Improvement in Handpicking Efficiency of Satsuma Mandarin Fruit with Combination Treatments of Gibberellin, Prohydrojasmon and Ethephon

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To improve labor-saving during harvests, the efficiency of handpicking fruit was examined for the satsuma mandarin with the plant growth regulators gibberellin (GA), prohydrojasmon (PDJ), and ethephon (ET). In this study, concentrations of plant growth regulators were set 5 mg·L\(^{-1}\) for GA and 50 mg·L\(^{-1}\) for PDJ, respectively. Spraying of a GA plus PDJ solution on Aug. 27, Sep. 21, and Oct. 27 (triplicate spraying) improved the success rate of handpicking (SRH), as compared with a control. Furthermore, ET treatment in addition to triplicate spraying of GA plus PDJ increased SRH. A one-time treatment of GA plus PDJ also showed a significant effect on handpicking efficiency when applied in mid to late September. It was clear that the effect of GA plus PDJ on SRH was improved when 400 mg·L\(^{-1}\) ET was used instead of 200 mg·L\(^{-1}\), but this ET concentration (400 mg·L\(^{-1}\)) caused massive leaf abscission (data not available). Spraying with 300 mg·L\(^{-1}\) ET alone showed 37.1% leaf abscission: therefore, we assumed that a GA plus PDJ treatment with a combination of less than 300 mg·L\(^{-1}\) ET would increase peel firmness without serious leaf abscission and a negative effect on SRH. In addition, the soluble solids and the acidity in the combination spraying of GA plus PDJ in late September with 300 mg·L\(^{-1}\) ET and less were almost the same as the control. Thus, our results indicated that the treatment of 5 mg·L\(^{-1}\) GA plus 50 mg·L\(^{-1}\) PDJ in late September combined with ET (200 mg·L\(^{-1}\) < ET < 300 mg·L\(^{-1}\)) from late October to early November was suitable for increasing SRH without impairing fruit quality and causing serious leaf abscission.

Key Words: abscission layer formation, citrus, labor-saving, peel firmness, plant growth regulator.

Introduction

The most time-consuming work for satsuma mandarin growers is harvesting, so the development of a handpicking method without a negative influence on fruit quality and tree health would be labor saving. Previous reports showed that the time required for harvesting by handpicking is less than half that of the usual harvesting method by clipping (Noro et al., 1965; Yamada et al., 1982). However, handpicking is not a practical method for satsuma mandarin production at present because the fruit peel near the peduncle is easily ripped by this method.

Previously, Kozaki et al. (1984) investigated fruit adhesion force and peel firmness in relation to the efficiency of handpicking using some citrus fruit varieties. The results indicated that handpicking efficiency was improved by two physical factors: a decrease in fruit adhesion force and an increase in peel firmness. Thus, we assumed that not only induction of abscission layer formation between the calyx and fruit, but also enhancement of peel firmness, are necessary to improve handpicking of satsuma mandarins.

It was reported that an abscission agent, ethephon (ET), was effective for the induction of abscission layer formation and an improvement in handpicking efficiency (Ikeda et al., 1984; Rasmussen, 1976), although spontaneous abscission layer formation between the calyx and fruit was not easy in the mature period in the satsuma mandarin, suggesting the importance of the application period for exerting the maximum effectiveness of ET. Ikeda et al. (1984) found that a 200 mg·L\(^{-1}\) ET application improved the efficiency of satsuma mandarin handpicking. Rasmussen (1976) also reported that 400 mg·L\(^{-1}\) ET had a satisfactory effect on loosening between the calyx and fruit of the satsuma mandarin fruit. In contrast, there are no reports about improving handpicking by artificially controlling peel firmness. Considering the peel puffing caused by reduced peel...
firmness in the satsuma mandarin, spraying of gibberel- lin (GA) and prohydrojasmon (PDJ) can strengthen peel firmness, which in turn could be a potential technique to improve handpicking efficiency (Makita and Yamaga, 2004; Sato et al., 2015). Thus, we assumed that the balance between the treatments for the induction of abscission layer formation between the calyx and fruit by ET and for strengthening peel firmness by GA plus PDJ, could be key points to improve handpicking.

In the present study, we investigated the effect of combined spraying of GA and PDJ on handpicking efficiency, and we set the concentrations of GA and PDJ to 5 mg·L\(^{-1}\) and 50 mg·L\(^{-1}\), respectively, according to the maximum permitted concentration of registration for reducing fruit puffing in satsuma mandarins in Japan. We then examined the effect of the combined spraying of GA, PDJ, and ET on handpicking efficiency.

Materials and Methods

Plant Materials

‘Silverhill’ satsuma mandarin (Citrus unshiu Marcow.) trees, 38 to 41-year-old, grafted onto trifoliate orange (Poncirus trifoliata (L.) Raf.) trees were used at an orchard of the NARO Institute of Fruit Tree and Tea Science, Division of Citrus Research, Okitsu, Shimizu, Shizuoka, Japan. The mature season of ‘Silverhill’ on this experimental site is late November to early December.

Solution preparation of plant growth regulators

Agricultural chemicals of GA (3.1% GA\(_3\) solution; Meiji Seika Pharma Co., Ltd., Tokyo, Japan), PDJ (5.0% PDJ solution; Meiji Seika Pharma Co., Ltd.), and ET (10.0% ethephon solution; Nissan Chemical Industries, Ltd., Tokyo, Japan) were used in this study. These chemicals were diluted with tap water to prepare their spray solutions (Table 1) just before spraying. These spray solutions were applied with a pressurized one L capacity hand sprayer (DIA SPRAYER No. 4130; FURUPLA, Tokyo, Japan).

Experiment 1: Effect of plant growth regulators on handpicking efficiency in 2010

Six satsuma mandarin trees (38 years old) were used. In each tree, four lateral branches were selected and three treatments (3GP, ET, and 3GP+ET) and the control were randomly assigned to each branch. For the 3GP treatment, a diluted solution containing 5 mg·L\(^{-1}\) GA and 50 mg·L\(^{-1}\) PDJ was sprayed three times (Aug. 27, Sep. 21, and Oct. 27). For the ET treatment, a diluted solution containing 200 mg·L\(^{-1}\) ET was sprayed on Nov. 9. For the 3GP+ET treatment, both the 3GP treatment and the ET treatment were conducted according to their respective methods. Untreated branches were assigned as the control. Ten fruits from a branch in each tree were handpicked on Nov. 30 and Dec. 6. On each handpicking day, the percentage of the fruit that did not have the peel ripped during handpicking was calculated and designated as the success rate of handpicking (SRH). To measure the soluble solids content (SSC) and acidity, five fruits from a branch of each tree were sampled on Nov. 30.

Experiment 2: Effect of the timing of GA plus PDJ on handpicking efficiency in 2011

Eight satsuma mandarin trees (39 years old) were used. For each tree, five lateral branches were selected

<p>| Table 1. Concentration and timing of plant growth regulators sprayed in the experiments. |
|---------------------------------------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Experiment (year)</th>
<th>Treatment</th>
<th>Concentration and timing of GA+PDJ</th>
<th>Concentration and timing of ET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment 1</strong></td>
<td>Control</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(2010)</td>
<td>3GP</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Aug. 27, Sep. 21, Oct. 27</td>
</tr>
<tr>
<td></td>
<td>ET</td>
<td>—</td>
<td>ET 200 mg·L(^{-1}) Nov. 9</td>
</tr>
<tr>
<td></td>
<td>3GP/ET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Aug. 27, Sep. 21, Oct. 27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ET 200 mg·L(^{-1}) Nov. 9</td>
</tr>
<tr>
<td><strong>Experiment 2</strong></td>
<td>Control</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(2011)</td>
<td>GP(Aug. 24)/ET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Aug. 24</td>
</tr>
<tr>
<td></td>
<td>GP(Sep. 12)/ET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Sep. 12</td>
</tr>
<tr>
<td></td>
<td>GP(Sep. 30)/ET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Sep. 30</td>
</tr>
<tr>
<td></td>
<td>ET</td>
<td>—</td>
<td>ET 200 mg·L(^{-1}) Oct. 26</td>
</tr>
<tr>
<td><strong>Experiment 3</strong></td>
<td>Control</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(2012)</td>
<td>GP/lowET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Oct. 2</td>
</tr>
<tr>
<td></td>
<td>GP/hiET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Oct. 2</td>
</tr>
<tr>
<td></td>
<td>lowET</td>
<td>—</td>
<td>ET 400 mg·L(^{-1}) Oct. 26</td>
</tr>
<tr>
<td></td>
<td>hiET</td>
<td>—</td>
<td>ET 400 mg·L(^{-1}) Oct. 26</td>
</tr>
<tr>
<td><strong>Experiment 4</strong></td>
<td>Control</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(2013)</td>
<td>GP</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Sep. 26</td>
</tr>
<tr>
<td></td>
<td>ET</td>
<td>—</td>
<td>ET 300 mg·L(^{-1}) Nov. 11</td>
</tr>
<tr>
<td></td>
<td>GP/ET</td>
<td>GA 5 mg·L(^{-1})+PDJ 50 mg·L(^{-1})</td>
<td>Sep. 26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ET 300 mg·L(^{-1}) Nov. 11</td>
</tr>
</tbody>
</table>
and four treatments (GP(Aug. 24)+ET, GP(Sep. 12)+ET, GP(Sep. 30)+ET, and ET) and the control were randomly assigned to each branch. For the GP(Aug. 24)+ET treatment, a diluted solution containing 5 mg L⁻¹ GA and 50 mg L⁻¹ PDJ was sprayed on Aug. 24. Additionally, a diluted solution containing 200 mg L⁻¹ ET was sprayed on Oct. 26. For the GP(Sep. 12)+ET treatment, a diluted solution containing 5 mg L⁻¹ GA and 50 mg L⁻¹ PDJ was sprayed on Sep. 12. Additionally, a diluted solution containing 200 mg L⁻¹ ET was sprayed on Oct. 26. For the GP(Sep. 30)+ET treatment, a diluted solution containing 5 mg L⁻¹ GA and 50 mg L⁻¹ PDJ was sprayed on Sep. 30. Additionally, a diluted solution containing 200 mg L⁻¹ ET was sprayed on Oct. 26. For the ET treatment, a diluted solution containing 200 mg L⁻¹ ET was sprayed on Oct. 26. For the GP+lowET treatment, both a GP treatment and an ET treatment were conducted according to their respective methods. Untreated branches were assigned as the control. Ten fruits from a section of each tree were handpicked and measured for SRH on Dec. 2 and Dec. 13. To measure the peel puncture force, peel tensile strength, and peel color score, five fruits from a section of each tree were sampled on Dec. 4 and Dec. 16. On Dec. 16, the SSC and acidity of juice in the sampled fruits were also measured. Leaf abscission was measured on a branch with almost 100 leaves before treatment by counting the leaves before (Sep. 24, 2013) and after (Jan. 14, 2014) treatment.

Measurement method of the peel puncture force, peel tensile strength, peel color score, SSC, and acidity

Peel puncture force and peel strength were measured in each fruit using a texture analyzer (TA-XT plus; Microstable Systems, UK). The maximum resistance force when a cylinder probe (2 mm in diameter) penetrated the peel in the equatorial region of the fruit was regarded as the peel puncture force. The maximum resistance force when a tensile grip probe pulled the ends of a peel piece 3 cm long and 1.5 cm wide, which was cut off along the longitudinal direction was regarded as the peel tensile strength. Peel color was evaluated using a color chart on which 11 classes of color samples, from green (0) to orange (10), are arranged. To measure SSC and acidity, the juice of five fruits was extracted, mixed, and filtrated. The SSC of the juice was measured with a digital refractometer (PAL-1; Atago Co., Ltd., Tokyo, Japan). The acidity of the juice was measured by titration with 0.1 N NaOH.

Statistical analysis

Data were subjected to analysis of variance, and the means were separated by Tukey’s test at $P < 0.05$ in the experiments using JMP 7.0 (SAS Institute Inc., USA). The percentage data of SRH, leaf abscission, and acidity were transformed using arcsine before statistical analysis.

Results

Experiment 1: Effect of plant growth regulators on handpicking efficiency in 2010

The SRHs for 3GP and 3GP+ET were higher than that for the control, although there was no significant difference in ET on Nov. 30 (Fig. 1). The SRHs for ET and 3GP+ET were higher than that for the control, although there was no significant difference in 3GP on Dec. 6. There was no difference in SSC (Table 2). The acidity in 3GP was higher than that in the control. These results suggested a possible SRH improvement because of 3GP+ET, but three treatments on different
dates were too costly and labor-intensive considering practical use; therefore, we investigated the effect of a one-time treatment (Aug. 24, Sep. 12, or Sep. 30) on SRH.

For the GP(Aug. 24)+ET treatment, both 5 mg·L\(^{-1}\) PDJ was sprayed three times (Aug. 27, Sep. 21, and Oct. 27). For the ET treatment, 200 mg·L\(^{-1}\) ET was sprayed on Nov. 9. For the 3GP+ET treatment, both the 3GP treatment and the ET treatment were performed.

Different letters indicate significant differences among the treatments at \(P<0.05\) by Tukey’s test (n = 6).

**Table 2. Effect of the combination treatment of GA plus PDJ and ET on fruit quality in 2010.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>SSC (°Brix)</th>
<th>Acidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10.0 a(^z)</td>
<td>0.82 b</td>
</tr>
<tr>
<td>3GP</td>
<td>9.7 a</td>
<td>0.95 a</td>
</tr>
<tr>
<td>ET</td>
<td>9.8 a</td>
<td>0.78 b</td>
</tr>
<tr>
<td>3GP+ET</td>
<td>9.5 a</td>
<td>0.83 ab</td>
</tr>
</tbody>
</table>

For the 3GP treatment, 5 mg·L\(^{-1}\) GA plus 50 mg·L\(^{-1}\) PDJ was sprayed three times (Aug. 27, Sep. 21, and Oct. 27). For the ET treatment, 200 mg·L\(^{-1}\) ET was sprayed on Nov. 9. For the 3GP+ET treatment, both the 3GP treatment and the ET treatment were performed. Measurements of SSC and titratable acidity on Nov. 30. 2010.

Different letters indicate significant differences among the treatments at \(P<0.05\) by Tukey’s test (n = 6).

**Experiment 2: Effect of the timing of GA and PDJ on handpicking efficiency in 2011**

The SRHs for GP(Sep. 12)+ET and GP(Sep. 30)+ET were higher than that for the control, although there was no significant difference in GP(Aug. 24)+ET or ET on Dec. 2 (Fig. 2). The SRHs for GP(Sep. 12)+ET, GP(Sep. 30)+ET, and ET were higher than that for the control, although there was no significant difference in GP(Aug. 24)+ET on Dec. 13. Each treatment of GP(Sep. 12)+ET and GP(Sep. 30)+ET showed a higher peel puncture force and tensile strength, but a lower color score (Table 3). There was no difference in SSC. The acidity levels in GP(Aug. 24)+ET and GP(Sep. 12)+ET were higher than that in the control. Consequently, spraying in mid to late September would be a suitable period to increase SRH, but 200 mg·L\(^{-1}\) ET seemed to be insufficient for peel coloration. As a result, we studied the effect of increased ET (400 mg·L\(^{-1}\)) on the parameters by comparison with 200 mg·L\(^{-1}\) ET.

**Table 3. Effect of timing of GA plus PDJ treatment on fruit firmness, peel color, and fruit quality in 2011.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Peel puncture force (kg)</th>
<th>Peel tensile strength (kg)</th>
<th>Peel color score</th>
<th>SSC (°Brix)</th>
<th>Acidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.38 b(^z)</td>
<td>0.82 b</td>
<td>10.0 a</td>
<td>10.8 a</td>
<td>0.59 b</td>
</tr>
<tr>
<td>GP(Aug. 24)+ET</td>
<td>0.38 b</td>
<td>0.90 b</td>
<td>9.8 a</td>
<td>10.7 a</td>
<td>0.71 a</td>
</tr>
<tr>
<td>GP(Sep. 12)+ET</td>
<td>0.49 a</td>
<td>1.04 a</td>
<td>7.9 b</td>
<td>10.4 a</td>
<td>0.71 a</td>
</tr>
<tr>
<td>GP(Sep. 30)+ET</td>
<td>0.45 b</td>
<td>1.02 a</td>
<td>8.3 b</td>
<td>10.6 a</td>
<td>0.63 ab</td>
</tr>
<tr>
<td>ET</td>
<td>0.37 b</td>
<td>0.84 b</td>
<td>10.0 a</td>
<td>10.8 a</td>
<td>0.66 ab</td>
</tr>
</tbody>
</table>

For the GP(Aug. 24)+ET treatment, both 5 mg·L\(^{-1}\) GA plus 50 mg·L\(^{-1}\) PDJ on Aug. 24 and 200 mg·L\(^{-1}\) ET on Oct. 26 were sprayed. For the GP(Sep. 12)+ET treatment, both 5 mg·L\(^{-1}\) GA plus 50 mg·L\(^{-1}\) PDJ on Sep. 12 and 200 mg·L\(^{-1}\) ET on Oct. 26 were sprayed. For the GP(Sep. 30)+ET treatment, both 5 mg·L\(^{-1}\) GA plus 50 mg·L\(^{-1}\) PDJ on Sep. 30 and 200 mg·L\(^{-1}\) ET on Oct. 26 were sprayed. For the ET treatment, 200 mg·L\(^{-1}\) ET was sprayed on Oct. 26. Measurements on Dec. 14, 2011.

Different letters indicate significant differences among the treatments at \(P<0.05\) by Tukey’s test (n = 40 for peel puncture force, peel tensile strength, and peel color score, and n=8 for SSC and acidity).
Experiment 3: Effect of the ET concentration on handpicking efficiency in 2012

The SRHs for GP+lowET, GP+hiET, and hiET were significantly higher than that for the control, regardless of handpicking time (Fig. 3). The treatment with GP

![Graph showing effect of ET concentration on handpicking efficiency]

The treatment with GP+lowET resulted in the highest peel puncture force, while treatment with hiET resulted in the lowest. Treatment with GP+lowET produced a higher peel tensile strength. The color scores with GP+lowET and GP+hiET were lower than those with other treatments, possibly due to the strength of peel firmness due to GP. The SSC in hiET was lower than that in the control (Table 4). There was no difference in acidity among the treatments. These results demonstrated the importance of balance in concentrations between chemicals with opposite effects, GA plus PDJ and ET. Moreover, we observed massive leaf abscission at 400 mg·L⁻¹ ET (hiET) (data not available).

Experiment 4: Effect of the 300 mg·L⁻¹ ET on handpicking efficiency in 2013

Since 400 mg·L⁻¹ ET resulted in serious leaf defoliation, we investigated the effect of 300 mg·L⁻¹ ET with a combination of GA plus PDJ on SRH. The SRHs for GP and GP+ET were significantly higher than that for the control, regardless of handpicking time, while that for ET was higher than that for the control on Dec. 13 (Fig. 4). Each treatment of GP and GP+ET resulted in a higher peel puncture force and tensile strength, but lower color scores. There was no difference in SSC or acidity among any treatments (Table 5). However, leaf abscission for ET and GP+ET was unexpectedly higher than that for the control (Fig. 5), suggesting that 300 mg·L⁻¹ ET may still be too high.

Discussion

Improving the efficiency of handpicking fruits using the plant growth regulators GA, PDJ, and ET was examined using satsuma mandarins. We intended to improve SRH by balancing concentrations of chemicals with opposite effects on peel firmness. Triplicate spraying of a GA plus PDJ solution improved SRH as compared with the control (Fig. 1). Furthermore, triplicate spraying of a combination of GA plus PDJ and ET in-

### Table 4. Effect of the ET concentration on fruit quality in 2012.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>SSC (°Brix)</th>
<th>Acidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>11.4 a'</td>
<td>0.56 a</td>
</tr>
<tr>
<td>GP+lowET</td>
<td>11.4 a</td>
<td>0.59 a</td>
</tr>
<tr>
<td>GP+hiET</td>
<td>10.7 ab</td>
<td>0.63 a</td>
</tr>
<tr>
<td>lowET</td>
<td>11.1 ab</td>
<td>0.58 a</td>
</tr>
<tr>
<td>hiET</td>
<td>10.5 b</td>
<td>0.64 a</td>
</tr>
</tbody>
</table>

For the GP+lowET treatment, both 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ on Oct. 2 and 200 mg·L⁻¹ ET on Oct. 15 were sprayed. For the GP+hiET treatment, both 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ on Oct. 2 and 400 mg·L⁻¹ ET on Oct. 26 were sprayed. For the lowET treatment, 200 mg·L⁻¹ ET was sprayed on Oct. 15. For the hiET treatment, 400 mg·L⁻¹ ET was sprayed on Oct. 26. Measurements on Dec. 17, 2012.

Different letters indicate significant differences among the treatments at P<0.05 by Tukey’s test (n=8).
creased SRH as compared with the control. To assess the practicality of this method, we carried out a one-time treatment. One-time treatment of GA plus PDJ also showed a significant positive effect on handpicking efficiency when applied in mid to late September (Fig. 2). However, it seemed that 200 mg·L⁻¹ ET may be insufficient for peel coloration (Table 3). As for the concentration of ET, 400 mg·L⁻¹ ET clearly improved SRH compared with 200 mg·L⁻¹ ET (Fig. 3). The above results are summarized as follows: (1) The combination treatment of GA plus PDJ and ET improved SRH. (2) The optimum timing of GA plus PDJ treatment is mid to late September. (3) The optimum concentration of ET was between 200 mg·L⁻¹ and 400 mg·L⁻¹. (4) 400 mg·L⁻¹ ET caused massive leaf abscission, but this is only our observation.

As mentioned earlier, the SRH after spraying with 400 mg·L⁻¹ ET was much improved, but the treatment was accompanied by massive leaf abscission (data not available). Therefore, we studied the effect of spraying of 300 mg·L⁻¹ ET: the result on SRH was acceptable, but this concentration still resulted in 37.1% leaf abscission (Fig. 5). Hirose et al. (1970) and Manago and Ogaki (1971) reported that treatment with more than 500 mg·L⁻¹ ET to degreen fruit in wase unshiu caused defoliation. Rasmussen (1976) reported that ET of 400 mg·L⁻¹ caused excessive defoliation with satisfactory loosening of the satsuma fruit. Therefore, considering handpicking and defoliation, the optimal concentration of ET is in the range of 200–300 mg·L⁻¹ ET to increase handpicking efficiency without causing defoliation.

Table 5. Effect of the 300 mg·L⁻¹ ET on fruit quality in 2013.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>SSC (°Brix)</th>
<th>Acidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10.1 az</td>
<td>0.49 a</td>
</tr>
<tr>
<td>GP</td>
<td>9.7 a</td>
<td>0.51 a</td>
</tr>
<tr>
<td>ET</td>
<td>10.3 a</td>
<td>0.47 a</td>
</tr>
<tr>
<td>GP+ET</td>
<td>10.0 a</td>
<td>0.50 a</td>
</tr>
</tbody>
</table>

For the GP treatment, 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ was sprayed on Sep. 26. For the ET treatment, 300 mg·L⁻¹ ET was sprayed on Nov. 11. For the GP+ET treatment, both a GP treatment and an ET treatment were performed. Measurements of SSC and titratable acidity on Dec. 4, 2013.

Different letters indicate significant differences among the treatments at P < 0.05 by Tukey’s test (n = 8).
massive defoliation and poor coloration. Kender et al. (2000) reported that calcium hydroxide applied with ET reduced ET-induced defoliation in ‘Robinson’ and ‘Sunburst’ tangerines. Pozo et al. (2004) showed applications of 1-Methylcyclopropene (1-MCP) with ET reduced ET-associated leaf abscission in orange fruits. In order to prevent massive defoliation with 400 mg·L⁻¹ ET and improve handpicking efficiency in the satsuma mandarin, calcium hydroxide and 1-MCP could be investigated as protective agents.

Next, we discuss the SRH in terms of the optimal treatment period. The increase in SRH with treatment by GA plus PDJ in late September caused an increase in peel firmness and peel tensile strength (Fig. 4). The SRH with a combination treatment of GA plus PDJ (from Sep. 12 to Oct. 2) and 200–300 mg·L⁻¹ ET (from Oct. 15 to Nov. 11) also increased peel firmness and peel tensile strength (Figs. 3 and 4). These results suggested that a GA plus PDJ treatment with 200–300 mg·L⁻¹ ET spraying increased peel firmness. Kozaki et al. (1984) observed that the efficiency of handpicking is enhanced by fruit adhesion force and peel firmness, especially peel firmness. Our results are the first to show the effect of combined spraying of GA and PDJ on handpicking efficiency for the satsuma mandarin. This study is also the first to provide information on the improvement of handpicking efficiency by the combination treatment of GA plus PDJ (from Sep. 12 to Oct. 2) and ET (from Oct. 15 to Nov. 11).

Sato et al. (2015) reported that the effect of combination spraying of GA plus PDJ on preventing peel puffing was the highest for a September treatment from tested spraying times from middle August to early November, so to increase peel firmness, the most efficient time for GA plus PDJ treatment is mid to late September. The timing of ET spraying had no influence on increasing SRH from mid-October to early November (Figs. 1–4).

Regarding fruit quality, especially SSC and acidity, the acidity with triplicate GA plus PDJ spraying was higher than that in the control (Table 2). The SSC in 400 mg·L⁻¹ ET treatment was lower than that in the control (Table 4). Sawano (2010) reported that 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ sprayed in early September to reduce fruit puffing in the satsuma mandarin resulted in decreasing SSC and increasing acidity in mature fruit. Hirose et al. (1970) and Manago and Ogaki (1971) reported that the SSC in juice decreased with ET treatment. In our study, one-time spraying of GA plus PDJ in late September had no influence on SSC or acidity (Table 5). Furthermore, the combined spraying of GA plus PDJ and less than 300 mg·L⁻¹ ET had less influence on SSC and the acidity of fruit (Table 3–5). Thus, the combination treatment of 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ in late September and less than 300 mg·L⁻¹ ET from late October to early November was suitable to increase SRH without impairing fruit quality. Conclusively, we found that the optimal conditions for achieving acceptable handpicking without impairing fruit quality and serious leaf abscission were as follows: treatment of 5 mg·L⁻¹ GA plus 50 mg·L⁻¹ PDJ in late September combined with ET (200 mg·L⁻¹ < ET < 300 mg·L⁻¹) from late October to early November.

For practical use, we should mention three demerits derived from handpicking that need to be addressed. First, because most handpicked fruits lose their calyces, it is difficult to sell them as fresh fruit. However, as handpicked satsuma mandarin fruits without calyces can be stored for about a month under low temperature conditions (Yamada, 1985), handpicked fruit could also be used as cut fruit and processed products. Second, Jozukuri and Yukinari (1976) reported that the number and length of vegetative shoots and the number of flowers in the spraying shoots from bearing shoots harvested by clipping were more than those by handpicking in ‘Hassaku’, which indicates the possibility that handpicking may reduce vegetative shoots and flowers in the spring. To overcome this difficulty, a treatment such as heavy pruning of the branches is needed. Another concern is Melanose. After handpicking, shoots or peduncles with calyx suffer dieback, leading to Melanose. However, the number of dieback branches is limited as handpicking has little effect compared to the total number of branches, so handpicking has little influence on Melanoses (Jozukuri and Yukinari, 1976).

Overseas, in an attempt to increase the performance of mechanical harvesting, the use of abscission chemicals has been promoted. Abscission agent chemicals make it easier for the fruit to detach from the stalk in one of the abscission zones, with the aim of increasing the detachment rate without affecting the fruit quality. One of the most widely studied abscission chemicals is ET (Li et al., 2008; Moreno et al., 2015; Pozo and Burns, 2009; Yuan and Burns, 2004). Recently, 5-chloro-3-methyl-4-nitro-1H-pyrazole (CMNP) was investigated as an abscission agent for oranges in Florida (Burns et al., 2003; Ebel et al., 2010; Hartmond et al., 2000; Kumar and Ebel, 2015, 2016; Li et al., 2008; Pozo and Burns, 2009; Yuan and Burns, 2004). When CMNP was used for ‘Valencia’ Oranges as an abscission agent, mature fruit were loosened selectivity with little leaf loss. Although CMNP was studied as an abscission agent for satsuma mandarins, CMNP treatment did not decrease the fruit attachment force (Iwagaki et al., 1977). In order to improve labor-saving during harvesting, new abscission chemicals suitable for the satsuma mandarin need to be developed.

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