Tree Growth, Flowering, and Fruiting of ‘Taishuu’ Japanese Persimmon Grafted onto Dwarfing Rootstocks

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The field performance of ‘Taishuu’ Japanese persimmon trees grafted onto clonally propagated rootstocks, ‘MKR1’ and FDR-1, was investigated over 10 years. These results were then compared with the performance of trees grafted onto seedling stocks (S) and own-rooted trees derived from micropropagation (O-R). ‘Taishuu’ scions on ‘MKR1’ and FDR-1 rootstocks grew well initially, but stopped growing taller at seven years after planting. Total shoot length and trunk cross-sectional area (TCSA) increased annually in all trees, while the differences in these parameters between S or O-R trees and ‘MKR1’ or FDR-1 trees continued to increase year after year. The graft union of trees grafted onto ‘MKR1’ swelled, and FDR-1 rootstock overgrew the ‘Taishuu’ scion. Trees grafted onto both ‘MKR1’ and FDR-1 bore female and male flowers soon after planting, and the percentage of shoots with female flowers relative to total shoots in ‘MKR1’- and FDR-1-grafted trees were higher than that in S and O-R trees each year. The numbers of shoots with male flowers varied from year to year in ‘MKR1’- and FDR-1-grafted trees, but did not appear to increase yearly. ‘MKR1’- and FDR-1-grafted trees almost completely inhibited secondary shoot occurrence in mid-June, and the percentages of dropped fruitlets between the middle of May and the end of July were almost always lower for ‘MKR1’- and FDR-1-grafted trees than for S and O-R trees. Cumulative yield efficiencies according to TCSA, canopy area, and canopy volume showed that ‘MKR1’- and FDR-1-grafted trees produced fruit most efficiently, although the total yields per tree were not significantly different between rootstocks. There were no significant differences in fruit quality between the rootstocks, except for the number of seeds. Concentric cracking and stylar-end cracking occurred in fruit of trees grafted onto ‘MKR1’ and FDR-1. However, the differences between the rootstock types were not large. The harvest date of ‘MKR1’ trees was significantly earlier than that of S and O-R trees. In conclusion, ‘MKR1’ and FDR-1 are both satisfactory dwarfing rootstocks for ‘Taishuu’, with high yield efficiency and inhibition of early fruit drop.

Key Words: Diospyros kaki, early fruit drop, graft union, male flower, yield efficiency.

Introduction

Commercial cultivars of Japanese persimmon (Diospyros kaki Thunb.) have been propagated by grafting scions onto seedlings of D. kaki, D. lotus, and other species. The generally vigorous trees that are grafted on these seedlings tend to grow larger, and thus growers encounter some difficulties in terms of orchard management (Tao and Sugiuira, 1992). Furthermore, micropropagated and own-rooted (O-R) trees of commercial cultivars also tend to grow vigorously (Tetsumura et al., 1999, 2010, 2015). In apple orchard systems, the use of dwarfing rootstocks has dramatically reduced worker injuries, required volumes of protectant sprays, and other culture expenses while increasing per-area productivity (Fazio et al., 2014). Therefore, candidate dwarfing rootstocks for Japanese persimmon have been...
sought and selected (Hattori et al., 2015; Kimura et al., 1985). At the same time, methods for efficient clonal propagation, micropropagation, and cutting propagation of these rootstocks have been developed (Kagami, 1999; Tetsumura et al., 2000, 2003, 2009, 2017). As a result, several studies on the orchard growth of the trees grafted onto these clonally propagated candidate rootstocks have been conducted, and the abilities of some rootstocks to effectively dwarf the scions have been demonstrated (Hattori et al., 2015; Tetsumura et al., 2010, 2015; Yakushiji et al., 2008).

Field evaluations of the leading persimmon cultivars in Japan, ‘Fuyu’ and ‘Hiratanenashi’, grafted onto cutting-propagated ‘MKR1’, previously known as “OD-1” or “Rootstock b”, showed that the dwarfed trees efficiently produced flowers and fruit without changes in fruit quality (Tetsumura et al., 2010, 2015). The developers of ‘MKR1’ applied to the Ministry of Agriculture, Forestry and Fisheries of Japan for its registration as a new variety, which was granted in March 2015. Since 2015, four dwarfing rootstocks, including ‘MKR1’, have been offered for field testing at 17 prefectoral research institutions in Japan. Regarding FDR-1, a ‘Fuyu’ persimmon tree grafted on the original seedling was incidentally found to be dwarfed in the orchard at the Fukuoaka Agriculture and Forestry Research Center, Japan (Tetsumura et al., 2017). There had been no previous reports about the growth of trees grafted onto clonally propagated FDR-1, partly because micropropagation had been the only method for its vegetative propagation due to the difficulty of rooting cuttings. Recently, however, 80% of FDR-1 cuttings rooted successfully in an improved irrigation system (Tetsumura et al., 2017). Meanwhile, methods of propagation of ‘MKR1’ cuttings had been improved and 100% rooting was achieved (Tetsumura et al., 2003, 2009). In addition, an easy method for softwood cutting propagation with a simple irrigation system was also developed (Hejazi et al., 2018).

‘Taishuu’ was released in 1995 by the National Institute of Fruit Tree Science, Japan, producing mid-season, large, pollination-constant non-astringent fruit with good texture (Yamane et al., 2001). Although it became an important cultivar in Japan and its cultivation area was more than 300 ha in 2016 (Ministry of Agriculture, Forestry and Fisheries of Japan, 2018), ‘Taishuu’ produces a relative excess of male flowers when the tree becomes old or weakened. This leads to an insufficient crop load, and thus some farmers are reluctant to plant ‘Taishuu’ nursery stocks (Akagi et al., 2014). ‘Hiratanenashi’ and ‘Fuyu’ trees do not bear male flowers, so there is no information about production of male flowers on these trees when grafted onto ‘MKR1’ or FDR-1 rootstocks. Hayashi et al. (2001) found that ‘Taishuu’ trees grafted onto D. kaki seedlings started bearing male flower buds four years after planting and all flower buds on the short shoots were male. The mean shoot length of young ‘Fuyu’ trees on ‘MKR1’ was shorter than when it was grafted onto the other rootstocks, although that was not the case with young ‘Hiratanenashi’ trees (Tetsumura et al., 2010). Concurrently, the shoots of adult trees grafted onto ‘MKR1’ were shorter in both ‘Fuyu’ and ‘Hiratanenashi’ (Tetsumura et al., 2015). Moreover, early fruit drop, an undesirable trait for fruit cultivation, rarely occurred in ‘Hiratanenashi’ and ‘Fuyu’ trees grafted onto ‘MKR1’ mainly due to inhibition of secondary shoot growth (Tetsumura et al., 2013b).

In this study, we evaluated the growth, flowering, and fruiting of ‘Taishuu’ Japanese persimmon trees grafted onto ‘MKR1’ and FDR-1 over 10 years. Findings were compared among trees grafted onto seedling rootstocks as well as O-R trees.

Materials and Methods

Plant materials and experimental design

‘MKR1’ rootstocks were obtained using the same procedure as described previously (Tetsumura et al., 2010). Softwood single-node stem cuttings collected from ‘MKR1’ root suckers were planted in a mist system in June 2006 (Tetsumura et al., 2003). Two months after taking cuttings, the rooted cuttings were transplanted into pots and raised in a greenhouse. O-R ‘Taishuu’ plantlets and FDR-1 rootstocks obtained by micropropagation (Tao and Sugiura, 1992) were planted in pots in the greenhouse in August 2006. In March 2008, scions of ‘Taishuu’ were grafted at a height of 15 cm onto the shanks of ‘MKR1’ and FDR-1 nursery rootstocks. Nursery stocks grafted onto one-year-old D. kaki seedlings with a 5-cm shank (Seedling, S) in the spring of 2008 were raised in an outdoor nursery, dug up in December 2008, and then heeled-in in moist sand until orchard planting. As a result, S trees were initially the largest.

In December 2008, all trees were planted in a row in Andosol (Kuroboku soil) in the orchard at the Field Science Center of the University of Miyazaki, Japan. Between-tree spacing was 3 to 4 m depending on the type of rootstock. The experimental design was a randomized complete block with five replications comprising one tree each. Trees were pruned for modified central leader training. Until the 2010 season, all female flowers were removed in early May and then from 2011 onwards, all but one female flower per shoot were removed and all female flowers on shoots with five or fewer leaves were thinned, in accordance with Japanese cultural methods for persimmon. All perfect (hermaphrodite) flowers were thinned in early May in all years. At the end of July, soon after the completion of the early fruit drop study, the leaf-fruit ratio per fruiting mother shoot was adjusted to 25 by fruit thinning. Pest and fertilizer management was conducted as recommended.
Evaluation of tree growth, flowering, and fructing

From 2009 onward, tree height was measured in January, before pruning. In January 2018, the ground area covered by the tree canopy (canopy area) and canopy volume of each tree were also measured according to the method of Kimura et al. (1985) in order to calculate cumulative yield efficiency. Lengths of one-year-old shoots were measured in December of 2008 to 2015, and the measured values were used to calculate total shoot length, number of shoots, and mean shoot length. Beginning in 2010, trunk cross-sectional areas (TCSAs) at 30 cm above the soil were measured in January. At the same time, the TCSAs of ‘MKR1’, FDR-1, and O-R were measured at 5 cm above the soil, and that of S was measured at 2 cm above the soil, to calculate the overgrowth index of each rootstock, which was defined as the TCSA at 5 or 2 cm above the soil divided by that at 30 cm.

From 2009 onward, the numbers of one-year-old shoots, female flowers, and one-year-old shoots bearing female or male flowers were counted before thinning female flowers. There were no shoots bearing both female and male flowers. Shoots bearing perfect flowers were counted as shoots bearing male flowers because they always bore flowers that were either male or perfect.

Beginning in 2011, dropped fruitlets were counted each week from the middle of May to the end of July, and the percentage of early fruit drop was estimated as the number of dropped fruitlets divided by the number of flowers on trees soon after thinning female flowers. In order to determine the relation between fruit drop and secondary growth, the rates of secondary shoot occurrence were calculated as the ratio of the number of one-year-old shoots showing secondary growth, which were counted in mid-June, to the number of one-year-old shoots.

All mature fruit with a color score of 5 (Yamazaki and Suzuki, 1980) at the apical region were harvested and weighed every seven days; the number of harvests per tree ranged from one to four. The median harvest date (50% harvest) was calculated as the number of days after initiation of harvest. The cumulative yield efficiency was calculated from the total fruit yields after planting per TCSA in 2018, the canopy area, or the canopy volume. During each harvest, the fruit qualities described below, most of which were investigated using the same method as in the previous report (Tetsumura et al., 2015), were evaluated for five average fruits per tree. Soluble solids content was measured with a digital refractometer (PAL-100; Atago Co., Tokyo, Japan) after juice extraction using a grater; fruit firmness was measured on two paired surfaces at the equatorial region using a fruit hardness tester (KM-5; Fujiwara Scientific Company Co., Tokyo, Japan) fitted with a cone tip plunger; skin color was measured at two different points on the equatorial region as the $a^*$ value, which is highly correlated ($R^2 = 0.98$) with color score (Yamazaki and Suzuki, 1980), using a colorimeter (CR-400; Konica Minolta, Inc., Tokyo, Japan); the number of seeds per fruit was counted; and the degree of physiological disorders on fruit, namely, calyx-end cracking (Fig. S1), concentric cracking (Fig. S2), and stylar-end cracking (Fig. S3), was evaluated. The degrees of all disorders were defined as 0 (none), 1 (slight), 2 (moderate), and 3 (severe). The means of these fruit quality data were multiplied by the ratios of the fruit number harvested on that date to the total fruit number, and the total of the transformed values was considered the data per tree.

Statistical analysis

All data, except for the degrees of physiological disorders, were subjected to one-way analysis of variance (ANOVA) to determine the significance of differences between rootstocks, and all percentage data were subjected to arcsin transformation prior to performing ANOVA. The means were evaluated using Tukey’s honestly significant difference test ($P < 0.05$). The degrees of all physiological disorders were subjected to the Kruskal-Wallis test, and the means were evaluated using the Steel-Dwass test ($P < 0.05$).

Results

Tree growth

S trees, which were the tallest among rootstock types at planting, were shorter in 2010 than in 2009 (Fig. 1) because their leaders were cut back severely at planting to alleviate transplanting shock, and they did not grow well during the first growing season. However, thereafter, they grew vigorously, as did the O-R trees. ‘MKR1’- and FDR-1-grafted trees also grew well, and at the end of the first growing season they were of similar height to the other trees. However, after the first season, they grew slowly. After 2015, ‘MKR1’- and

![Fig. 1. Effects of rootstock on tree height in ‘Taishuu’ persimmon. Data represent the means of five replications each. Means in the same year followed by the same letter are not significantly different at $P < 0.05$ according to Tukey’s test.](image-url)
FDR-1-grafted trees stopped growing taller, reaching around 2.1 m and 1.8 m in height, respectively, although these heights were not significantly different.

The total shoot lengths of S trees were consistently the longest and those of ‘MKR1’- and FDR-1-grafted trees were the shortest (Fig. 2). The total shoot lengths of O-R trees increased as rapidly, as did those of S trees, although they had been the shortest at planting. The number of shoots increased each year in all tree treatments, except in ‘MKR1’- and FDR-1-grafted trees in 2014 (Fig. 2). In 2013, heavy fruit loads weakened the trees, and in the following spring, the rate of budbreak was lower than average. As a result, in 2014, the mean shoot lengths of ‘MKR1’- and FDR-1-grafted trees were longer than previous or later years, and the total shoot lengths steadily increased in 2014, as in the other years (Fig. 2). From planting to the second year after planting, the mean shoot length of S trees decreased considerably and that of O-R trees increased. The mean shoot lengths of ‘MKR1’- and FDR-1-grafted trees tended to be shorter than those of S and O-R trees from the third year of planting, except for 2014 (Fig. 2). Mean shoot lengths of ‘MKR1’- and FDR-1-grafted trees were 14.5 cm and 12.6 cm, respectively, whereas those of S and O-R trees were 23.7 cm and 22.6 cm, respectively, for all six years from 2010 to 2015.

TCSA, which is positively and linearly related to the canopy volume of Japanese persimmon trees (Yakushiji et al., 2008), increased in all tree treatments after planting (Fig. 3). However, the TCSAs of ‘MKR1’- and FDR-1-grafted trees increased so slowly that the difference between their indices and those of S and O-R trees grew over time.
Graft union

The shapes of graft unions varied with the rootstock (Fig. 4). The graft union of ‘MKR1’ trees swelled, like that between ‘MKR1’ and ‘Hiratanenashi’ scions (Tetsumura et al., 2010). As for FDR-1 trees, the rootstocks overgrew the scions (Fig. 4) and the overgrowth was apparent at five years after planting (Fig. 3). Some S trees showed overgrowth symptoms similar to FDR-1 trees, so that the overgrowth indices of S trees were not significantly different from those of FDR-1 trees (Fig. 3).

Flowering

‘MKR1’- and FDR-1-grafted trees bore female flowers soon after planting, and S and O-R trees did a year later (Table 1). Although there were no significant differences in the number of female flowers between the tree treatments in the first five years, S and O-R trees

Table 1.  Effects of rootstock on number of female flowers, number of shoots with male flowers, female flower thinning, and number of shoots with flowers per number of total shoots in ‘Taishuu’ persimmon.

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<td>279 a</td>
<td>357 a</td>
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<td><strong>Number of shoots with female flowers per number of total shoots (%)</strong></td>
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<td>43 a</td>
<td>43 b</td>
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<td>51 b</td>
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<td>50 ab</td>
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<td>73 a</td>
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<td>86 a</td>
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<td>8 c</td>
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<td>42 a</td>
<td>38 b</td>
<td>18 b</td>
<td>60 b</td>
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<td><strong>Number of thinned female flowers per number of female flowers (%)</strong></td>
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<td>66 b</td>
<td>49 b</td>
<td>46 b</td>
<td>56 b</td>
<td>59 b</td>
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<td>23 c</td>
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<td>47 c</td>
<td>26 c</td>
<td>61 b</td>
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<td>2 b</td>
<td>3 c</td>
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<td>1 c</td>
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<td>0.0 b</td>
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<td><strong>Number of shoots with male flowers per number of total shoots (%)</strong></td>
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Means were derived from five replications each.

* Means in the same year followed by the same letter are not significantly different at $P<0.05$ according to Tukey’s test.
tended to bear more female flowers than ‘MKR1’- and FDR-1-grafted trees thereafter because they produced more shoots (Fig. 2). However, the number of shoots with female flowers per total shoots was higher in ‘MKR1’- and FDR-1-grafted trees than in S and O-R trees each year, and the differences were significant nearly every year. ‘MKR1’- and FDR-1-grafted trees bore such an excess of female flowers for optimal fruit production that more female flowers had to be thinned than in S and O-R trees after 2011, the first harvest year. Conversely, almost all female flowers on S and O-R trees were borne on shoots with more than five leaves. Thus, few (zero to several percent) shoots required complete removal of female flowers (Table 1).

FDR-1-grafted trees bore male flowers in the second year after planting, as did ‘MKR1’-grafted trees in the third year (Table 1). The number of shoots with male flowers varied from year to year in trees grafted onto both ‘MKR1’ and FDR-1 rootstock types, but did not seem to increase across years. S trees did not bear male flowers for the first four years, but continued to bear male flowers after that, and the percentage of shoots with male flowers was the highest among all tree treatments in 2017. O-R trees did not bear male flowers for at least the first five years, and from then on, there were few shoots with male flowers.

Fruit drop and secondary growth

Kajiura (1942b) reported that secondary shoot growth in June caused early fruit drop in the ‘Fuyu’ persimmon, and Tetsumura et al. (2010) reported that the ‘MKR1’ rootstock inhibited this secondary growth in ‘Fuyu’ and ‘Hiratanenashi’ scions. Therefore, the effect of rootstock on the relationship between secondary shoot growth and early fruit drop was investigated. Grafting onto ‘MKR1’ and FDR-1 rootstocks almost completely inhibited secondary shoot growth (Table 2). S and O-R trees also inhibited secondary shoot growth after 2013, the fifth year following planting, although they did produce some secondary shoots until then. Despite this fact, the percentages of dropped fruitlets were almost always lower in ‘MKR1’- and FDR-1-grafted trees than in S and O-R trees and these differences were significant after 2013. However, it should be noted that this trend was not seen in 2016 and in the same year the secondary shoots of ‘MKR1’- and FDR-1-grafted trees occurred irregularly compared with the other years.

Fruiting and fruit quality

The first harvest year was 2012, and all trees had produced fruit since 2013. However, as mentioned above, the heavy fruit loads in 2013 resulted in decreased fruit yields in the following year in ‘MKR1’- and FDR-1-grafted trees (Table 3). In 2015 and 2016, the yields of all trees were low because of damage caused by typhoons. Especially in 2016, a powerful typhoon hit just before the harvest and many bearing shoots were broken. The total yield of S trees was two-fold and threefold that of ‘MKR1’- and FDR-1-grafted trees, respectively, although the differences were not significant because yields of individual S trees varied widely, from 6 to 71 kg per tree. All indices of cumulative yield efficiency showed that ‘MKR1’- and FDR-1-grafted trees produced fruit most effectively (Table 3).

As shown in Table 4, there were no significant differences in fruit quality between the rootstocks, except in number of seeds. Although the reasons for differences in the number of seeds are unknown, the differences were too small to be considered a problem. Substantial concentric cracking and stylar-end cracking occurred in fruit of ‘MKR1’- and FDR-1-grafted trees. However, the reasons for this disorder are unknown. The harvest date of ‘MKR1’-grafted trees was significantly earlier than that of S and O-R trees.

Table 2.  Effects of rootstock on secondary shoot growth and early fruit drop in ‘Taishuu’ persimmon.

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Year 2011</th>
<th>Year 2012</th>
<th>Year 2013</th>
<th>Year 2014</th>
<th>Year 2015</th>
<th>Year 2016</th>
<th>Year 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling</td>
<td>7 a</td>
<td>13 a</td>
<td>4 a</td>
<td>1 a</td>
<td>2 a</td>
<td>3 a</td>
<td>1 a</td>
</tr>
<tr>
<td>‘MKR1’</td>
<td>2 bc</td>
<td>0 bc</td>
<td>0 b</td>
<td>0 a</td>
<td>0 b</td>
<td>5 a</td>
<td>0 a</td>
</tr>
<tr>
<td>FDR-1</td>
<td>0 c</td>
<td>3 c</td>
<td>1 ab</td>
<td>0 a</td>
<td>0 b</td>
<td>4 a</td>
<td>0 a</td>
</tr>
<tr>
<td>Own-rooted</td>
<td>5 ab</td>
<td>10 ab</td>
<td>4 a</td>
<td>1 a</td>
<td>1 ab</td>
<td>1 a</td>
<td>1 a</td>
</tr>
</tbody>
</table>

Means were derived from five replications each.

a The percentage of shoots showing secondary growth, counted in mid-June, relative to the number of shoots.

b The percentage of the number of dropped fruitlets between the middle of May and the end of July relative to the number of flowers on trees soon after flower thinning.
Discussion

We have demonstrated that ‘MKR1’ is an effective dwarfing rootstock for ‘Fuyu’ and ‘Hiratanenashi’ persimmons, achieving a higher yield efficiency without diminished fruit quality (Tetsumura et al., 2010, 2015). The objective of the present study was to test whether ‘MKR1’ could be an effective rootstock for excellent new persimmon cultivars such as ‘Taishuu’. Another objective was to characterize the growth of trees grafted onto FDR-1. Although the original FDR-1 seedling rootstock had a dwarfing effect on ‘Fuyu’ scions, the growth of trees grafted onto clonally propagated FDR-1 rootstocks was not tested.

‘Taishuu’ trees grafted on ‘MKR1’ grew to around 2 m in height after the seventh year following planting (Fig. 1) and did not continue to grow taller, just as ‘Fuyu’ and ‘Hiratanenashi’ trees on ‘MKR1’ planted in the same orchard also did not grow taller after the seventh year following field establishment (Tetsumura et al., 2015). However, ‘MKR1’-grafted trees grew so steadily that the total shoot length (Fig. 2) and TCSA (Fig. 3) increased each year during the experiment, while the differences in total shoot length and TCSA between ‘MKR1’-grafted trees and S or O-R trees increased. Canopy area and canopy volumes that were measured from 2014 also showed the same tendency to increase as TCSA (data not presented).

‘Taishuu’ trees grafted onto FDR-1 became dwarfed, as did those on ‘MKR1’ (Fig. 1); they grew to around 2 m in height. We confirmed that FDR-1 was a promising dwarfing rootstock in this study. The original “Rootstock-a” (R-a) seedling rootstock had a dwarfing effect on ‘Hiratanenashi’ trees, but the trees on rootstocks propagated by cuttings were vigorous in another location (Tetsumura et al., 2010). Hence, the field performance of trees grafted onto clonally propagated rootstocks must be confirmed before bringing these rootstocks into commercial use, even if a cultivar originally grafted onto a seedling rootstock is dwarfed and otherwise suitable.

The characteristic appearance of graft unions between ‘Taishuu’ and ‘MKR1’ was similar to that of graft unions between ‘Hiratanenashi’ and ‘MKR1’ (Tetsumura et al., 2010). FDR-1 rootstocks overgrew against ‘Taishuu’, as did the original FDR-1 tree in the orchard at the Fukuoka Agriculture and Forestry Research Center against ‘Fuyu’. Thus, FDR-1 may overgrow against any scion. However, it is unlikely that the abnormal graft union accounts for the dwarfing because some S trees with vigorous growth also showed overgrowth similar to FDR-1 trees. The abnormality in
Secondary shoot growth was not frequent in 'MKR1'- and FDR-1-grafted trees except in 2016, when 4–5% of the shoots showed secondary growth (Table 2). Thus, the trend in early fruit drop percentage, that is, a higher percentage in S and O-R trees and a lower percentage in 'MKR1'- and FDR-1-grafted trees, was not observed in 2016. Therefore, there seems to be a direct relationship between secondary shoot growth and early fruit drop, which was previously confirmed by Kajiura (1942b). However, even in 2014 and 2017, when there was no significant difference in secondary shoot growth and 1% or less of shoots showed secondary growth on any rootstock type, 'MKR1' and FDR-1 rootstocks significantly inhibited early fruit drop. One of the factors causing fruit drop in persimmons is insufficient sunlight (Kajiura, 1942a), and in 2015, the duration of sunshine in June and July was much shorter than usual. As a result, all of the trees in this study dropped more fruit than usual, although 'MKR1'- and FDR-1-grafted trees dropped a significantly lower percentages of fruit than did S and O-R trees. Basically, 'MKR1' and FDR-1 rootstocks inhibited early drop of 'Taishuu' fruit when the trees did not produce secondary growth.

All the trees grew well in each year analyzed, as shown by total shoot length (Fig. 2) and TCSA (Fig. 3), but fruit yields did not increase consistently (Table 3) across years, partially due to typhoons. Moreover, the yields from 'MKR1'- and FDR-1-grafted trees in 2014 decreased from those in 2013, in which the heavy fruit load weakened the trees. When 'MKR1'- and FDR-1-grafted trees are young and small, fruit set should be avoided to promote tree growth. In the meantime, all indices of the yield efficiency of 'MKR1'- and FDR-1-grafted trees were significantly higher than those of S and O-R trees (Table 3); 'Fuyu' and 'Hiratanenashi' trees grafted onto 'MKR1' showed the highest yield efficiency (Tetsumura et al., 2010, 2015). These high yield efficiencies were partly due to the inhibition of early fruit drop. Kurahashi (1998) investigated the relationship between the distribution ratio of photosynthate and the mean shoot length by using a large number of 'Saijo' persimmon trees showing high or low productivity, and concluded that the photosynthate was effectively distributed to fruit, not to shoots or old branches, when the mean shoot length was 12–15 cm. Thus, the mean shoot lengths of 'MKR1'- and FDR-1-grafted trees from 2010 to 2015 (14.5 cm and 12.6 cm, respectively) were thought ideal for efficient fruit production. The mean shoot length of adult 'Fuyu' trees grafted onto 'MKR1' was 14–16 cm, and that of 'Fuyu' on R-a, which has lower productivity, was 28–38 cm (Tetsumura et al., 2015).

On the whole, although fruit quality investigated in this study may have been affected by the rootstock, the trends were not consistent (Tetsumura et al., 2015). For example, average individual fruit weight of O-R trees was smaller than that of the other trees until 2016, but equalized in 2017 (data not presented). Tetsumura et al. (2010) also found that differences in fruit quality of 'Fuyu' and 'Hiratanenashi' trees on some rootstocks varied across years, even though these differences may also have been affected by the rootstock. Although the differences between the rootstocks were not large, further investigation of possible physiological fruit
disorders and number of seeds is necessary. ‘MKR1’-grafted trees sprouted, flowered, and reached full bloom 2 to 5 days earlier than S and O-R trees (Tetsumura et al., 2013a). The advancement of these growth stages likely resulted in the earlier harvesting date observed in this study. Although climatic conditions during fruit development directly affect skin coloring of persimmon fruit (Niikawa et al., 2014), which determines harvest date, the conditions affecting fruit development in the present study were the same for all trees within any year.

In conclusion, the ‘MKR1’ rootstock is a dwarfing rootstock for ‘Taishuu’ that also results in high yield efficiency and inhibition of early fruit drop, similar to results found in previous reports with ‘Fuyu’ and ‘Hiratanenashi’ (Tetsumura et al., 2010, 2013b, 2015). Therefore, ‘MKR1’ should be able to produce dwarf scions of many other cultivars. Scions grafted onto FDR-1 grew similarly to the same cultivars grafted onto ‘MKR1’ and also efficiently produced fruit. Hence, FDR-1 is also a promising dwarfing rootstock for persimmon. Recently, FDR-1 rootstock was also found to effectively inhibit physiological fruit drop of ‘Akiou’ and ‘Soshu’ persimmons (Okumura et al., 2018), which are new cultivars that show heavy early fruit drop (Chijiwa et al., 2013; Suzuki and Niikawa, 2018).

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Literature Cited


