20 days before ripening at 20 °C.

\textsuperscript{a} Evaluated into four levels; non, light, moderate, and severe.

\textsuperscript{c} Evaluated into four levels; very good, good, fair, and poor.

\textsuperscript{x} Average ± SD of four fruits.

Fig. 4. Time course changes in ethylene and carbon dioxide productions of wax-coated cherimoya fruit at different storage temperatures. ‘El Bumpo’ fruit were dipped into either 0 (water) or 100% concentration of fruit wax, fan-dried, and stored at 25 °C. Vertical bars indicate SD (n=6).

Fig. 5. Waxed (above) and non-waxed (below) fruit, 9 days after the treatment. Fruit were dipped into either 0 (water) or 100% concentration of fruit wax, fan-dried, and stored at 25 °C.

were significantly longer in the fruit coated with a 100% wax (Fig. 4), while their ripening was delayed by more than 5 days compared to the control. As the wax concentration increased, the ripening period was extended (Table 4). The percentage weight loss of the waxed fruit after ripening was less than that for non-waxed fruits (Table 4). Thus, wax coating reduced peel browning and kept the fruit in good appearance (Fig. 5); it had no effect on TSS and eating quality (Table 4).

Discussion

Experiment 1.

Generally, irregular ripening occurs on fruit ripened over 30 °C because of an interference or impediment of the ethylene formation cycle (Yu et al., 1980). In this
study, the ethylene production rate in ‘Libby’ fruit was suppressed at 30 °C and 35 °C, and although the fruit softened, their eating quality was reduced. Ethylene might be responsible for the onset of physiochemical changes in cherimoya during ripening, because of a temporal coincidence between starch degradation, loss of firmness and rise of sugar content (Martinez et al., 1993). Our data reveal a tie between restricted starch degradation and retarded ethylene production. Physiochemical activities, such as respiration and ethylene synthesis, increased at 15 °C and 20 °C for ‘Libby’ and at 15 °C for ‘Big Sister’. The optimum ripening temperature for ‘Cavendish’ bananas (Inaba et al., 1984) and atemoya fruit (Wills et al., 1984) was reported to be between 20 °C - 25 °C and 20 °C respectively, whereas it might be lower for cherimoya. The patterns of respiration and ethylene production for ‘Libby’ and ‘Big Sister’ were similar to those reported previously on cherimoya ‘Chaffey’ (Koshiyachinda and Young, 1975), sourosop (Bruinsma and Paul, 1984), and ‘Delicious’ apple (Fan et al., 1999). The peak of respiratory climacteric occurred before the ethylene climacteric.

**Experiment 2.**

The optimum storage duration and temperatures differ among cherimoya cultivars. 20-day storage period at 10 °C is satisfactory for ‘Bay Ott’ and ‘Big Sister’ as they ripened normally at 20 °C and maintained good eating quality. Although ‘Bay Ott’ produced a low level of ethylene during storage at 10 °C for 20 days, the fruit attained a clear ethylene peak at 20 °C. Palma et al. (1993) reported a similar trend for ‘Concha Lisa’ cherimoya fruit, which had delayed ethylene production and ripened 15 days after storage at 10 °C. Alique et al. (1994) reported that ‘Fino de Jete’ cherimoya fruit stored at 8 °C for 12 days ripened normally at 20 °C. Conversely, ‘Chaffey’, ‘El Bumpo’ and ‘Mariella’ suffered from chilling injury after 20 days of storage at 10 °C, which resulted in peel and pulp browning and depressed eating quality. Similar symptoms of chilling injury have been reported on ‘African Pride’ atemoya fruit (Wills et al., 1984), ‘Fino de Jete’ cherimoya fruit (Fuster and Prestamo, 1980), and bananas (Murata, 1979). Alique et al. (1994) also reported that ‘Fino de Jete’ cherimoya fruit lost their ability to ripen and had off-flavors and severe skin browning when refrigerated at 6 °C for more than 5 days. Therefore, we conclude that storage duration at 10 °C differs among cultivars. We found that ‘Bay Ott’ and ‘Big Sister’ fruit could be stored for 20 days at 10 °C in ambient atmosphere. It is beneficial for growers to grow ‘Bay Ott’ and ‘Big Sister’ to extend the marketing period of cherimoya because they are more resistant to chilling injury than other cultivars.

**Experiment 3.**

The wax coating with Koto Fresh (KF-8000DX) extended the storage of cherimoya to some extent. Cherimoya cultivars coated with 100% wax extended their storage life more than 5 days, accompanied by reduced respiration and ethylene rates. The coating also resulted in less weight loss, in better fruit appearance, and reduced fruit spoilage (Fig. 3). Tarutani and Kitagawa (1995) reported that wax coating on citrus in Japan extended the shelf-life by reducing respiration and transpiration. Hardenburg (1971) noted that packaging of fruit is effective to keep their freshness by increasing relative humidity around the fruit and by reducing water loss or respiration of the fruit. Packaging ‘Tonewase’ fruit, an astringent Japanese persimmon cultivar, in perforated polyethylene bag reduced water loss, retarded the onset of ethylene production and delayed fruit softening (Nakano et al. 2001). Ben-Yehoshua et al. (1979) also reported that reducing water loss by packaging citrus fruit individually in polyethylene film suppressed production of water-stress-induced ethylene production. Our data show that wax coating reduced water loss and respiration and ethylene production.
rates which may be related to water–stress–induced ethylene production. Additionally, the wax coating improved fruit appearance in cherimoya so that the treatment before shipping cherimoya may be beneficial to maintain fruit quality.

In conclusion, we recommend that ‘Bay Ott’ and ‘Big Sister’ fruit, which are more cold resistant than other cherimoya cultivars, be coated with 100% wax, stored in polyethylene bags for 20 days at 10 °C. They should then be ripened at 20 °C to minimize weight loss and tissue browning while maintaining good appearance and good eating quality. Less cold tolerant cultivars should be stored for a shorter duration at 10 °C, but otherwise receive similar post–harvest treatments.

Literature Cited


貯蔵温度とワックス処理がチェリモヤ果実のエチレン生成、呼吸活性および棚持ち期間に及ぼす影響

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要

チェリモヤの貯蔵温度が果実の呼吸およびエチレン生成に及ぼす影響を調査した。‘Libby’果実ではエチレンの生成は15℃と20℃で最も高く、30℃以上では著しく抑制された。果実の処熟に要する日数は15℃で9-11日、20℃では8日であった。チェリモヤの最適処熟温度は15-20℃であった。最適な貯蔵期間を知る目的で、5品種の果実を10℃で20日間貯蔵し、その後に20℃で処熟させた。‘Bay Ott’と‘Big Sister’では正常に処熟したが、‘Chaffey’、‘El Bumpo’および‘Mariella’では果皮と果肉が褐変し、食味が劣った。‘Bay Ott’と‘Big Sister’は他のチェリモヤ品種に比べて低温での貯蔵に耐えることができるかった。果実に青果用ワックスを処理した結果、果皮の褐変、果実からの水分蒸散が抑制され、エチレンと二酸化炭素の生成が著しく抑制され、処熟に要する期間が5日長くなった。