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Improvement of Storability and Shelf-life of ‘Blackamber’ Plums Treated with 1-methylcyclopropene

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Rapid softening is one of the most important factors that limits the market life of plums. To avoid this problem, ‘Blackamber’ plums were treated with 0, 150, 300 and 600 ppb of 1-methylcyclopropene (1-MCP) and their quality evaluated after 15, 30 and 50 days of storage at 0 ºC, immediately and after 6 days at 25 ºC. 1-MCP treatment effectively decreased ethylene production during storage and shelf-life in fruits kept 15 and 30 days at 0 ºC. In contrast, fruits kept for 50 days at 0 ºC showed a significant increase in ethylene production during shelf-life. Changes in ethylene production by 1-MCP were associated with a decrease of firmness loss and maintenance of titratable acidity but not with the development of red flesh colour. Soluble solids content of the fruit was not affected by the 1-MCP treatment. In this assay no significant symptoms of chilling injury (CI) or rot were observed. Overall, the results presented in this assay ascertained ethylene on quality changes in ‘Blackamber’ plums. They also showed that 1-MCP could be considered commercially to improve the storage life and resistance to mechanical bruising in ‘Blackamber’ plums without prejudicial effects on quality.

Key Words: Prunus salicina plums, 1-MCP, ripening, cold storage, shelf-life

INTRODUCTION

The high rate of softening and susceptibility to CI are the two main factors which limit the postharvest life of plums (Plich, 1999). At present, cold storage is the technology most widely used to slow ripening, and therefore, the softening of this fruit. The most suitable temperatures are those near 0 ºC but above the freezing point of the fruit (Mitchell and Kader, 1989). However, following extended storage duration in these conditions, the fruit develop CI symptoms that are characterised by browning and gel breakdown (translucency) of the pulp (Taylor et al., 1993a, b; Taylor et al., 1994).

Depending on its ripening behaviour, plum varieties can be divided into climacteric and suppressed climacteric fruits (Abdi et al., 1997). In the climacteric plums, the production of ethylene is increased and triggers the ripening process. In suppressed climacteric plums, the ethylene production rates increase only during the later period of ripening, and at low rates when compared to the climacteric cultivars. In general, changes in ripening attributes in suppressed climacteric plums were not directly correlated to ethylene production, which was sometimes produced at insufficient levels to trigger the ripening process (Abdi et al., 1997, 1998).

‘Blackamber’ plums present a typical climacteric ripening behaviour and its quality parameters sharply change in relation to harvest date. As in other climacteric species, ripening of harvested fruit triggers a softening, increase in soluble solids content (SSC) and decrease in titratable acidity (TA). Although all these maturity indexes are strictly related to the ripening of the fruit, the best indicator of ripening is likely the flesh colour (Crisosto et al., 2004). In general, fruit maturity directly determines the consumer acceptance and the market potential of the fruit. According to Crisosto et al. (2004), plums with high SSC levels (>12%) had high consumer acceptance regardless of acidity values. In contrast, plums that showed lower SSC values (between 10 and 11.9%) were discarded when they also exhibited high acidity.

1-MCP is an innocuous gas used at very low concen-
tration which inhibits ethylene action by blocking the ethylene receptors. It can therefore slow down the ripening process as well as the senescence of the fruit (Sisler and Serek, 1999). In recent years an extensive work has been done in describing the effects of 1-MCP in fruit ripening (Blankenship and Dole, 2003). 1-MCP effectively reduced in plums ethylene and CO₂ production, and delayed ripening in climacteric and climacteric-suppressed plums (Abdi et al., 1998; Dong et al., 2001; Dong et al., 2002; Argenta et al., 2003; Martínez-Romero et al., 2003; Menniti et al., 2004). However, inhibitors of ethylene may also have detrimental effects on stone fruit during storage, reducing its ability to ripen normally after storage and/or producing storage disorders (Dong et al., 2002).

In a previous study carried out in ‘Blackamber’ plums (Candan, 2003), we showed that a treatment with 600 ppb of 1-MCP delayed the ripening as well as the occurrence of symptoms such as flesh browning. However, this treatment also reduced the development of juice and flavour in the fruit. The objective of the present study was to evaluate the effect of lower doses of 1-MCP. Emphasis was given to fruit quality and especially on the effect on fruit firmness in order to improve fruit manipulation, and on the content in sugar and acidity in order to increase consumer acceptance. The final objective was to improve the storage of ‘Blackamber’ plums without reducing its eating quality and without producing storage disorders.

**MATERIALS AND METHODS**

**Plant Material and Treatments**

‘Blackamber’ plums were harvested on 22 December 2003 from a commercial orchard in Rio Negro (Argentina), according to fruit firmness. The fruit were immediately taken to the laboratory, where a 20 fruit sample was used to determine the harvest maturity. Fruit of similar size and free of defects were chosen and stored at 0 ºC for quick cooling. The following day, the fruit were treated with 150, 300 and 600 ppb of 1-MCP (SmartFresh® 0.14%) for 24 h at 0 ºC in a cold storage chamber and according to the manufacturer recommendations. At the time of the treatment, the fruit had a pulp temperature of ~9 ºC. Control fruit also remained under similar storage conditions. No wax or fungicides were applied and fruits were packaged on a platform with two tray-liners and no plastic bag. The fruits were stored at 0°C and 85% RH for 15, 30 and 50 days, and the quality parameters evaluated after removal from the chamber and after 6 days of shelf-life at room temperature (~25°C).

**Methods**

**Ethylene Production**

For each sample, three replicates of eight fruits each, were used to determine rates of ethylene production. Fruit of similar size were sealed in 3L jars for 30 min at room temperature (~25°C). Gas samples of 1 mL were withdrawn from each jar and the concentrations of ethylene determined using a GC14-A Shimadzu gas chromatograph equipped with an activated aluminium column and a FID detector. Temperatures were 110, 40 and 250 ºC for injector, oven and detector, respectively. Helium was used as a gas carrier at 1.25 kg/cm.

**Firmness, SSC and TA**

Firmness was measured on both sides of each fruit, after peeling, and using a manual penetrometer with an 8 mm plunger. Two slices of flesh were taken from each fruit and juiced to determine SSC (ºBrix) with an auto temperature compensated refractometer (Atago) and TA (%) by titrating 10 mL of juice with NaOH 0.1 N to pH 8.2. For each sample, three replicates of 20 fruits each were assessed.

**Colour Assessment**

The intensity of the red colour of the epidermis was determined by taking two measurements from different sides of five fruits per sample using a Minolta CR300 tristimulus colorimeter and expressing the values as chroma ((a² + b²)½). In addition, the percentage of fruit with red pulp and their colour intensity was recorded, and expressed as an index of flesh colour (FC), where Grade 1 was <25% red pulp, Grade 2 was 25 to 50%, Grade 3 was 50 to 75% and Grade 4 was >75%.

\[
\text{Index FC} = \frac{\sum \text{(Grade of intensity x Number fruit at this grade)}}{\text{total fruit}}.
\]

**CI and Rot**

The percentage of fruit affected as well as the intensity of the internal translucency and browning symptoms were recorded, and expressed as an index of CI. The scale of CI was defined visually according to the percentage of affected pulp and where: Grade 1 was <25%, Grade 2 was 25 to 50%, Grade 3 was 50 to 75% and Grade 4 was >75%.

\[
\text{Index CI} = \frac{\sum \text{(Grade of intensity x Number of fruit at this grade)}}{\text{total fruit}}
\]

The percentage of rotten fruit was also recorded.
Percentage of Ripe Fruits

Sensory analyses were carried out after the shelf-life by a non-trained panel to estimate whether the fruit was ‘ready to eat’ in relation to defined ranges of flesh firmness. Panelists were volunteers experienced in fruit tasting and selected among the staff working in the INTA institute.

Statistical Analysis

All data obtained from the trial were analysed using ANOVA, carried out with GLM procedure from SAS v.8.2. The four treatments were compared for each storage and shelf-life period. Least significant differences (LSD) between treatments (α = 0.05) were calculated at each evaluation date.

RESULTS

Ethylene Production

The rate of ethylene production at harvest was 0.50nL/g.h (Table 1) corresponding to mature but unripe plums (Kader and Mitchell, 1989). Immediately after removal from cold storage, the rate of ethylene production remained low for all treatments (Figure 1A). During storage, values between 10 and 30nL/g.h were observed in the control fruit but these values remained lower than 7nL/g.h for the 1-MCP treated fruits. 1-MCP reduced the rate of ethylene production after 30 and 50 days of cold storage. After 6 days of shelf-life at ~25°C (Figure 1B), ethylene production increased in all the 1-MCP treated fruits. Control fruits had significantly higher rates of ethylene production after 15 and 30 days at 0°C. Later, ethylene production decreased significantly whereas it increased in the 1-MCP treated fruits.

Flesh firmness

During cold storage (Figure 2A), all the 1-MCP doses were effective for maintaining firmness at values higher to the bruising threshold (14 N). After 15 and 30 days of storage, the differences in firmness between control and treated fruits were 4.5 or 9 N, respectively. Maximum differences were observed after 50 days of storage, when control fruits (~13 N) presented half of the firmness value of the treated fruits (~27 N). At this time, the losses of firmness for the control fruits during storage were 63% and only 25% for the treated fruits.

All the fruits ripened much more rapidly during the shelf-life (Figure 2B). After 15 days of storage and 6 days shelf-life, the control fruits softened completely (~0 N). In contrast, fruits treated with 1-MCP had firmness values of 25 to 31 N. After 30 days, all the

Table 1. Maturity parameters at harvest of ‘Blackamber’ fruits.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean* ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>88.8 ± 11.5</td>
</tr>
<tr>
<td>Ethylene production (nL/g.h)</td>
<td>0.50 ± 0.28</td>
</tr>
<tr>
<td>Firmness (N)</td>
<td>35.5 ± 5.8</td>
</tr>
<tr>
<td>TA (%)</td>
<td>2.66 ± 0.12</td>
</tr>
<tr>
<td>SSC (°Brix)</td>
<td>16.0 ± 0.4</td>
</tr>
<tr>
<td>Epidermis colour (Chroma)</td>
<td>10.2 ± 0.7</td>
</tr>
<tr>
<td>FC index</td>
<td>0.36 ± 0.17</td>
</tr>
</tbody>
</table>

* Values represent means of 30 fruits for weight, firmness, epidermis and FC. TA and SSC values were determined in the juice of 30 different fruits (five determinations) and ethylene production from three replicates of eight fruits each.
1-MCP treated fruits remained significantly firmer and at a value higher or similar to the threshold value for bruising. Later, fruit softened to values inappropriate with commercial requirements.

**TA and SSC**

In general, fruits lost acidity during cold storage and even more following ripening at room temperature. Regardless of the doses, 1-MCP treatment, significantly reduced the acidity loss especially after 50 days of storage at 0°C (Figure 3A), and after 15 and 30 days of storage when the fruits were kept 6 days at 25°C for ripening (Figure 3B). No significant difference between treatments were found after 50 days of storage plus 6 days shelf-life. SSC was 16.0 °Brix at harvest (Table 1). No significant changes in SSC were found between control and 1-MCP treated fruits during cold storage and post-storage ripening (Figure 3C and D).

**Epidermis and Flesh Colour**

The fruit was harvested with a Chroma value of 10.2. The 1-MCP treatment delayed the changes in epidermis colour during storage and the Chroma values remained significantly higher than in control fruit during storage (Figure 4A). Chroma value decreased significantly both in control and 1-MCP treated fruits (reddening of the skin) when the fruit was kept at 25°C (Figure 4B). Except after 50 days storage, 1-MCP treated fruit remained significantly greener (higher value of Chroma). At harvest and as generally observed for unripe plums, most of the fruit did not have red pigment in the flesh and the FC index was 0.36 (Table 1). During cold storage, the control fruits exhibited a slight increase of FC index during the first 30 days, but coloured much more rapidly later (Table 2). This increase in pulp colouration was reduced by the 1-MCP treatment during storage irrespective of the dose. At room temperature, the red pulp colour significantly increased similarly to the control fruit but to a significantly lower extent.

**CI and Rot**

In all cases, very slight CI incidence was found. The CI index was less than 0.5 and no significant differences were found between treatments (Table 2). No rot was observed either in control or in 1-MCP treated fruits.

**Percentage of ‘Ready to Eat’ Fruits**

According to sensory analysis, the firmness values that classify the fruit as ‘ready to eat’ were between 5 to 15N. After 6 days of ripening, and irrespective to the storage duration, nearly 100% of the control fruits were below 5N. In contrast, 1-MCP treated fruit was considered as ‘ready to eat’ even after 30 days storage and 6 days shelf-life. After 50 days storage, 1-MCP treated fruit was acceptable immediately after removal but rapidly lost firmness and was rejected.

**DISCUSSION**

1-MCP treatment significantly reduced ethylene production and delayed the climacteric ethylene peak in ‘Blackamber’ plums, as was also observed in other climacteric plum cultivars (Dong et al., 2002; Argenta...
et al., 2003). This inhibitory effect was found both during storage and also at room temperature following storage for up to 30 days. After 50 days at 0°C plus shelf-life, 1-MCP treatment was unable to prevent ethylene production and ripening.

The largest difference in firmness between control and treated fruit was observed after 50 days of cold storage. Maximum differences coincided with maximum differences in ethylene production and showed that ethylene was produced at cold temperature, at least at low internal levels, sufficient to trigger ripening. These results also showed that the firmness loss and ethylene production are related in ‘Blackamber’ plums. Such a relationship has been observed in other cultivars such as ‘Red Rosa’ and ‘Royal Zee’ (Dong et al., 2001, 2002). It has been suggested that softening is the ripening process most sensitive to ethylene (Lelièvre et al., 1997). Our results were consistent with this theory and showed the interest of the 1-MCP treatment in extending the commercial life of

**Figure 3.** Changes in titratable acidity and soluble solids content of ‘Blackamber’ plums treated with 1-methylcyclopropene, after 15, 30 and 50 days at 0°C. Concentrations: (○) 0, (▲) 150, (◆) 300 and (■) 600 ppb. (A) and (C) Changes immediately after removal from cold storage. (B) and (D) Changes after the same periods of cold storage and 6 days at 25°C. Data represent means of three replicates of 20 fruits each. Vertical bars represent the LSD (α = 0.05) between treatment means for each evaluation date.

**Table 2.** Effect of 1-MCP doses on red FC or CI index in ‘Blackamber’ plums stored at 0°C for 15, 30 and 50 and following 0 or 6 days at 25°C.

<table>
<thead>
<tr>
<th>Days at 0°C</th>
<th>15 Days of Shelf-life</th>
<th>30 Days of Shelf-life</th>
<th>50 Days of Shelf-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-MCP (ppb)</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td><strong>FC index</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.55 a</td>
<td>2.68 a</td>
<td>0.75 a</td>
</tr>
<tr>
<td>150</td>
<td>0.37 a</td>
<td>2.02 b</td>
<td>0.63 a</td>
</tr>
<tr>
<td>300</td>
<td>0.40 a</td>
<td>1.43 b</td>
<td>0.53 a</td>
</tr>
<tr>
<td>600</td>
<td>0.52 a</td>
<td>1.57 b</td>
<td>0.52 a</td>
</tr>
<tr>
<td><strong>CI index</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.00 a</td>
<td>0.00 a</td>
<td>0.07 a</td>
</tr>
<tr>
<td>150</td>
<td>0.22 a</td>
<td>0.18 a</td>
<td>0.03 a</td>
</tr>
<tr>
<td>300</td>
<td>0.00 a</td>
<td>0.07 a</td>
<td>0.00 a</td>
</tr>
<tr>
<td>600</td>
<td>0.00 a</td>
<td>0.00 a</td>
<td>0.00 a</td>
</tr>
</tbody>
</table>

*Data represent means of three replicates of 20 fruits each. For each period of storage, treatments followed by the same letter were not significantly different (LSD, α = 0.05). Values in the same column for the same index followed by the same letter are not significantly different at a 5% level.
plums beyond 30 days at 0°C. The retention of firmness in 1-MCP treated fruits during storage and at room temperature may also improve the resistance of the fruit to mechanical bruising. According to Crisosto et al. (2004), ‘Blackamber’ should have firmness values higher than 14 N to avoid mechanical bruising. This may be achieved by treating the fruit with 1-MCP but only when the fruit was cold stored for less than 1 month.

During storage, 1-MCP treatment maintained fruit at higher firmness values. After transfer to room temperature, this effect was reversible and the 1-MCP treated fruits softened and lost acidity. This is assumed to be due to the synthesis of new receptors that make possible the action of ethylene (Sisler and Serek, 1999). Abdi et al. (1998) observed that suppressed climacteric plums are unable to achieve normal ripening without exogenous application of ethylene or analogues. In the present trial, the 1-MCP treatment only delayed ripening. This result is of practical interest because it showed that the 1-MCP treatment might be applied to improve the storage behaviour of ‘Blackamber’ plums without detrimental effects on fruit quality.

Although firmness was the parameter most affected, loss of titratable acidity and change in pulp colour were also lowered by 1-MCP treatments. A similar effect on acidity was also observed in the ‘Royal Zee’ and ‘Laetitia’ plums (Dong et al., 2002; Argenta et al., 2003). These results showed that the changes in acidity and flesh colour in ‘Blackamber’ plums were at least in part ethylene dependent. In contrast SSC changes appeared to be ethylene independent. This specific behaviour for SSC highlighted the idea that SSC levels at harvest had to be considered as the most important parameter to take into account before treating the plum with 1-MCP. Although 1-MCP treatment also delayed the loss of acidity, the excess of acidity appears to be a secondary factor for consumer acceptance. Plums are more acceptable when SSC levels are above 12% (Crisosto et al., 2004). Thus, 1-MCP treatment appears to be a practical way to improve the storability of ‘Blackamber’ plums without affecting their organoleptic quality.

Changes in pulp colour, which may be considered as a marker of over-ripening in this cultivar, were consistently delayed by 1-MCP treatment especially during storage. This observation contrasted with those of Dong et al. (2002), who clearly found an increase of the development of internal red colour in 1-MCP treated ‘Royal Zee’ plums after transfer to room temperature.

In our work, ‘Blackamber’ plums were classified by taste test as ‘ready to eat’ when firmness ranged 5 to 15 N. According to Crisosto (1994), plums with 9 to 13.5 N flesh firmness are considered ‘ready to eat’. Untreated ‘Blackamber’ plums retained their eating quality until 30 days of storage. After transfer to room temperature, these fruit softened quickly and became overripe. In contrast, 1-MCP treated fruits stored up to 30 days, remained firmer and were ‘ready to eat’ during the entire shelf-life period. These results are of commercial interest because they showed that 1-MCP may be used to extend the commercial life of ‘Blackamber’ plums and to increase the number of commercially acceptable fruits during the same period. This treatment, by its action on firmness, may also improve the resistance of the fruit to mechanical damage. As no significant differences were found between doses, a dose of 150 ppb appeared to be sufficient to obtain these beneficial effects.

Figure 4. Changes in epidermis colour of ‘Blackamber’ plums treated with 1-methylcyclopropene, after 15, 30 and 50 days at 0°C. Concentrations: (C) 0, (▲) 150, (◆) 300 and (■) 600 ppb. (A) Changes immediately after removal from cold storage. (B) Changes after the same periods of cold storage and 6 days at 25°C. Data represent means of three replicates of 20 fruits each. Vertical bars represent the LSD (α = 0.05) between treatment means for each evaluation date.
ACKNOWLEDGEMENTS

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