ANATOMY OF PALM STEMS : I. *CHRYSALIDOCARPUS LUTESCENS* WENDL.

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ABSTRACT

Mature stem anatomy of *Chrysalidocarpus lutescens* Wendl. has been described with special reference to the variability in anatomical features at different heights of a stem. The features, such as—distribution of vascular bundles per unit area, fibrous to vascular ratio, the length of metaxylem elements, the number of bars on the perforation plate, and the ground parenchyma pattern, exhibited definite trends of variations not only from periphery to the centre of the stem but also from base to the apex. Amongst features which remained relatively constant at all the levels in aerial stem were the typically lunate nature of the dorsal sclerenchyma and a single metaxylem element for most of the fibrovascular bundles.

INTRODUCTION

Though anatomy of palm stems had attracted the attention of early workers like Von Mohl (1824, 1849), Karsten (1848), Branner (1884), and Schoute (1912), much emphasis was laid on the course of vascular bundles and the mode of secondary growth. These aspects have been further elucidated by later workers, like Monoyer (1925), Ball (1941), and Zimmermann and Tomlinson (1965).

Kaul (1941-1942, 1960) and Tomlinson (1961) have dealt with systematic significance of stem anatomy. Still various criteria viz., distribution of fibrovascular bundles per square area, transectional shape of the fibrous cap of the fibrovascular bundles, the fibrous to vascular ratio, the number of metaxylem elements and the nature of perforation plates on them, the ground parenchyma pattern, etc., were employed to distinguish different species of *Palmoxylon* by Stenzel (1904), Sahni (1931, 1964) and others remain to be tested for their diagnostic value on the basis of study of extant species of palms. The only attempt made in this direction is that of Swamy and Govindrajalu (1961) who traced the trends of variability in tissues and cell-types in a stem of *Phoenix sylvestris*.

Recognising the importance of such studies, a scheme on the anatomy of palm stems has been undertaken in this laboratory, primarily to study the variability in structural features in a mature stem and to recognise the diagnostic characters which could be relied upon for systematics. Present communication—a part of this project, deals with an arecoid palm, *Chrysalidocarpus lutescens*.

MATERIAL AND METHODS

Thirty year old stem measuring 7.5 m in height of *Chrysalidocarpus lutescens* growing in the botanical garden of our institute served as the material. The stem was cut transversely into eight pieces, each measuring 90 cm in length. Cut pieces were serially numbered from base to the apex. Transections passing through cortical, dermal, subdermal, and central vascular zones were prepared from the upper surface of each piece using Leitz's table microtome and were used for studying microscopic features. The splinters of wood from dermal, subdermal and central zones of each piece were macerated separately for studying various cell-types. Distribution of vascular bundles in each zone of vascular cylinder was measured directly from transversely cut polished upper surface of each piece. All numerical figures included in this account represent averages of hundred counts.

OBSERVATIONS

Descriptive anatomy

Internally, the stem is differentiated into the outer narrow cortex enclosing a wider central cylinder. The *epidermis* has radially extended, rectangular cutinised cells. The *hypodermis* is not distinctly differentiated from the inner ground parenchyma of the cortex. The outer narrow strip of cortex is traversed by four to six or more rows of fibre strands of successively increasing dimensions from periphery to centre. The ground parenchyma has small circular cells—thin-walled, and chlorenchymatous at the top levels of the stem but slightly thick-walled and transversely extended at the middle level (Pl. 1, Fig. 1). This sclerotic outer part peals off irregularly at the basal levels of the stem, exposing the sclerosed outer tissues of the cortex. The inner wider part of cortex (Pl. 1, Fig. 2) has vertically traversing fibre bundles, fibrovascular bundles, leaf-trace bundles and diminutive vascular bundles distributed in the ground parenchyma. Of these, fibre bundles are numerous, circular and evenly distributed ; other bundles are lesser in number. Diminutive vascular bundles are of hydro- or leptocentric-type with very much reduced vascular tissue surrounded by fibrous sheath. A few, small conjoint vascular bundles are also found. Leaf-trace bundles have lunate dorsal fibre cap enclosing in the median sinus a lunate patch of phloem ; xylem elements are many, distributed in the extended part of slightly lignified ventral parenchymatous sheath. The ground parenchyma has circular cells at the top levels of stem, but rectangular, tangentially oriented, slightly sclerotic cells towards base. At the rooting level, the cortex is quite massive, consisting mainly of distantly distributed fibre bundles in the outer part with conspicuously radially extended sheets of parenchyma (Pl. 1, Fig. 3). The inner part includes roots in various stages of emergence and a few vascular bundles. Unspecialized cells containing pigmented material are very common in the ground tissue of the cortex at all the levels except at rooting level where they are very few.

The *vascular cylinder* can be distinguished into conventional dermal, subdermal and central vascular zones on the basis of distributional pattern of the vascular bundles and the orientation of vascular tissues in them.

Dermal zone is marked by comparatively crowded arrangement of vascular bundles with their vascular tissues normally oriented, i.e. directed towards centre of the stem. Vascular bundles just beneath the cortex are usually smaller than the inner ones. They are oval in transverse outline and have most highly developed fibrous tissues than those of the other zones. Each vascular bundle has very well-developed lunate to reniform, mostly lunate, radially extended dorsal fibre-cap, including a small patch of phloem in the median-sinus. The xylem is mostly represented by a single metaxylem element ensheathed ventrally by rows of slightly thick-walled parenchyma (Pl. 1, Fig. 5). Vascular bundles with two widely separated metaxylem elements and with protoxylem elements are occasionally met with. The fibres of the dorsal cap get progressively more sclerosed from top to the base of the stem. Within each bundle, sclerosis starts in the fibres adjacent to the phloem and progresses centrifugally towards periphery. Leaf-trace bundles are occasionally seen along their associated bundles (Pl. 1, Figs. 6, 14). The vascular bundles are surrounded by two to three rows of tabular parenchyma which is distinctly marked from the general ground tissue towards the base of the stem but becomes less and less demarcated towards the apex. The general ground parenchyma has circular, compactly arranged cells (Pl. 1, Figs. 5, 6, 14) which become thin-walled towards the top of the stem. Radial strips of tangentially elongated cells are more common towards the base of the stem but become progressively less in number and are completely eliminated at the level of 6 m above the base.

Subdermal zone has less crowded vascular bundles than the dermal zone. In majority of them, the vascular tissue is directed towards the centre of the stem (Pl. 1, Figs. 7, 8, 15). The leaf-trace bundles are more prominent in this zone than in the dermal (Pl. 1, Figs. 7, 8). They have a lunate dorsal fibre-cap including a wide patch of phloem in the median-sinus, which is sometimes divided into two compartments by intrusion of the dorsal cap fibres. The metaxylem elements are mostly two, rarely one or four, widely separated by an isthmus of sclerotic parenchyma. A varying number of protoxylem elements are found scattered in the ventral thick-walled parenchymatous tissue. The leaf-trace bundles are mostly associated on their ventral side by an arc of diminutive vascular bundles which are often found in the process of division. Many of these bundles lack protoxylem elements though some show their presence. Occasionally, small bundles are seen in the process of splitting from the lateral sides of leaf traces also. A few diminutive vascular bundles not associated with leaf-traces are also seen scattered in the ground tissue.

The vertically traversing fibrovascular bundles are typically similar to those of the dermal zone but have lesser radial width for their dorsal fibre-caps and better developed ventral sclerotic parenchymatous sheath. In a few of them, the phloem is divided into two compartments ; each vascular bundle is ensheathed by two to three layers of tabular parenchyma, more well-marked towards stem base but less so towards the apex. The general ground parenchyma is of circular cells, rather thick-walled towards the base but thin-walled towards the apex ; radial streaks of tangentially stretched parenchyma cells are more prominently developed towards the base of the stem (Pl. 1, Figs. 7, 8), but become lesser above and are not seen above 4.5 m height.

Central vascular zone has least crowding of vascular bundles, and random orientation of vascular tissues (Pl. 1, Figs. 11-13). The vascular bundles are rounded in outline and smaller than those of the dermal and subdermal zones ; the dorsal-caps are much narrow with sharply angular lateral lobes ; the phloem is occasionally divided into two compartments ; the single metaxylem element (rarely two) is surrounded ventrally by well-developed sheath of sclerotic parenchyma which occasionally embeds protoxylem elements also. The leaf-trace bundles, similar to those in the subdermal zone, are also seen here but their associated vascular bundles are not prominently developed (Pl. 1, Figs. 12, 13). The ground tissue shows a lot of variation along the height of the stem. At extreme base, just above the rooting level, each vascular bundle has well-developed two to three layered tabular parenchyma of small oval cells surrounded by several layers of radiating parenchyma of tubular elongated cells (Pl. 1, Figs. 12, 13) ; a few triangular lacunae are also found (Pl. 1, Fig. 12) which soon get eliminated higher up the stem. The radiating parenchyma progressively gets reduced at successive higher levels ; at 3.6 m level above the base, it is almost reduced to a single row of rectangular cells forming a cylinder around the tabular parenchymatous sheath of the vascular bundles (Pl. 1, Fig. 11) ; at and above 4.5 m level, the entire ground parenchyma becomes homogeneous with circular, loosely arranged cells. The unspecialized cells containing the pigmented material are found scattered in the ground tissue in all the zones of the central cylinder but become more prominent towards the stem apex.

The rooting level of the stem presents marked differences in the anatomy (Pl. 1, Figs. 9, 10) as compared to the aerial stem. At this level, the leaf-trace bundles are entirely lacking from the vascular cylinder. Almost all the vascular bundles of the dermal and subdermal zones have xylem tissue represented by a round patch of vessels (Pl. 1, Figs. 9, 10) ; clearly recognisable metaxylem strands are lacking ; vascular bundles of the dermal zone have tangentially extended dorsal fibre caps (Pl. 1, Fig. 9) while those of the subdermal zone have radially extended caps (Pl. 1, Fig. 10). The bundles of the central zone are rounded with lunate dorsal cap including a single patch of phloem in the median-sinus; metaxylem element is single, encircled ventrally by poorly developed sheath of parenchyma. Some vascular bundles run radially from central to the dermal zone. The ground tissue has thin-walled cells. In the dermal zone radial strips of cells are seen diverging from the vascular tissues of the bundles (Pl. 1, Fig. 9) ; subdermal zone has angular, compactly arranged cells (Pl. 1, Fig. 10) while the central zone has large circular cells. Unspecialized cells containing pigmented material are occasionally found in the ground parenchyma.

Throughout the height of the stem, peripheral fibres of fibrovascular strands are associated with stegmata having star-shaped silica bodies. Fibrous strands are entirely lacking from the vascular cylinder at all the levels of the stem. The metaxylem elements have multiseriate scalariform pittings on their walls (Pl. 1, Fig. 4). The end plates have varying number of bars.

Variability in numerical features

1. *Distribution of fibrovascular bundles*—The pattern of distribution of fibrovascular bundles in each zone of the vascular cylinder along the height of the stem is represented in Table 1. At any given level, maximum number of vascular bundles per unit area is found in the dermal and minimum in the central zone. In each zone the values successively increase from base to the apex of the stem. This trend is more marked in the subdermal and central zones.

Table 1—Pattern of distribution of vascular bundles in the stem of *C. lutescens*

Height in metre from base	Dermal zone cm²	Sub-dermal zone cm²	Central zone cm²
0.95	156	88	76
1.89	148	112	96
2.83	156	116	104
3.78	164	144	116
4.72	176	152	144
5.65	180	164	152

2. *Size of vascular bundles and the fibrous to vascular ratio* (Table 2)—In general the vascular bundles of the subdermal zone are more radially elongated than those of the dermal and central zones. The transectional area of the vascular tissue shows increasing trend from dermal to central zones. Correspondingly, the fibrous to vascular ratio also

Table 2—Pattern of variation in size of vascular bundles, vascular tissues, and fibrovascular ratio in the stem of *C. lutescens*

Height in metres from base	Dermal ozne					Sub-dermal zone					Central zone				
	L.Vb. μm	B.Vb. μm	L.Vt. μm	B.Vt. μm	F/V	L.Vb. μm	B.Vb. μm	L.Vt. μm	B.Vt. μm	F/V	L.Vb. μm	B.Vb. μm	L.Vt. μm	B.Vt. μm	F/V
0.95 ..	600	280	120	112.6	132.8	700	440	300	280	63.2	454	340	364	320	18.4
1.89 ..	626	280	144	172	127.6	600	400	300	260	41.4	560	400	370	283.4	17.2
2.83 ..	689.2	414.6	208	226.6	1100.4	708	420	444	350.6	26	..	..	..	..	..
3.78 ..	696.4	492	252	247.0	90.4	672	212	358	296	42.6	..	..	..	..	..
4.72 ..	618	540	276	312	57.4	780	510.6	404	412.2	27.8	544	402	374	362.8	11.6
5.65 ..	700	600	284	280.6	84.0	720	444	320	296	44.8	648	420	420	380	14.4
6.60 ..	740	646	292	280	98.0	590	368	304	280	32.4	314	392	358	354	12.0
7.55 ..	680	624	304	282	60.2	612	360	280	306	30.0	..	..	..	..	..

L.Vb.=length of vascular bundle ; B.Vb.=breadth of vascular bundle ; L.Vt.=length of vascular tissue ; B.Vt.=breadth of vascular tissue ; F/V=fibrous to vascular ratio.
*Measurements do not include leaf-trace bundles.

Table 3—Length, breadth and number of bars on the end plate of metaxylem element in the stem of *C. lutescens*

Height in metre from base	Dermal zone			Sub-dermal zone			Central zone		
	Length μm	Breadth μm	Bars	Length μm	Breadth μm	Bars	Length μm	Breadth μm	Bars
0.95 ..	2308.37	133. 4	18. 9	2095.2	137.74	25.4	2657.8	187.21	22.22
1.89 ..	1210.56	222.42	14. 6	2104.41	201.17	30.63	2074.35	178.09	18.27
2.83 ..	1731.06	157.14	15.75	2200.44	195.55	17.83	1940.0	204.47	16.56
3.78 ..	1069.71	161.18	13.04	2086.47	178.48	16.36	2056.20	148.41	14.46
4.72 ..	1353.15	167.42	12.66	1660.15	161.79	15.27	1787.22	152.27	12.86
5.65 ..	747.09	166.66	8.92	785.89	151.12	11.22	1210.85	147.73	12.08
6.60 ..	764.65	142.88	6.92	785.02	139.87	5.56	1231.9	120.66	8.19
7.55 ..	663.28	145.20	5.28	752.52	145.01	7.32	1022.57	119.5	6.98

increases from central to the dermal zone. Along the height of the stem, however, in each zone the ratio shows a decreasing trend, more marked in dermal and subdermal zones than in the central.

3. *Metaxylem elements*—The gamut of variability exhibited by metaxylem elements in each zone along the height of the stem is represented in table 3. In each zone, the length of the vessel element tends to decrease along the height of the stem. At all the levels, shortest vessels are found in the dermal zone ; the longest vessels are mostly associated with central zone except at one or two basal levels where vessels of the subdermal zone are longer than the central. In general, the vessel length shows increasing trend from dermal to central zones. The negative correlation between length and breadth of vessels is also evident; the longer vessels being narrower than the shorter.

There is a positive correlation between the vessel length and the number of bars on the end plate. In each zone, correlated with decrease in vessel length along the height of the stem the number of bars on the end-plate also shows decreasing trend.

DISCUSSION

Amongst different anatomical features presented by the stem of *Chrysalidocarpus lutescens*, the fairly stable ones throughout the height of the stem are the lunate shape of the dorsal fibre-cap and the presence of one metaxylem vessel for most of the bundles.

Based on the transectional form of sclerenchyma of fibrovascular bundles, palm stems were classified into five groups., viz. Sagitata, Cordata, Reniformia, Lunaria and Vaginata by Stenzel (1904), who also stated that this character may often vary in different parts of a same cross section. In *Chrysalidocarpus*, however, typical lunate shape was retained by majority of the bundles, although the extent of development of the sclerenchyma varied from dermal to central zone. It seems that, as suggested by Sahni (1964), the form of sclerenchyma can serve as the best single character which can be conveniently used to group the palm species.

Systematic significance of number of metaxylem elements per vascular bundle has also been recognised by Tomlinson (1961). According to him in most of arecoid palms, to which *Chrysalidocarpus* belongs, and in some Lepidocaryoid and Sabaloid palms a single wide metaxylem element is present in majority of vascular bundles. In *Elaeis* and *Borassodendron* one to two wide vessels are found. *Chamaerops* and *Trachycarpus* have several vessels, while in rest of the palms there are usually two wide metaxylem vessels. However, Zimmermann and Tomlinson (1965) have opined that a single palm stem could have single metaxylem element at one level and two at others. Such possibilities would have to be verified by studying many other palms. In *Chrysalidocarpus*, atleast, such variation is not found throughout the aerial height of the stem. Even at rooting level, majority of the vascular bundles of the central zone have single metaxylem vessel though dermal and subdermal bundles have a patch of vessels. Our unpublished observations show that in majority of palms dermal zone of the rooting level is characterised by a patch of vessels for the vascular bundles. This feature is probably associated with connection of vascular tissues of the stem with those of roots.

The ground parenchyma pattern in *Chrysalidocarpus* also exhibits striking variability along the height of the stem, though Tomlinson (1961) appears to have overlooked this feature in this species. Fully differentiated parenchyma pattern is found only at the basal levels of the aerial mature stem and is more evident in the central zone. This appears to be the case in almost all the palm stems since the late secondary growth, which causes the differentiation in ground tissue starts from the base of the stem and progresses towards the apex (SCHOUTE, 1912). However, as shown by KAUL (1941-42, 1960) and TOMLINSON (1961) pattern of differentiation obviously appears to be characteristic for different taxa of palms and hence has a great diagnostic value provided fully differentiated parts of stem are compared.

In some vascular bundles of subdermal and central zones, the phloem is divided into two compartments by median intrusion of dorsal cap fibres. This feature appears to be rare in palm stems and has been recorded also in this species by TOMLINSON (1961).

In *Chrysalidocarpus*, pure fibrous strands are entirely lacking from all the levels of the central cylinder. It was UNGER (1845) who for the first time proposed to classify palms into two groups based on presence or absence of fibre bundles in the vascular region of the stem. STENZEL (1904) was of the opinion that their presence is more common in the fossil palm stems rather than in living. TOMLINSON (1961) has recorded their presence in *Bactris*, *Cocos*, *Erythrea*, *Leopoldinia* and *Wallichia*. Thus presence or absence of pure fibrous strands in the central cylinder also affords an additional character of systematic value.

Numerical features, like distribution of vascular bundles per square area and the fibrous to vascular ratio, have also been given importance in classification of palm stems by MOHL (1849) and STENZEL (1904). As shown here in *Chrysalidocarpus*, and in *Phoenix* by SWAMY AND GOVINDARAJULU (1961) both these features show definite trends of variations not only along the height of the stem but also from periphery to the centre. The total amount and the trend of variability of such criteria—if studied in detail for number of palm stems, may prove to be of diagnostic value for different groups.

Diagnostic significance to the number of bars on the perforation plate of the metaxylem element was suggested by MAHABALE (1958). In *Chrysalidocarpus* and *Phoenix* various attributes of the metaxylem element, like—the length, breadth and the number of bars on the end plate, show correlated variations from periphery to the centre and from base to the apex of the stem.

It is interesting to note in both these palms that contrary to the trends of vessel specialisation within different organs of monocotyledons founded by CHEADLE (1943), the length of metaxylem vessels tend to decrease along the height of the stem in all the three regions. Further, at any given level, it tends to increase from dermal to central zones. How far these peculiarities are connected with secondary growth in these arborescent monocotyledons is yet to be understood.

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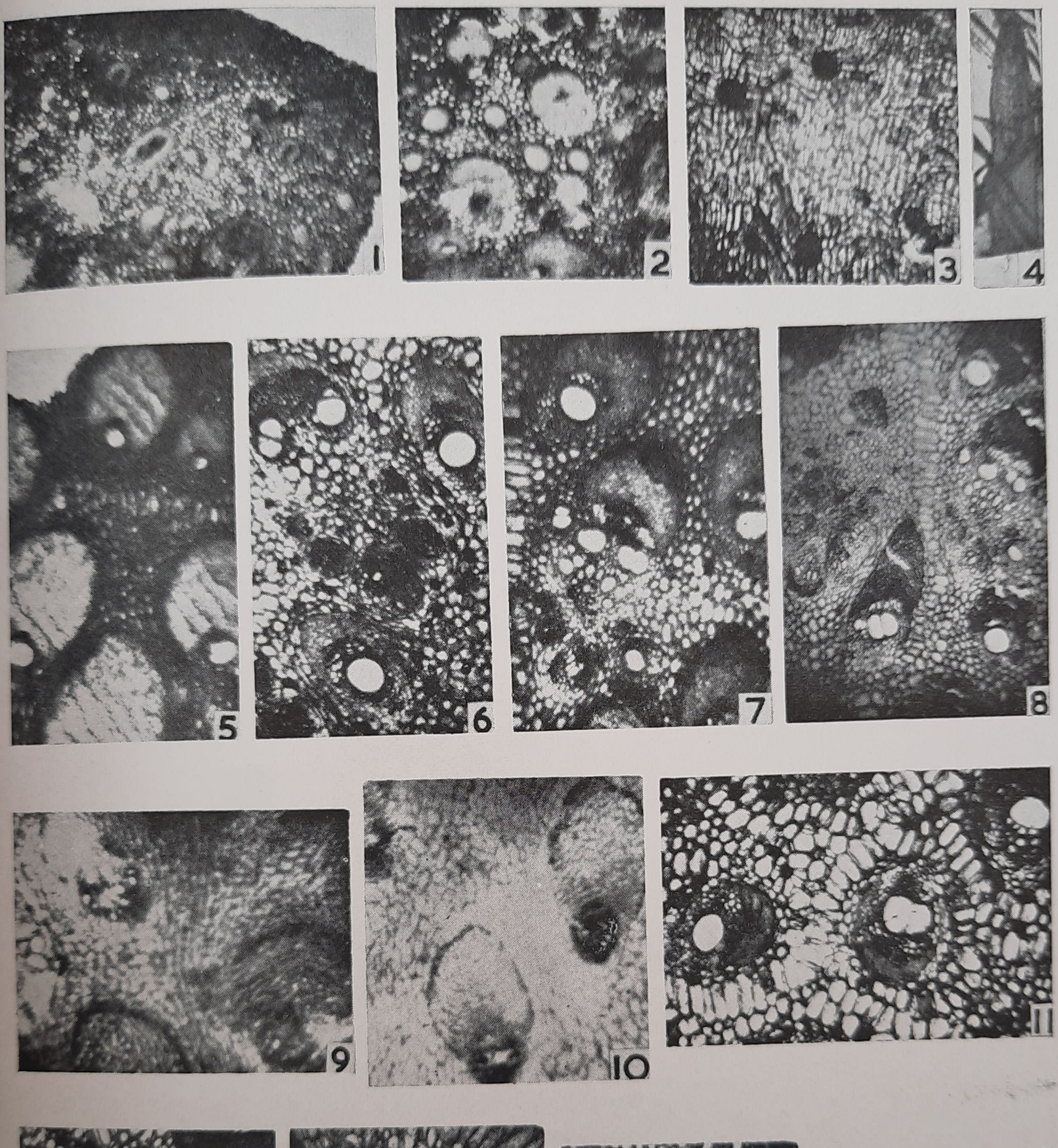
EXPLANATION OF PLATE 1

Figs. 1 to 3 and 5 to 15—T. S. of stem × 80. Fig. 1. Cortex 5.6 m above base. Fig. 2. Inner part of cortex. Fig. 3. Outer part of cortex at the rooting level. Fig. 4. Metaxylem vessel from central zone of the basal level × 80. Figs. 5, 6, 14. Dermal zone, 3.78 m above the base. Figs. 7, 8. Sub-dermal zone, 3.78 m above base. Fig. 9. Dermal zone rooting level. Fig. 10. Sub-dermal zone, rooting level. Fig. 11. Central zone, 3.78 m above base. Figs. 12, 13. Central zone, 0.95 m above base. Fig. 15. Sub-dermal zone, 6.6 m above base. (Arrows point to leaf trace bundles.)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