

## Rooting ability of leafy-stem cuttings of hybrid Shorea (Dipterocarpaceae)

Kenzo, T.; Ichie, T.; Kamiya, K.; Ngo, Kang Min; Lum, Shawn Kaihekulani Yamauchi

2019

Kenzo, T., Ichie, T., Kamiya, K., Ngo, K. M., & Lum, S. K. Y. (2019). Rooting ability of leafy-stem cuttings of hybrid Shorea (Dipterocarpaceae). *Journal of Tropical Forest Science*, 31(3), 324-331. doi:10.26525/jtfs2019.31.3.324

<https://hdl.handle.net/10356/142725>

<https://doi.org/10.26525/jtfs2019.31.3.324>

---

© 2019 Forest Research Institute Malaysia. All rights reserved. This paper was published in *Journal of Tropical Forest Science* and is made available with permission of Forest Research Institute Malaysia.

*Downloaded on 18 Jun 2024 02:08:17 SGT*

# ROOTING ABILITY OF LEAFY-STEM CUTTINGS OF HYBRID *SHOREA* (DIPTEROCARPACEAE)

Kenzo T<sup>1</sup>\*, Ichie T<sup>2</sup>, Kamiya K<sup>3</sup>, Ngo KM<sup>4,5</sup> & Lum SKY<sup>4,5</sup>

<sup>1</sup>Department of Plant Ecology, Forestry and Forest Products Research Institute, Tsukuba, Ibaraki 305-8687, Japan

<sup>2</sup>Faculty of Agriculture, Kochi University, Nankoku, 783-8502, Japan

<sup>3</sup>Faculty of Agriculture, Ehime University, Matsuyama, Ehime 790-0865, Japan

<sup>4</sup>Asian School of the Environment, Nanyang Technological University, 639798, Singapore

<sup>5</sup>Natural Sciences and Science Education Academic Group, National Institute of Education, Nanyang Technological University, 637616, Singapore

\*mona@affrc.go.jp

Submitted July 2018; accepted Jan 2019

Although cutting is a useful method for vegetative propagation and tree breeding, there is a difference in rooting ability between tree species and even between node positions within a species. A large number of F<sub>1</sub> hybrids of *Shorea* (*Shorea curtisii* × *S. leprosula*) (Dipterocarpaceae) have recently been found in Singapore. Given that some of the hybrid traits appear to have higher physiological performances than those of their parent species, understanding the rooting ability of the leafy-stem cuttings of F<sub>1</sub> hybrids may contribute to performance improvement in dipterocarp trees. In this study, we compared the rooting abilities of cuttings taken from seedlings of F<sub>1</sub> hybrids and their parent species at different node positions. The cuttings of F<sub>1</sub> hybrids showed rooting ability with small internode differences, and the rooting rate (32.2%) was almost intermediate between those of *S. curtisii* (42.0%) and *S. leprosula* (21.0%). The rooting rates of hybrids and parents fell into the middle range of previously reported values for 21 closely related *Shorea* species. Overall, the rooting ability of F<sub>1</sub> hybrids is comparable with that of their parent species and/or other *Shorea* species in the red meranti group. Thus, F<sub>1</sub> hybrids could be mass propagated through cuttings.

Keywords: Dipterocarp, hybridisation, *Shorea curtisii*, *Shorea leprosula*, red meranti, vegetative propagation

## INTRODUCTION

Members of Dipterocarpaceae (dipterocarp trees), particularly species in the genus *Shorea*, dominate the canopy layers of Southeast Asian tropical rainforests and are important sources of commercial timber (Ghazoul 2016). Although the interspecific hybridisation of dipterocarp species is rare in natural rainforests (Ashton 1969, Thomas 2003), frequent hybridisation has recently been found between three closely related *Shorea* species in the section *Mutica* (*S. leprosula*, *S. parvifolia* and *S. curtisii*) in a small, isolated area of the tropical rainforest in Bukit Timah Nature Reserve, Singapore (Kamiya et al. 2011). Surprisingly, approximately 20% of the trees that had reached reproductive size were confirmed by DNA analysis to be the F<sub>1</sub> hybrids of two locally rare *Shorea* species (*S. leprosula* and *S. parvifolia*), and the proportion of those in the seedling and sapling stages reached 40% (Kenzo et al. 2016). Moreover, hybrids often exhibit heterosis, such

as high growth rates, drought tolerance and characteristics that are superior to those of their parent species (Arnold 2006). The hybrid *Shorea* seedlings found in Singapore grow best under relatively dry and high irradiance conditions and may therefore have better drought tolerance than their parents (Kenzo et al. 2016).

Leafy-stem cuttings contribute to the mass propagation of tree species and to tree breeding (Hartmann et al. 1997). If seedling cuttings of the *Shorea* hybrids show high rooting ability and superior characteristics compared to those of the parental species, the cutting method would be beneficial for the improvement of dipterocarp tree breeding. Although cuttings have been used to propagate tropical tree species, such as *Acacia* spp., *Eucalypts* spp., *Hevea brasiliensis* and *Tectona grandis*, the rooting ability of cuttings drastically varies both within and between tree species (Webster & Baulkwill 1989, Tewari 1999,

Kha 2000, Assis et al. 2004, Tate & Page 2018). In addition, in several species, rooting ability varies according to the age of the stock plant and even the position of the node within the same shoot (Dick and Aminah 1994). For example, the rooting ability of the shoots of young saplings and coppices is generally higher than that of mature trees (Itoh et al. 2003). To develop the appropriate propagation techniques based on cuttings, understanding the rooting ability at different node positions in shoots from young saplings and coppices in each tree species is necessary (Dick & Aminah 1994).

Given that many dipterocarp species exhibit uncertain reproductive intervals with most flowering only once every 5 to 10 years (Ichie et al. 2005), the development of leafy-stem cutting techniques for dipterocarp species may provide a stable supply of seedlings for the establishment of commercial and environmental plantations in Southeast Asia (Ahmad 2006). Although stem cuttings from some dipterocarp tree species have been commercialised for plantations in the region, the establishment of cutting techniques for the hybrids of dipterocarp species may enable the production of germplasm with high environmental adaptability and growth ability (Sakai & Subiakto 2007). Some reports have shown that the rooting ability of dipterocarp trees varies according to the species, tree age and shoot-node position, and that several dipterocarp species lack rooting ability (Momose 1978, Kantarli 1993, Noraini and Liew 1994, Itoh et al. 2003). In the present study, to understand the rooting ability of cuttings from *Shorea* hybrids, the study 1) compared the rooting ability of leafy-stem cuttings taken from F<sub>1</sub> *Shorea* hybrids (*Shorea curtisii* × *S. leprosula*) and their parent species at different node positions, and 2) reviewed previous studies on closely related *Shorea* species (red meranti group) and compared the rooting ability of the hybrids and that of their parent species.

## MATERIALS AND METHODS

### Plant materials, study site and cutting preparation

The F<sub>1</sub> hybrids of *Shorea* (*S. curtisii* × *S. leprosula*) were selected, given that the seedlings of this hybrid are easily found at the Bukit Timah Nature Reserve (1° 21' N, 103° 46' E) in Singapore

(Kenzo et al. 2016). The forest vegetation is typical of the coastal hill forests of the southern Malay Peninsula and dominated by members of the family Dipterocarpaceae (Kenzo et al. 2016). *Shorea curtisii* and *S. leprosula* produce timber of good quality and are distributed over similar geographical ranges in the Malay Peninsula, Borneo and Sumatra but exhibit different morphological and ecological traits (Ashton 1982). *Shorea curtisii* dominates ridges in hill-dipterocarp forests and occasionally in coastal hill-dipterocarp forests, whereas *S. leprosula* commonly grows on well-drained soil in lowland-dipterocarp and hill-dipterocarp forests (Ashton 1982, Kamiya et al. 2012). These species coexist on the same coastal hills and inland mountain ranges in Malaysia (Symington 2004).

Branches for cuttings were collected from wild ones in Bukit Timah in February 2012. Stock plants were young wild saplings approximately 1–2 m in height and had grown in large canopy gaps under direct sunlight. The rooting experiment was performed in a laboratory at the National Institute of Education, Nanyang Technological University, Singapore in February 2012. The cuttings were cut to a length of approximately 10 cm with one leaf and node. The position of each node was also recorded in the cuttings from tip to base of sampled branches sequentially. The leaf area was approximately halved to reduce water loss through transpiration (Aminah et al. 1997a). The ends of the cuttings on the planting media side were dipped into powder that contained 0.1% naphthyl acetic acid-containing talc to induce rooting (Sakai & Subiakto 2007). The river sand that had been sterilised through autoclaving was used as a planting medium. The trays containing cuttings were covered with plastic, and humidity was maintained above c.a. 90% (Aminah et al. 2000). Light intensity was approximately 200 (μmol photon m<sup>-2</sup> s<sup>-1</sup>), which is the preferred light intensity for the rooting of several *Shorea* species, including *S. leprosula* (Aminah et al. 1997b). The temperature in the laboratory was controlled approximately from 23–28 °C by air conditioning. The rooting rate (rooting cuttings/the total cuttings, %) was investigated 3 months after planting, because the rooting induction of most dipterocarp trees, including *Shorea*, usually occurs within 3 months after planting (Sakai & Subiakto 2007).

## Comparison of the rooting rates of related *Shorea* species by a literature survey

The rooting ratios of 21 *Shorea* species in the red meranti group were quantified by literature survey. A total of 256 measurements from 27 reports were collected, including journal papers, proceedings and books. The rooting rate of sections in red meranti such as *Brachypterae*, *Mutica*, *Ovalis*, *Rubella* and *Pachycarpae* were also compared, because many ecological and physiological traits such as drought and freezing tolerance and the growth rate significantly varied according to the section even in the same red meranti group (Sasaki 2011).

### Statistical analysis

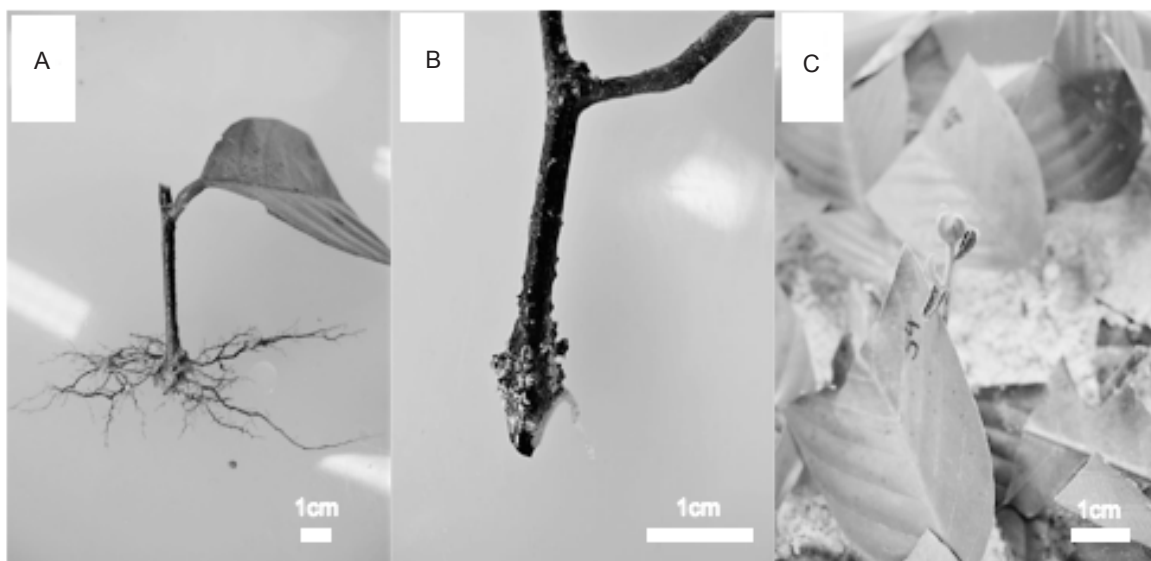
A  $X^2$ -test was performed to assess statistically significant differences between the rooting ratios of different species. Fisher's exact test was used

to examine the relation between the existence of rooting of each species and the node positions below the apex (Sokal & Rohlf 1995). All analysis were conducted using SPSS for Windows v 22.

## RESULTS

### Differences in rooting ratios between hybrids and their parents

The cuttings of hybrids (Figure 1A, Table 1) and both parent species (Figure 1B, Table 1) exhibited a capacity to form adventitious roots. Newly developed shoots and leaves were also found in several cuttings (Figure 1C). The rooting ratios of the hybrids and their parent species differed significantly (Table 1,  $X^2$ -test,  $X^2 = 18.3$ , d.f. = 2,  $p < 0.001$ ). *Shorea curtisii* (42.0%) exhibited the highest rooting ratio, followed by hybrids (32.3%) and *S. leprosula* (21.0%).



**Figure 1** Examples of cuttings after 3 months, A = a rooted cutting of the F<sub>1</sub> hybrid (*Shorea curtisii* × *S. leprosula*), B = a rooted cutting of *S. curtisii*, C = a new shoot from a cutting of *S. leprosula*

**Table 1** Number of the total cuttings, rooted cuttings and rooting rate (%) after three months

Species	Total cuttings	Rooted cuttings	Rooting rate (%)
Hybrid	115	37	32.2
<i>Shorea curtisii</i>	138	58	42.0
<i>Shorea leprosula</i>	219	46	21.0
Total	472	141	29.9

There were significant differences in the rooting rate between the parent species and the hybrid ( $X^2$ -test,  $X^2 = 18.3$ ,  $df = 2$ ,  $p < 0.001$ )

### Differences in the rooting ratios of cuttings taken at different node positions

The rooting ratios of cuttings taken from different node positions did not differ significantly for hybrids and their parent species (Table 2, Fisher's exact test,  $p > 0.05$  for all species), though the rooting rate of hybrid cuttings taken from the terminal position was approximately half (21.4%) of those from the second to fourth positions ( $> 40\%$ ).

### Comparison of the rooting rates of related *Shorea* species

Rooting rates significantly differed between *Shorea* species (Table 3, 15 species with more than three measurements, ANOVA,  $p < 0.05$ ). For example, the rooting rate of *S. ovata* in the section *Mutica* was only 2.3%, while *S. balangeran* (68.5%), *S. parvistipulata* (60.0%), *S. platyclados* (65.5%) and *S. selanica* (53.5%) in the section *Brachypterae*, *S. parvifolia* (53.9%) in the section *Mutica*, *S. ovalis* (51.2%) in the section *Ovalis* and *S. macrophylla* (56.4%) in the section *Pachycarpae* (Table 3) exhibited rooting rates of more than 50%. Intersectional differences exhibited by the three sections, that included more than five species each, were not significant (Table 4, ANOVA,  $p > 0.05$ ). The average rooting rate of the section *Mutica*, which includes *S. curtisii* and *S. leprosula*, was 31.1%.

## DISCUSSION

### Rooting ability of hybrid *Shorea*

The rooting ability of the  $F_1$  hybrid (*S. leprosula*  $\times$  *S. curtisii*) is intermediate between those of its parent species, which is similar to the intermediate growth and survival rates of *Shorea* hybrids reported in a natural forest (Kenzo et al. 2016). These results contrast with the growth rate and photosynthesis of the hybrids of several tree species that exhibit heterosis (i.e. superior characteristics compared to their parent species) (Orians et al. 1999). Similar intermediate growth and physiological characteristics have been reported for several hybrid species, such as *Salix* spp. and *Picea* spp. (Major et al. 2003, Arnold 2006). On the other hand, the improvement of dipterocarp trees using hybrids may be possible, because obvious heterosis of growth performance have been found in successional hybrids, such as the backcross between parent species and  $F_1$  hybrids (*S. leprosula*  $\times$  *S. curtisii*) under nursery conditions (Kenzo et al. 2019).

The similarity in rooting ability between node positions in *Shorea* hybrid and parent species indicated that cutting propagation is possible regardless of node positions except, in some instances, for the first node from the shoot apex. The rooting ability of cuttings taken from some *Shorea* species at the first node from the shoot apex is low (Aminah 1990). Noraini and

**Table 2** Number of total cuttings (TC), rooted cuttings (RC) and rooting rate (RR) in each node position below the apex

Species node position	Hybrid			<i>Shorea curtisii</i>			<i>Shorea leprosula</i>		
	TC	RC	RR(%)	TC	RC	RR(%)	TC	RC	RR(%)
1	28	6	21.4	37	15	40.5	41	8	19.5
2	22	9	40.9	33	12	36.4	38	8	21.1
3	17	7	41.2	19	8	42.1	33	7	21.2
4	14	7	50.0	15	10	66.7	29	4	13.8
5	9	2	22.2	12	5	41.7	23	8	34.8
6	8	1	12.5	8	4	50.0	15	3	20.0
7 <	17	5	29.4	14	4	28.6	40	8	20.0
Fisher's exact test	P=0.37			P=0.50			P=0.76		

There were no significant differences in the rooting rate between the positions of the hybrid and parent species (Fisher's exact test,  $p > 0.05$ )

**Table 3** Average rooting rate (RR), minimum (Min) and maximum (Max) rooting rates among 21 species in the red meranti group of *Shorea* (Dipterocarpaceae)

Species	Section	RR (%)	Min (%)	Max (%)	Number of experiment	References*
<i>Shorea balangeran</i>	<i>Brachypterae</i>	68.5 ± 9.8 <sup>abc</sup>	43.0	91.0	4	22
<i>Shorea johorensis</i>	<i>Brachypterae</i>	42.7 ± 8.5 <sup>abcd</sup>	0.0	79.0	9	14, 18, 21, 22, 26
<i>Shorea parvistipulata</i>	<i>Brachypterae</i>	60.0 <sup>N/A</sup>	-	-	1	22
<i>Shorea pauciflora</i>	<i>Brachypterae</i>	29.5 ± 5.3 <sup>bcd</sup>	0.0	99.0	30	3, 13, 18, 21, 22, 26, 27
<i>Shorea platyclados</i>	<i>Brachypterae</i>	65.5 ± 4.3 <sup>abc</sup>	50.0	77.0	6	2, 22, 24
<i>Shorea pubistyla</i>	<i>Brachypterae</i>	7.0 <sup>N/A</sup>	-	-	1	16
<i>Shorea selanica</i>	<i>Brachypterae</i>	53.5 ± 8.8 <sup>abcd</sup>	30.0	69.0	4	22
<i>Shorea smithiana</i>	<i>Brachypterae</i>	34 ± 14.6 <sup>abcd</sup>	0.0	65.0	4	21, 22
<i>Shorea acuminata</i>	<i>Mutica</i>	43.4 ± 6.5 <sup>abc</sup>	0.0	83.0	26	1, 13, 20, 22, 27
<i>Shorea curtisii</i>	<i>Mutica</i>	20.5 ± 3.8 <sup>abcd</sup>	12.0	32.0	6	19
<i>Shorea leprosula</i>	<i>Mutica</i>	44.4 ± 3.1 <sup>abcd</sup>	0.0	94.0	70	1, 2, 4-8, 13, 18, 19, 21, 22, 24, 26, 27
<i>Shorea macroptera</i>	<i>Mutica</i>	22.3 ± 5.1 <sup>cd</sup>	0.0	48.0	14	2, 10, 13, 14, 27
<i>Shorea ovata</i>	<i>Mutica</i>	2.3 ± 0.9 <sup>d</sup>	0.0	5.0	8	13, 27
<i>Shorea parvifolia</i>	<i>Mutica</i>	53.9 ± 4.6 <sup>a</sup>	0.0	83.0	27	1, 2, 10, 14, 20-22, 26
<i>Shorea ovalis</i>	<i>Ovalis</i>	51.2 ± 9.7 <sup>abc</sup>	0.0	80.0	9	1, 2, 9, 18, 22
<i>Shorea beccariana</i>	<i>Pachycarpae</i>	30.0 <sup>N/A</sup>	30.0	30.0	1	14
<i>Shorea macrophylla</i>	<i>Pachycarpae</i>	56.4 ± 4.5 <sup>a</sup>	12.8	81.0	20	12, 16, 17, 22
<i>Shorea pinanga</i>	<i>Pachycarpae</i>	39.0 ± 5.0 <sup>N/A</sup>	34.0	44.0	2	22, 23
<i>Shorea splendida</i>	<i>Pachycarpae</i>	49.0 <sup>N/A</sup>	-	-	1	11
<i>Shorea stenoptera</i>	<i>Pachycarpae</i>	26.0 <sup>N/A</sup>	-	-	1	22
<i>Shorea albida</i>	<i>Rubella</i>	26.1 ± 6.3 <sup>abcd</sup>	3.6	77.8	12	15, 16
All species		41.3 ± 1.7	0.0	99.0	256	

Different letters indicate significant differences between species (15 species tested in more than three experiments, ANOVA with Bonferroni test,  $p < 0.05$ ); N/A = not applicable to the statistical result; scientific names and phylogeny were according to Ashton (1982) and Kamiya et al. (2005); \*references are, 1 = Ahmad 2006, 2 = Aminah 1991, 3 = Aminah 1995, 4 = Aminah et al. 1995, 5 = Aminah et al. 1997a, 6 = Aminah et al. 1997b, 7 = Aminah et al. 1999, 8 = Aminah et al. 2000, 9 = Aminah et al. 2005, 10 = Aminah et al. 2006, 11 = Brodie 2003, 12 = Chai 2003, 13 = FDPM et al. 1996, 14 = Itoh et al. 2002, 15 = Kitaoka et al. 2011, 16 = Latifa & Kasik 2000, 17 = Lo 1985, 18 = Nakamura & Kimura 1996, 19 = Noraini & Liew 1997, 20 = Noraini & Ling 1993, 21 = Priadjati et al. 2001, 22 = Sakai & Subiakto 2007, 23 = Sakai & Yamamoto 1995, 24 = Sakai et al. 2002, 25 = Srivastava & Manggil 1981, 26 = Tolcamp & Priadjati 1996, 27 = Yamate & Hirasawa 1995

**Table 4** Average rooting rate among sections of the red meranti group of *Shorea* (Dipterocarpaceae)

Section	Rooting rate (%)	Minimum rooting rate (%)	Maximum rooting rate (%)	Number of species
<i>Brachypterae</i>	45.1 ± 7.4	7.0	68.5	8
<i>Mutica</i>	31.1 ± 7.9	2.3	53.2	6
<i>Ovalis</i>	51.2	-	-	1
<i>Pachycarpae</i>	40.1 ± 5.7	26.0	56.5	5
<i>Rubella</i>	26.1	-	-	1

There were no significant differences between sections (ANOVA,  $p > 0.05$ )

Liew (1997) also found that the rooting rate of the node from the terminal position of each seedling shoot was lower compared to that from the middle position in *S. curtisii*. In this study, the rooting rate of hybrid cuttings taken from the terminal position was approximately half (21.4%) of those from the second to fourth positions (> 40%). This reduction, however, was not obvious in the parent species. Although clear reasons for the different rooting abilities of cuttings taken from different node positions are not known, the growth environment, starch content, node concentration and the shoot age of a stock plant may affect rooting abilities (Dick & Aminah 1994). The relatively higher average rooting rate of *S. curtisii* (42%) than that of the hybrids (32%) and *S. leprosula* (21%) may be related to their high-sprouting ability during the sapling stage. High-sprouting species usually store large amounts of resources, such as starch and nitrogen, in their shoots and roots (Kenzo et al. 2013) and these stored resources may also facilitate cuttings' survival and rooting (Dick & Aminah 1994). In the Bukit Timah forest, the saplings of *S. curtisii* exhibit higher sprouting rates than other species (e.g. the sprouting rate of *S. curtisii* is 46%, whereas those of hybrid and *S. leprosula* are less than 20%). Thus, high-sprouting rate of *S. curtisii* saplings may be indicative of the high resource storage that may support the high rooting ability of this species, though the high sprouting rate may also effect adventitious root development (Dick & Aminah 1994).

### Rooting ability among related *Shorea* species and sections in red meranti

Although interspecific rooting rates varied widely from 2% in *S. ovata* to 69% in *S. balangeran* among 21 *Shorea* species in the red meranti group, the hybrid in the present study had intermediate rooting ability (32%) in the group. This rooting rate indicates that *Shorea* hybrid seedlings may be mass-propagated through cuttings. By contrast, the rooting rates of parent species differed from those previously reported. For example, it was found that the rooting rate of *S. curtisii* was 42%, but Noraini and Liew (1997) reported a rate of 20.5%. The rooting rate of *S. leprosula* (21%) was approximately half of the previously reported values (44%), though the rates varied from 0% to 94% among the reports. The different

rooting rates observed in previous studies may be attributed to large variations in the size, age and growth conditions of stock plants, planting media, nursery conditions and applied hormones. On the other hand, small intersectional differences in the rooting rates of the red meranti group indicate that the rooting rate is more species-specific than section-specific (Dick & Aminah 1994). However, phylogenetically dependent rooting ability may exist in some *Shorea* groups as shown by the different rooting and sprouting abilities observed in the bare-root planting experiment performed by Mori (1980). For example, species in the Anthoshorea group (white meranti group), such as *S. assamica*, *S. bracteolata*, *S. hypochra* and *S. roxburghii*, may have higher rooting abilities and more starch reserves than those in the red meranti group (Mori 1980). The former species exhibited high rooting rates (usually more than 80–100%) (Aminah 1991, Tolkamp & Priadjadi 1996). Mori (1980) and Sasaki (2011) hypothesised that species distributed over seasonal tropical forests (e.g. Anthoshorea group) have high rooting ability given their large amounts of stored resources that confer high tolerance to stress and disturbance, such as fire and drought in the forests. In fact, *S. obtusa*, which is a typical dry deciduous forest species, has almost 100% rooting ability (Smits 1983). Further studies on the rooting ability and resource storage of cuttings among various sections of *Shorea* species, including those distributed over seasonal tropical forests, may improve the current understanding of the cutting traits and success of the mass propagation of various *Shorea* species, including hybrids, in tropical Asia.

### CONCLUSIONS

The rooting ability of F<sub>1</sub> hybrid cuttings is intermediate between those of their parent species (*S. curtisii* and *S. leprosula*), indicating its negligible heterosis. A small difference in the rooting rate between node positions also indicated that the hybrid and parent species studied can be successfully propagated through cuttings taken across most node positions. The rooting rates of hybrids and parents fell into the middle range of previously reported values for closely related 21 *Shorea* species (red meranti group). Thus, F<sub>1</sub> hybrids could be mass-propagated through cuttings.

## ACKNOWLEDGEMENTS

The authors would like to thank the National Parks Board, Singapore, Center for Tropical Forest Science – Arnold Arboretum Asia Program and the National Institute of Education, Singapore, for their kind support towards the study. This study was conducted with permission from National Parks Board, Singapore (NP/RP 857, 972-1 to -7). The authors would also like to thank Sano M and Tanaka-Oda A for their kind support towards the study. This work was partly supported by JSPS KAKENHI Grant (21780155, 24688017, 16K07795, 17H04623 & 17H04602), and by the Environment Research and Technology Development Fund (RF-1010, S-9), Ministry of the Environment, Japan.

## REFERENCES

- AHMAD DH. 2006. Vegetative propagation of dipterocarp species by stem cuttings using a very simple technique. Pp 69–77 in Suzuki K et al. (eds) *Plantation Technology in Tropical Forest Science*. Springer, Tokyo.
- AMINAH H. 1990. A note on the rooting of *Shorea bracteolata* stem cuttings. *Journal of Tropical Forest Science* 3: 187–188.
- AMINAH H. 1991. Rooting ability of stem cuttings of eleven dipterocarp species. *Malaysian Applied Biology* 20: 155–159.
- AMINAH H. 1995. Rooting of *Shorea pauciflora* stem cuttings from coppice shoots. *Journal of Tropical Forest Science* 8: 134–136.
- AMINAH H, DICK JM, LEAKEY RRB ET AL. 1995. Effect of indole butyric acid (IBA) on stem cuttings of *Shorea leprosula*. *Forest Ecology and Management* 72: 199–206.
- AMINAH H, DICK JM & GRACE J. 1997a. Rooting of *Shorea leprosula* stem cuttings decreases with increasing leaf area. *Forest Ecology and Management* 91: 247–254.
- AMINAH H, DICK JM & GRACE J. 1997b. Influence of irradiance on water relations and carbon flux during rooting of *Shorea leprosula* leafy stem cuttings. *Tree Physiology* 17: 445–452.
- AMINAH H, DICK JM & GRACE J. 1999. Effect of photon irradiance and fertiliser levels on the growth of *Shorea leprosula* stock plants and the rooting ability of their subsequent stem cuttings. *Journal of Tropical Forest Science* 11: 79–99.
- AMINAH H, DICK JM, GRACE J ET AL. 2000. The influence of misting frequencies on the water relations and rooting physiology of *Shorea leprosula* leafy stem cuttings. *Journal of Tropical Forest Science* 12: 431–443.
- AMINAH H, AZWANI AAF & HAMZAH M. 2005. Effects of media on leafy stem cuttings of *Shorea ovalis* (Meranti Keping). *Malaysian Forester* 68: 174–179.
- AMINAH H, HASNITA RN & HAMZAH M. 2006. Effects of indole butyric acid concentrations and media on rooting of leafy stem cuttings of *Shorea parvifolia* and *Shorea macroptera*. *Journal of Tropical Forest Science* 18: 1–7.
- ARNOLD ML. 2006. *Evolution Through Genetic Exchange*. Oxford University Press, Oxford.
- ASHTON PS. 1969. Speciation among tropical forest trees: some deductions in the light of recent evidence. *Biological Journal of the Linnean Society* 1: 155–196.
- ASHTON PS. 1982. Dipterocarpaceae. Pp 237–552 in Van-Steenis CGGJ (ed) *Flora Malesiana, Ser. 1 Spermatophyta. Vol. 9(2)*, Martinus Nijhoff Publishers, Dordrecht.
- ASSIS TF, FETT-NETO AG & ALFENAS AC. 2004. Current techniques and prospects for the clonal propagation of hardwoods with emphasis on *Eucalyptus*. Pp 303–333 in Walter C & Carson M (eds) *Plantation Forest Biotechnology for the 21st Century*. Research Signpost, Kerala.
- BRODIE JF. 2003. Factors affecting the rooting ability of *Dryobalanops oblongifolia* and *Shorea splendida* (Dipterocarpaceae) stem cuttings. *Journal of Tropical Forest Science* 15: 109–116.
- CHAI EOK. 2003. Mass vegetative propagation research of *Shorea macrophylla* (Enkabang Jantong) by cuttings at the Sarawak indigenous tree center (SITC), Tatau, Sarawak, Malaysia. Pp 179–187 in Aminah H et al. (eds) *Proceedings of the Seventh Round-Table Conference on Dipterocarps*, APAFRI, Kuala Lumpur.
- DICK JM & AMINAH H. 1994. Vegetative propagation of tree species indigenous to Malaysia. *The Commonwealth Forestry Review* 73: 164–171.
- FDPM, (FORESTRY DEPARTMENT PENINSULAR MALAYSIA), PSFD (PERAK STATE FORESTRY DEPARTMENT) & JICA (JAPAN INTERNATIONAL COOPERATION AGENCY). 1996. *5 Year Report (1991–1996) on the Multi-Storied Forest Management Project in Peninsular Malaysia*. Forestry Department Peninsular Malaysia (FDPM), Perak State Forestry Department (PSFI) & Japan International Cooperation Agency (JICA), Kuala Lumpur.
- GHAZOUL J. 2016. *Dipterocarp Biology, Ecology and Conservation*. Oxford University Press, Oxford.
- HARTMANN HT, KESTER DE, DAVIES FT ET AL. 1997. *Plant Propagation: Principles and Practices*. 6<sup>th</sup> edition. Prentice-Hall Inc., New Jersey.
- ICHIE T, KENZO T, KITAHASHI Y ET AL. 2005. How does *Dryobalanops aromatica* supply carbohydrate resources for reproduction in a masting year? *Trees* 19: 704–711.
- ITOH A, YAMAKURA T, TAN S ET AL. 2003. Effects of resource plant size on rooting of *Dryobalanops lanceolata* cuttings. *Journal of Forest Research* 8: 117–121.
- ITOH A, YAMAKURA T, KANZAKI M ET AL. 2002. Rooting ability of cuttings relates to phylogeny, habitat preference and growth characteristics of tropical rainforest trees. *Forest Ecology and Management* 168: 275–287.
- KAMIYA K, HARADA K, TACHIDA H ET AL. 2005. Phylogeny of PgiC gene in *Shorea* and its closely related genera (Dipterocarpaceae), the dominant trees in Southeast Asian tropical rain forests. *American Journal of Botany* 92: 775–788.
- KAMIYA K, GAN YY, LUM SK ET AL. 2011. Morphological and molecular evidence of natural hybridization in *Shorea* (Dipterocarpaceae). *Tree Genetics and Genomes* 7: 297–306.
- KAMIYA K, NANAMI S, KENZO T ET AL. 2012. Demographic history of *Shorea curtisii* (Dipterocarpaceae) inferred from chloroplast DNA sequence variations. *Biotropica* 44: 577–585.



- KANTARLI M. 1993. *Vegetative Propagation of Dipterocarps by Cuttings in ASEAN Region*. Review Paper No. 1, ASEAN-Canada Forest Tree Seed Centre Project, Saraburi.
- KENZO T, ICHIE T, YONEDA R ET AL. 2013. Ontogenetic changes in carbohydrate storage and sprouting ability in pioneer tree species in Peninsular Malaysia. *Biotropica* 45: 427–433.
- KENZO T, ICHIE T, NORICHIKA Y ET AL. 2016. Growth and survival of hybrid dipterocarp seedlings in a tropical rain forest fragment in Singapore. *Plant Ecology and Diversity* 9: 447–450.
- KENZO T, KAMIYA K, NGO KM ET AL. 2019. Overlapping flowering periods among *Shorea* species and high growth performance of hybrid seedlings promote hybridization and introgression in a tropical rainforest of Singapore. *Forest Ecology and Management*. 435: 38–44.
- KITAOKA A, UCHIDA Y & ASAISHI H. 2011. Production of cuttings in a peat swamp species from Sarawak, Malaysia. Pp 89–99 in Suzuki K et al. (eds) *Plantation Technology in Tropical Forest Science*. Springer, Tokyo.
- KHA LD. 2000. Studies on natural hybrids of *Acacia mangium* and *A. auriculiformis* in Vietnam. *Journal of Tropical Forest Science* 12: 794–803.
- LATIFAH T & KASIK V. 2000. A study of the vegetative propagation of some indigenous tree species in Sarawak. Pp 126–129 in Ogino K et al. (eds) *Proceedings of Workshop on Forest Ecosystem Rehabilitation, Kuching*. Forest Department Sarawak, Kuching.
- LO YN. 1985. Root initiation of *Shorea macrophylla* cuttings: effect of node position, growth regulators and misting regime. *Forest Ecology and Management* 12: 42–52.
- MAJOR JE, MOSSELER A, BARS DC ET AL. 2003. Morphometric, allometric and developmentally adaptive traits in red spruce and black spruce. II. Seedling and mature tree assessment of controlled intra- and inter-specific hybrids. *Canadian journal of Forest Research* 33: 897–909.
- MOMOSE Y. 1978. Vegetative propagation of Malaysian trees. *Malaysian Forester* 41: 219–223.
- MORI T. 1980. *Physiological Studies on Some Dipterocarp Species of Peninsula Malaysia as a Basis for Artificial Regeneration*. Research Pamphlet No. 78, Forestry Department Peninsula Malaysia, Kuala Lumpur.
- NAKAMURA K & KIMURA S. 1996. Technique of vegetative propagation on dipterocarps. *Tropical Forestry* 36: 37–46.
- NORAINI ABS & LIEW TS. 1994. Effects of plant materials, cutting positions, rooting media and IBA on rooting of *Shorea leprosula* (Dipterocarpaceae) Cuttings. *Pertanika Journal of Tropical Agricultural Science* 17: 49–53.
- NORAINI ABS & LIEW TS. 1997. Anatomical evidence of rooting ability of *Shorea leprosula* MiQ. and *Shorea curtisii* Dyer ex King cuttings. *Malaysian Forester* 60: 38–45.
- NORAINI ABS & LING TT. 1993. A note on the rooting of *Shorea acuminata* and *Shorea parvifolia* leafy stem cuttings. *Journal of Tropical Forest Science* 6: 206–208.
- ORIANI CM, BOLNICK DI, ROCHE BM ET AL. 1999. Water availability alters the relative performance of *Salix sericea*, *Salix eriocephala*, and their F<sub>1</sub> hybrids. *Canadian Journal of Botany* 77: 514–522.
- PRIADJATI A, SMITS WT & TOLKAMP GW. 2001. Vegetative propagation to assure a continuous supply of plant material for forest rehabilitation. Pp 19–30 in Hillegers PJM & Iongh HHD (eds) *The Balance Between Biodiversity Conservation and Sustainable Use of Tropical Rain Forests*. The Tropenbos Foundation, Wageningen.
- SAKAI C & SUBIAKTO A. 2007. *Manual of Mass Propagation Technique of Dipterocarps Species by KOFFCO System*. The collaboration project among FORDA, JICA, Komatsu Ltd, Bogor.
- SAKAI C, SUBIAKTO A, NURONIAH HS ET AL. 2002. Mass propagation method from the cutting of three dipterocarp species. *Journal of Forest Research* 7: 73–80.
- SAKAI C & YAMAMOTO Y. 1995. Vegetative propagation of dipterocarps. *Tropical Forestry* 33: 23–29.
- SASAKI S. 2011. Ecology and physiology of Dipterocarpaceae. Pp 3–22 in Suzuki K et al. (eds) *Plantation Technology in Tropical Forest Science*. Springer, Tokyo.
- SMITS WTHM. 1983. Vegetative propagation of *Shorea obtusa* and *Agathis dammara* by means of leaf cuttings and stem cutting. *Malaysian Forester* 46: 175–185.
- SOKAL RR & ROHLF FJ. 1995. *Biometry. The Principles and Practice of Statistics in Biological Research*. 3<sup>rd</sup> edition. W. H. Freeman and Company, New York.
- SRIVASTAVA PBL & MANGGIL P. 1981. Vegetative propagation of dipterocarps. *Malaysian Forester* 44: 301–313.
- SYMINGTON CF. 2004. *Foresters' Manual of Dipterocarps*. Second edition. Malayan Forest Records 16. Forest Research Institute Malaysia, Kuala Lumpur.
- TATE HT & PAGE T. 2018. Cutting propagation of *Santalum austrocaledonicum*: the effect of genotype, cutting source, cutting size, propagation medium, IBA and irradiance. *New Forests* 49: 551–570.
- TEWARI DN. 1999. *A Monograph on Teak (Tectona grandis Linn.f.)*. International Book Distributors, Dehradun.
- THOMAS SC. 2003. Comparative biology of tropical trees: a perspective from Pasoh. Pp 171–194 in Okuda T et al. (eds) *Pasoh: Ecology of a Lowland Rain Forest in Southeast Asia*. Springer, Tokyo.
- TOLKAMP GW & PRIADJATI A. 1996. The effect of different stock plant types (hedge orchards) and cutting media on the rooting ability of 14 Dipterocarp species. Pp 197–215 in Appanah S & Khoo KC (eds) *Proceedings of the Fifth Round Table Conference on Dipterocarps. Chiang Mai, Thailand 7–10 November 1994*. Forest Research Institute Malaysia, Kuala Lumpur.
- WEBSTER CC & BAULKWILL WJ. 1989. *Rubber. Tropical Agriculture Series*. Longman Science & Technical, Essex.
- YAMATE H & HIRASAWA T. 1995. Rooting of cuttings of dipterocarps. *Tropical Forestry* 33: 48–52.