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Original Article

Effect of position and size of leaflets on rooting and rhizome formation of ZZ plant (*Zamioculcas zamiifolia* (Lodd.) Engl.) leaflet cuttings

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ABSTRACT

Rooting and rhizome formation was compared of ZZ plant leaflet cuttings taken from the apical, middle, and basal positions of the petiole. Leaflets from each position were propagated as a whole leaflet, an upper half leaflet segment and a lower-half leaflet segment. Whole leaflets from the basal position had greater size and fresh weight than those from the middle and the apical positions, respectively. The upper and the lower half leaflet segments were comparable in size but the lower ones had greater fresh weight. The three cutting types from different positions yielded 90–100% success in rooting and rhizome formation with one small rhizome per cutting on average. However, the root number, root quality score and rhizome size of the whole leaflet cuttings were significantly greater than those of the lower half leaflet segments and the upper ones, respectively. The initial size and fresh weight of cuttings positively correlated with the size of the rhizome produced. The first new shoot produced from the whole leaflet cuttings was larger than that of the lower half leaflet segments and the upper ones, respectively. These results suggested that leaflets taken from the apical, middle and basal positions of the petiole were equally capable of rooting and rhizome formation. An attempt to increase the number of propagules by using leaflet segments was feasible at the expense of a reduced root number per cutting, root quality, size of rhizome and size of a new shoot.

Introduction

Zamioculcas zamiifolia (Lodd.) Engl. is an ornamental plant in the family Araceae that has been known by several common names such as aroid palm, arum fern, emerald frond, money plant, fat boy and ZZ plant or ZZ in short. It is a stemless herbaceous perennial with stout, fleshy petioles bearing alternate pinnate dark green glossy leaflets that arise directly from thick, tuber-like rhizomes (Huxley, 1994). It has become a popular indoor pot plant worldwide due to its unique appearance, ability to tolerate low light conditions and drought and its resistance to diseases and insect pests (Chen and Henny, 2003). ZZ plants can be propagated asexually by rhizome division, leaflet cutting, and petiole cutting. To propagate from a leaflet cutting, an individual leaflet is directly inserted into rooting medium or large leaflets may be cut horizontally in half into two pieces to increase the number of propagules and propagated by sticking the basal cut end into the rooting media (Cutter, 1962). Under optimum conditions in a shade house with photosynthetically active radiation (PAR) at 100–200 μmol/m^2/s, 24–32 °C and 60–100% RH, a small rhizome formed at the base of cuttings within 1 mo after sticking, followed by emergence of adventitious roots and after another one mo or more, the first shoot emerged from a newly formed rhizome (Chen and Henny, 2003). The first new leaf was small with two pinnate leaflets on a short and slim petiole. As a rhizome grows larger, it produces leaves with more leaflets of larger size on a longer and stout petiole (Cutter, 1962). A whole leaflet cutting generally yields only one rhizome per leaflet, while the upper half leaflet segments (horizontal cut the whole leaflet at midpoint perpendicular to the midrib) with more wounded surface area produced 3–5 small rhizomes per piece, particularly under an extended light period (daily light integral) to 16 h (Lopez et al., 2009). Propagation by leaflet cutting has a high success rate and rooting stimulant application is not necessary (Chen and Henny, 2003). However, the ZZ plant grows very slowly. Starting with leaflet cutting, it takes one yr or more to reach a salable size. Therefore, a method that increases the rhizome size may promote leaf growth of this plant. Leaflet cuttings propagated in peat moss or sand and rice husk charcoal mix (1:1 by volume) produced a larger rhizome with better root quality and the new shoot emerged earlier compared to those in coir dust and rice husk charcoal mix or coir dust and sand mix (Sinthanayothin et al., 2014). Seneviratne et al. (2013) reported that basal leaflets without

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a rachis were the best choice for cuttings compared to a leaflet from the middle, and apical positions of a petiole; however, the rooting percentage and the size of the new rhizome obtained were not mentioned. Furthermore, two leaflets with a rachis (larger leaf area) from those three positions did not perform better than a single leaflet without a rachis.

The objective of the current study was to investigate the effect of the position and size of leaflets on rooting, rhizome formation and subsequent shoot growth of ZZ plant leaflet cuttings. Whole leaflets, as well as leaflet segments (upper halves and lower halves obtained by horizontally cutting a leaflet at its midpoint), were compared.

Materials and methods

Healthy and uniform mature leaves of ZZ plants with 18–20 leaflets on a petiole were obtained from stock plants maintained in a lath house. Five leaflets were taken from the apical, middle and basal positions of each petiole. They were cut horizontally (perpendicular to the midrib) at the midpoint into upper half and lower half segments or left as whole leaflets. The areas of each whole leaflet and the half segments were recorded using a leaf area meter (LI-3100; LI-COR Inc.; Lincoln, NE, USA) and their fresh weight determined. Cuttings were then disinfected in thiram solution (tetramethylthiuram, wettable powder, 80% active ingredient) for 15 min and allowed to dry in the shade before sticking into propagation media. Whole leaflets and half leaflet segments were then propagated in a plastic tray filled with rooting media containing sand and coir dust (1:1 by volume) and maintained in a 70% shaded lath house covered with black saran netting. The average temperature and relative humidity during propagation were 32 °C and 85%, respectively. Cuttings were watered thoroughly every other day using tap water. Rooting stimulant was not applied.

The rooting and rhizome formation of each cutting was determined after sticking in the propagation media for 60 d. The number of rhizomes per cutting and rhizome size (width and length) were recorded. The rooting percentage and number of roots per cutting were determined. The root quality was scored visually using a scale of 1–5 based on root numbers and their vigor, where: 1 = very poor, with less than 3 roots per cutting, roots small and either too short or too long; 2 = poor, with 3–4 roots per cutting, roots small and either too short or too long; 3 = fair, with 5–6 roots per cutting, roots large and healthy and 3–5 cm long; 4 = good, with 6–7 roots per cutting, roots, large and healthy and 3–5 cm long; and 5 = very good, with more than 8 roots per cutting, roots large and healthy and 3–5 cm long. Rooted cuttings were then transplanted into a 10 cm plastic pot (~500 cm^3) filled with soil mix (topsoil, sand, coir dust, rice husk charcoal, and manure; 1:1:1:1:0.5 by volume) with one cutting per pot. They were maintained in the same lath house and watered every two d. The length of the first shoot and its leaflet were determined after transplanting for 60 d.

The experiment was conducted in a completely randomized design. Each treatment consisted of 15 whole leaflets or half leaflet segments (three replications per treatment, five pieces per replication). Data were subjected to analysis of variance and mean separation was determined using Duncan's multiple range test. The relationships among the size of cuttings, fresh weight of cuttings and size of rhizome produced were determined using regression analysis.

Results

Initial size of cuttings

Leaflets from the basal position of the petiole had larger areas and fresh weights than those from the middle and the apical positions, respectively. When the leaflets from each position were cut horizontally at the midpoint, the upper and the lower half segments were comparable in area and the lower halves tended to have slightly greater fresh weight than the upper ones (Table 1).

Rooting and rhizome formation

Leaflet cuttings produced small rhizomes and adventitious roots readily after sticking into rooting media for 2.5 mo. All three types of leaflet cuttings from different positions yielded 90–100% rhizome and adventitious root formation, with one rhizome per cutting in general. Only a few whole leaflet cuttings from the apical position and upper half leaflet segments from the basal position became rotten before forming rhizomes and adventitious roots. Whole leaflet cuttings had greater root numbers (~six roots/cutting) than the lower half segments (~five roots/cutting) and the upper half segments (three roots/cutting), respectively. Whole leaflet cuttings and lower half leaflet segments had comparable root quality scores which were greater than for the upper half leaflet segments. Whole leaflet cuttings produced larger rhizomes than the lower half segments and the upper ones, respectively. Leaflet position did not influence the rhizome size produced (Table 2).

Initial sizes and fresh weight of cuttings were positively correlated with the size of the rhizome produced (Figs. 1 and 2). The larger size cuttings tended to produce larger rhizomes.

Subsequent growth of new shoot

A new shoot with two leaflets began to emerge 45 d after transplantation of rooted cuttings into a 10 cm pot. However, shoot emergence varied greatly within a treatment. Large rhizomes did not necessarily produce a new shoot faster than smaller ones and some rooted cuttings stayed green and alive without producing any new shoot at 60 d after transplanting. The whole leaflet cuttings produced a larger new shoot than the lower half leaflet segments and the upper ones, respectively. Leaflet cuttings taken from the basal position of the petiole tended to produce a new shoot with greater length and larger size of leaflets than those from the other positions (Table 3).

Discussion

Leaflets of ZZ plants were reported to develop in basipetal sequence and to show a basipetal gradient in leaf size (Arunika et al., 2006). The leaf area and fresh weight of leaflets from different positions in the current study agreed well with this

Table 1
Area and fresh weight of whole leaflets, upper half and lower half leaflet segments from apical, middle, and basal positions of the petiole before sticking into rooting media.

Leaflet position	Area (cm^2)	Fresh weight (g)
Whole leaflet		
Apical	21.9^{c,†}	1.26^{c,†}
Middle	29.9^{b}	1.69^{b}
Basal	34.5^{a}	2.02^{a}
Upper half		
Apical	12.7^{ef}	0.64^{f}
Middle	15.8^{def}	0.80^{ef}
Basal	17.0^{de}	0.86^{def}
Lower half		
Apical	11.6^{f}	0.74^{ef}
Middle	15.8^{def}	1.02^{cde}
Basal	17.6^{d}	1.13^{cd}

† Means superscripted with different letters in the same column are significantly different ($p < 0.05$).

Table 2
Rooting and rhizome formation of *Zamioculcas zamiifolia* leaflet cuttings (whole leaflets, upper half, and lower half leaflet segments) taken from different petiole positions after sticking into rooting media for 2.5 mo.

Leaflet position	Rooting			Rhizome formation		Rhizome size (cm)	
	(%)	Roots/cutting	Score	(%)	Rhizomes/cutting	Length	Width
Whole leaflet							
Top	90	6.2[a,†]	3.3[ab,†]	90	0.9[b,†]	1.49[a,†]	1.24[a,†]
Middle	100	6.8[a]	3.5[a]	100	1.0[b]	1.69[a]	1.33[a]
Bottom	100	6.3[a]	3.5[a]	100	1.0[b]	1.69[a]	1.36[a]
Upper half							
Top	100	2.9[c]	2.1[c]	100	1.3[a]	0.82[d]	0.72[d]
Middle	100	3.3[c]	2.3[c]	100	1.1[b]	1.00[c]	0.79[d]
Bottom	90	3.3[c]	2.2[c]	90	1.0[b]	0.92[cd]	0.76[d]
Lower half							
Top	100	4.6[bc]	3.0[ab]	100	1.0[b]	1.12[c]	0.90[c]
Middle	100	5.2[b]	3.2[ab]	100	1.0[b]	1.29[b]	1.10[b]
Bottom	100	4.8[b]	3.1[ab]	100	1.0[b]	1.29[b]	1.10[b]

[†] Means superscripted with different letters in the same column are statistically different ($p < 0.05$).

previous report. This developmental gradient seemed to affect the rooting ability of cuttings in other species. Leaf-bud cuttings of *Schefflera arboricola* taken from sub-apical positions had a lower rooting percentage and rooted more slowly than cuttings taken from more basal regions (Hansen, 1986). Seneviratne et al. (2013) also suggested that basal leaflets of ZZ plants without a rachis were the best choice for cuttings compared to a leaflet from the middle and apical positions of a petiole. All types of leaflet cuttings in the current study yielded 90–100% success in rooting and rhizome formation within 60 d of propagation, indicating that the position and size of leaflets did not affect the ability of leaflet cuttings to root and form rhizomes. All types of leaflet cuttings rooted and formed rhizomes uniformly without any application of plant growth regulators. This suggested that substances required for the initiation of adventitious roots and rhizome such as auxins, rooting cofactors and carbohydrates were readily available and sufficient in both the larger tissues of the whole leaflets and the smaller tissues of the upper and lower half segments of leaflets from different positions along the petiole. Generally, each cutting produced one rhizome at the bottom cut end of the whole leaflets and the lower half segments, and at the midrib area of the cut end of the upper half segments. In another study, 3–5 small rhizomes per piece of upper half segments could possibly occur when cuttings were propagated under increased daily light interval conditions (Lopez et al., 2009). Cutter (1962) reported that de-differentiation of tissues associated with vascular bundles in the midrib and minor veins of ZZ plant leaflet cuttings resulted in the formation of the rhizome. This discrepancy in numbers of rhizomes produced was in part due to the differences in leaflet conditions and propagation environment.

Whole leaflet cuttings which were larger in size and fresh weight had greater root numbers per cutting and larger rhizomes and produced larger-sized new shoots than those of the half leaflet segments (Table 2; Figs. 1 and 2). This could be explained by the source-sink relationship effect where the whole leaflets or their segments served as a source to supply photoassimilate to the active sinks including adventitious roots and a starch-rich rhizome (Cutter, 1962). The growth of the whole leaflets and their segments was limited because they had already fully expanded at the time the cutting was taken. Photosynthesis of the cuttings was generally low after excision from the source plant and remained low until adventitious roots emerged (Davis, 1988). Therefore, the growth of adventitious roots and rhizome of ZZ plant leaflet cuttings during propagation was largely determined by the amount of carbohydrate reserves in the source and the photosynthetic capacity of the cuttings after root emergence. An increase in sink demand of the enlarging storage roots of sweet potato in a rooted, single-leaf cutting system was associated with an expression of genes for starch synthesis and modification (Kim et al., 2005). A similar pattern was assumed to occur in ZZ plant leaflet cuttings. An increased daily light interval that may increase photosynthesis of leaflets during propagation could enhance the rhizome size and root numbers per cutting (Hutchinson et al., 2012).

Unlike rooting and rhizome formation which was very uniform, the emergence of a new shoot from a developing rhizome of the ZZ plant leaflet cuttings was not uniform, regardless of the initial size of the rhizome at transplanting. The non-uniform emergence of the first new shoot had never been mentioned in other studies and the control mechanism of shoot emergence in this plant is still not known. Chen and Henny (2003) reported the time to first shoot

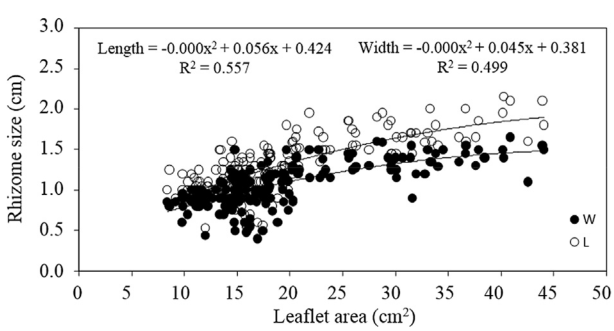

Fig. 1. Relationship between leaf area of leaflet cuttings and rhizome size (W = width and L = length) produced, with the range in leaf area due to leaflet position on the petiole and type of cutting (whole leaflet, upper half and lower half leaflet segments).

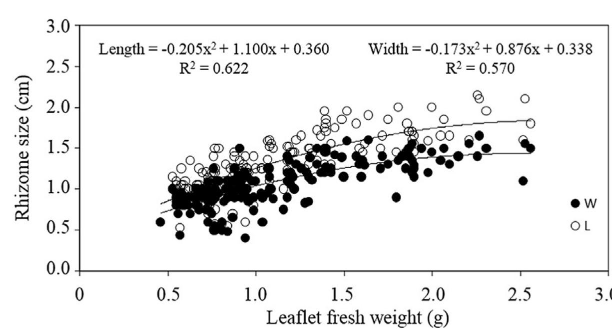

Fig. 2. Relationship between fresh weight of leaflet cuttings and rhizome size (W = width and L = length) produced, with the range in fresh weight due to leaflet position on the petiole and type of cutting (whole leaflet, upper half and lower half leaflet segments).

Table 3
Length of the first shoot and its leaflets of rooted leaflet cuttings at 60 d after transplantation, where leaflet cuttings were taken from different petiole positions and three types of cutting (whole leaflet, upper half and lower half leaflet segments) were compared.

Leaflet position	Length (cm)	
	First shoot	Leaflet
Whole leaflet		
Apical	4.20[b,†]	5.57[a,†]
Middle	4.51[b]	5.22[a]
Basal	6.06[a]	5.66[a]
Upper half		
Apical	1.06[d]	2.36[cd]
Middle	0.99[d]	2.02[d]
Basal	1.91[c]	2.61[cd]
Lower half		
Apical	1.39[cd]	2.74[bc]
Middle	1.55[cd]	2.84[bc]
Basal	1.97[c]	3.11[b]

[†] Means with different letters in the same column are statistically different using Duncan's multiple range test ($p < 0.05$).

emergence of ZZ plant leaflet cuttings was around 65 d after propagation. In the current study, some leaflet cuttings with delayed shoot emergence (time to emergence of the first new shoot >80 d after propagation) produced a larger new shoot with four pinnate leaflets (data not shown). The conditions and treatments which can induce more uniform shoot emergence of rooted leaflet cuttings of ZZ plants are of interest.

In summary, leaflet cuttings taken from the apical, middle and basal parts of the petiole of ZZ plants either propagated as the whole leaflet cutting, the upper half or the lower half leaflet segments were all capable of forming rhizomes and adventitious roots within 75 d of sticking into rooting media with a high success rate of up to 90–100%. All three types of cuttings generally produced a single rhizome but whole leaflet cuttings produced a larger rhizome and more roots per cutting than the lower half and the upper half leaflet segments, respectively. The root quality of cuttings from the whole leaflets and the lower half leaflet segments was comparable and better than that of the upper half ones. The influence of leaflet position on the rhizome and adventitious root formation of cuttings was not significant. The initial size and fresh weight of cuttings positively correlated well with the size of the rhizome produced. The first shoot emerged within 45 d after transplantation of rooted cuttings into a 10 cm pot. The length of the first shoot and its leaflets was also greater in the whole leaflet cuttings than those of the lower half and the upper half leaflet segments, respectively.

Conflict of interest

The authors declare that there are no conflicts of interest.

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