Comparison of growth, yield, and fruit quality of own-rooted and grafted 'Spirit of '76' mango trees grown in pots©

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Abstract

To assess the practicality of using pots to grow mango cultivar 'Spirit of '76' (*Mangifera indica* L.) trees using their own roots propagated by air layering and trees grafted onto Taiwanese native-strain rootstock were planted in pots containing approximately 25 L of soil. The growth, yield, and fruit quality of the trees were monitored and measured for 7 years after planting. Trunk diameter was significantly smaller in the own-rooted compared with the grafted trees for the first 5 years, but there was no difference between the two after 6 years. The trunk diameter of the own-rooted trees was also significantly greater than the scion diameter of the grafted trees after 3 years. The total green-branch length was at least as long in the own-rooted trees as it was in the grafted trees after 3 years, and the leaf number tree^{-1} was greater in own-rooted than in grafted trees after 4 years. There were no significant differences in height between the two tree types. Fresh and dry weights were significantly greater for leaves, green branches, thick branches, above-ground parts of trees, fine roots, and whole trees, but significantly lower for the trunks of own-rooted trees compared with those of grafted trees. However, there were no significant differences in the weights of thick roots and under-ground parts of trees between the two tree types. The dry matter top/root biomass (T/R) ratio was significantly higher (47%) in own-rooted trees, but the fresh weight T/R ratio did not differ significantly between the two tree types. In addition, there were no significant differences in yield tree^{-1}, fruit numbers tree^{-1}, or fruit quality between own-rooted and grafted trees. Based on these results, it is suggested that own-rooted mango trees may be grown in pots because their growth characteristics are similar to, or perhaps even better than, those of grafted trees, and yield and fruit quality do not differ between the two.

INTRODUCTION

Because mango (*Mangifera indica* L.) trees are generally vigorous, fruit production is often stabilized by laying underground sheets to restrict root elongation (Yonemoto, 2005) or by growing trees in pots. Pot culture can produce good yields of high-quality fruits by optimizing and automating the supply of nutrients and water; the approach is gradually becoming more popular with farmers. Trees planted in pots also tend to bear fruits 40-60 cm higher on the tree compared with trees planted in the ground, depending on the height of the pot. In addition, because mango seedlings are grafted at a height of approximately 25-30 cm above the ground to improve grafting success rate, the rootstock of grafted seedlings tends to become longer, and the fruit positions even higher.

In Japan, the flower cluster and fruits are hung at the top of the crown to improve their color because fruit with good color has a higher commercial value. Often trees are covered with a fruit net before harvesting to ripen fruits on the trees; this is more practical if fruits are not located too high up. One effective method of lowering the fruit position is to utilize own-rooted trees rather than grafting.

By using own-rooted trees, it is possible to position the scaffold branch closer to the ground. In addition, by excluding vigorous rootstocks it may be possible to suppress tree vigor. Own-rooted nursery trees must be propagated by vegetative methods that include

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using cuttings or air layering. However, propagating mango trees using cuttings is extremely difficult. Only young seedlings can be rooted (Mukherjee et al., 1967; Yamashita et al., 2006), and rooting from older seedlings or cuttings from cultivars in the adult phase is nearly impossible.

Fumuro (2011) investigated vegetative propagation by air layering 'Irwin' and 'Aikou' mangoes and discovered that own-rooted nursery trees can be propagated by spraying a 2000-ppm 1-naphthaleneacetic acid solution on the girdled part of a branch. The propagation efficiency of air layering is lower than that of cuttings, but it is an effective method for investigating the growth characteristics, yield, and fruit quality of own-rooted trees. In addition, the use of pots to culture mango trees was introduced relatively recently and little research has been done (Fumuro, et al., 2009; Fumuro, 2011; Yonemoto et al., 2007); therefore, the effect of using pots to grow mangoes on tree growth, yield, and fruit quality over a period of years has not been established.

To assess the practicality of using pots to grow 'Spirit of '76' mango (*M. indica* L.) own-rooted trees propagated by air layering and trees grafted onto Taiwanese native strain rootstock were planted in pots, and tree growth, yield, and fruit quality were monitored and measured over a 7-year period.

MATERIALS AND METHODS

Planting and culture methods

1. Production of own-rooted and grafted nursery trees.

'Spirit of '76' trees planted in a greenhouse (width: 9 m, length: 54 m) at Kindai University experimental farm (Yuasa, Wakayama Prefecture, Japan) were used. Air layer propagation was performed on August 8, 2008 according to the method described by Fumuro (2011). On October 9, 2008, rooted branches (Figure 1) were removed and planted in small pots (diameter: 13.5 cm, height: 11 cm). On June 20, 2009, the own-rooted nursery trees were transferred to 25-L pots made of a non-woven fabric (diameter: 32 cm, height: 35 cm) and filled with a mixture of mountain soil, perlite, compost, and vermiculite (volume ratio: 1:1:1:1).

Figure 1. Rooting of air-layered mango cultivar 'Spirit of '76' (October 9, 2008).

To generate the grafted nursery trees, 'Aikou' scions were grafted onto 2-year-old rootstocks (Taiwanese native strain seedlings) on June 9, 2009 and planted in 9-L polythene pots (diameter: 24 cm, height: 24 cm). On October 22, 2009, they were transferred to pots made of non-woven fabric, as described above. Both the own-rooted trees and the rootstocks of the grafted ones were 2 years old; five trees of each type were used in this study.

2. Pot spacing and cultivation management.

Pots were arranged 1.4 m apart in the greenhouse in rows 1.5 m apart. In November

2012, all pots were transferred to a smaller plastic house (width: 6 m, length: 18 m) with the same space between pots, and growth was continued. The greenhouse was heated from early December to ensure a minimum temperature of 6°C. This minimum temperature was gradually increased from mid-February, and then maintained at 18-20°C from the middle of March until late April during the flowering period. A fan was used for ventilation to ensure the internal air temperature remained below 30°C until and below 35°C after the flowering period.

Approximately 3 L of tap water was dispensed for irrigation using an automatic timer once every 2 d in December and January, once daily from February until April, twice daily in May and June, 4× daily in July and August, 2-3× daily in September and October, and once daily in November.

Approximately 40 g of slow-release fertilizer ($N:P_2O_5:K$ = 10:10:10%) was supplied to each tree in February, March, April, May, June, July, September, and November. Approximately 2 L pot^{-1} of liquid fertilizer ($N:P_2O_5:K:Mg:B:Mn$ = 2:5:4:3:5:1%) diluted 1000-fold was applied in March. Assuming 476 pots 1000 m^{-2}, the annual quantities of nitrogen, phosphoric acid, and potassium supplied were approximately 15.3 kg each.

Pruning began when harvest was almost complete and ended in late September. As part of the training method, 2-3 scaffold branches tree^{-1} and an appropriate number of bearing shoots were set within a crown diameter of 1.3 to 1.4 m. In 2015, no pruning was carried out due to the dissecting survey taking place in October. Disease and pest control were performed according to conventional procedures.

3. Fruit management and harvesting.

The flowering period of the own-rooted and grafted trees was almost identical, and full bloom occurred toward the end of April. The harvesting periods were August 15 to September 25, 2011, August 12 to September 30, 2012 (Figure 2), and August 23 to September 27, 2013. The trees were covered with a bag-shaped net before harvesting, and the fruits were allowed to drop into the net. In 2014 and 2015, pollination by insects (bees) was not very successful, and the fruit yield was poor.

Figure 2. The own-rooted (left) and grafted (right) mango cultivar 'Spirit of '76' trees when fruit reached maturity in 2012.

Measurements

1. Tree growth.

The trunk diameters, leaf numbers tree^{-1}, and green-branch lengths tree^{-1} were all measured in late December every year from 2009 until 2014, and also in October 2015 (before the dissecting survey).

The trunk diameters were measured using calipers. The measurements were made at 10 cm above the ground in grafted trees and approximately 3 cm above the ground in the own-rooted trees because the scaffold branches of the own-rooted trees were close to the ground. In the grafted trees, scion diameters were also measured 3 cm above the graft. The lengths of green branches with less than 10% lignification were measured, and the total green-branch length was calculated. Tree heights were measured in October 2015 at the time of the dissecting survey.

2. Fresh and dry weights of each organ.

The dissecting survey was performed between October 7 and 15, 2015 (Figures 3 and 4). The trees were 8 years old at the time of dissection. The different parts of the tree were categorized as follows: leaf, green branch, trunk, thick root (≥1 mm in diameter), and fine root (<1 mm in diameter). Because the scions of the grafted trees were 20-30 cm above the ground, these trunks included the stems of the rootstock seedlings. After the fresh weight of each organ sample was measured, it was dried, and the dry matter percentage was determined. The total dry weight of each organ was calculated by multiplying the dry matter percentage by the total fresh weight of each organ.

Figure 3. The own-rooted (left) and grafted (right) mango cultivar 'Spirit of '76' trees before dissection in 2015.

Figure 4. The under-ground part of own-rooted (left) and grafted (right) mango cultivar 'Spirit of '76' trees after dissection in 2015.

Forty leaves were randomly sampled from each tree, and leaf area was measured using an automatic leaf area meter (AAM-9; Hayashi Denko Co Ltd., Tokyo, Japan). The average leaf area tree^{-1} was calculated by multiplying the average leaf area and the total number of leaves tree^{-1}.

As part of the dissecting survey, tree trunks were cut using a saw at the position used to measure their diameters. The contours were copied onto paper and the area of each trunk's cross-section was measured using an automatic leaf area meter.

3. Yield and fruit quality.

After weighing, fruit quality data on 10 fruits harvested between late August and early September in 2011, 2012, and 2013 were recorded. In 2014 and 2015, no yield measurements were made due to the very small number of fruits produced in these years.

Peel color (Hunter's L-, a-, and b-values) was measured using a color-difference meter (CR-400; Konica-Minolta, Tokyo, Japan) positioned centrally on the side of each fruit. Flesh firmness was determined using a Magness-Taylor-type fruit penetrometer with an 11.3-mm-diameter plunger (FT011; Effegi, Alfonsine, Italy) by removing a piece of peel 3 cm in diameter with a sharp knife. The maximum force generated when the plunger penetrated 7 mm into the flesh through the cut surface was recorded. Measurements were performed on both sides of the fruit, and the average value was calculated. In addition, flesh was collected from a central point on both sides of the fruit. Juice from the fruit was squeezed and filtered through gauze, and total soluble solids (TSS) together with titratable acidity were determined. TSS was determined using a refractometer (PAL-1; Atago Co. Ltd., Tokyo, Japan), and the titratable acid was determined by the titration method with 0.1 N NaOH to a phenolphthalein endpoint and converted into citric acid content.

Statistical analysis

The data obtained in this study were subjected to analysis of variance (ANOVA) followed by a Tukey-Kramer's multiple range test and *t*-tests.

RESULTS

Tree growth

The trunk diameters increased with age in both types of tree (Figure 5). The diameter of own-rooted trees was significantly smaller than that of grafted trees for the first 5 years, but no significant difference was observed between the two after 6 years. The trunk diameter of the own-rooted trees was significantly greater than the scion diameter of the grafted trees after 3 years. The trunk cross-section area was approximately 50 cm^2 in both types of tree (Table 1).

Table 1. Comparison of total leaf areas per tree, trunk cross-sectional areas, and heights of own-rooted and grafted 8-year-old mango cultivar 'Spirit of '76' trees.

Propagation method	Total leaf area (m^2 tree^{-1})	Trunk cross-sectional area (cm^2)	Tree height (m)
Own-rooted	8.98±1.18[1]	46.5±6.0	2.22±0.17
Grafted	7.15±1.14	56.1±9.6	2.04±0.12
Significance[2]	*	NS	NS

[1]Average ± standard deviation.

[2]NS, *; non-significance and significance at *P*=0.05, respectively.

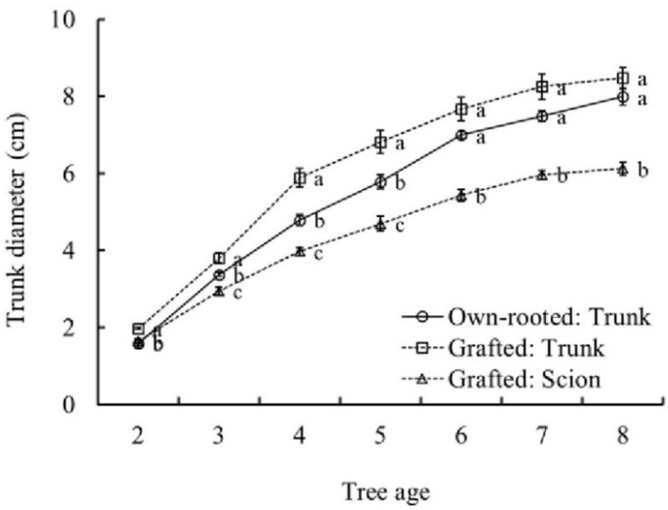

Figure 5. Annual changes in trunk diameters of own-rooted and grafted mango cultivar 'Spirit of '76' trees grown in pots. Vertical bars represent ± standard error (n=5). Values followed by the same letter indicate no significant difference (P<0.05) according to Tukey-Kramer's multiple-range test.

In 4-, 6-, and 8-year old trees, the total green-branch length in own-rooted trees was greater than that in grafted trees (Figure 6). The total green-branch length in 8-year old own-rooted trees was 21 m, approximately 45% higher than that in grafted trees.

The leaf number tree^{-1} of the own-rooted trees was greater than the number in grafted trees after 4 years (Figure 7). In 8-year old own-rooted trees, this included approximately 1750 leaves, 38% more than in grafted trees of the same age. The leaf area tree^{-1} of 8-year old own-rooted trees was significantly higher than that of grafted trees (Table 1). There was no significant difference in height between the two tree types.

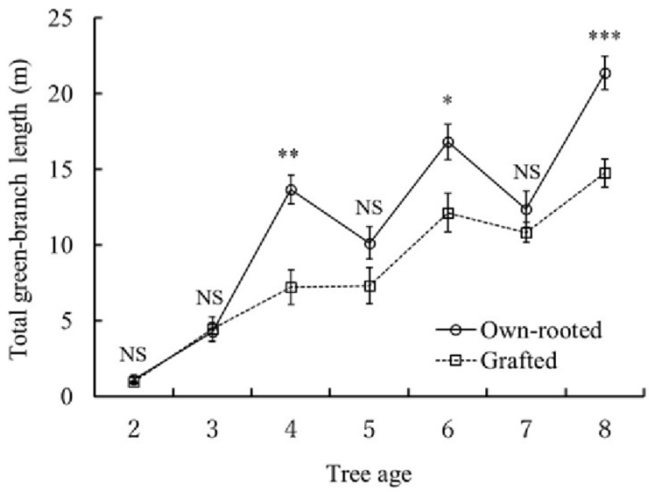

Figure 6. Annual changes in total green-branch length tree^{-1} of own-rooted and grafted mango cultivar 'Spirit of '76' trees grown in pots. Vertical bars represent ± standard error (n=5). NS, *, **, and *** indicate not significant and significant at P=0.05, 0.01, and 0.001, respectively, using t-tests.

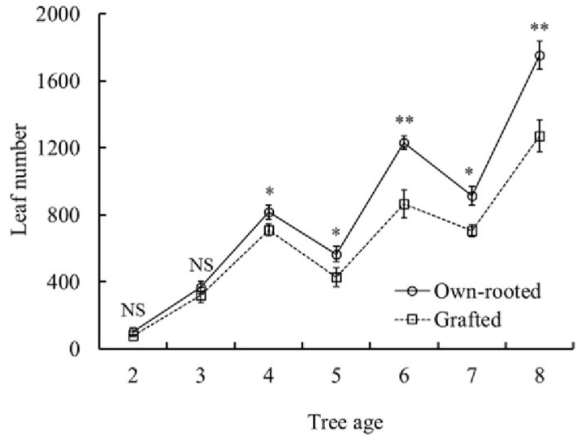

Figure 7. Annual changes in leaf number tree^{-1} of own-rooted and grafted mango cultivar 'Spirit of '76' trees grown in pots. Vertical bars represent ± standard error (n=5). NS, *, and ** indicate not significant and significant at P=0.05, and 0.01, respectively, using t-tests.

Fresh and dry weights of each organ

Fresh and dry weights were significantly greater for leaves, green branches, thick branches, above-ground parts of trees, fine roots, and whole trees, but significantly lower for the trunks of own-rooted trees compared with those of grafted trees (Table 2). However, there were no significant differences in the weights of thick roots and under-ground parts of trees between the two tree types. The fresh and dry weights of whole own-rooted trees were approximately 12 and 5 kg, respectively; this is approximately 22 and 33% greater than those of grafted trees, respectively.

The top/root weight (T/R) ratio is calculated as the weight of the above-ground part minus the leaves, divided by the weight of the under-ground part. The dry matter T/R ratio was 47% higher in own-rooted trees compared with grafted ones, but fresh weight T/R ratios did not differ significantly between the two tree types.

Yield and fruit quality

The yield tree^{-1} was approximately 1.4 kg in 4-year-old, 2.5 kg in 5-year-old, and 3.3 kg in 6-year-old trees, with no significant differences between the two tree types (Table 3). There were also no significant differences between the two types of tree in the number of fruits tree^{-1} or the average fruit weight. In addition, there were no significant differences in peel color, soluble solid contents, or organic acid contents (Table 3). In both tree types, the soluble solid contents were 19-21%, and the organic acid contents were 0.20-0.32, with only small annual variations.

DISCUSSION

The annual changes in trunk diameters, total green-branch lengths tree^{-1}, leaf numbers tree^{-1}, and the results of the dissecting survey of 8-year old trees all suggest that the growth characteristics of own-rooted 'Spirit of '76' trees are similar to, or perhaps even better than, those of grafted trees. In addition, compared with own-rooted 'Aikou' trees grown in pots containing the same soil volumes (Fumuro, 2016), both of our 'Spirit of '76' tree types were more vigorous. The Taiwanese native strain used as rootstock in this study is vigorous (Yonemoto, 2008), and the vigor of trees grafted onto Taiwanese native strain seedlings tends to be enhanced. Therefore, the vigorous growth characteristics of the grafted trees may result from the influence of the rootstock. The 'Spirit of '76' cultivar used to generate the scions is also vigorous (Ishihata, 2000), and the additional influence of the rootstock could enhance the growth of grafted trees synergistically. However, the vigorous growth of the own-rooted trees was thought to result from the growth characteristics of the scion cultivar.

Table 2. Comparison of fresh and dry weights of own-rooted and grafted 8-year-old mango cultivar 'Spirit of '76' trees.

	Propagation method	Above-ground part (kg)					Under-ground part (kg)			Whole tree (kg)	T-R ratio
		Leaf	Green branch[1]	Thick branch	Trunk	Total	Thick root[2]	Fine root[3]	Total		
Fresh weight	Own-rooted	2.72	0.89	4.84	0.44	8.90	1.93	1.32	3.25	12.15	1.90
	Grafted	1.97	0.68	2.47	1.69	6.81	2.54	0.59	3.13	9.94	1.62
	Significance	**[4]	*	***	***	*	NS	***	NS	*	NS
Dry weight	Own-rooted	1.23	0.31	2.09	0.18	3.80	0.71	0.38	1.09	4.89	2.36
	Grafted	0.90	0.23	0.81	0.62	2.56	0.95	0.16	1.11	3.67	1.61
	Significance	**	**	***	**	**	NS	***	NS	**	*

[1]Branches which ratio of lignification was less than 10%.
[2]Roots of 1 mm or more in diameter, including the root crown.
[3]Roots less than 1 mm in diameter.
[4]NS, *, **, ***; non-significance at P = 0.05, significance at P = 0.05, 0.01 or 0.001 by t-test, respectively.

Table 3. Comparison of yields and fruit qualities of own-rooted and grafted 8-year-old mango cultivar 'Spirit of '76' trees.

Tree age	Propagation method	Yield (kg tree^{-1})	Fruit number (no. tree^{-1})	Fruit weight (g)	Peel color			Flesh firmness (N cm^{-2})	Total soluble solids (%)	Organic acid (%)
					L-value	a-value	b-value			
4	Own-rooted	1.26	2.5	504	46.5	25.3	17.0	11.8	21.1	0.32
	Grafted	1.59	3.3	482	46.9	19.8	18.1	10.2	20.1	0.31
	Significance	NS[1]	NS	NS	NS	NS	NS	NS	NS	NS
5	Own-rooted	2.80	4.6	608.0	47.3	17.3	17.4	7.3	20.0	0.22
	Grafted	2.25	3.6	625.5	45.9	18.5	18.7	6.8	20.5	0.20
	Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS
6	Own-rooted	3.45	6.0	574.6	45.7	19.7	18.3	7.4	19.6	0.20
	Grafted	3.14	5.4	582.2	44.0	22.7	17.7	6.4	18.9	0.27
	Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]NS; non-significance at P=0.05 by t-test.

In this study, pollination by insects was not particularly successful, and fruit production was poor in 2014 and 2015. A strong relationship has been reported between tree growth and fruit load (Fumuro et al., 1999; Fukuda et al., 1991), and photosynthetic products may have been diverted from fruits to other organs. In a previous study, Tamashiro et al. (2003) reported that mango root growth is significantly suppressed by fruit load and that roots grow more vigorously, as does the rest of the tree, after harvesting.

In this study, the growth of the roots and the rest of the tree may have been more vigorous due to the low fruit load. Oya et al. (2015) compared 8-year-old own-rooted 'Kosui' Japanese pear trees propagated by cuttings with grafted ones; they detected no difference in growth (measured as dry matter weight) between the two. Ram (1993) reported that the growth of own-rooted mango trees propagated by air layering was slower than that of grafted trees; however, in our study, the growth of the own-rooted trees was similar to, or perhaps better than, that of grafted trees.

In the grafted trees, a relatively long main root gradually enlarged and developed into a thick root crown, whereas in the own-rooted trees, the branch rooted by air layering became the root crown, and some of the first roots to extend from this gradually developed into thick roots.

In the own-rooted trees, the root crown was short. However, some lateral roots developed, and the thick roots and root crown in the own-rooted trees did not differ significantly from those in the grafted trees. However, the fresh and dry weights of fine roots in the own-rooted trees were approximately 2.2- and 2.4-fold greater than those of grafted trees, respectively. Therefore, the own-rooted trees might be more capable of producing new roots than the Taiwanese native strain, resulting in the greater fine root weight of the own-rooted trees.

The dry weight of above-ground part in own-rooted trees was significantly greater than that in grafted trees, although the dry weight of under-ground part did not differ significantly between the two. Therefore, the dry matter T/R ratio was significantly higher in own-rooted compared with grafted trees. The T/R ratio of grafted apple trees, which was approximately 2.2, reportedly did not differ among different rootstock varieties (Fukuda and Takishita, 1993), similar to the case with the own-rooted mango trees in this study.

The yield tree^{-1} increased with tree age from 2.3 to 3.5 kg pot^{-1} until 2013, but was not particularly high overall. The yield calculated for 6-year-old trees, assuming 460 pots 1000 m^{-2}, was estimated at approximately 1.6 t in the own-rooted trees and 1.4 t in the grafted ones. When the target yield 1000 m^{-2} was set to 2.5 t, both types of tree produced approximately half the required total. Therefore, to ensure adequate yields, it is important that insect pollination is well managed. The fruit quality analyses demonstrated that soluble solid contents, organic acid contents, and flesh firmness did not differ significantly between the two tree types, and these parameters achieved the required standards for this cultivar.

Few studies have investigated the cultivation of own-rooted mango trees over many years, and their economic life has not been determined. Farmers often use 60- to 80-L pots, whereas in this study, we used 25-L pots, and the smaller soil capacity may well shorten the economic life of the trees. Over the 7-year period, both tree types studied here maintained their vigor. Nonetheless, the influence of pot soil volume on the economic life of the trees needs to be assessed over longer periods of time.

There were no significant differences in height between the two tree types. In both tree types, the tree height and fruit position were relatively tall. This is because 'Spirit of '76' is a vigorous cultivar, and it was unable to widen the tree crown by enlarging the interval between pots because of a small facility. As a result, cut back of branches could not be sufficiently conducted to achieve the required reduction in tree height, even for the own-rooted trees.

These results demonstrate that own-rooted mango tree growth characteristics are similar to, or perhaps even better than, those of grafted trees, and that yield and fruit quality do not differ between the two. The cultivation of own-rooted mango trees in pots should therefore be considered a practical and economically viable option.

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