Selection of Interstocks for Dwarfing Japanese Persimmon (Diospyros kaki Thunb.) Trees

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Effects of interstocks on the growth and fruit quality of ‘Fuyu’ Japanese persimmon (Diospyros kaki Thunb.) were investigated to select an effective dwarfing interstock of this species. The performance of four interstocks (Ac-1, Ac-2, Y clones, and a seedling of Diospyros rhombifolia) was evaluated in combination with ‘Aogaki’ (D. kaki) seedling rootstocks and ‘Fuyu’ scions over a six-year period. Ac-1 and Y interstocks moderately reduced the tree size without influencing yield efficiency (yield per unit of crown area). In contrast, Ac-2 and D. rhombifolia interstocks reduced both tree size and fruit yield (kg/tree), and many of these trees died within a few years after planting. Annual fluctuations and no consistent trends were observed in the fruit weight among control and interstock trees. These results show the possibility of dwarfing ‘Fuyu’ trees by using Ac-1 and Y as interstock.

Key Words: dwarfing interstock, fruit quality, ‘Fuyu’ persimmon.

Introduction

The Japanese persimmon (Diospyros kaki Thunb.), an important and widely cultured fruit species in Japan, is one of the tallest fruit trees, and tree vigor has thus far been controlled by the choice of an appropriate rootstock or interstock in practical culture; however, no ideal dwarfing rootstocks or interstocks have been developed for this species, and there is considerable demand for dwarfed trees that can facilitate practices in the orchard. Dwarfed trees often have advantages in terms of fruit production. For instance, a dwarfing rootstock would reduce vegetative growth and permit high-density planting, which would in turn produce good yields. In apple trees (Malus spp.), the rootstock influences the fruit size (Bessho et al., 1986), maturity, and storability (Autio, 1991). Even though some persimmons have been selected as dwarfing rootstock candidates (Kagami, 1999; Kimura et al., 1985; Wada et al., 2004), their propagation by means of cuttings is still difficult due to their poor rooting ability. In studies of apple trees, dwarfing rootstocks have been used as interstock (Webster, 1994) and were found to reduce the growth of the scion; however, there have been no reports of the use of dwarfing rootstock candidates as interstock in the production of Japanese persimmon. The dwarfing effect of the interstock has already been reported in ‘Jiro’ persimmon (Manago et al., 2000); however, it is possible that the observed growth had been affected by pruning or crop load.

Therefore, the objectives of this study were to elucidate the dwarfing potential of interstock trees of Japanese persimmon using unpruned and non-bearing trees, and to evaluate the fruit quality of these trees by conventional cultivation.

Materials and Methods

Plant materials

For the interstock, three dwarfing rootstock candidates (Ac-1, Ac-2, and Y) and seedlings of D. rhombifolia were used. The origin of each interstock candidate is shown in Table 1. Ac-1 and Ac-2 originated from Aichi Prefecture as dwarfing rootstocks of ‘Fuyu’ persimmon (Kimura et al., 1985). Y was also selected from...
Yamanashi Prefecture, Japan as a dwarfing rootstock candidate of ‘Nishimurawase’ persimmon (Yamada et al., 1988). The shoot tips of the rootstock candidates were excised, sterilized, and cultured (Fukui et al., 1989), and then rooted in vitro (Fukui et al., 1988). Rooted plants were then transferred to potting soil. The seeds of *D. rhombifolia* were sown in vermiculite in 1994, and the seedlings were transplanted into the soil.

The ‘Fuyu’ scions of Japanese persimmon grafted onto different interstocks were prepared as follows. One-year-old rootstock candidates and seedlings of *D. rhombifolia* were grafted onto one-year-old ‘Aogaki’ (*D. kaki* Thunb.) seedlings as interstocks in 1995 and grown for one year. In 1996, interstocks were cut to a length of 10 cm, and ‘Fuyu’ scions were grafted onto the interstocks. The control trees were ‘Fuyu’ scions grafted onto ‘Aogaki’ seedlings. All grafted trees were planted in 1997 in the orchard at the Grape and Persimmon Research Station, National Institute of Fruit Tree Science. One half of the control and interstock trees were pruned and permitted to bear fruit. The other half were not pruned, and all the florets were removed to eliminate the crop load, which would affect tree growth. The form of pruned trees was a central leader type and the number of primary scaffold branches was four. The experimental design was a randomized block; the treatments and replications are shown in Table 1. Within-row spacing was 3 m, and between-row spacing was 6 m. The bearing trees were pruned from March 1999 and their height was maintained below 3.5 m by pruning. The trees started to bear fruit in 2000. One to two florets were left on each shoot in mid-May, and the others were thinned. The leaf-to-fruit ratio was adjusted to 25 after fruit thinning was completed in mid-June. In 2001, all florets on Ac-2 and *D. rhombifolia* interstock trees were thinned from the trees because these trees lacked sufficient vigor to sustain fruit production. Unpruned trees were allowed to grow naturally throughout the study period. Watering, fertilization, and disease and pest control were similar for pruned and unpruned trees.

**Assessment of the scion growth on different interstocks**

The growth of the interstock and control trees was assessed in September, 1997 and in December, 1997–2005. The tree height, total shoot length, and number of shoots were determined. For unpruned trees, data were collected from 1997 to 2003. The canopy diameters of unpruned control trees exceeded 3 m in 2003; therefore, their growth was limited as a result of crowding. Therefore, unpruned trees were cut down in the spring of 2004. The trunk diameter of the pruned trees was measured in 2005 at 10 cm above the grafted union with the scion to calculate the trunk cross-sectional area (TCA). The canopy diameters of the pruned trees were determined by the average of two different diameters made by two diagonal primary scaffold branches from 2001 to 2005 to calculate the canopy area of the tree.

**Assessment of fruit yield and quality**

Fruit were harvested in mid or late November from 2000 to 2005. At each harvest, the total fruit yield of each tree was determined. In addition, soluble solid contents (SSC) and fruit weight were determined for 10 to 15 fruit from each tree from 2000 to 2004. SSC was measured with a digital refractometer (PR-100, Atago Co., Tokyo, Japan). The peel color (a* and b* value) was determined in 2000, 2001, and 2004 using two different points in the equatorial zone using a handheld color meter (MR-3000, Nippon Denshoku Co., Tokyo, Japan). These values were determined immediately after the fruit were harvested. The mean values for the fruit quality parameters were separated using the Tukey-Kramer HSD test (*P* = 0.05) provided by the JMP software (SAS Institute, Inc., Cary, NC, USA).

**Results**

**Growth characteristics**

The mean height of unpruned interstock trees was lower than that of the control trees from September 1997 to 2003 (Fig. 1). The height of pruned Ac-1 and Y interstock trees was slightly lower than that of control trees. In both pruned and unpruned trees, the height of Ac-2 and *D. rhombifolia* interstock trees was less than that of other trees after 2002, and the height of Ac-1 and Y interstock trees was almost the same. The total shoot length of unpruned control trees was longer than that of interstock trees after transplanting (Fig. 2). Both unpruned and pruned trees of Ac-2 and *D. rhombifolia* interstock trees had obviously shorter total shoot length than trees with other treatments after 2001. In pruned control trees, the total shoot length was longer than that in other interstock trees, but it gradually decreased after 2003. From 1999 to 2003, unpruned control trees produced a larger number of shoots than interstock trees.

| Table 1. Treatments and numbers of replications of control and interstock trees of ‘Fuyu’ persimmon. |
|---------------------------------------------------------------|
| **Interstocks** | **Origin of the interstock** | **Numbers of unpruned trees** | **Numbers of pruned trees** |
| Control         | —                             | 7                              | 6                              |
| Ac-1            | Aichi pref.                  | 7                              | 10                             |
| Ac-2            | Aichi pref.                  | 8                              | 7                              |
| Y               | Yamanashi pref.              | 8                              | 7                              |
| *D. rhombifolia*| Seedlings of *D. rhombifolia*| 6                              | 6                              |
Pruned control trees produced a larger number of shoots from 2000 to 2003 than interstock trees, but the number was reduced in 2004 to the same level as that for Ac-1 and Y interstock trees. The survival rate of both pruned and unpruned trees was higher in the control, Ac-1, and Y interstock trees, whereas Ac-2 and D. rhombifolia interstock trees had lower survival rates (Table 2). Typical longitudinal sections of control and interstock trees 6 years after planting are shown in Figure 4. Graft unions among the scion, interstocks, and rootstocks were visibly successful in all treatments. The control and Ac-1 and Ac-2 interstock trees showed overgrowth of the rootstock or interstock, whereas Y and D. rhombifolia interstock trees showed that of the scion.

**Fruit yield**

The cumulative yield, TCA, and cumulative yield efficiency (yield per unit of TCA) are shown in Table 2. The cumulative yield of Ac-2 and D. rhombifolia interstock trees was markedly lower than that of control trees. The cumulative yield efficiency was slightly lower in Ac-1, Ac-2, and Y and markedly lower in D. rhombifolia interstock trees than in control trees. The fruit weights of the trees from 2000 to 2005 are shown in Table 3. The fruit yield of control trees was higher than that of interstock trees every year. Ac-1 and Y interstock trees had similar fruit production, and their fruit yield was higher than that of Ac-2 and D. rhombifolia interstock trees. The fruit yields per unit of canopy area (kg·m$^{-2}$) are shown in Table 4. In 2003 and 2004, there was no difference in fruit yield per unit canopy area between the control and Ac-1, Ac-2, and Y interstock trees, but the fruit yield was considerably lower in D. rhombifolia interstock trees.

**Fruit quality**

The fruit quality of the control and interstock trees is shown in Table 5. The fruit weight differed significantly between the control and some of the interstock trees in most years, but these were annual fluctuations, and no consistent interstock effects were observed. SSC was significantly higher in Ac-2 interstock trees than in the other trees in 2003. In 2004, Ac-2 and D. rhombifolia interstock trees showed significantly higher SSC than the other trees. Ac-2 interstock trees showed significantly higher a* and lower b* values than the other trees in 2003 and 2004, but no consistent trend was observed in...
Discussion

The use of dwarfing rootstocks or interstocks can effectively control the growth of fruit trees. For example, apple dwarfing rootstocks had a dwarfing effect on the scion cultivar when used both as rootstocks and interstock (Carlson and Oh, 1975; Kume et al., 1985; Webster, 1994); the longer the interstock, the greater the effect on the tree growth. This is because the interstock can limit the nutrient and water supply to the scion, thereby controlling its growth.

Table 2. Effects of interstocks on cumulative fruit yield, trunk cross-sectional area (TCA), cumulative yield efficiency (yield per unit of TCA), and the survival rates of control and interstock trees of ‘Fuyu’ persimmon.

| Interstocks   | Cumulative yield (kg) from 2000–2005 | TCA (2005) (cm²) | Cumulative yield efficiency (kg·cm⁻²) | Survival rates of the trees (%) | Unpruned | Pruned |
|---------------|--------------------------------------|------------------|--------------------------------------|--------------------------------|----------|--------|
| Control       | 185.6                                | 87.9             | 2.1                                  | 86                             | 100      |        |
| Ac-1          | 129.1                                | 66.6             | 1.9                                  | 86                             | 100      |        |
| Ac-2          | 52.9*                                | 30.2             | 1.8                                  | 50                             | 71       |        |
| Y             | 120.1                                | 66.8             | 1.8                                  | 88                             | 100      |        |
| D. rhombifolia| 46.2*                                | 48.7             | 0.9                                  | 17                             | 33       |        |

* The survival rates of the trees were determined in 2003 (unpruned) and 2005 (pruned).

Table 3. Mean annual fruit yield of control and interstock trees of ‘Fuyu’ persimmon from 2000 to 2005.

| Interstocks     | Fruit yield (kg/tree) |       |       |       |       |       | Average from 2000 to 2005 |
|-----------------|-----------------------|-------|-------|-------|-------|-------|--------------------------|
|                 | 2000      | 2001     | 2002     | 2003     | 2004     | 2005     |                          |
| Control         | 19.0±11.1* | 18.9±2.0 | 30.7±6.3 | 48.8±5.1 | 38.1±5.6 | 30.2±6.3 | 31.0                     |
| Ac-1            | 7.7±2.8   | 14.4±1.6 | 17.8±2.9 | 36.2±3.7 | 29.5±3.9 | 23.5±2.0 | 21.5                     |
| Ac-2            | 8.1       | —        | 6.8±1.2  | 19.6±2.2 | 12.7±0.9 | 5.8±0.8  | 10.6                     |
| Y               | 9.2±4.7   | 10.0±2.2 | 20.5±3.0 | 35.0±3.0 | 26.7±1.7 | 18.7±3.7 | 20.0                     |
| D. rhombifolia  | 5.4       | —        | 7.0      | 13.9     | 10.3     | 9.6      | 9.2                      |

* Mean ± SE.
trees exhibited a reduction in tree height, total shoot length, and number of shoots. Even though the Ac-2 interstock and seedlings of *D. rhombifolia* interstock produced the most conspicuous dwarfing effect, 6 of the 15 (40%) Ac-2 interstock trees and 9 of the 12 (75%) *D. rhombifolia* interstock trees died within a few years after planting. The trunks of Ac-2 interstock trees were frequently rolled and exhibited other symptoms of stress (such as yellowing), whereas the leaves of other interstock or control trees retained their normal appearance. As water status has an important effect on photosynthesis in the Japanese persimmon (Koshita et al., 2006), this increased water stress is probably responsible for the observed dwarfing of *D. rhombifolia* interstock trees.

Yellowing and rolling of the leaves and inhibition of growth can also be symptoms of graft incompatibility (Cummins and Aldwinkle, 1983). In our study, severe graft incompatibility between *D. rhombifolia* and *D. kaki* and rolling of scion leaves were observed (data not shown). Yamada et al. (1997) also suggested the presence of graft incompatibility between the ‘Fuyu’ persimmon and *D. rhombifolia* because ‘Fuyu’ scions grafted onto *D. rhombifolia* died within a few years of planting. Our results suggest that Ac-2 and *D. rhombifolia* interstock

### Table 4. Mean annual fruit yield per unit of canopy area of control and interstock trees of ‘Fuyu’ persimmon.

| Interstocks | 2001 | 2002 | 2003 | 2004 | 2005 | Average from 2000 to 2005 |
|-------------|------|------|------|------|------|--------------------------|
| Control     | 1.99±0.26 | 2.24±0.41 | 3.27±0.38 | 1.90±0.18 | 1.41±0.22 | 2.16 |
| Ac-1        | 1.92±0.16 | 1.75±0.21 | 3.26±0.25 | 2.14±0.17 | 1.65±0.20 | 2.14 |
| Ac-2        | —     | 1.36±0.32 | 3.11±0.41 | 1.94±0.21 | 0.86±0.12 | 1.82 |
| Y           | 1.30±0.26 | 2.27±0.16 | 3.02±0.16 | 2.02±0.17 | 1.02±0.11 | 1.93 |
| *D. rhombifolia* | —     | 1.61 | 2.55 | 1.51 | 1.20 | 1.71 |

* Mean ± SE.

### Table 5. Average fruit weight, soluble solids content and peel color (a*, b*) of control and interstock trees of ‘Fuyu’ persimmon.

| Interstocks | 2000 | 2001 | 2002 | 2003 | 2004 | Average from 2000 to 2004 | Soluble solids content (SSC) (%) | Average from 2000 to 2004 | a* | Average from 2000 to 2004 | b* | Average from 2000 to 2004 |
|-------------|------|------|------|------|------|--------------------------|-------------------------------|--------------------------|------|--------------------------|------|--------------------------|
| Control     | 292 a | 328 a | 309 a | 375 ab | 322 b | 326 | 16.1 a | 17.5 a | 18.0 a | 16.5 | 16.6 | 16.7 | 16.3 |
| Ac-1        | 271 b | 303 b | 306 b | 368 bc | 340 a | 318 | 15.6 b | 17.1 a | 17.5 b | 16.6 | 16.6 | 16.3 | 16.3 |
| Ac-2        | 283 ab | — | 301 a | 389 a | 330 ab | 326 | 15.4 b | — | 17.4 | 17.7 | 16.3 | 16.6 | 16.7 |
| Y           | 263 b | 321 a | 308 a | 358 c | 322 b | 314 | 16.0 ab | 16.9 b | 17.4 b | 16.4 | 16.4 | 16.7 | 16.3 |
| *D. rhombifolia* | 307 a | — | 309 a | 362 bc | 299 c | 319 | 15.6 ab | — | 16.8 b | 16.8 | 16.4 a | 16.4 a | 16.4 |

* Means within a column followed by different letters differ significantly at P<0.05 by Tukey-Kramer HSD test.
trees are not likely to be useful in practical culture, even though they effectively reduced scion growth.

The rootstocks of grafted fruit trees often have a strong influence on fruit quality (Autio, 1991; Bessho et al., 1986; Webster and Wertheim, 1993); therefore, to select a practical dwarfing interstock, assessment of the characteristics of the fruit produced by interstock trees is required. Our result revealed no substantial differences in fruit weight or SSC among the control, and Ac-1 and Y interstock trees. Similarly, Manago et al. (2000) reported that the fruit of ‘Maekawajiro’ persimmon grafted onto ‘Shidare-kaki’ and ‘Nishimurawase’ interstocks showed no differences from the control in terms of harvest time, fruit size, and fruit quality; however, significantly higher SSC and a* value were observed in fruits from Ac-2 interstock trees in 2003 and 2004 (Table 5). This coloration might have resulted from weakening of the trees caused by E. betagenesis damage. A ringing treatment is reported to reduce vegetative growth (Fumuro, 1997). This treatment has been reported to slightly increase the coloration and Brix of the fruit (Fujimoto and Maesaka, 1998) and, thus, damage to the trunk by E. betagenesis seems to have a similar effect as ringing the trunk.

The fruit yield per unit of canopy area and the yield efficiency are important factors in determining whether a rootstock or an interstock will be useful in practical cultivation. Our results (Tables 3 and 4) demonstrate that the D. rhombifolia interstock is unsuitable for practical cultivation because of its extremely low yield, both in absolute terms and per unit of canopy area; however, Ac-1 and Y interstocks produced fruit yields per unit of canopy area similar to those observed in control trees (Table 4).

We concluded that it would be practical to use dwarfed ‘Fuyu’ trees with Ac-1 and Y interstocks because scion growth was sufficiently decreased without drastically influencing the yield or fruit quality.

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