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Morpho-Anatomical Diversity of Roots of *Syzygium cumini* Skeels (Myrtaceae): An Adaptive Strategy Under Stress Ecosystem

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ABSTRACT

The paper describes for the first time the comparative morphology and anatomy of aerial and terrestrial roots of *Syzygium cumini* Skeels with special reference to an adaptive strategy**.** The aerial roots differ from terrestrial roots by its ephemeral nature, reddish pink to brownish colour with plenty of lenticels, lysigenous cavity and polyarch condition. Origin and occurrence of aerial roots with plenty of lenticels, lysigenous cavity in cortex and periderm indicate high adaptive strategy under stress ecosystem for survival and sustainable growth. *An adaptive* significance of morphological and anatomical features in dimorphic roots has been evaluated.

Key words: Adaptation, Aerial root, Anatomy, Myrtaceae.

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Introduction

Syzygium cumini Skeels (Myrtaceae) is an evergreen tree, indigenous to India, mainly distributed in temperate, subtropical and tropical regions of the world. The morphology and anatomy of dimorphic roots have received relatively more attention in families of monocots than the dicots. Except for a few notable exceptions like *Melaleuca linarifolia* and *Metrosideros hypericifolia* studied earlier by Lignier (1887), Solereder (1908), Musson and Carne (1910), Metcalfe and Chalk (1950), the root anatomy in majority of the myrtaceous forms has not been studied in great details. Although, earlier studies indicated taxonomic significance of anatomical characters for more than hundred years (Metcalfe & Chalk, 1950; Radford et al., 1974; Al-Edany & Al-Saadi, 2012).

The importance of the relationship between structure and function in plants has been recently recalled, considering that major metabolic and physiological processes are ultimately regulated by the physics of plant structure (Brodribb, 2009). The coordination between structure and function in plants is apparent when considering ecological trends in the evolution of morpho- anatomical traits. Adaptation to stress condition is based on many morpho-anatomical traits expressed in different organs at different levels. Therefore, in the present study, an attempt has been made to describe the dimorphic (aerial and terrestrial) roots of *S. cumini* with special reference to *an adaptive* significance of morphological and anatomical features for the first time. A preliminary account of these roots has already been reported by Misra and Singh (2007a).

Materials and Methods

The dimorphic roots of *S. cumini* were collected from Roxburgh Botanical Garden of Botany Department, University of Allahabad, Allahabad during the rainy season, soon after the onset of first monsoonic rains. Thereafter, the plant was identified with help of herbarium specimens deposited at Botany Department, University of Allahabad, Allahabad and perusual of literature (Roxburgh, 1832; Duthie, 1879; Bailey, 1949; Willis, 1973; Misra & Verma, 1992; Mabberly, 2008). The roots were taken out from plants and washed thoroughly in running tap water to remove the soil particles attached to its surface and subsequently, the material was fixed in FAA (Formaldehyde, Ethanol and Acetic Acid). Both aerial as well as terrestrial roots have been studied *in situ* as well as in *ex situ*. The study of external morphology was done by the technique adapted by Misra and Singh (2000a). Both hand and microtome sections were prepared for the present study. The roots were further macerated by Schulze's technique (Jeffrey, 1917; Johansen, 1940; Jane, 1956) and vascular elements were separated.

Presence of cutin in the roots was tested with Sudan IV and other microchemical tests for presence of lignin and starch were made by phloroglucinol and iodine solutions respectively. The terminology used in the present text is followed after Jeffrey (1917), Metcalfe and Chalk (1950), Esau (1965a,b), Mouseth (1988) and Fahn (1997).

Observations

External Morphology

S. cumini is a large evergreen tree with numerous branches. The plant shows the presence of aerial as well as terrestrial roots. Both aerial and terrestrial roots are positively geotropic; the aerial roots in the plant are usually produced during the rainy season and project out from the bark of stems (Figs. 1A, G, 4G, 8C, 9D). Thereafter these roots persist almost throughout the year from July to April. The young aerial roots are pink in colour with soft texture. The terrestrial roots are perennial, light brown to grey and woody in texture. Normally the aerial roots are unbranched, however, branching if present at all is rare and wherever the branching is present, the branches may be equal or unequal. However, in terrestrial roots, the branching is more common and present in several orders (Fig. 4A). The tips of the aerial roots are often swollen and rough in texture than in their terrestrial roots (Figs. 1H, 4H, 8D). The diameter of aerial roots range from 0.3 mm to 15 mm.

Anatomy

In transverse section (T.S.), the aerial and terrestrial roots show a distinct demarcation of epidermal, cortical and vascular regions (Figs. 2, 3, 5). The epidermis is the outermost layer and it is unilayered. It is composed of tight placed thin walled cutinized cells and it shows unicellular, papillate to tubular root hairs (Figs. 1 C-E, 2, 4C, D). The root hairs of terrestrial roots on the other hand are long and tubular and occur in greater numbers than in their aerial roots. In older roots, the epidermis is often interrupted by large number of lenticels (Figs. 2, 7B, 9B).

The epidermis is followed by cortex composed of parenchymatous cells. The cells of cortex show large number of inter cellular spaces and lysigenous cavities. These are present both in aerial as well as in terrestrial roots. Lysigenous cavities in the cortex are more elongated in shape and usually greater in number (Figs. 1F, G, 3; 4E, F; 5; 7B, D; 9B). It appears that these cavities arise from dissolution of cells leaving long elongated cavities in the cortex and these serve as an aerating structure. The cells of the aerial roots of cortex often contain more tannin or tannin like substances than their terrestrial roots. The cortical region of aerial roots is 14 to 29 cells in thickness, whereas in the terrestrial roots the cortex is 7 to 16 cells in thickness (Figs. 2, 3, 5). In aerial roots, the cortical cells are larger in size than in the terrestrial roots.

The endodermis is the innermost layer of the cortex and forms a single-layered compact, barrel shaped structure around the ring of vascular bundles. The radial and tangential walls of endodermis are thickened. The thickenings may be present in form of suberized casparian strips. Just opposite to the protoxylem points and also at the other places, some cells of endodermis remain thin walled passage cells (Figs. 2, 5). The cells of endodermis also contain tanniniferous cells. Next to endodermis, there is a single-layered pericycle. It consists of thin walled single layered parenchcymatous cells. These cells also contain tannin or tannin like substances. The lateral root arises from this region (Figs. 8C, 9D). Next to the pericycle, there is a stelar region. It shows vascular bundles and pith. The vascular bundles are radially arranged with alternating xylem and phloem. The number of vascular strands varies in both aerial and terrestrial roots. The vascular bundles are usually exarch and centripetal in nature. Centripetal phloem always occurs radially to the xylem. The number of vascular bundle range from 8 to 14 in aerial roots and from 4 to 6 in terrestrial roots (Figs. 2, 3, 5, 9).

The pith is centrally located and it is composed of parenchymatous cells. It occupies a large area in aerial roots, while it is less developed in terrestrial roots. Like that of cortical and endodermal cells, the parenchymatous cells of the pith also contain tannin or tannin like substances.

Both aerial as well as terrestrial roots show secondary growth (Figs. 1G, 3, 4E-G, 5, 7C, 9B-D). However, in terrestrial roots secondary growth is well developed, while it is less developed in its aerial roots. During secondary growth, the cambium produces large amount of secondary xylem on the inner side and small amount of secondary phloem on the outer side. Amount of secondary xylem is more in terrestrial roots whereas in aerial root it is less. The vascular rays are present opposite to the proto xylem points. Vessels are more prevalent in terrestrial roots than the aerial roots. The periderm is present in mature roots and it is usually produced by cork cambium.

The macerated residues of the roots show the presence of tracheary elements comprising of the tracheids as well as vessel with various kind of thickenings (Figs. 6 A-N). Tracheids are narrower, long and tapered at both the ends with scalariform bordered pits. The size of tracheids varies from 1221 µm to 1544 µm in length and from 16 µm to 22 µm in width in terrestrial roots whereas tracheids of aerial roots varies from 1020 µm to 1240 µm in length and 11 to 22 µm in width. The vessel elements are short with wide lumen. The secondary wall of vessels shows scalariform thickening and bordered pits. The pits are multiseriate and subopposite or alternate. The size of vessels of terrestrial roots varies from 111 µm to 832 µm in length and 44 µm to 55 µm in width whereas vessels of aerial roots varies from 233 µm to 377 µmin length and 22 µm to 44 µm in width. Perforations are simple and present at both sides, distal as well as proximal ends. The distal ends are narrow and tapered, projecting like a short or long narrow tail. The perforations may be either circular or elliptical in shape, and their size ranges from 22 µm 44 µm in length and 98 µm to 44 µm in width in terrestrial roots, where as in aerial roots it ranges from 14 µm to 33 µm in length and 32 µm from to 40 µm in width.

Morpho-Anatomical Adaptations

Plant of *S. cumini* Skeels shows morpho-anatomical adaptation under stress condition. The aerial roots arise endogenously from the pericyclic region and ultimately project out from the bark of stems (Figs. 1A, G, 4G, 8C, 9D). The aerial roots are usually produced during the rainy season which was grown under excessive moisture habitat. This excessive moisture indicates oxygen deficit condition. Under this condition, the plant shows origin of aerial roots and aerenchyma formation in the cortex of dimorphic roots (Figs. 1A, F-G, 3,4E-F, 5, 7A, B, D, 9B). The aerial roots are usually produced during the rainy season. In these roots the epidermis is often interrupted by a large number of lenticels and to establish a connection with the atmosphere. This enhanced development of internal gaseous exchange which facilitates the transport of oxygen from shoots to terrestrial roots. In addition, the plant also adapts anatomically with large number of lysigenous cavities under stress condition which improved delivery of oxygen to the plant. This helps to sustain and facilitate the metabolic process through lenticels of aerial roots.

Discussion and Comparison

Plants develop a suite of morphological, anatomical and physiological responses in order to deal with stress condition imposed by various factors (Armstrong, 1979; Laan et al., 1989; Vartapetian & Jackson, 1997; Jackson & Armstrong, 1999; Mc Donald et al., 2002; Colmer, 2003; Evans, 2003; Colmer et al., 2006; Shimamura et al., 2010; Teakle et al., 2011; Armstrong & Armstrong, 2014). Every plant organ is ideally designed to fulfill metabolic and physiological processes in specific environmental conditions and its survival depends upon the ability to harmonize structure and function to withstand desiccation without permanent damage (Maximov, 1931). The dimorphic roots (aerial and terrestrial) have been described for the first time in *Syzygium cumini.* Although, occurrence of aerial roots is considered as a characteristic feature of monocots (Gill & Tomlinson, 1975; Singh & Misra, 2012). There are relatively scanty reports on occurrence of aerial roots in dicotyledonous plants (Misra et al, 1997; Misra & Singh, 2000 a, b, 2002, 2004 a, b, c, 2005; 2007 a, b, 2008 a, b, Singh, 2002; Singh & Misra, 2012). Root systems are morphologically diverse with categories of roots having distinct capacities to form aerenchyma in flood or waterlogged or marshy soils. Solereder (1908) stated that the myrtaceous plants are characterized by the occurrence of schizogenous cavities present in the leaves as well as in axes whereas lysigenous cavities abundantly occur in the central region of the cortex of *S. cumini.* Aerenchyma is abundant and appears as the most important feature facilitating longitudinal oxygen transport to sustain root aeration in plants of aquatic and moist habitats. Adequate supply of O_2 to plant organs requires enhanced development of internal gas spaces, principally by formation of aerenchyma which have been demonstrated by earlier workers (Armstrong et al., 1994; Evans, 2003). Enhancement of oxygen transport from shoot to root tip by the formation of aerenchyma and also a barrier to radial oxygen loss (ROL) in roots is common in waterlogging-tolerant plants (Teakle et al., 2011). But plants of *S. cumini* are strictly terrestrial in nature. The development of aerial roots with plenty of lenticels, lysigenous cavity in cortex and periderm formation indicates high adoptive features for survival and sustainable growth under stress condition in this tree species. The presence of numerous lenticels on the surface of these dimorphic

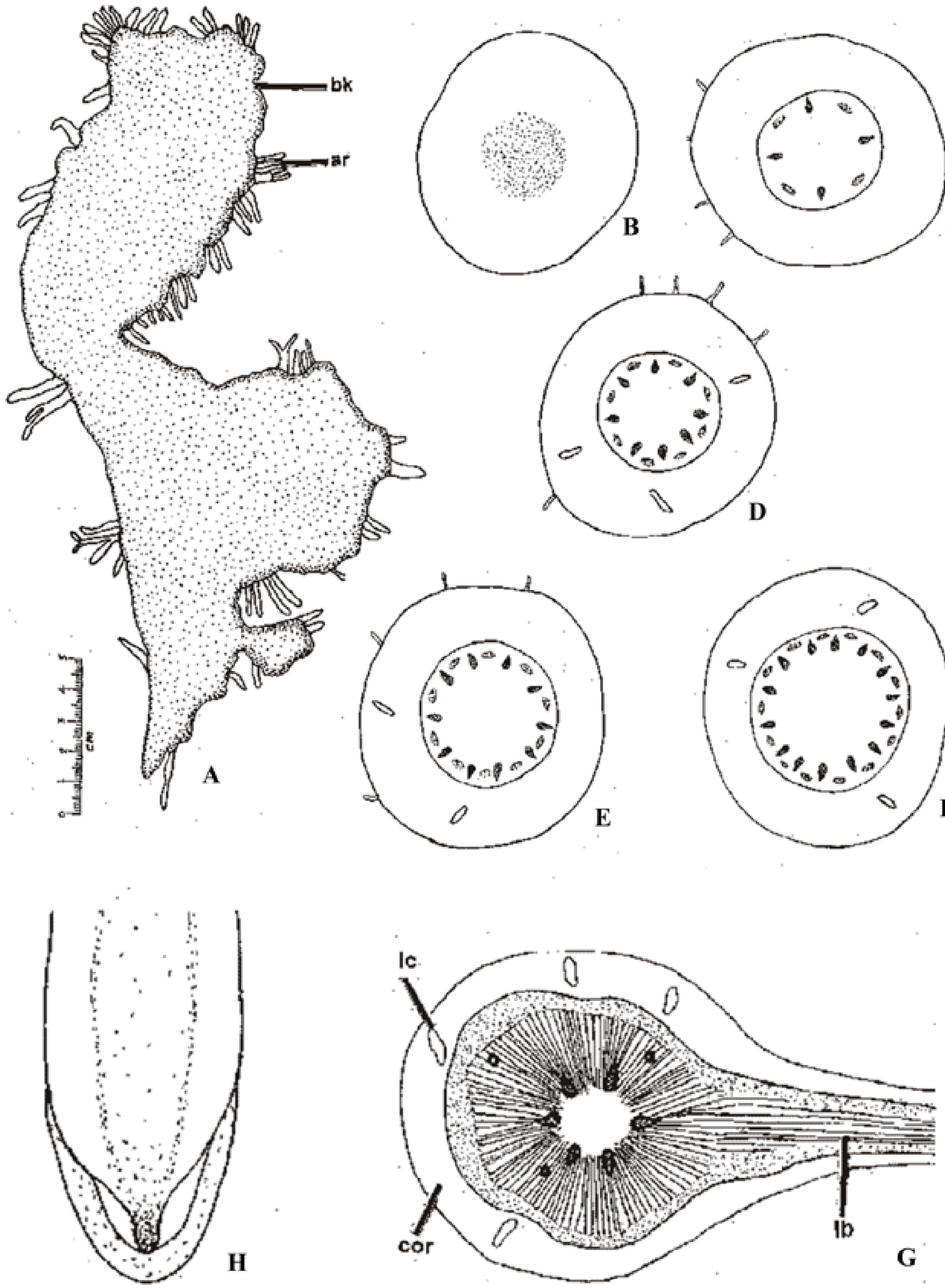

Fig. 1: Aerial roots of *Syzygium cumini*. A) Part of bark with aerial roots, B-F) Topographic sketches of transverse sections at different selected levels from apex to base. X 30, G) T.S. showing endogenous lateral branching. X 30, H) L.S. of root tip. X 30.
(ar-aerial root, bk-bark, cor-cortex, lb- lateral branching, lc- lysigenous cavity).

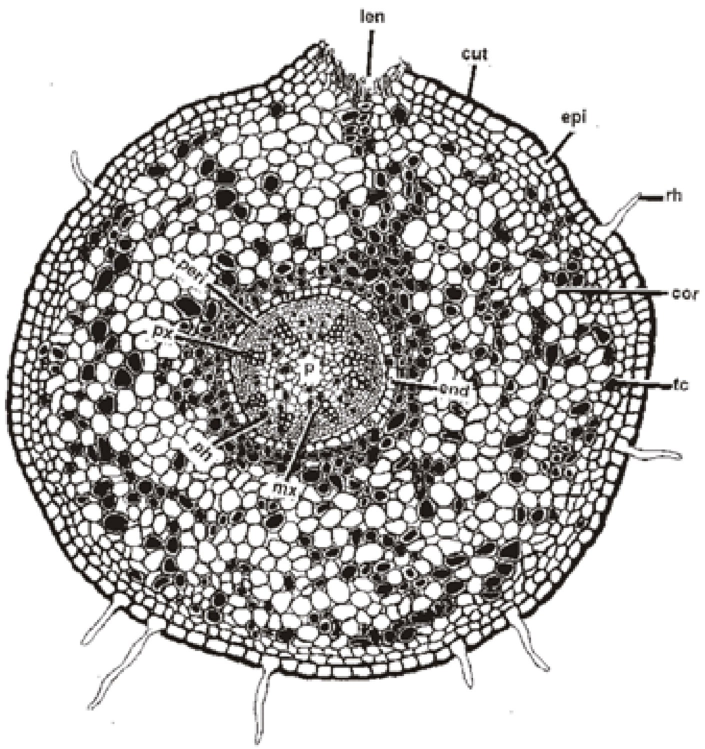

Fig. 2: T.S. of young aerial root of *Syzygium cumini* showing cellular details x 90
(cor- cortex, cut- cuticle, end- endodermis, epi- epidermis, len- lenticels, mx- metaxylem, p= pith, peri- pericycle, ph- phloem, px- protoxylem, rh- root hair, te- tannineferous cell).

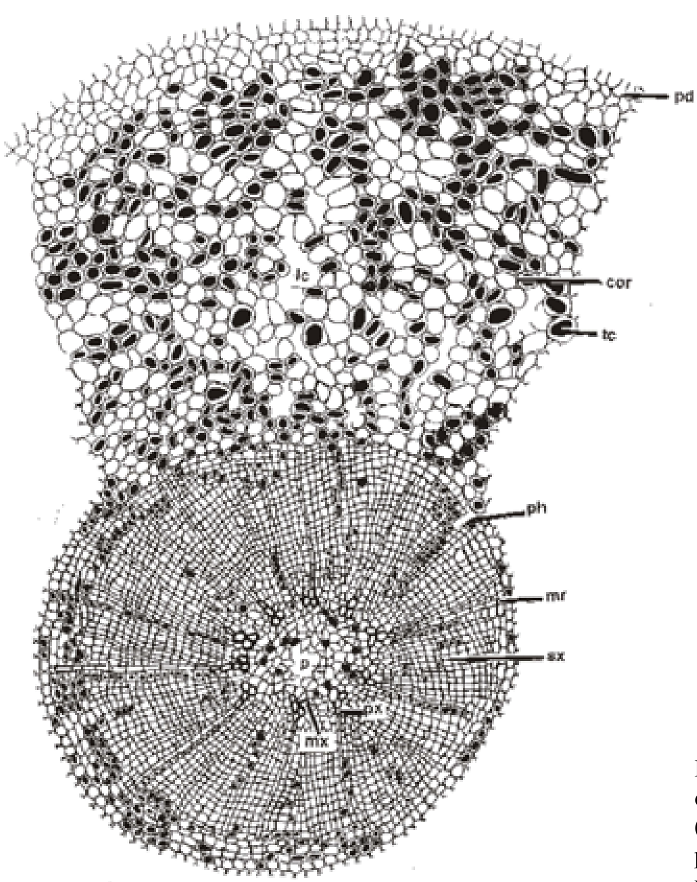

Fig. 3: T.S. of mature aerial root of *Syzygium cumini* showing cellular details x 90
(cor- cortex, le- lysigenous cavity, len-lenticel, mx- metaxylem, p=pith, pd- periderm, ph- phloem, px- protoxylem, sx- secondary xylem, te- tannineferous cell).

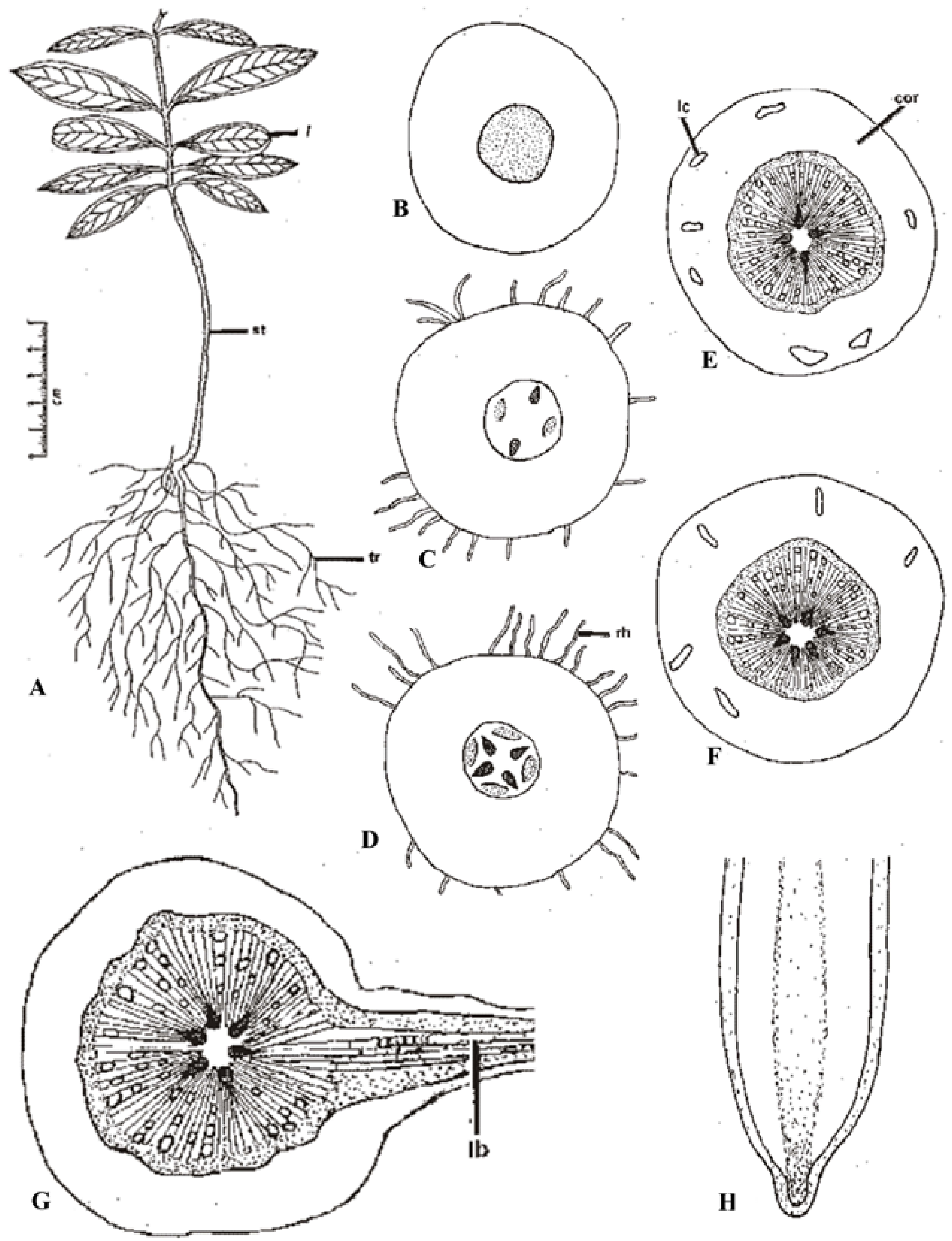

Fig. 4: Terrestrial roots of *Syzygium cumini*. A) External features of young plant with terrestrial roots, B-F) Topographic sketches of transverse sections at different selected levels from apex to base. x 30. G) T.S. showing endogenous lateral branching. x 30. H) L.S. of root tip x 30.
(cor- cortex, l- leaf, lb- lateral branching, lc- lysigenous cavity, rh- root hair, st- stem, tr- terrestrial root).

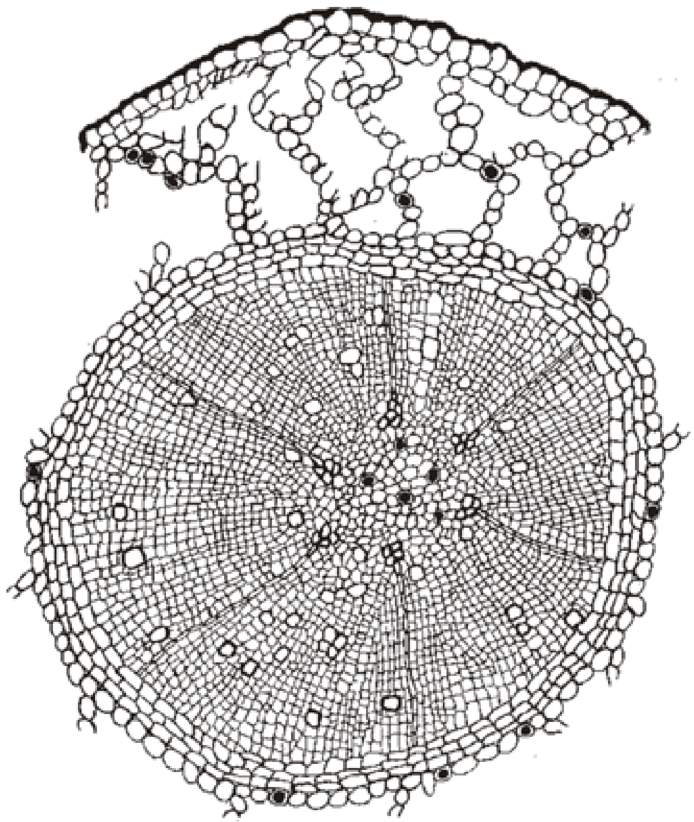

Fig. 5: T.S. of mature terrestrial root of *Syzygium cumini* showing cellular details x 90.

roots and plentiful air spaces in their cortex suggests that they serve as aerating organ in terrestrial plant like those of mangrove plants. Perhaps, the origin and development of such morpho-anatomical features indicate oxygen deficient ecosystem.

In the present study, authors have concluded that the development of aerial root along with aerenchyma formation is induced by poor aeration in plants. The internal ventilation through aerenchyma promotes survival and sustainable growth of plants because it allows plants to breathe and to fulfill metabolic processes. It is not only advantageous as internal gas spaces for aquatic plants but also for all those plants that survive under oxygen deficient condition. The morpho-anatomical adaptations play a significant role in improved survival and sustainable growth of plant species.

Aerenchymatous root cortex has also been reported in roots of many other terrestrial plant by Beckel (1956); Misra and Singh, (2000 a, b, 2004) and Singh, (2002). The chlorophyllous and lignified cells have been described in the cortex of the climbing roots of *Metrosideros hypericifolia* (Metcalfe & Chalk, 1950). Other features recorded in the same species include the normal absence of root hairs except when their formation is induced by treatment in a moist chamber, the conspicuous endodermis, the vessels of the xylem of the central cylinder with small lumen and very thick walls. The vessels in the absorbing roots are rather larger and the cortex does not convert to mechanical tissue whereas the dimorphic roots of *S. cumini* have well developed root hairs and lack chlorophyllous cells. Esau (1965a) have stated that if the parent root has more than two xylem poles the branch roots arise opposite to these poles, which is common in dicotyledons. Similar finding also have been reported in *S. cumini*. As described in the observations, the dimorphic roots present a large number of interesting morpho-anatomical features and resemble fundamentally to the other dicot roots but they differ in combination of morpho-anatomical characters as mentioned in Table 1.

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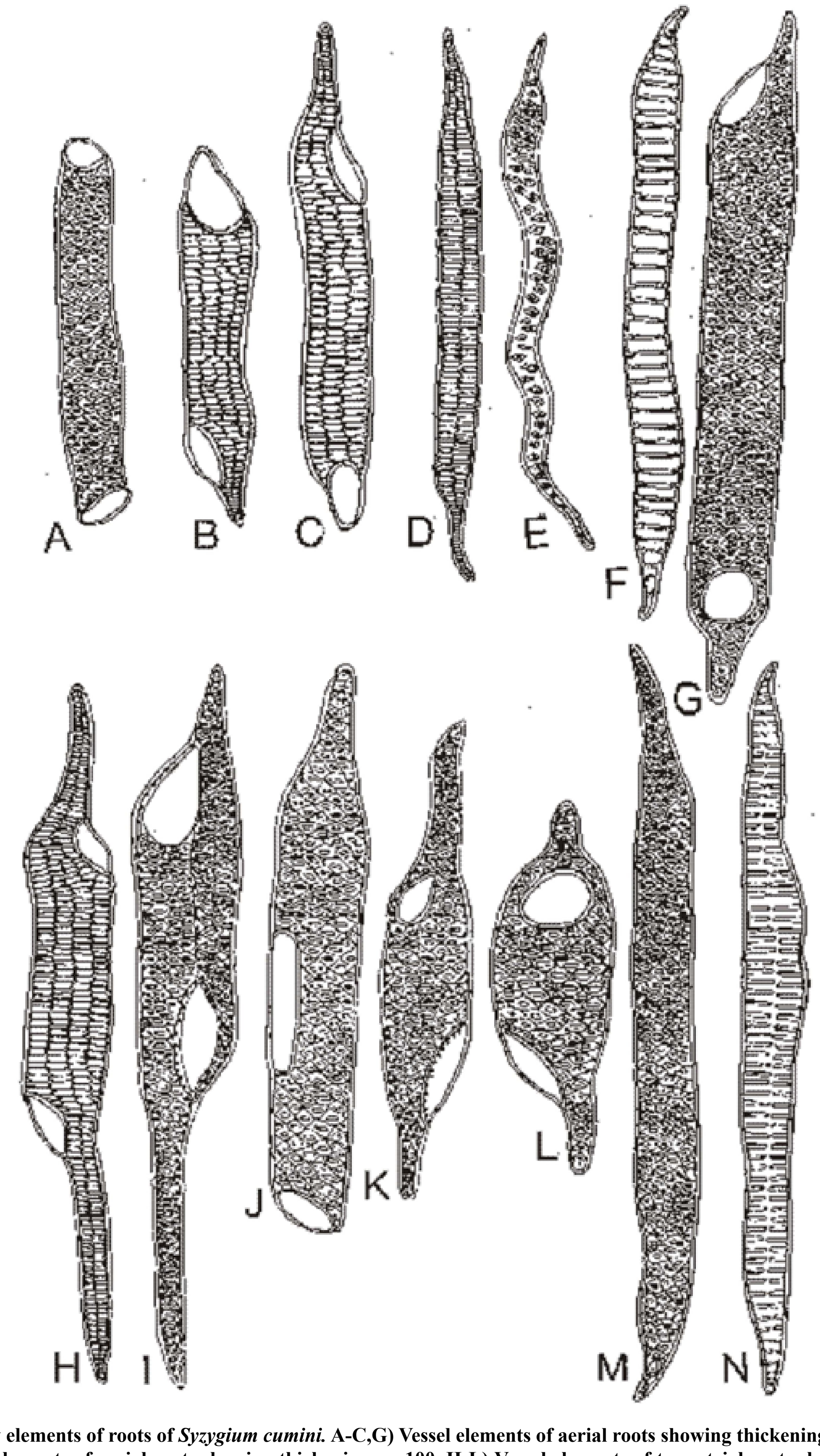

Fig. 6: Tracherary elements of roots of *Syzygium cumini.* A-C,G) Vessel elements of aerial roots showing thickenings and pits. X 100. D-F) Tracheidial elements of aerial roots showing thickenings. x 100. H-L) Vessel elements of terrestrial roots showing thickenings and pits. X 100. M-N) Tracheidial elements of terrestrial roots showing thickening. X 100.

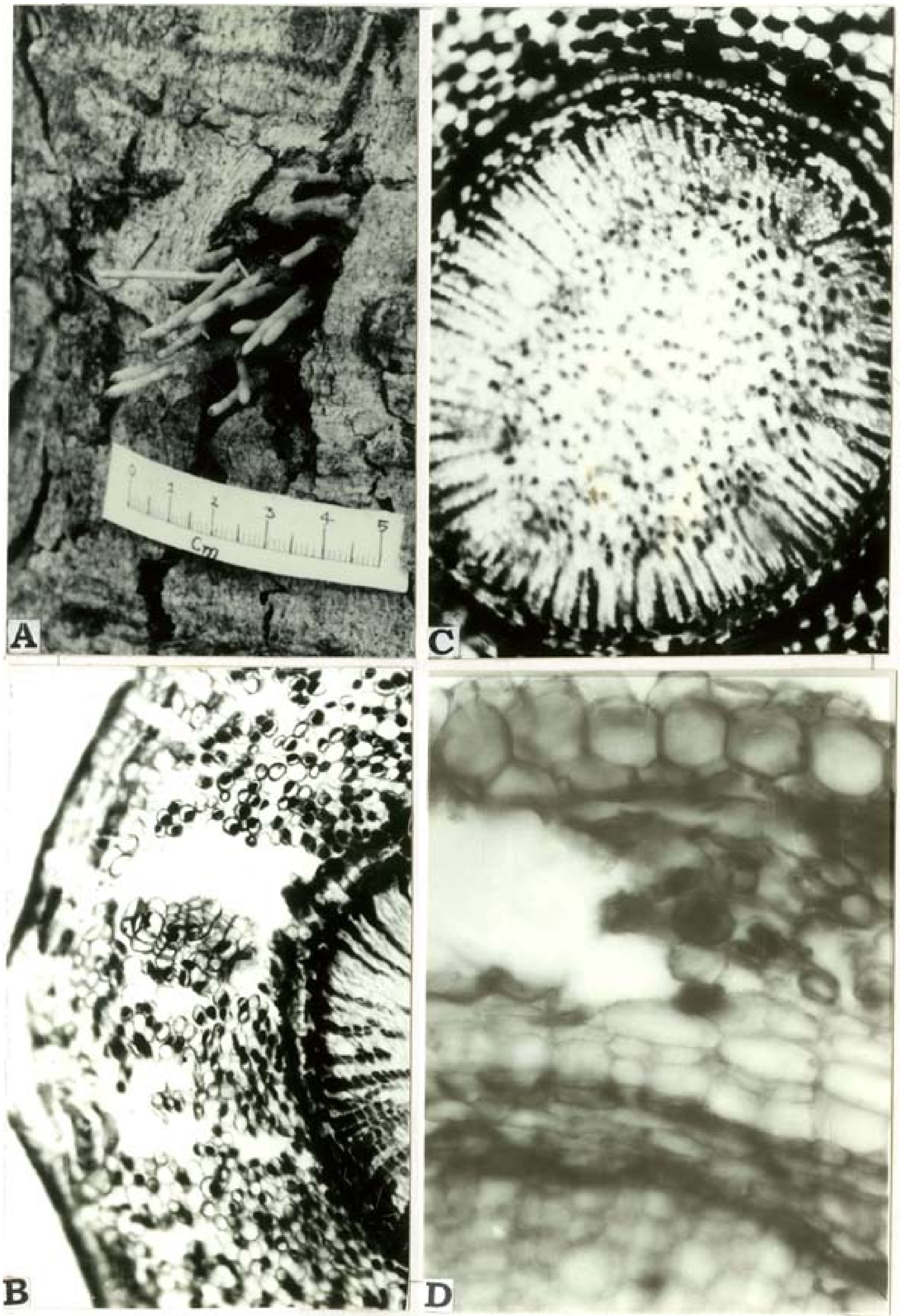

Fig. 7: Aerial roots of *Syzygium cumini*. A) Part of old stem with aerial roots. B) Outer region showing epidermis, and cortex with lanticel and lysigenous cavity in T.S. C) Central region with white pith in T.S. x 200. D) Magnified view of outer region with lysigenous cavity in T.S. x 400.

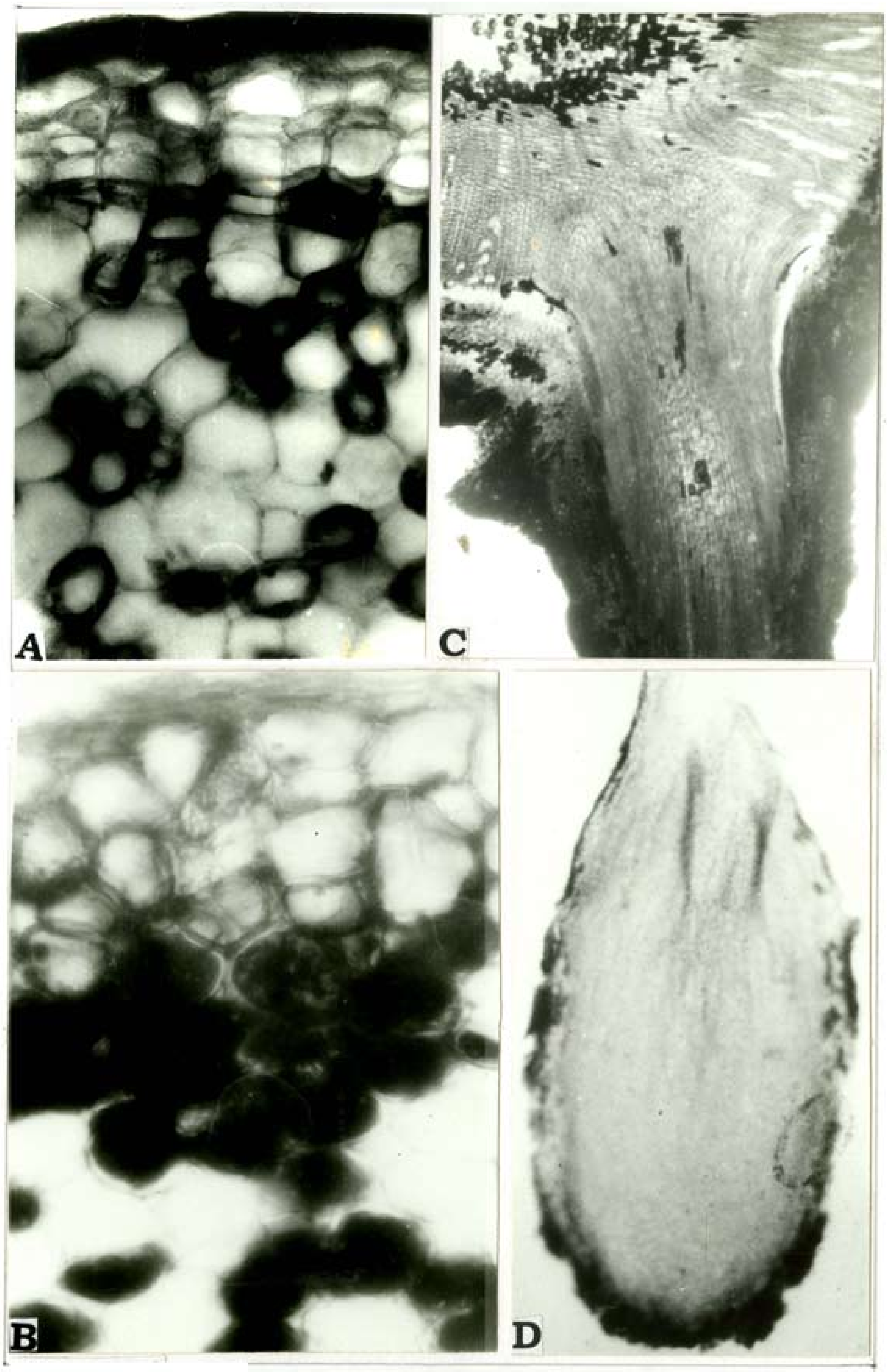

Fig. 8: Aerial roots of *Syzygium cumini*. A) Magnified view of outer region with periderm in T.S. x 400. B) Cortical cells with tannin in T.S. x 400. C) Endogenous lateral branching in T.S. x 150. D) Root tip in L.S. x 250.

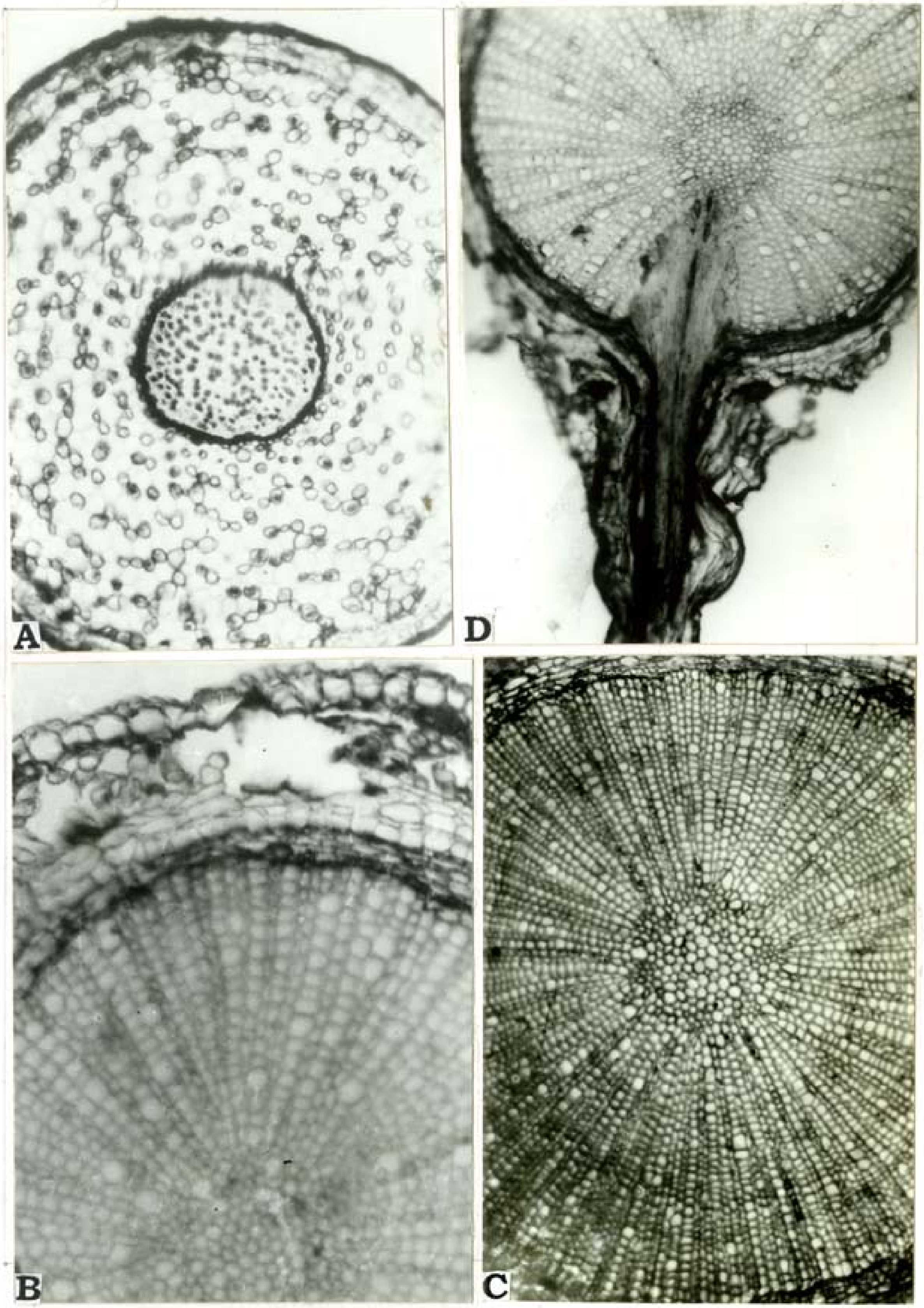

Fig. 9: T.S. terrestrial roots of *Syzygium cumini*. A) Young root showing cellular details. X 150. B) Part of root cellular details. X 250. C) Magnified view central region showing cellular. X 150. D) Root showing endogenous lateral branching x 200.

Table 1. **Comparison of aerial and terrestrial roots of *Syzygium cumini* Skeels**.

Characters	Aerial Roots	Terrestrial Roots
Duration & Timing	July to April	Throughout the Year–perennial.
Nature	Soft in nature	Tuberous and woody
Colour	Pink	Light–brown to grey
Branching	Usually unbranched, rarely branched	Usually branched.
Root hair	Papillate, less in number	Long tubular and more in number
Cortex	Wider, 14 to 29 cells in thickness	7 to 16 cells in thickness
Air Cavities	Present in the cortex, elongated, narrow, lysigenous but less in number.	Large, broad and elongated in shape, lysigenous but more in number.
Vascular bundle	Polyarch, Protoxylem ranges from 8 to 14 and exarch.	Tetrarch to hexarch, and exarch.
Pith	Wide and well developed	Reduced and less developed.
Secondary growth	Scanty developed, number of wood vessels is less.	Well developed with vessels.
Rays	Less conspicuous	More prominent
Periderm	Poorly developed	Well developed
Lenticels	More in number	Less in Number
Tannin	More in amount, mostly cells of roots contain tannin.	Very less in amount.
Vessel	Less in number, smaller in size ranges from 233 µm to 377 µm in length and 2 µm to 44 µm in width.	More in number and ranges from 111 µm to 832 µmlength and 44µmto 55µm in width.

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