Effects of Storage Temperature on the Postharvest Quality of Three Asparagus Cultivars Harvested in Spring

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The effects of storage temperature (5°C, 10°C, and 15°C) on the appearance, weight, and ascorbic acid content of 3 asparagus cultivars—‘UC157’, ‘Gijnlim’, and ‘Purple Passion’—cultivated as green asparagus in open fields were investigated over a 4-day storage period. In addition, we investigated the respiration rate (CO₂ production rate), which is closely related to the qualitative deterioration of fresh produce. Among the 3 cultivars, ‘Gijnlim’ had the loosest spear-head and the highest ascorbic acid content immediately after harvest. The extent of opening of the spear-head during the 4-day storage period varied among the cultivars, and was most marked in ‘Gijnlim’ and was least in ‘Purple Passion’. Discoloration of the cut end of the spear was found to be dependent upon the storage temperature to a greater extent than the individual cultivars. ‘Gijnlim’ had marked discoloration at 10°C. Moreover, ‘Gijnlim’ had the largest decline in weight among the 3 cultivars at each of the 3 temperatures examined. A similar tendency was observed in the decline in ascorbic acid content. The respiration rate of ‘Purple Passion’ within 2–8 h after harvest tended to be smaller than that of ‘UC157’ and ‘Gijnlim’. These findings suggested that there are differences among the cultivars with respect to the rates of changes in postharvest quality. ‘Gijnlim’ tended to deteriorate faster than ‘UC157’ and ‘Purple Passion’, suggesting that strict temperature control and/or packaging might be required to maintain the quality of ‘Gijnlim’ harvested in the spring.

Key Words: Asparagus officinalis, freshness retention, high-yield cultivar, respiration rate.

Introduction

Many efforts have been made internationally to seek high-quality and high-yielding cultivars of asparagus (Asparagus officinalis L.). For instance, a global trial for comparisons of cultivars (International Asparagus Cultivar Trial, IACT) has been instituted (Cermeno et al., 2008; González, 2008; Mulder and Lavrijsen, 2008). Although the mainstream cultivar in Japan continues to be ‘UC157’, such cultivar trials have gradually resulted in the increased appearance of newer asparagus cultivars (Motoki, 2008). In Hokkaido Prefecture, which has the largest growing area of asparagus in Japan (MAFF, 2009), it has been noted that ‘Gijnlim’ crops have increased in area size (Motoki et al., 2008) due to its enhanced yield performance as compared to ‘UC157’ (Knaflewski, 1996; Motoki et al., 2008; Uragami et al., 1993). In the same way, new cultivars have also gradually been established in other regions of Japan (Furuichi et al., 2003; Shimizu et al., 2009; Sonoda et al., 2006).

As a strategy for expanding the consumption of farm products and improving competitiveness in the market, the creation of value-added products has increased. In the case of asparagus, ‘Purple Passion’ (Benson et al., 1996) has impressive market potential due to its unique appearance and characteristic functional ingredients.
(Maeda et al., 2005). ‘Purple Passion’ contains more anthocyanin on the skin of spears than green varieties and, as a result, the spears have a deep purple colour when they are harvested from an open field or greenhouse. Such diversification of asparagus cultivation appears to have become a common trend.

Asparagus has a short shelf life due to its high rate of respiration (Fuchs et al., 2008); therefore, controlling its postharvest quality to prevent deterioration is a major concern. For asparagus, deterioration of quality occurs during storage (Tomita and Yanagida, 1982). Optimum storage conditions with respect to temperature and/or gas composition have been reported previously (Gariépy et al., 1991; Nakamichi and Miyoshi, 1982); however, the cultivars examined in these reports—‘Mary Washington 500W’ (Nakamichi and Miyoshi, 1982; Tomita and Yanagida, 1982) and ‘Martha Washington’ (Gariépy et al., 1991)—are no longer popular. The postharvest quality of the current cultivars in Japan has not been clarified; therefore, it should be investigated along with that of other promising cultivars, which are expected to contribute to the expansion of asparagus production in Japan. Moreover, methods for maintaining freshness must be developed to accommodate the different cultivars.

In this study, we investigated the effects of cultivar characteristics and storage temperature on the postharvest quality of 3 different cultivars—‘UC157’, the most planted cultivar in Japan; ‘Gijnlim’, a high-yield cultivar that is expected to expand asparagus cultivation; and ‘Purple Passion’, a representative purple cultivar. The respiration rates were also investigated on the basis of previous reports where the respiration rate was found to be related to the deterioration of fresh produce (Suzuki et al., 2005; Techavuthiporn et al., 2008a, b).

### Materials and Methods

#### Plant materials

The plants used for analyses (‘UC157’, ‘Gijnlim’, and ‘Purple Passion’) were 7 years old and cultivated in the open fields of the Hokushin Branch of the Nagano Vegetable and Ornamental Crops Experiment Station (latitude 37° N, longitude 135° E, altitude 346 m). All investigations were carried out in mid-May, 2009. The planting density of each cultivar was 22,222 plants per ha (1.5 × 0.3 m, single-line planting), and 80 plants were planted per cultivar. The other growing and harvest conditions were based upon the standard methods for green asparagus production at the experiment station (Motoki et al., 2004). Spears were harvested daily, and the spears selected for analysis were harvested on the same day per analysis. We tried to adjust the spear conditions to those of the below-mentioned respiration measurement; therefore, the top sections (length, 120 mm; weight, approximately 8.5 g) of each spear were used for analysis although most harvested spears were 250 mm length.

#### Storage conditions

For all experiments, storage temperatures were set to 5°C, 10°C, and 15°C, with a relative humidity of 90–95%, under dark conditions.

### Experiment 1. Effects of cultivar and storage temperature on the quality of asparagus

#### 1. Spear-head tightness and discoloration

Spear-head tightness and discoloration of the cut end of the spear were evaluated on the basis of the scales described in Table 1. Then, both parameters were calculated using the following formula:

$$
\Sigma(S \times N \times n^{-1})
$$

where $S$ stands for the symptom scores, $N$ the number of spears with each symptom score, and $n$ the total number of spears. In each of the tests, 3 spears were used per treatment for 3 replications.

#### 2. Weight loss rate

Sample spears were weighed to 0.1 kg (approximately 12 spears) and bundled. Spears were placed upright in chambers adjusted to the specified temperature. After 4 days of storage, the weights of the spears were measured, and the weight loss rate for each treatment was calculated using the following formula:

$$
W_l = 100 \times (1 - W_a \times W_i^{-1})
$$

where $W_l$ is the weight loss rate (%), $W_a$ the weight after 4 days of storage, and $W_i$ the initial weight (0.1 kg). In each of the tests, 3 spears were used per treatment for 3 replications.

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### Table 1. Scoring scheme for estimating the quality of appearance of asparagus.

<table>
<thead>
<tr>
<th>Spear-head tightness</th>
<th>Score</th>
<th>Discoloration at the cut end of spear</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight</td>
<td>1</td>
<td>Free</td>
<td>0</td>
</tr>
<tr>
<td>Loose with no lateral branches</td>
<td>2</td>
<td>Slight</td>
<td>1</td>
</tr>
<tr>
<td>Loose with lateral branches</td>
<td>3</td>
<td>Little</td>
<td>2</td>
</tr>
<tr>
<td>Lateral branches (≤ 10 mm) that appear from spear-head</td>
<td>4</td>
<td>Moderate</td>
<td>3</td>
</tr>
<tr>
<td>Lateral branches (&gt; 10 mm) that appear from spear-head</td>
<td>5</td>
<td>Severe</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme (with rotting)</td>
<td>5</td>
</tr>
</tbody>
</table>
3. Measurement of the ascorbic acid content

A whole spear was crushed using a mortar and pestle to produce a paste, which was then wrapped in gauze and squeezed by hand. The ascorbic acid content in the resulting juice was immediately measured by a reflectometer (RQflex 10; Merck KGaA, Darmstadt, Germany) on the basis of the method of Fujiwara et al. (2005). Measurement was carried out for spears obtained immediately after harvest and after 4 days of storage. The concentration of ascorbic acid was determined on the basis of water loss in the spears, and the content of ascorbic acid after 4 days’ storage was calculated using the following formula:

\[ A_a = W_a \times A_c \times W_i^{-1} \]

where \( A_a \) is the revised ascorbic acid content, \( W_a \) the weight after 4 days of storage, \( A_c \) the content of ascorbic acid after 4 days of storage and \( W_i \) the initial weight. Three spears were used per treatment with 3 replications.

Experiment 2. Effect of cultivar and storage temperature on the respiration rate of asparagus

We used acrylic airtight cylinders (width, 99.6 mm; height, 127.5 mm) with inlet septa for gas chromatography to measure the CO\(_2\) production rate. Approximately 12 spears were placed upright in cylinders maintained at the specified temperature. Cylinders were closed tightly within 2–8 h after harvest. The CO\(_2\) concentration in the headspace just after closing and just before opening was measured by a gas analyzer (Checkpoint O\(_2\)/CO\(_2\); PBI-Dansensor A/S, Ringsted, Denmark) to calculate the CO\(_2\) production rates for each treatment. Other sample conditions were the same as those for Experiment 1. Each test was repeated 3 times.

Statistical analysis

For measurements of the ascorbic acid content and respiration rate for each cultivar under the 3 temperature conditions, the Tukey-Kramer test was used to distinguish group differences after confirmation of the homogeneity of variances by Bartlett’s test. The significance level in both tests was set at 0.05.

Results

Experiment 1. Effects of cultivar and storage temperature on the quality of asparagus

1. Immediately after harvest

Among the 3 cultivars, ‘Gijnlim’ was found to have the highest value for spear-head tightness (Table 2). For all cultivars, no discoloration was observed at the cut end of the spear. The ascorbic acid content of ‘Gijnlim’ (144.1 mg/100 gFW) was significantly higher than that of ‘UC157’ (118.1 mg/100 gFW) and ‘Purple Passion’ (122.1 mg/100 gFW) (Table 3).

2. Four days after harvest

The Spear-head tightness of ‘UC157’ determined at 5°C, 10°C, and 15°C 4 days after harvest was estimated to be 2.0, 1.7, and 2.0, respectively (Table 2). For ‘Gijnlim’, the scores at each temperature were higher than those of ‘UC157’ at 3.0 (5°C), 2.7 (10°C), and 3.7 (15°C). The Spear-head development scores of ‘UC157’ and ‘Gijnlim’ were within the ranges of 1.7–2.0 and 1.4–1.8, respectively. On the other hand, the score of ‘Purple Passion’ at 5°C and 10°C was 1.0 in both cases, and this score was the same as the initial score determined immediately after harvest. The Spear-head of ‘Purple Passion’ tended to be tighter than those of the other 2 cultivars under the same temperature conditions, although the score at 15°C increased to 1.3 times the initial score. With respect to discoloration, a similar tendency was observed in ‘UC157’ and ‘Purple Passion’ at each of the temperatures measured while ‘Gijnlim’ discoloration was marked high (2.3 at 10°C and 2.7 at 15°C). Weight loss rates for ‘UC157’, ‘Gijnlim’, and ‘Purple Passion’ were 1.0%, 1.1%, and 0.8%, respectively, at 5°C; 1.6%, 2.7%, and 1.4%, respectively, at 10°C; and 2.9%, 5.8%, and 2.9%, respectively, at 15°C (Fig. 1). No significant differences in the ascorbic

<table>
<thead>
<tr>
<th>Point of determination</th>
<th>Storage temperature (°C)</th>
<th>Cultivar</th>
<th>Spear-head tightness*</th>
<th>Discoloration of cut end*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately after harvest</td>
<td>—</td>
<td>UC157</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gijnlim</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Purple Passion</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4 days after harvest</td>
<td>5</td>
<td>UC157</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gijnlim</td>
<td>3.0</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Purple Passion</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>UC157</td>
<td>1.7</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gijnlim</td>
<td>2.7</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Purple Passion</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>UC157</td>
<td>2.0</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gijnlim</td>
<td>3.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Purple Passion</td>
<td>1.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

*Σ (Symptom score × Number of spears in each symptom score)/Total number of spears.
Each symptom score was estimated as per Table 1.
acid content were found among the 3 cultivars at each temperature (Table 3); however, the rate of reduction of ascorbic acid in ‘Gijnlim’ was found to be higher than that in ‘UC157’ and ‘Purple Passion’ at all temperatures.

**Experiment 2. Effect of cultivar and storage temperature on the respiration rate of asparagus**

The respiration rates of ‘UC157’, ‘Gijnlim’, and ‘Purple Passion’ were 143, 155, and 137 mg·kg⁻¹·h⁻¹, respectively, at 5°C; 223, 229, and 191 mg·kg⁻¹·h⁻¹, respectively, at 10°C; and 334, 350, and 295 mg·kg⁻¹·h⁻¹, respectively, at 15°C. The lowest rate was observed in ‘Purple Passion’ under all conditions (Table 4).

**Discussion**

Three different cultivars (‘Gijnlim’, ‘UC157’, and ‘Purple Passion’) were compared to determine the factors that contribute to maintaining the postharvest quality of asparagus. We first examined the development of spear-head opening under different temperature conditions during storage. ‘Gijnlim’ was found to have a loose spear-head than those of ‘UC157’ and ‘Purple Passion’ just after harvest (Table 2). This result is consistent with those of Motoki et al. (2008) and Uragami et al. (1993), wherein the spear-heads of ‘Gijnlim’ were found to be looser than those of ‘UC157’. This spear-head looseness continued during the 4-day storage period; however, there was no particular tendency with respect to spear-head development and storage temperature (Table 2). These findings suggest that the process of spear-head opening varies among cultivars and is little affected by the storage temperature. In addition, ‘Purple Passion’ appears to maintain its spear-head tightness compared to the other 2 cultivars.

We examined the change in discoloration of the 3 cultivars from harvest to the end of the 4-day storage period under different temperature conditions. Few differences were observed among cultivars with regard to discoloration of the cut end of the spears (Table 2), although a slight additional discoloration in ‘Gijnlim’ at 10°C was noted. In all cultivars, discoloration increased with storage temperature, indicating that the storage temperature affects the extent of discoloration.
The main factor in the weight loss of fresh produce is the decline of water content via transpiration from the plant surfaces. We also measured the weight loss rate for each cultivar. At each temperature, the weight loss rate of ‘Gijnlim’ was found to be greater than that of ‘UC157’ and ‘Purple Passion’. The weight loss rate of ‘Gijnlim’ at 15°C was found to be especially high (over 5%). In general, the commercial value of fresh produce is considered to be lost with a loss of 5% or more of water content (Shiina, 2003). Thus, our results indicated that ‘Gijnlim’ had lost its commercial value after 4 days of storage at 15°C. This finding suggests that the surface area of ‘Gijnlim’ might be excessive because of its loose spear-head.

The ascorbic acid content measured immediately after harvest was found to be significantly higher in ‘Gijnlim’ than in ‘UC157’ and ‘Purple Passion’ (Table 3); however, the reduction rate of ascorbic acid in ‘Gijnlim’ after 4 days of storage was found to be higher than that of the other cultivars (Table 4). In some examples of vegetables, including asparagus, acceleration of the reduction rate of ascorbic acid has been observed under conditions that favour high respiration rates, such as O₂-rich environments (Saito et al., 2000; Serrano et al., 2006; Suzuki et al., 2005). Techavuthiporn et al. (2008a, b) reported that the respiration rate is related to the decline in the levels of ascorbic acid in broccoli, cabbage, cauliflower, and spinach; therefore, the high rate of decline in ascorbic acid levels observed in ‘Gijnlim’ may be due to a high rate of respiration.

In this study, we identified differences in the deterioration of postharvest quality among 3 asparagus cultivars. The rates of deterioration of ‘UC157’ and ‘Purple Passion’ were similar while that of ‘Gijnlim’ was found to be faster. This finding suggests that handling ‘Gijnlim’ during the spring harvest requires strict temperature control and/or packaging. Our future research will focus on the development of techniques for maintaining the freshness of asparagus based on these differences in the 3 cultivars.

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