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Comparison of growth, yield, and fruit quality between trees grafted onto rootstocks propagated by air layering and trees grafted onto seedling in mango 'Aikou' pot culture

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Abstract

Growth, yield, and fruit quality were compared at 8 years after planting between Aikou mango trees grafted onto rootstock propagated by air layering and those grafted onto seedling rootstock under pot culture. The rootstock used in this study was a Taiwanese native strain. The two types of trees were planted in 25-L pots constructed of non-woven fabric. The trunk diameter of the air-layered rootstock trees was significantly smaller than that of the seedling rootstock trees until the trees were 5 years old, but there was no difference between the two tree types after 8 years old. Moreover, no significant difference was observed in total length of green branches and numbers of leaves per tree except at 8, or 6 and 8 years of age. The fresh and dry weights of the leaves, green branches, thick branches, and fine roots of the air-layered rootstock trees were significantly greater than those of the seedling rootstock trees. The total weight of the aboveground parts of the air-layered rootstock trees was significantly greater than that of the seedling rootstock trees, but no significant difference was observed in the total weight of the underground parts between the tree types. The fresh weight of an entire air-layered rootstock tree was significantly greater than that of a seedling rootstock tree. The top/root (T/R) fresh weight ratio of the air-layered rootstock trees was significantly greater than that of the seedling rootstock trees. No significant differences in yield or fruit quality were observed between the two tree types. These results indicate that the use of rootstock propagated by air layering during mango nursery tree production is practical, as the growth, yield, and fruit quality of the air-layered rootstock trees and seedling rootstock trees were similar.

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INTRODUCTION

Mango (*Mangifera indica* L.) nursery trees are normally propagated from seeding cultivars for rootstock. The germinated seedlings are grown for approximately 2 years, and the scion is grafted onto the rootstock. Most mango growers purchase nursery trees from dealers, but some farmers produce nursery trees on their own to reduce costs.

In Japan, the seeds of a vigorous Taiwanese native strain are used. The seeds are relatively easy to obtain and are used to grow the mango rootstock.

If trees of the Taiwan native strain are planted, the rootstock can be produced without purchasing seeds, and nursery trees can be propagated by grafting. However, the rootstock cannot be produced if these trees do not flower and bear fruit. In such a case, the rooted shoots can be propagated for rootstock by air layering using the shoots of the Taiwanese native strain, and the nursery trees can be propagated by grafting.

Efficient air-layering techniques for mango have been reported by Fumuro (2011), and a 100% rooting rate was obtained for shoots of the Taiwanese native strain using the same method (Fumuro, unpublished). Fumuro (2017) found no significant differences in growth, yield, or fruit quality of mango cv. Aikou (Sasaki et al., 2005) own-rooted trees propagated by air layering and grafted trees propagated by conventional methods in pots. A prolonged life span of pot-planted trees may also be possible by using own-rooted trees. However, there is no information regarding the yield, fruit quality, or life span of trees produced using a rootstock propagated by air layering.

In this study, at 8 years after planting, the growth, yield, and fruit quality of Aikou mango trees grafted onto a rootstock propagated by air layering were compared with those of trees grafted onto seedlings of the native Taiwanese strain to assess the practicality of using rootstocks propagated by air layering.

MATERIALS AND METHODS

Nursery tree production

Production of nursery trees grafted onto air-layered rootstocks

Taiwanese native strain trees planted in a greenhouse (width: 7.6 m, length: 22 m) at Kindai University's experimental farm (Yuasa, Wakayama Prefecture, Japan) were used in this study. Air layer propagation was performed on 9 September 2008 according to the method of Fumuro (2011). On 12 November 2008, rooted branches (Figure 1) were removed and planted in small pots (diameter: 13.5 cm, height: 11 cm). Aikou scions were grafted onto nursery trees of the Taiwanese native strain on 9 June 2009. On 20 September 2009, the air-layered rootstock trees were transferred to 25-L pots constructed of a non-woven fabric (diameter: 32 cm, height: 35 cm) that were filled with a mixture of mountain soil, perlite, compost, and vermiculite (volume ratio: 1:1:1:1).

Figure 1. Rooting of air-layered Taiwanese native mango strain.

Production of nursery trees grafted onto seedling rootstocks

Aikou scions were grafted onto 2-year-old rootstocks (Taiwanese native strain seedlings) planted in 8.5-L poly pots (diameter: 24 cm, height: 24 cm) on 15 June 2009. The grafting position was about 24 cm above the ground. On 22 October 2009, the plants were transferred to pots constructed of non-woven fabric, as described above. Both the air-layered rootstock trees and seedling rootstock trees were 2 years old.

Cultivation management

Until October 2012, each pot was managed within a large plastic film greenhouse (width: 9 m, length: 54 m, height: 4.3, two buildings, 972 m^2). The pots were arranged 1.4 m apart in the greenhouse in rows separated by 1.5 m. In November 2012, all pots were transferred to a smaller plastic greenhouse (width: 6 m, length: 18 m, height: 4 m, 108 m^2) 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 increased gradually beginning in mid-February and 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 that the internal air temperature remained < 30°C until flowering and < 35°C after flowering. Irrigation was controlled using an automatic timer. Approximately 50 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. Assuming 476 pots per 1,000 m^2, approximately 19 kg each of nitrogen, phosphoric acid, and potassium were supplied annually. Pruning began when the harvest was almost complete and ended in late September. As part of the training method, two to three scaffold branches per tree and an appropriate number of bearing shoots were set within a crown diameter of 1.3–1.4 m. No pruning was carried out in 2016, as a dissecting survey occurred in October. Diseases and pests were controlled according to conventional procedures.

Fruit management and harvesting

The flowering period during each year in both tree types was generally the same. The full bloom period fluctuated with the year but occurred between late March and late April.

In June of every year, the fruits were thinned out so that the leaf-fruit ratio (ratio of the number of leaves to fruits) was 60. Each fruit was covered with a bag-shaped net before harvesting, and tree-ripe fruits that naturally dropped in the net were harvested from late July until early November every year.

Measurements

Tree growth

Four of the air-layered rootstock trees and five of the seedling rootstock trees were used for the following measurements.

The trunk diameter, number of leaves per tree, and length of the green branches per tree were measured in late December every year from 2009 until 2015, and in October 2016 (before the dissecting survey). The trunk diameters were measured using calipers, and the measurements were made 10 cm above the ground. The lengths of green branches with less than 10% lignification were measured, and the total length of the green branches was calculated. Tree heights were measured in October 2016 at the time of the dissecting survey.

Fresh and dry weights of each organ

The dissecting survey was performed between 11 and 24 October 2016. The trees were 9 years old at the time of dissection. The different parts of the tree were categorized as follows: leaves, green branches, thick branches, trunk, thick roots (≥ 1 mm in diameter, including the shoot-derived wood), and fine roots (< 1 mm in diameter), and the fresh weight of each organ was measured. Each organ sample was dried, and the percentage of dry matter was determined. The total dry weight of each organ was calculated by multiplying the percentage of dry matter by the total fresh weight of each organ. The top/root (T/R) ratio was calculated by dividing the weight of the aboveground parts of trees excluding the leaves by the weight of the underground part of the trees.

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 total leaf area per tree was calculated by multiplying the average leaf area and the number of leaves per tree. 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 the automatic leaf area meter.

Yield and fruit quality

The harvested fruits were weighed, and the yield, number of fruits per tree, and average fruit weight were calculated. About 10–20 fruits from both tree types harvested from late August to mid-September at the peak of harvest every year were used to measure fruit quality.

Peel color (Hunter's L-, a-, and b-values) was assessed 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 made 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 the total soluble solids (TSS) and titratable acidity were determined. The TSS value was determined using a refractometer (PAL-1; Atago Co. Ltd., Tokyo, Japan), and the titratable acidity was determined by the titration method with 0.1 N NaOH to a phenolphthalein endpoint and converted to citric acid content.

Statistical analysis

The data obtained in this study were subjected to the *t*-test. A p-value < 0.05 was considered significant.

RESULTS

Tree growth

Trunk diameters increased with age in both tree types (Figure 2). The average trunk diameter of the air-layered rootstock trees was significantly smaller than that of the seedling rootstock trees until the trees were 5 years old, but there was no difference between the two tree types after 8 years old.

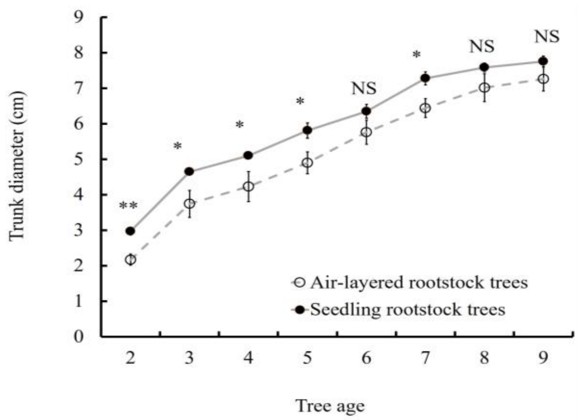

Figure 2. Annual changes in trunk diameters of the air-layered rootstock trees and the seedling rootstock trees in ‘Aikou’ mango grown in pots. Vertical bars represent ± standard error. NS and * indicate not significant and significant at P = 0.05, using *t*-tests.

The trunk cross-sectional areas of the air-layered rootstock trees and the seedling rootstock trees were 38.2 and 44.6 cm^2, respectively (Table 1).

Table 1. Comparison of the total leaf area per tree, trunk cross-sectional area, and tree height of the air-layered rootstock trees and the seedling rootstock trees in ‘Aikou’ mango.

Propagation method of rootstock	Total leaf area (m^2/tree)	Trunk cross-sectional area [z] (cm^2)	Tree height (m)
Air-layered	9.4	38.2	2.39
Seedling	7.1	44.6	2.08
Significance [y]	*	NS	**

[z] Trunk cross-sectional areas were measured at 10 cm above the ground.
[y] NS, *, and **, a non-significant difference at P = 0.05 and significant differences at P = 0.05 or 0.01, respectively (*t*-test).

No significant difference in the total length of the green branches per tree was observed between the tree types except at 8 years old (Figure 3).

The numbers of leaves per tree increased with age in both tree types, but no significant difference was detected except at 6 and 8 years old (Figure 4). However, the lead areas of the air-layered rootstock trees were larger in 9-year-old trees than in the seedling rootstock trees (9.4 and 7.1 m^2, respectively; Table 1).

The air-layered rootstock trees were taller than the seedling rootstock trees (2.39 and 2.08 m, respectively).

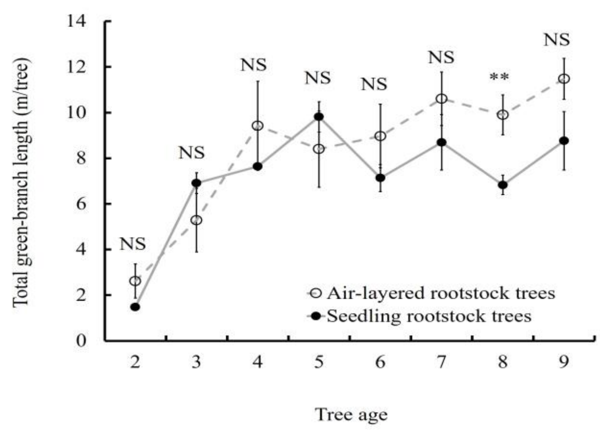

Figure 3. Annual changes in total green-branch length per tree of the air-layered rootstock trees and the seedling rootstock trees in ‘Aikou’ mango. Vertical bars represent ± standard error. NS and ** indicate not significant and significant at P = 0.05, and 0.01, respectively, using *t*-tests.

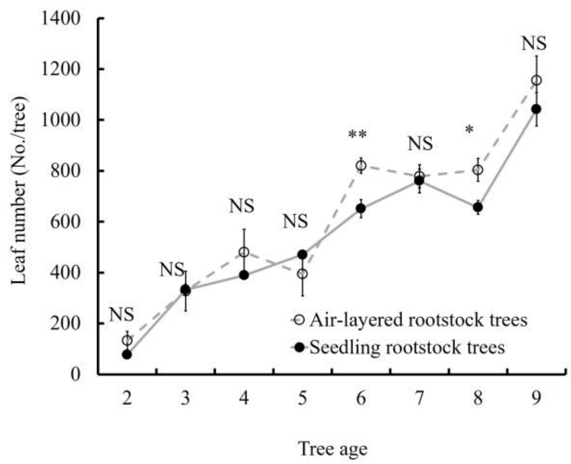

Figure 4. Annual changes in leaf number per tree of the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango grown in pots. Vertical bars represent ± standard error. NS, *, and ** indicate not significant and significant at P = 0.05, and 0.01, respectively, using t-tests.

Fresh and dry weights of each organ

The fresh and dry weight values of the tree types tended to be similar (Table 2 and 3).

The fresh and dry weights of the leaves, green branches, thick branches, and fine roots were significantly greater in the air-layered rootstock trees than in the seedling rootstock trees. The total fresh and dry weights of the aboveground parts were significantly greater in the air-layered rootstock trees than in the seedling rootstock trees, but there was no significant difference in the total weight of the underground part between the tree types.

The average fresh weight of a whole air-layered rootstock tree was 13.6 kg and significantly greater than that of a seedling rootstock tree (12.1 kg). However, no significant difference in the dry weights of the whole trees was observed between the tree types.

The fresh weight T/R ratio of the air-layered rootstock trees, which was calculated as the weight of the aboveground parts minus the leaves divided by the weight of the underground parts, was 2.79, and significantly higher than that of the seedling rootstock trees (2.31). However, the dry weight T/R ratios did not differ significantly between the two tree types.

Table 2. Comparison of the fresh and dry weights of the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango.

	Propagation method of rootstock	Above-ground part (kg)				
		Leaf	Green branch[z]	Thick branch	Trunk	Total
Fresh weight	Air-layered	3.14	0.64	6.05	1.00	10.83
	Seedling	2.38	0.4	4.9	1.47	9.15
	Significance[w]	*	*	*	NS	**
Dry weight	Air-layered	1.33	0.18	2.1	0.37	3.98
	Seedling	1.07	0.11	1.71	0.52	3.41
	Significance	*	*	*	NS	*

[z] Branches which a ratio of lignification < 10%.
[w] NS, *, **, and ***, a non-significant difference at P = 0.05 and significant differences at P = 0.05, 0.01, or 0.001, respectively (t-test).

Table 3. Comparison of the fresh and dry weights of the air-layered rootstock trees and the seedling rootstock trees in in ‘Aikou’ mango.

	Propagation method of rootstock	Under-ground part (kg)			Whole tree (kg)	T-R ratio
		Thick root[y]	Fine root[x]	Total		
Fresh weight	Air-layered	2.1	0.66	13.59	13.59	2.79
	Seedling	2.5	0.43	12.08	12.08	2.31
	Significance[w]	NS	***	*	*	*
Dry weight	Air-layered	0.76	0.16	4.90	4.90	2.88
	Seedling	0.91	0.11	4.43	4.43	2.29
	Significance	NS	**	NS	NS	NS

[y] Roots ≥ 1 mm in diameter, including the shoot-derived wood.
[x] Roots < 1 mm in diameter.
[w] NS, *, **, and ***, a non-significant difference at $P = 0.05$ and significant differences at $P = 0.05$, 0.01, or 0.001, respectively (*t*-test).

The states of the tree before dissecting and the underground part after dissecting of the tree types are shown in Figure 5 and 6, respectively.

Figure 5. The air-layered rootstock trees (left two) and the seedling rootstock trees (right two) before dissection.

Figure 6. The under-ground parts of the air-layered rootstock tree (left) and the seedling rootstock tree (right).

Yield and fruit quality

The yield per tree was 6.3–7.9 kg in the 6–9-year-old trees, and no significant difference was detected between the two tree types (Figure 7).

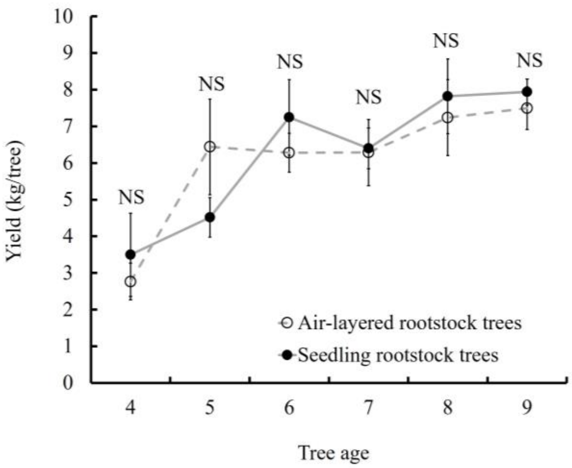

Figure 7. Annual changes in yield per tree of the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango grown in pots. Vertical bars represent ± standard error. NS indicate not significant at P = 0.05, using t-tests

There were also no significant differences between the two tree types in numbers of fruits per tree or average fruit weight, which were 10.3–13.6 and 539–653g, respectively (Figures 8 and 9).

In addition, no significant differences were observed in peel color, flesh firmness, soluble solid content, or citric acid content (Table 4).

The L-values of both tree types were 35.6–38.3, the a-values were 9.3–18.8, the b-values were 8.1–15.6, flesh firmness was 5.0–9.1 N·cm^{-2}, soluble solid contents were 15.2–17.4%, and citric acid contents were 0.13–0.20, with only small annual variations.

The state of fruiting in the air-layered rootstock trees and the seedling rootstock trees are shown in Figure 10.

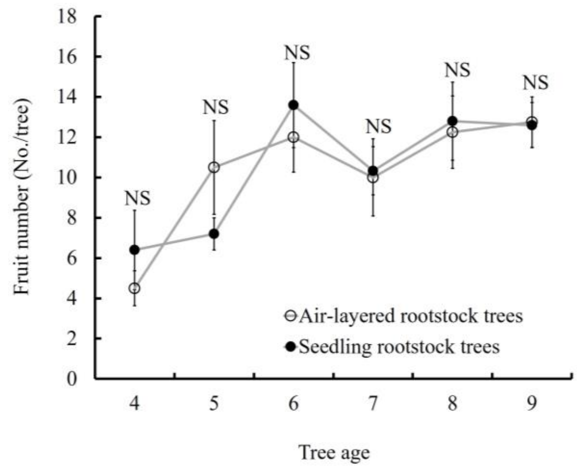

Figure 8. Annual changes in fruit number of the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango grown in pots. Vertical bars represent ± standard error. NS indicate not significant at P = 0.05, using t-tests.

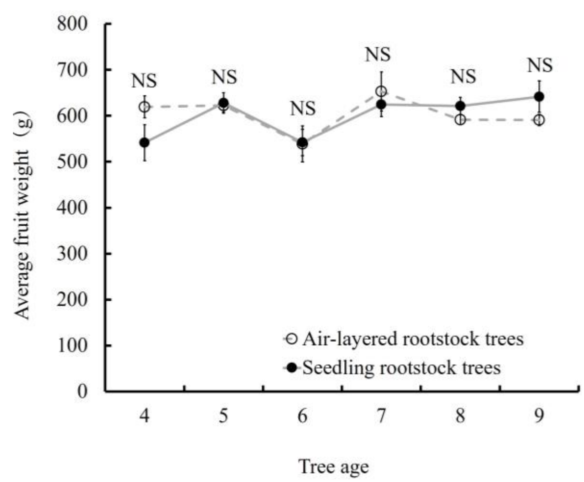

Figure 9. Annual changes in average fruit weight of the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango grown in pots. Vertical bars represent ± standard error. NS indicate not significant at P = 0.05, using t-tests.

Table 4. Comparison of fruit quality in the air-layered rootstock trees and the seedling rootstock trees in 'Aikou' mango.

Tree age	Propagation method of rootstock	Peel color			Flesh firmness	Total soluble solids	Citric acid
		L-value	a-value	b-value	($N \cdot cm^{-2}$)	(%)	(%)
4	Air-layered	37.1	10.6	8.1	8.6	16.4	0.20
	Seedling	36.6	10.3	10.0	9.1	15.8	0.18
	Significance	NS[z]	NS	NS	NS	NS	NS
5	Air-layered	37.2	16.2	10.9	5.5	16.5	0.14
	Seedling	35.9	14.2	10.3	5.1	16.6	0.15
	Significance	NS	NS	NS	NS	NS	NS
6	Air-layered	38.3	12.2	13.8	7.6	16.2	0.18
	Seedling	38.1	18.8	12.8	7.4	16.3	0.18
	Significance	NS	NS	NS	NS	NS	NS
7	Air-layered	35.7	15.4	11.8	7.9	15.8	0.14
	Seedling	35.6	16.6	11.4	7.2	16.2	0.17
	Significance	NS	NS	NS	NS	NS	NS
8	Air-layered	37.1	14.4	15.6	5.0	15.5	0.13
	Seedling	35.6	11.4	14.3	6.5	15.2	0.17
	Significance	NS	NS	NS	NS	NS	NS
9	Air-layered	36.2	14.7	12.9	8.0	17.4	0.18
	Seedling	37.9	9.2	16.3	7.3	17.0	0.16
	Significance	NS	NS	NS	NS	NS	NS

[z] NS, non-significant difference at $P = 0.05$ (*t*-test).

Figure 10. State of fruiting in the air-layered rootstock trees (left) and the seedling rootstock trees (right) in 2016.

Discussion

Tree growth

No large differences in trunk diameter, green branch length, or number of leaves per tree were observed (Figure 2, 3, and 4). Therefore, the growth of the air-layered rootstock trees was not inferior to that of the seedling rootstock trees.

In contrast, the air-layered rootstock trees were about 0.3 m taller than the seedling rootstock trees (Table 1). The Aikou trees used in this study are vigorous, and it is easier to increase their tree height than that of 'Irwin', which is the leading cultivar in Japan.

Mango is cultivated in greenhouses in Japan, but the flower clusters and fruits are lifted above the tree crown to promote fruit color. The fruit is covered with a net or bag for tree-ripe fruit production, so the lower the tree height the better. As tree height can be reduced by pruning and training, these treatments make it possible to lower the height of air-layered rootstock trees.

Fresh and dry weights of each organ

The growth of the aboveground parts of trees is closely related to the growth of the underground parts (Fumuro, 1999; Fumuro et al., 1999). Thus, both the aboveground and underground parts must be measured to assess growth. The dissecting survey revealed no significant difference in the weight of the underground parts between the two tree types, but the aboveground parts of the air-layered rootstock trees were significantly heavier than those of the seedling rootstock trees (Table 2).

Fumuro (2017) found that own-rooted Aikou trees propagated by air layering had significantly higher T/R ratios compared to grafted trees propagated using conventional methods. In this study, the air-layered rootstock trees had significantly higher fresh weight T/R ratios compared to the seedling rootstock trees, indicating that the air-layered rootstock trees allowed growth of the aboveground parts with fewer underground parts compared to the seedling rootstock trees.

Although no significant difference was observed in the weight of the thick root between the tree types, the weight of the fine roots of the air-layered trees was significantly greater than that of the seedling rootstock trees, suggesting that the productivity of air-layered rootstock trees is higher than that of seedling rootstock trees. More sustainable fruit production can be realized with a higher T/R ratio and more fine roots.

There is a risk of a decrease in tree vigor caused by root clogging in pot culture. Root clogging in pot culture is caused mainly by enlargement of thick roots and an increased number of fine roots within a restricted root zone. This is accompanied by suppression of new root growth and deterioration of water permeability. However, in this study, no decrease in tree vigor was observed as a result of root clogging after 8 years of culture.

Yield and fruit quality

No study has compared yields and fruit quality between air-layered rootstock mango trees and seedling rootstock trees in culture. In this study, yields were nearly constant for 6 to 8 years in both tree types (Figure 7). The yield per 1,000 m^2 calculated for the average of 6 years, assuming 476 pots per 1,000 m^2, was estimated to be approximately 2.8 t for the air-layered rootstock trees and 2.9 t for the seedling rootstock trees, and no difference between the two tree types was detected.

Fumuro (2011b) reported that the yields of 3- and 4-year-old Aikou trees managed with a leaf-fruit ratio of 60 were 1.2 and 2.2 $kg \cdot m^{-2}$, respectively (5- and 6-year-old roots), which was higher than the values in this study. The average fruit weight of Aikou is greater with a higher leaf-fruit ratio (Fumuro, 2011b). The average leaf-fruit ratio value for 6 years was nearly 60, but differences were detected between years. The average fruit weight in both tree types, excluding the 4- and 6-year-old trees (Figure 9), roughly reached the standard fruit weight (600–700 g) of the Aikou cultivar (Fumuro, 2011b).

Some fluctuations in fruit quality were observed between years, but no significant difference was detected between the two tree types, and the fruit quality roughly reached the standard for the Aikou cultivar (Fumuro, 2011b), which is 16–17% in TSS, 0.15–0.20% in citric acid content, and 7–8 $N \cdot cm^{-2}$ in flesh firmness (Table 3).

Pots with a soil capacity of 40–80 L are typically used for mango pot culture (Yonemoto, 2008). This study implies that cultivation of mango can be continued for at least 8 years even in a small pot with a soil capacity of about 25 L. The pots used in this study were made of non-woven fabric with excellent water permeability and breathability, but the pots that are usually used are constructed of plastic, with inferior water permeability and breathability. In the future, it will be necessary to measure the effects of pot material and size on growth, yield, and fruit quality.

In conclusion, using mango rootstocks propagated by air layering of nursery trees is practical, as the growth, yield, and fruit quality of the air-layered rootstock trees and seedling rootstock trees were found to be similar.

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