Successive cambia in the mangrove *Avicennia*: a study on the three-dimensional structure of the cambia and the functioning of the internal phloem tissue

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Abstract

Background: Mangrove trees form unique forest at the edge of the land and sea. Amongst mangrove trees, the genus *Avicennia* L. stands out by successive cambia *i.e. having not one cambial layer but subsequent active cambia* and the organization of successive cambia seems to be very complex in three dimensional aspects and even in transverse sections. Further, secondary growth by successive cambia can offer *Avicennia* ecological advantages. Mangrove trees are subjected to variable demand for water transport in both time and space. Embolism *i.e. air bubble formation in the xylem sap, enlargement and therewith block the water transport,* is not a permanent process and plants can overcome the embolism removing the air bubbles in the embolized vessels. Among the different mechanisms suggested, osmotically driven mechanism *i.e. helps the embolized vessel in refilling making an osmotic gradient across the pit membrane, by which the water-filled vessel and gas-filled vessel is separated,* is widely accepted. Moreover, sugar molecules in the phloem conduits or/and wood parenchyma, supply to the embolized vessel segment that induces the water flow into the gas-filled vessel from adjacent water-filled vessel. Physiology of the phloem, then, has become more interesting for further investigations. Tracing method *i.e. introducing a tracer (this can be a dye, radio-isotopes or fluorescein) into the phloem,* has become a promising tool in terms of investigation the phloem physiology. If the tracer is a dye then its subsequent distribution can be readily followed from its colour.
Aims: This study aimed (i) at clarifying the organization of the three-dimensional structure of successive cambia of the mangrove species *Avicennia marina* (Forssk.) Vierh. at the cellular level through serial sectioning of wood stem (ii) to search the best method for the insertion of liquid (0.1% safranin solution) in to the phloem using *Bougainvillea* sp. (iii) to investigate whether the sugar molecules produced in the successive bands of parenchyma and phloem cells in *Avicennia marina* are involved, as osmotic driving force, in refilling embolized vessels and hence, in securing hydraulic conductivity.
Results: (i) The number of cells and the cell types markedly vary with vertical distance, especially in the branching points of the vascular tissue. These changes with vertical distance are due to cellular changes in parenchyma, sclerenchyma and fiber cells. (ii) the flap technique with mid vein is the best method to perfuse the dye into the plant. The distance travelled by the dye was 11 cm (SE +/- 1.52) relative to the point where it was perfused. (iii) the hypothesis that sugar molecules, in the successive phloem and parenchyma bands, help in refilling embolized vessels, through making an osmotic gradient, was not supported by the results.

Conclusion: (i) Parenchyma cells and xylem fiber cells arrangement and number of cells play the major role during the switching/changing of the branching pattern of the vascular tissues with vertical distance. (ii) The dye can be perused into the plant but selective labeling of the phloem is doubtful. The best method for the perfusion is the flap technique with mid vein (iii) the water loss from the non-covered parts of the stem (transpiration) seems to play a major role in the creation of embolisms. Prevention of water loss from the stem helps to keep an optimal hydraulic conductivity.
On account of the functional significance, given by the different cell types and arrangement of cells in successive cambia, hydraulic structure, promising optimal conductivity help *Avicennia* to cope with conflicting environmental conditions. Hence, *Avicennia* has become more eurytopic locally. These adaptations may also help us to clarify the large latitudinal distribution of *Avicennia.*

Keywords
mangrove forest, *Avicennia*, successive cambia