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Vessel-Length Distribution in Stems of Rattan (*Calamus* SPP.)

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ABSTRAK

Taburan panjang vesel di dalam batang rotan manau (Calamus manan Miq.), rotan dok (C. ornatus Blume) dan rotan jelayang (C. peregrinus Furtado) telah dihitung melalui pengukuran kemasukan partikel. Oleh kerana panjang sampel rotan yang terhad, kelas vesel terpanjang yang ditentukan adalah di bawah 40 cm. Dianggarkan 71-80% vesel yang dikira didalam batang rotan adalah melebihi 36 cm panjang. Peratus tertinggi vesel di dalam kelas ini adalah Calamus manan diikuti oleh C. peregrinus dan C. ornatus. Taburan vesel yang terpendek adalah di kelas 6-9 cm panjang yang merangkumi 27% vesel yang dikira untuk batang C. peregrinus. Taburan vesel terpendek di dalam batang C. manan adalah 9-12 cm panjang (6%) dan di dalam batang C. ornatus adalah 12-15 cm panjang (8%). Vesel pendek yang bertaburan di dalam batang rotan mungkin disebabkan oleh vesel terhenti atau percantuman dengan vesel lain di kompleks bekas daun berdekatan bahagian buku atau vesel metaxylem kecil yang bertabur di bahagian luar batang rotan. Cara yang terbaik untuk menganggarkan taburan panjang vesel adalah dengan menggunakan sampel yang lebih panjang dari vesel terpanjang yang bertabur di dalam batang berkenaan.

ABSTRACT

Vessel-length distributions in the stems of rotan manau (Calamus manan Miq.), rotan dok (C. ornatus Blume) and rotan jelayang (C. peregrinus Furtado) have been calculated from measurements of particle penetration. Due to the limitation of the length of the samples, the longest class of vessel determined was below 40 cm. Approximately, 71-80% of the vessels that were counted for the rattan stems were more than 36 cm long. The largest percentage of vessel in this class was Calamus manan followed by C. peregrinus and C. ornatus. The shortest vessel-length distributed was in the class of 6-9 cm long which constituted 27% of the vessels counted in the stem of C. peregrinus. The shortest vessel-length distributed respectively in C. manan and C. ornatus were in the class of 9-12 cm long (6%) and 12-15 cm long (8%). The shorter vessels found distributed in the rattan stems could either be the vessels that end or form bridges at the leaf trace complex near the leaf base (nodal section) or could be the smaller metaxylem vessels that are distributed near the periphery of the rattan stem. The appropriate way of estimating the distribution of vessel-length of any stem is to use sample in the experiment longer than the longest available vessel.

INTRODUCTION

The macroscopic and microscopic study of vessel, a conducting unit of the xylem consisting of a finite number of individual elements arranged end to end, have been established well over a century (Zimmermman *et al.* 1982). In palm stems, particularly *Calamus* spp., the metaxylem vessel present in the vascular bundle may consist of one or two vessels. They are composed of an axial series of elements which are joined together to form a tube-like structure of indeterminate length serving primarily for water conduction (Tomlinson and Zimmermman 1967). Mostly a simple perforation plate interconnects the vessel elements with each other. However, scalariform perforation plates are also present in smaller metaxylem vessel elements for *Calamus* spp. (Bhat *et al.* 1988).

Vessel elements for *Calamus* spp. vary greatly in diameter. For instance, in *Calamus manan*, the smallest pores near the outer layer have an average diameter of 400 µm while the largest in the central layer has a diameter more than 700 µm (Zaidon *et al.* 1996). The metaxylem vessels contribute an average of 17% of the total volume of the *Calamus* stems. Vessels in the rattan stem are far too long to be seen in their entirety in single microtome sections. Maceration may reveal individual elements that can be interpreted as vessel ends (Bierhorst and Zamora 1965; Handley 1936), but terminal elements are thus seen only in isolation.

Length and arrangements of vessels within the xylem are of interest to anyone studying the hydraulic construction of long distance transport channels of plants with relevant implications of physiology, pathology, stem preservation and other disciplines. However, very little, if any information on vessel length distribution in the stems of *Calamus* spp. is known.

This paper reveals the distribution of vessel length in the stem of some *Calamus* spp. The principle paint infusion method (Zimmermman and Jeje 1981) was used whereby the number of vessels that are cut open at both ends in successively shorter pieces of wood was determined.

MATERIALS AND METHODS

Five, fresh stems of each rotan manau (*Calamus manan* Miq.), rotan dok (C. *ornatus* Blume) and rotan jelayang (C. *peregrinus* Furtado) were selected for the study. The longest rattan stems for individual species available for this study were about 40 cm.

Vessel-length distribution measurements in the three rattan species were made by the alkyd-paint infusion technique (Zimmermman and Jeje 1981). Paint particles, when sufficiently small, can pass through scalariform plates, but they cannot pass vessel-to-vessel pit membranes. The infusion of paint was done from the morphological upper end to confine measurement to an axial direction and avoid complications of vessels from the main stem passing into branches.

The ends of the stem were trimmed with a razor blade and washed under running water to remove debris or particles from the end surfaces. They were then vacuum-infiltrated with distilled water to remove any air that might have been drawn into the vessels during drying. This was done by dipping the lower end into distilled water while the other end was connected to a water vacuum pump. A partial-vacuum (22 mm Hg) was applied and water was allowed to flow through the stem for a few minutes.

The paint suspension was prepared by diluting 1 part of commercial alkyd-paint (The special paint people, Southampton, England) which is red in colour, and easily seen against the colour of the rattan, to 50 parts of white spirit (Bartoline Ltd., Beverley, England). Initially, several formulations of paint suspension were tried, but it was found that the above formulation yielded a good result where the painted vessels could easily be seen under the microscope. The suspension was left standing for a day while the larger particles settled. The red suspension used for the infusion contained very small particles *ca.* 7 µm diameter (measured under the projecting microscope). Such particle size is believed to be easily carried along vessels of *Calamus* species. On the other hand, such particles presumably pass neither through the vessel walls nor through pit membranes. Zimmermann and Jeje (1981) reported that small particles less than 1 µm cannot pass through vessel walls of shrubs or diffuse-porous hardwoods but can pass through scalariform perforation plates. They also found that the particles did not penetrate the vessel ends when a pressure of 0.5 to 1 atm was applied.

A schematic diagram of the apparatus used to infuse the paint into rattan is illustrated in *Fig. 1*. A sharpened stainless steel tube (5 mm internal diameter) was tapped into the shaved upper end surface of the sample at one side. The screw on the surface of the steel tube is to release any air bubbles formed in the solution, which may resist further paint movement within the vessels. The polyethylene tubing was filled with 250 ml of paint suspension and was fed by gravity (80 cm height) into the sample, which lay in a horizontal position. The process was continued until the rate of uptake slowed down. Air pressure (0.68 atm) from a compressor was then applied at the upper end of the tubing. Pressure injection takes the suspension to the vessel ends and gradually increases their local concentration by lateral solvent loss (i.e. filtration) (Zimmermann and Jeje 1981). This process took approximately 30 minutes.

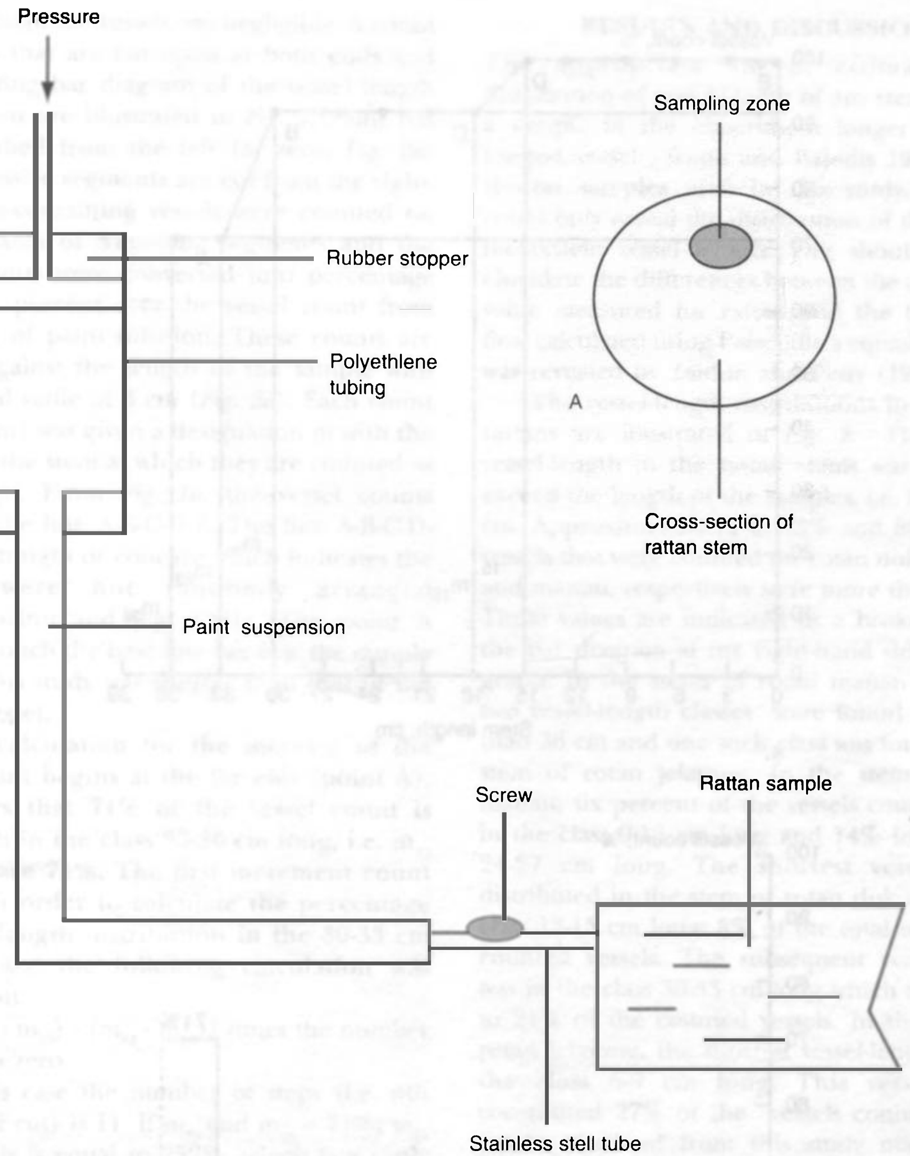

Fig 1. Schematic diagram of the apparatus used to infuse alkyd-paint into a rattan sample. A: The paint applicator is tapped into the shaved end near the periphery of the rattan stem for random sampling

At the end of the infusion time, the sample was removed from the apparatus and both end surfaces were trimmed with a razor blade to remove excess suspension. The sample was then cut into segments of 3 cm long and faces of the segments for vessel counting were trimmed smoothly with a razor blade. These were left to dry overnight at room temperature. The paint-containing vessels were counted under a magnifying microscope (40X, digital positiometer microscope, Stemi DRC, Zeiss, Germany). A geometrical analysis developed by Zimmermann and Jeje (1981) was employed to estimate the average vessel-length distribution, which is described below.

Interpretation of Data

Fig. 2 illustrates how the calculations were carried out using a hypothetical rattan stem with 71% of its vessel (as shown in *Fig. 2b*) is more than 33-36 cm long, 21% is 30-33 cm long and 8% is 15-18 cm long. The calculations of the distribution of vessel-length were made assuming that the effect of blockage on the movement of

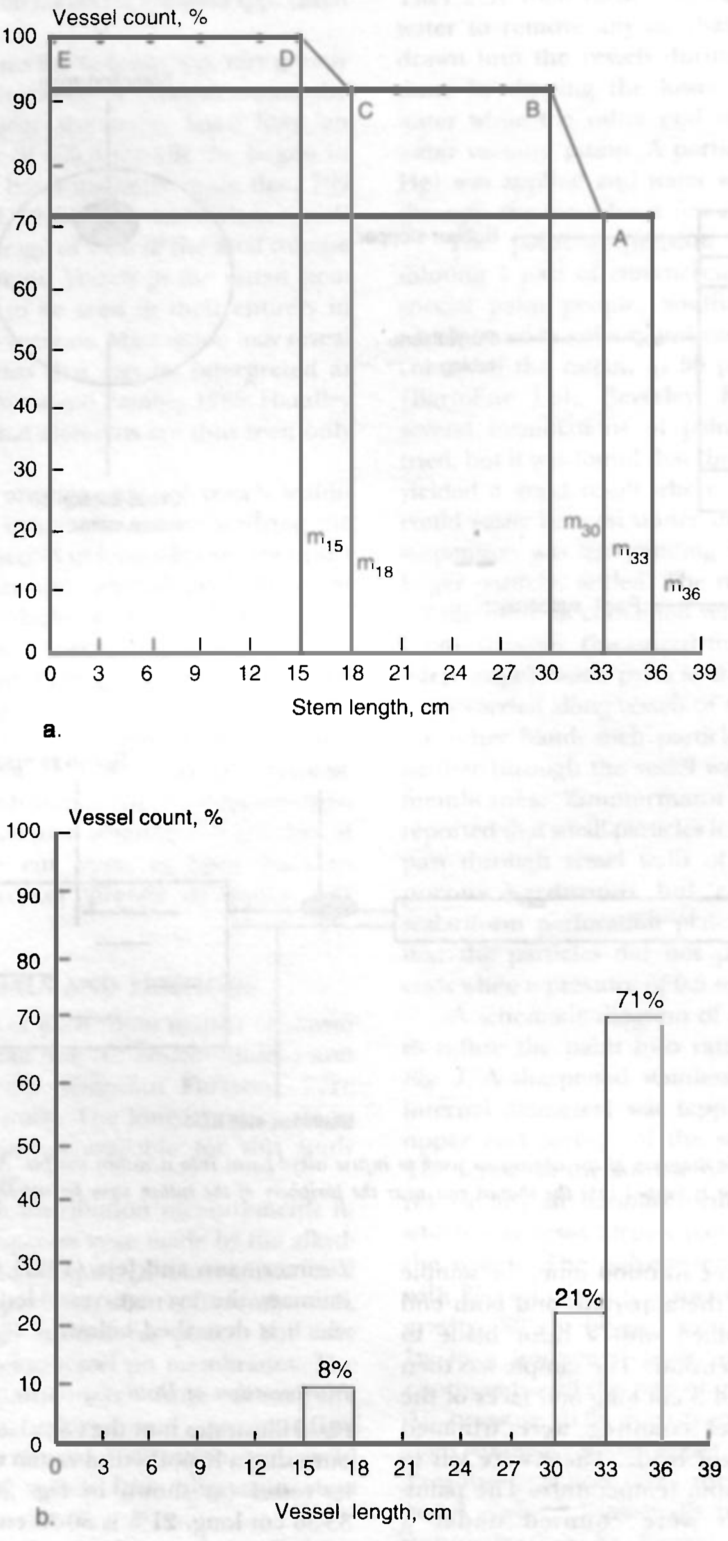

Fig 2. a: A count of vessels that are cut open at both ends, follows the line A-B-C-D-E; b: The resulting bar diagram shows vessel length distribution

paint through the vessels was negligible. A count of vessels that are cut open at both ends and the resulting bar diagram of the vessel length distribution are illustrated in *Fig. 1.* Paint has been applied from the left (at zero, *Fig. 2a*) and successive segments are cut from the right. The paint-containing vessels were counted on the cut faces of 3-cm-long segments and the vessel counts were converted into percentage value, i.e. percent over the vessel count from the point of paint infusion. These counts are plotted against the length of the sample with an interval value of 3 cm (*Fig. 2a*). Each count (in percent) was given a designation m with the length of the stem at which they are counted as a subscript. From *Fig. 1a*, the vessel counts result in the line A-B-C-D-E. The line A-B-C-D-E is not straight or concave which indicates the vessels were not randomly arranged (Zimmermann and Jeje 1981). The point A does not touch the base line because the sample used in this study was shorter than that of the longest vessel.

The calculation for the increase of the vessel count begins at the far end (point A). It appears that 71% of the vessel count is more than in the class 33-36 cm long, i.e. m_{33} and m_{36}, are 71%. The first increment count is m_{33} . In order to calculate the percentage of vessel length distribution in the 30-33 cm length class, the following calculation was carried out:

$[(m_{30} - m_{33}) - (m_{33} - m_{36})]$ times the number of steps to zero.

In this case the number of steps (i.e. nth number of cut) is 11. If m_{36} and m_{33} = 71%, m_{30} = 92%, this is equal to 252%, which is a vastly exaggerated. However, for the next adjacent calculation a virtual count at $[(m_{30}- m_{33}) - (m_{33}- m_{30})]$ x 10 yielded = -231%. Addition of these two values yields 21%, i.e. 21% of the vessels are in 30-33 cm length class. At 27-30 cm class, the vessel count does not change and the calculation will yield zero. The calculation continues step by step until the 15-18 cm length class. At this point the calculated value is $[(m_{12}- m_{15}) - (m_{15} - m_{18})]$ x 6 = 48%, it follows that -40% in the next adjacent calculation. The net results are 8%, indicating vessels of the 15-18 cm length class. From here to zero, results are similarly zero. The resulting vessel length distribution is shown in the lower half of *Fig. 2b*.

RESULTS AND DISCUSSION

The appropriate way of estimating the distribution of vessel-length of any stem is to use a sample in the experiment longer than the longest vessel (Skene and Balodis 1968). The shorter samples used in this study, however, could only reveal the distribution of the shorter metaxylem vessel length. This should help to elucidate the differences between the actual flow value measured for rattan and the theoretical flow calculated using Poiseuille's equation, which was revealed by Zaidon and Petty (1998).

The vessel-length distributions in the three rattans are illustrated in *Fig. 3.* The longest vessel-length in the rattan stems was found to exceed the length of the samples, i.e. beyond 36 cm. Approximately, 71%, 73% and 80% of the vessels that were counted for rotan dok, jelayang and manau, respectively were more than 36 cm. These values are indicated by a broken line in the bar diagram at the right-hand side of each graph. In the stems of rotan manau and dok, two vessel-length classes were found to be less than 36 cm and one such class was found in the stem of rotan jelayang. In the stem of rotan manau, six percent of the vessels counted were in the class 9-12 cm long and 14% in the class 24-27 cm long. The shortest vessel-length distributed in the stem of rotan dok was in the class 12-15 cm long: 8% of the total number of counted vessels. The subsequent vessel-length was in the class 30-33 cm long which amounted to 21% of the counted vessels. In the stem of rotan jelayang, the shortest vessel-length fell in the class 6-9 cm long. This vessel-length constituted 27% of the vessels counted. The results obtained from this study may not be reliable due to the presence of gum in some of the vessels which may obstruct the movement of the paint. Nevertheless, in some cases, the paint could be seen passing through the vessels which were partially occluded with the gummy substance.

Two arguments probably help to explain the lower amount of shorter vessel lengths found distributed in the rattan stem. First, the shorter vessels could be the vessels that end or form bridges at the leaf trace complex near the leaf base (nodal section), and second, the shorter vessels could be the smaller metaxylem vessels that are distributed near the periphery of the rattan stem.

In the stem of palm (*Raphis excelsa*), Zimmermann *et al.* (1982) revealed that the

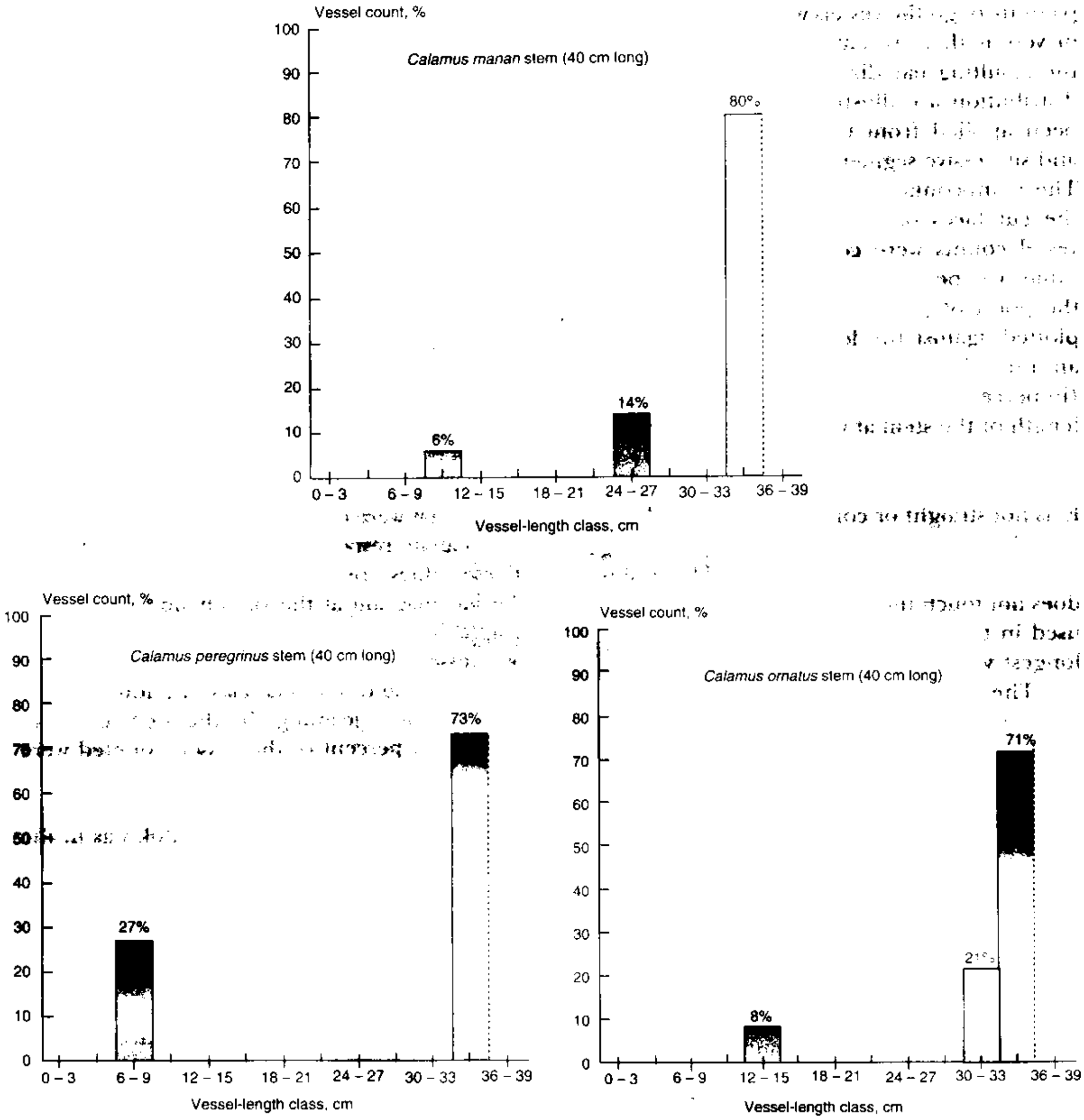

Fig 3. Vessel length distribution in rattan stems. a: C. manan; b: C. peregrinus and c: C. ornatus

axial bundles follow a helical path in which some of the vessels reach the stem centre while the others may end or form bridges at the leaf trace complex near the leaf base. They noted that the vessels of the 0-5 cm length class were the vessels of the leaf trace complex area, while the longer vessels were primarily those of the axial bundles reaching the stem centre. These phenomena might occur in the stem of the rattans. The distinctive scattering of the paint-containing vessels on the cut surface at the far end of the stem indicate that the axial bundles follow the helical path as in the stem of *Raphis excelsa*.

It has also been known for many years that the vessel length in a woody material is positively correlated with vessel diameter (Handley 1936; Greenidge 1952). This was further reviewed by Zimmermann and Jeje (1981). The authors reported that in ring-porous trees, particularly red oak (*Quercus rubra*) which have large diameter (ca. 300 μm) earlywood vessels, have vessels in a class of 8-10 m long. They also noted very long vessels (ca. 8 m) in a shrub stem of grapevine (*Vitis labrusca*), whose vessel diameter is also large. However, the length of the narrow latewood vessels of red oak is much shorter: the longest vessels measured were less than 1 m. In addition, the authors also found that a diffuse-porous stem (*Acer saccharum*) and a shrub (*Vaccinium corymbosum*) both of vessel diameter *ca.* 75 μm, did not have vessels longer than 32 cm and 1.3 m, respectively. This might also occur in the stem of the rattan as the vessels vary considerably in diameter. For example, rotan manau's vessel diameter ranges from 277 to 406 μm (Zaidon *et al.* 1996). Due to the large vessel diameter of the rattans, it is not suprising that some of the vessels can be as long as the stem of the plant. This argument can only be confirmed if the sample employed for this measurement is longer than that of the longest vessel. Such samples were not available.

CONCLUSION

The distribution of vessel length in the stems of *Calamus* spp has been successfully determined using the alkyd-paint infusion method described by Zimmermman and Jeje (1981). The appropriate way of estimating the distribution of vessel-length of any stem is to use a sample in the experiment longer than the longest vessel. The following conclusion was drawn based on the limited length of the samples. The longest vessel-length in the rattan stems exceed 36 cm in which rotan manau having the highest proportion followed by rotan jelayang and dok. The shortest vessel length recorded for rotan manau was in the class of 9-12 cm, rotan jelayang, in the class of 6-9 cm, while rotan dok, in the class of 12-15 cm. The shorter vessels found in the rattan stems could either be the vessels that end or form bridges at the leaf trace complex near the leaf base (nodal section) or the smaller metaxylem vessels that are distributed near the periphery of the rattan stem.

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