HISTOLOGICAL STUDIES ON THE ROOTS OF ORCHIDS FROM TAIWAN*

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Abstract: The anatomical and histological studies were made on the developing roots of more than ten species of orchids from Taiwan. The present investigation has revealed that with the exception of the apical organization, the various tissues in all the roots show very similar patterns. In which, as is seen in transverse sections from the periphery of the root centripetally, they can regularly be divided into the following tissues: a one to several layered, dead celled velamen; a uniseriate thick walled exodermis with short and long cells which are interposed with each other; a multiseriate parenchymatous cortex proper; a one cell layered, thick-walled endodermis which is interrupted by the thin-walled cells (endodermal passage cells) at the regions opposite to every protoxylem pole; a central stele with several groups of xylem and the same number of groups of phloem peripherally arranged surrounding the sclerified pith. The variation of some tissues, especially the velamen, are here discussed based on phylogeny as well as on environmental conditions. The uniseriate velamen more strongly retains the nature of a normal epidermis than does the multiseriate ones. The multiseriate velamen may have lost its original function of absorption during its phylogenetic advancement.

INTRODUCTION

The studies on the detailed structure of the growing root of *Dendrobium kwashotense* (an orchid from Taiwan) has been made by the senior worker (1970). Though the structure of orchid roots have been studied by many workers both on anatomical and physiological features (Dycus and Knudson, 1957; Engard, 1944; Gessner, 1956; Mulay and Deshpande, 1959; Mulay and Panikkar, 1956; Withner, 1959), and furthermore, the Orchidaceae represents a very important and extensive section of the flora in Taiwan (Masamune, 1933) so far comparatively little attention has been paid to it by local botanists. Many orchids which are known as ornamental plants in Taiwan as well as in the other places bear aerial or epiphytic roots. From the data provided by the earlier workers, such as Curtis (1917), Engard (1944), Mulay and Deshpande (1959), Mulay and Panikkar (1956), Withner (1959) and the senior author (1970) the histology of the roots of many orchids show a very similar organization. In which they regularly can clearly be divided into root cap, velamen, exodermis, cortex proper, endodermis and central stele. In the

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present report, the authors intend to give a better understanding and try to add more intensive information about the internal structure of aerial roots of orchids which may be of value in the study of other vascular plants. The aerial roots of ten species of orchids were studied. Since the developmental pattern of various tissues in each plant is more or less similar to that reported in the previous paper (Chiang, 1970), a comparative study is here made of the mature structures of each of these ten orchids.

MATERIALS AND METHODS

The following ten species of orchid roots were used in the present work:
Arundina chinensis Bl.
Bulbophyllum uraiense Hay.
Dendrobium fimbriatolabellum Hay.
D. flaviflorum Hay.
Eria arisanensis Hay.
Haraella odorata Kudo
Phalaenopsis amabilis Blume var. *aphrodite* Ames
Sarcanthus fuscomaculatus Hay.
Sarccolabium formosanum Hay.
Thrixspermum saruwatarii (Hay.) Schltr.

All of the plants used were collected in the field in Taiwan and cultivated in a vinyl house in Taipei. The plants were irrigated every day. Two types of aerial roots ('free aerial roots' which develop in the air, and 'climbing or adhesive roots' which attach to a solid object) were collected for their root tips as well as other parts of the roots early in the mornings during 1967–1969. All root tips were collected while they were in a state of active growth, and were immediately fixed in formalin acetic-alcohol solution (FAA). Materials were then dehydrated in tertiary butanol series and embedded in tissuemat, serially sectioned at the thickness of 8–10 μ in various planes, and stained with safranin-fast green combination (Johansen, 1940) or tannic acid and iron alum with safranin and orange G (Sharman, 1943). Most of the materials were too hard to be sectioned smoothly, so before sectioning they were soaked in water for several days to two months after embedding in the tissuemat.

RESULTS

I. Apical organization

Several ways have been used to explain the behaviour of root apical meristems, There is the histogen theory (Hanstein, 1868; Janczewski, 1874a, b), Körper-Kappe theory (Schüepp, 1917), the concept of initial cells in the promeristem (Guttenberg,

1947; Clowes, 1950) and the presence of a quiescent center in the distal region of the root tip (Clowes, 1954). Though people can not get complete information on all the kinds of root tips by using any one of these concepts, yet all of them are convenient in some aspects for the histological study of the root meristem. The histogen theory and the concept of initial cell groups are used in describing the cell pattern in the promeristem in the present investigation. Three to seven root tips for each species were examined in this work. All of the root promeristems of the same species show the same pattern of histological constitution.

One-group celled type. Five histogen types have been recognized in the root tips of orchids in the present investigation. Eight out of twelve species representing ten genera have one group of cells in their promeristems (Fig. 1, Table 1); in which all of the root tissues are derived from a common mass of cells. The cell pattern

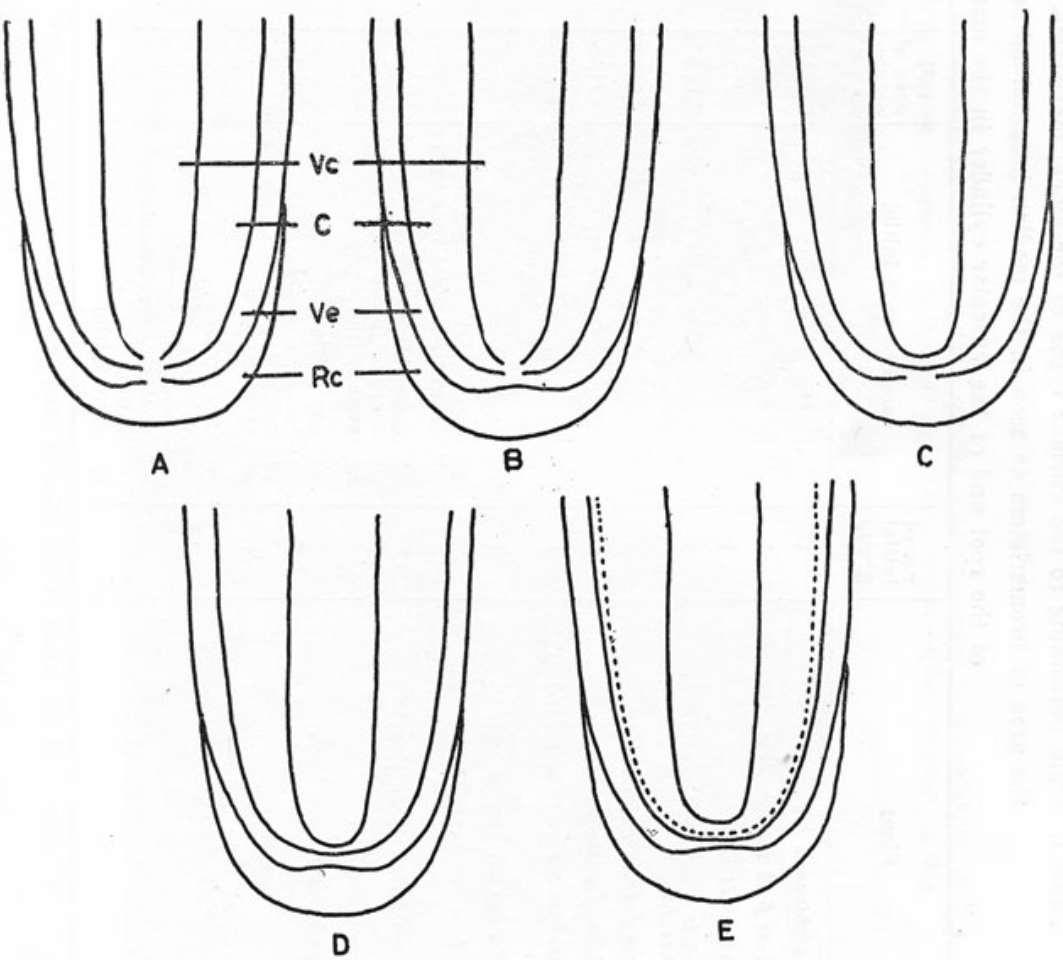


Fig. 1. Diagrams showing various types of apical meristems and derivative tissues in root tips. Key to labeling: C, cortex; En, endodermis; Ex, exodermis; Id, idioblast; Rc, root cap; Vc, vascular cylinder; Ve, velamen.

Table 1. Data pertaining to the various types of the apical meristems, and the relationship between the area of promeristem as seen in the median longitudinal section, the diameter of the root and of the vascular cylinder in the mature root.

Plant	no. of initial group	name of each initial	(μ^2) area of promeristem*	diameter (μ) root (R)	diameter (μ) vascular cylinder (V)	no. of v. b. group	V/R (%)	row of velamen	drawing cf.
Arundina chinensis Bl.	1	—	69.83	1,100	320	7	29.09	2	Fig. 1A
Dendrobium fimbriatolabellum Hay.	1	—	70.74	1,600	300	13	18.20	6	Fig. 1A
Eria arisanensis Hay.	1	—	413.44	660	220	6	33.33	1	Fig. 1A
Phalaenopsis amabilis Blume var. *aphrodite* Ames	1	—	1,529.50	3,500	415	14	11.85	2	Fig. 1A
Sarcanthus fuscomaculatus Hay.	1	—	3,515.75	3,250	910	18	28.00	4	Fig. 1A
Sarccolabium formosana Hay.	1	—	716.63	3,000	360	10	12.00	3	Fig. 1A
Thrixspermum saruwatarii (Hay.) Schltr.	1	—	1,470.00	1,320	380	9	28.78	3	Fig. 1A
Pleione formcsana Hay.**	1	—	—	—	—	—	—	—	Fig. 1A
Bulbophyllum uraiense Hay.	2	1) cap initial 2) velamen-cortical-stele initial	—	600	205	6	34.20	1	Fig. 1B
Dendrobium kwashotense Hay.***	3	1) cap-velamen initial 2) cortical initial 3) stele initial	—	—	—	—	—	—	Fig. 1C
Dendrobium flaviflorum Hay.	4	1) cap initial 2) velamen initial 3) cortical initial 4) stele initial	—	1,325	405	12	30.56	9	Fig. 1D
Haraella odorata Kudo	5	1) cap initial 2) velamen initial 3) exodermal initial 4) cortex proper-endodermal initial 5) stele initial	—	1,240	180	10	14.52	2	Fig. 1E

* The region where the root tissues of the primary meristem (protoderm, ground meristem and procambium) are still not distinguishable.

** Slide courtesy of Chen. *** Chiang, 1970.

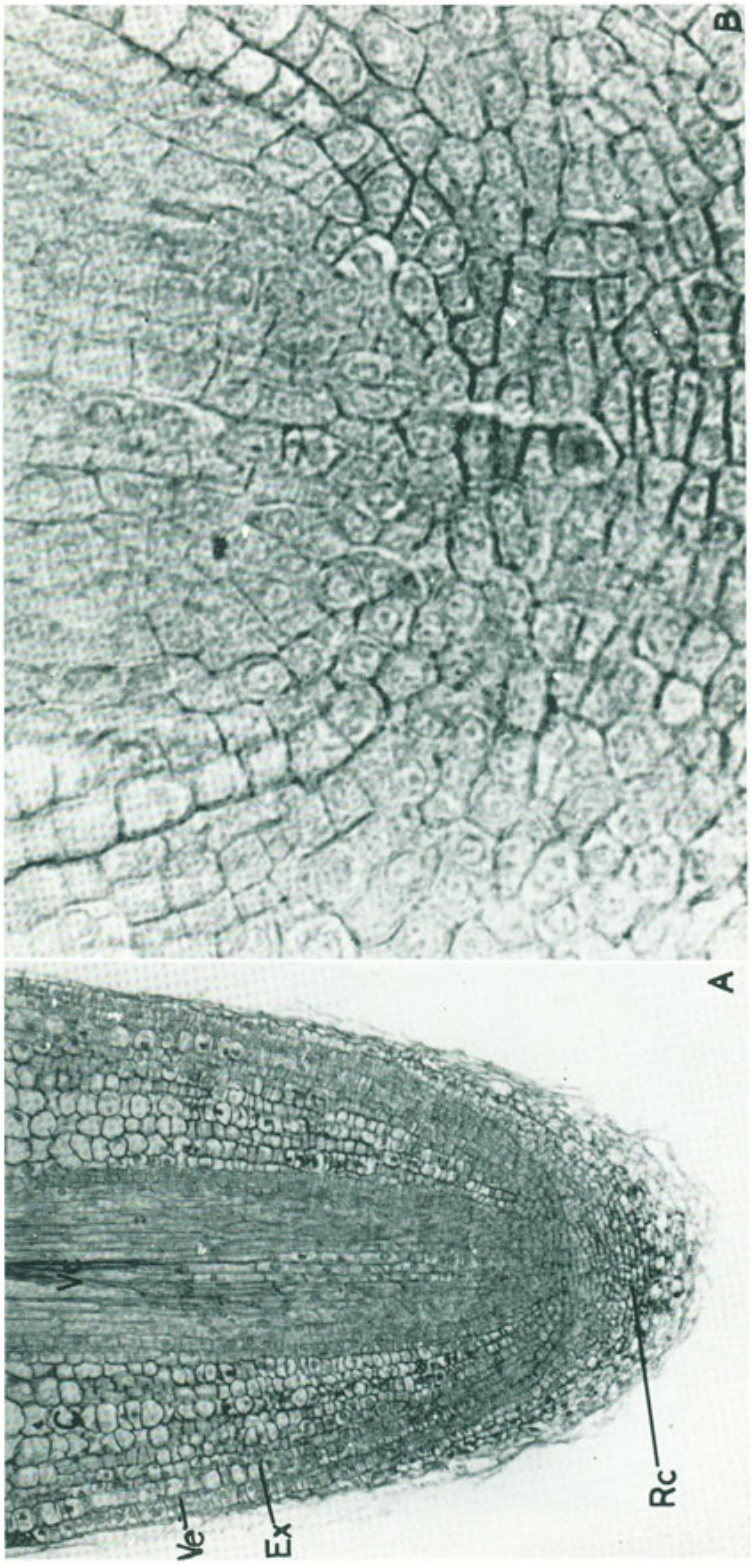


Fig. 2. Median longitudinal section of the root tip of *Arundina chinensis* Bl. through the apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region, ×480. See Fig. 1. for labeling.

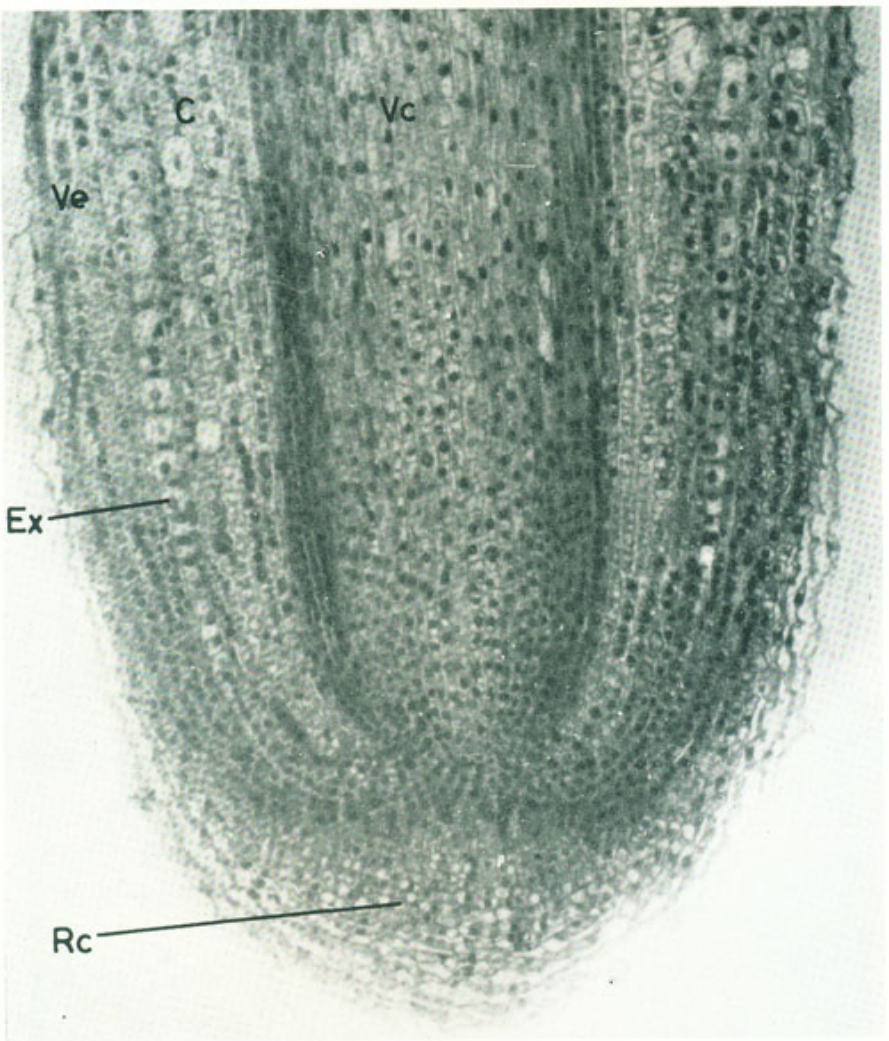


Fig. 3. Median longitudinal section of the root tip of *Dendrobium fimbriatolabellum* Hay. through the promeristematic region, ×140. See Fig. 1. for labeling.

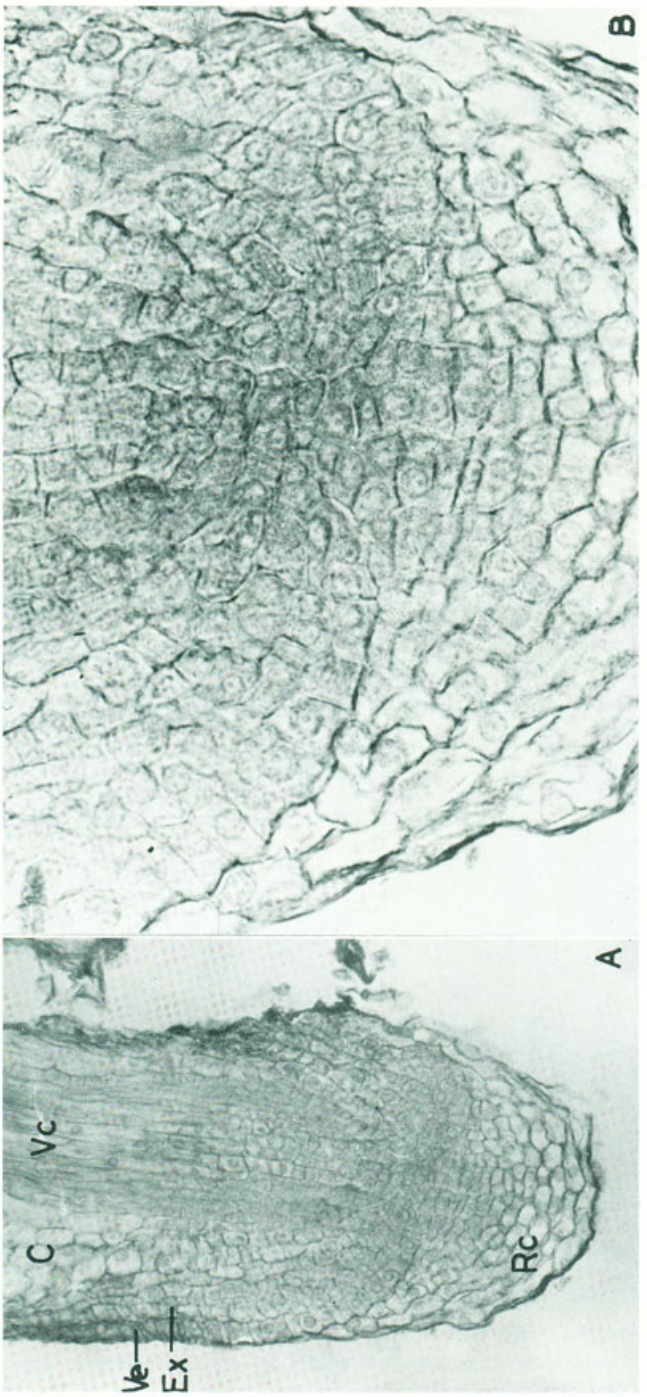


Fig. 4. Median longitudinal section of the root tip of *Eria arisanensis* Hay. through the apical meristem. Fig. A. ×188. Fig. B. Enlargement of promeristematic region, ×560. See Fig. 1. for labeling.

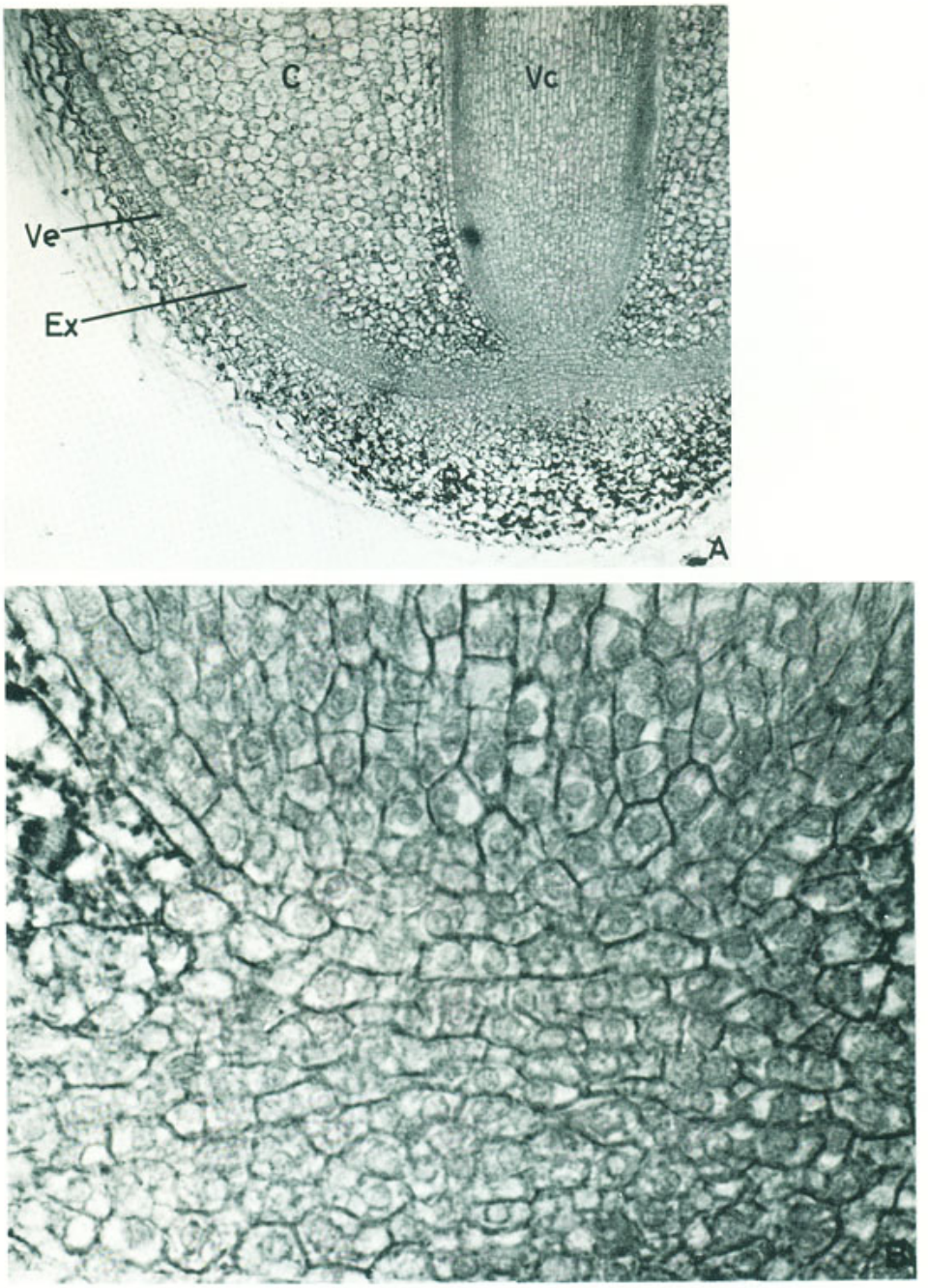


Fig. 5. Median longitudinal section of the root tip of *Phalaenopsis amabilis* Blume var. *aphrodite* Ames through the root apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region, ×480. See Fig. 1. for labeling.

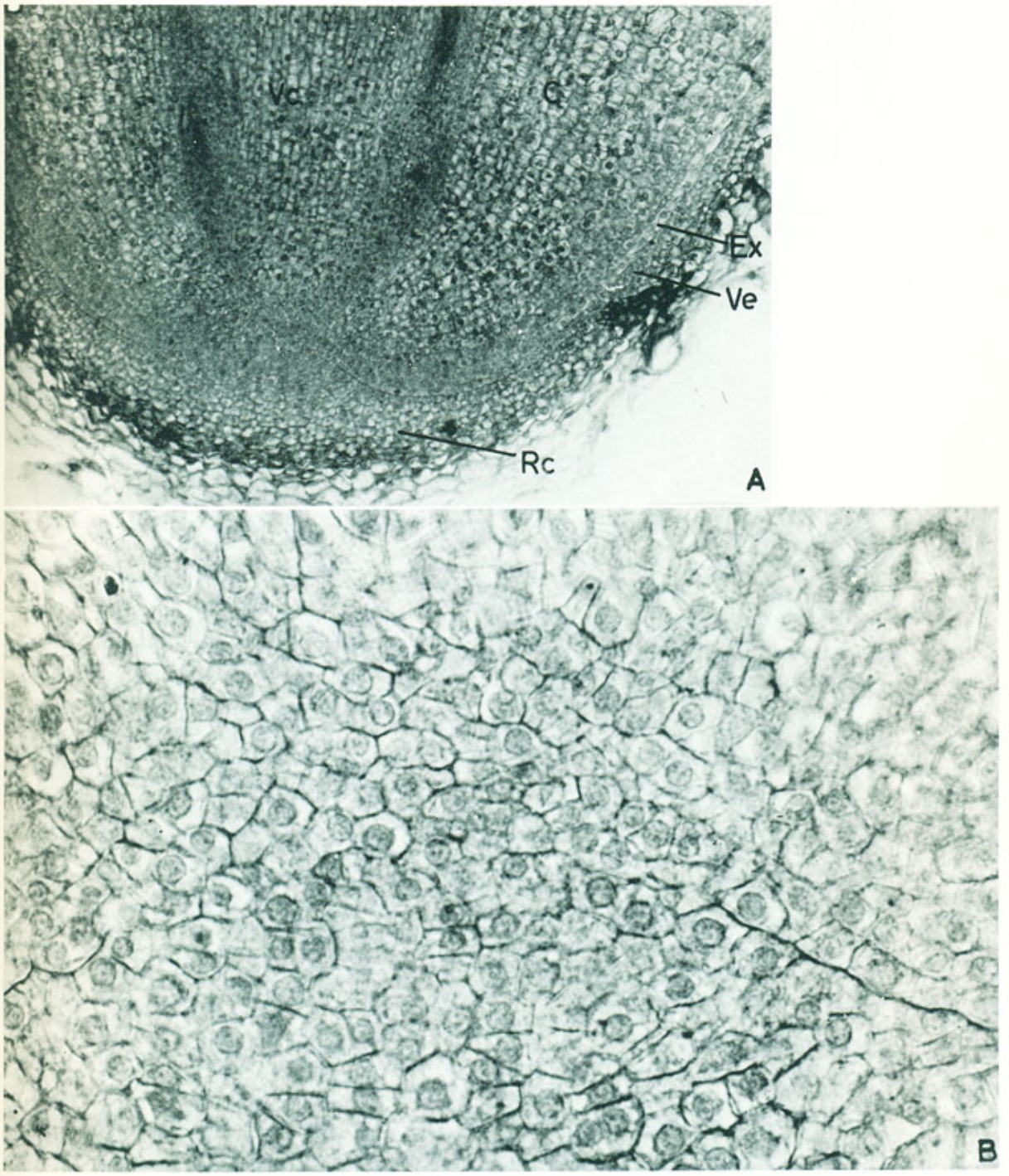


Fig. 6. Median longitudinal section of the root tip of *Sarcanthus fuscomaculatus* Hay. through the apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region, ×480. See Fig. 1. for labeling.

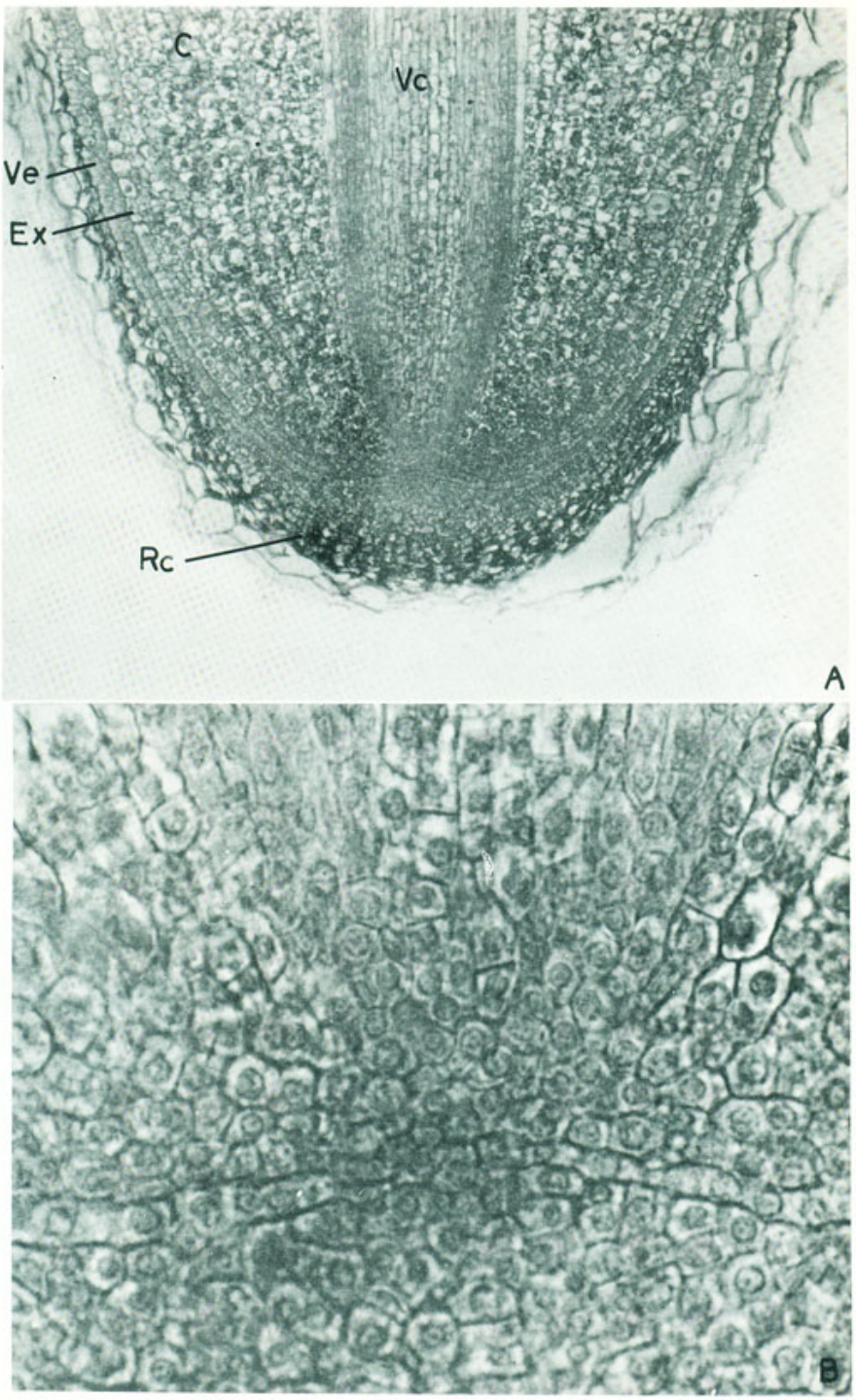


Fig. 7. Median longitudinal section of the root tip of *Sarccolabium formosanum* Hay. through the apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region. ×480. See Fig. 1. for labeling.

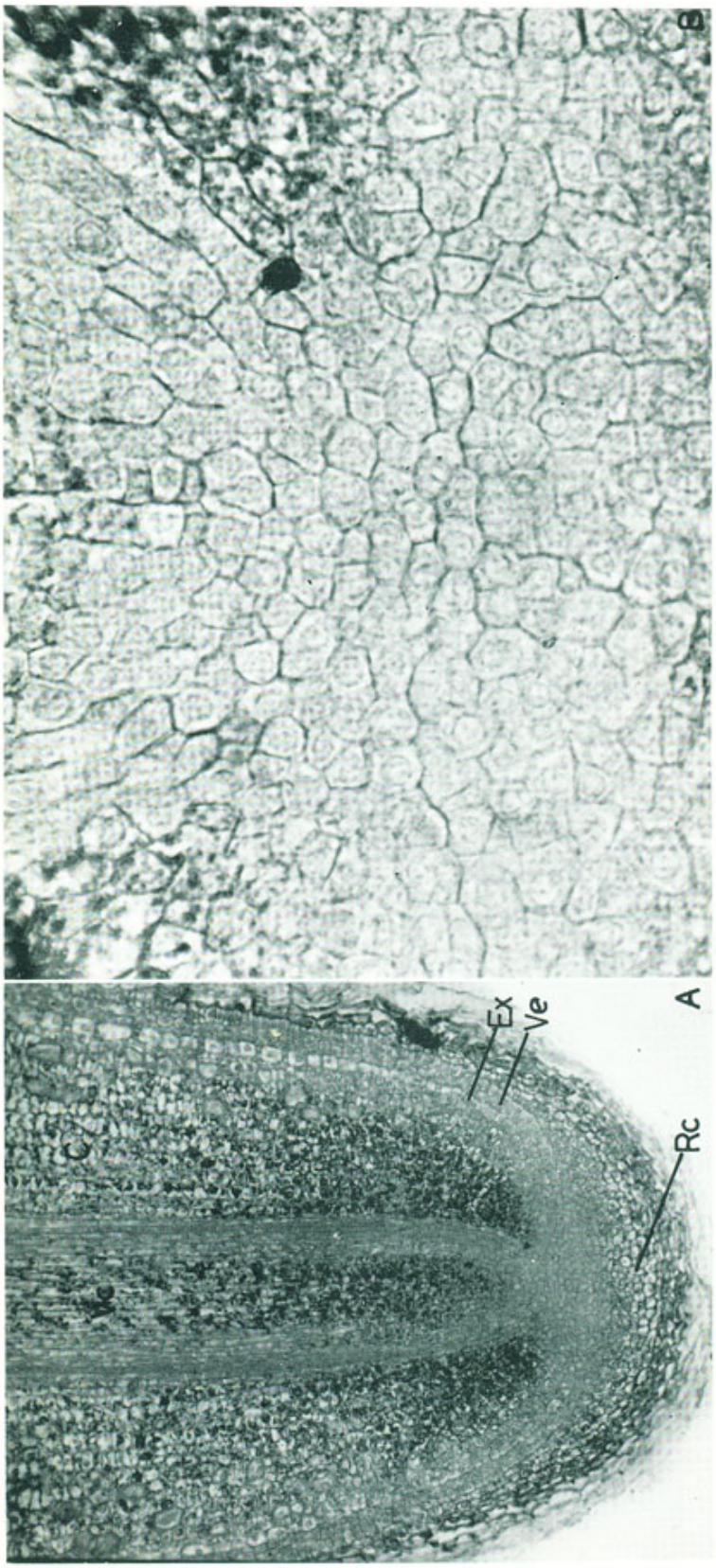


Fig. 8. Median longitudinal section of the root tip of *Thrixspermum saruwatarii* (Hay.) Schltr. through the apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region, ×480. See Fig. 1. for labeling.

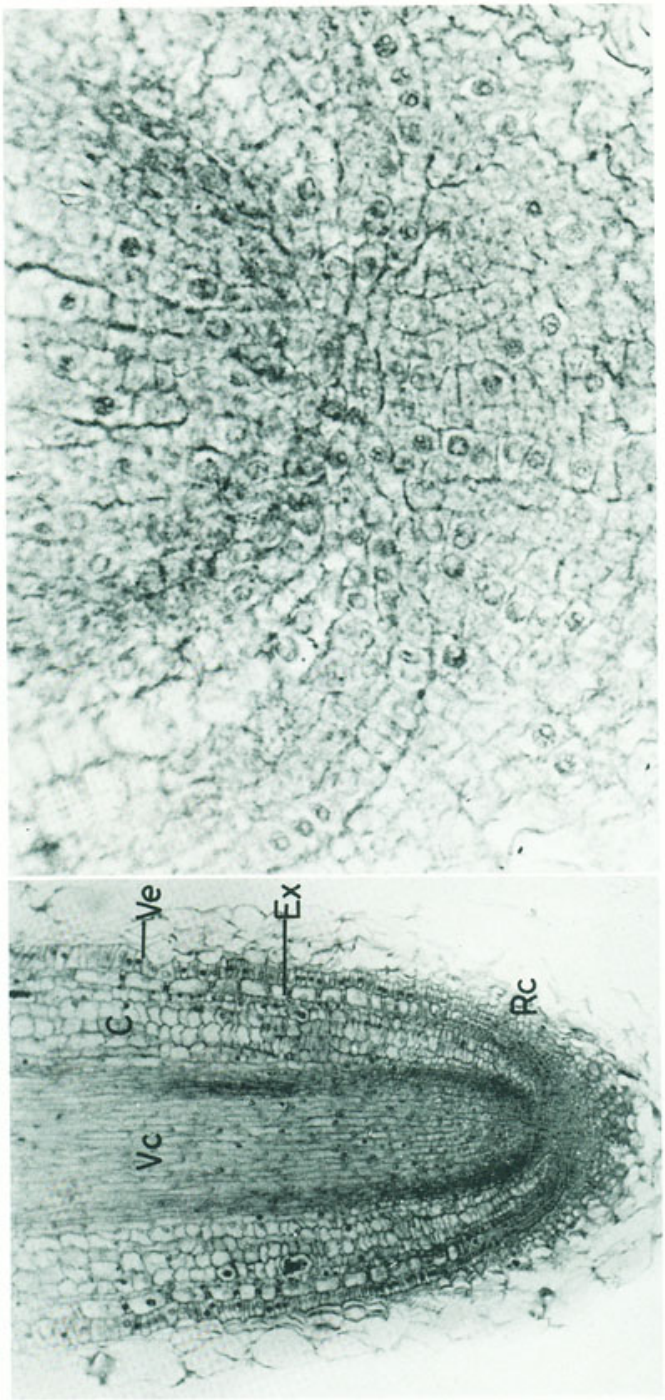


Fig. 9. Median longitudinal section of the root tip of *Bulbophyllum uraiense* Hay. through the apical meristem. Fig. A. ×95. Fig. B. Enlargement of promeristematic region, ×400. See Fig. 1. for labeling.

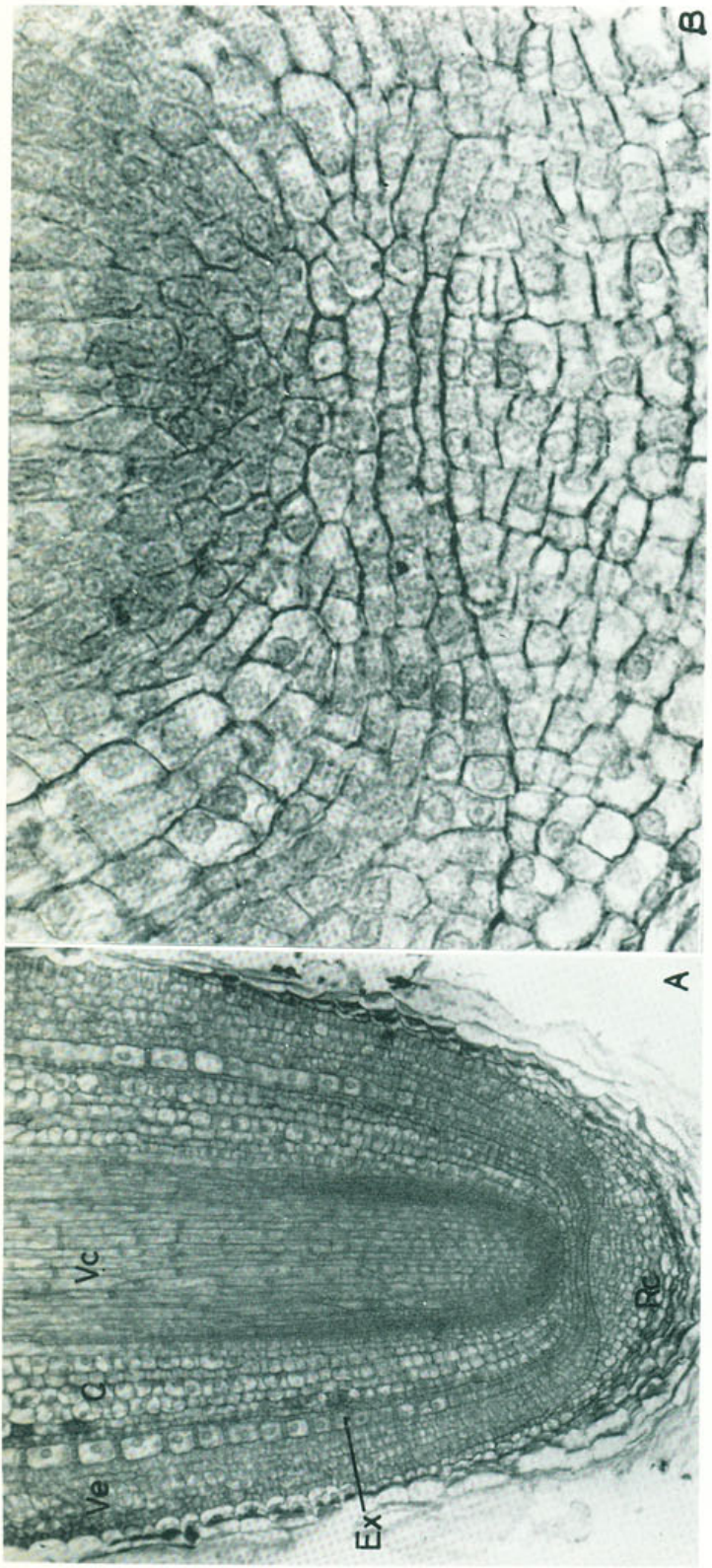


Fig. 10. Median longitudinal section of the root tip of *Dendrobium flaviflorum* Hay. through the apical meristem. Fig A. ×95. Fig. B. Enlargement of the promerisematic region, ×480. See Fig. 1. for labeling.

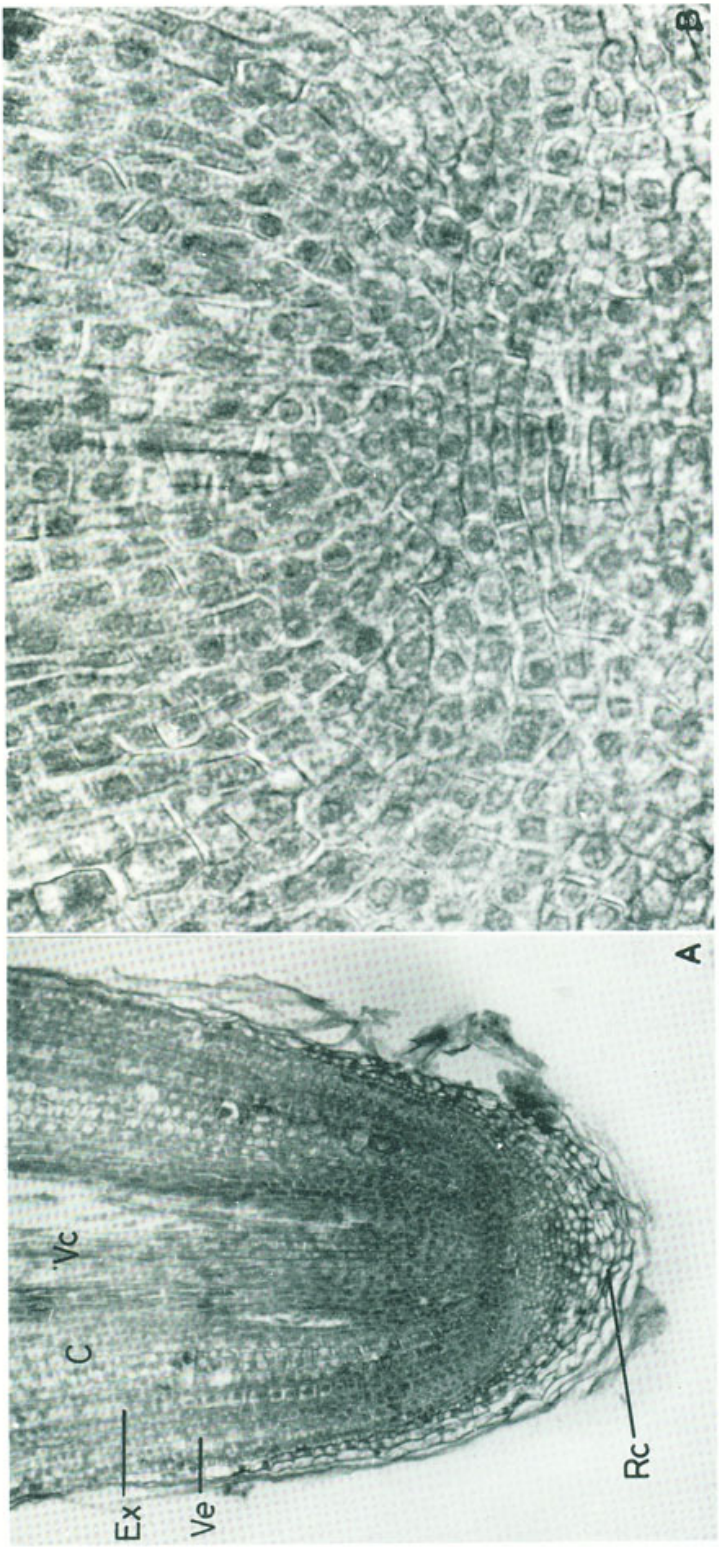


Fig. 11. Median longitudinal section of the root tip of *Haraella odorata* Kudo through the apical meristem. Fig. A. ×95. B. Enlargement of the promeristematic region, ×480. See Fig. 1. for labeling.

of these cells is too difficult to identify one histogen from another. They are: *Arundina chinensis, Dendrobium fimbriatolabellum, Eria arisanensis, Phalaenopsis amabilis, Pleione formosana, Sarcanthus fuscomaculatus* and *Thrixspermum saruwatarii.*

Among the plants having the one-group celled promeristem pattern, there are some differences among them in cell shape, cell arrangement and cell size at their extreme embryonic cells (Fig. 12). In the promeristem of the root tip of *Arundina chinensis* there is only a one or two celled layer in height and two cells in width (Figs. 1, 2, 12A). All the tissue initials (such as root cap, velamen, cortex and central stele) can be traced from the region which is very close to the center of promeristem from which all of the root tissues are derived. The roots of *Arundina chinensis, Eria arisanensis* have a rather simple cell constitution in their root meristems. It has four cells arranged in two tiers (Fig. 4, 12B). The initial cells in the promeristems of *Arundina* and *Eria* are very few, similar to each other in their shape and compactly arrangement and occupy a rather small area (Table 1). In the root tip of *Sarccolabium formosanum* the promeristem is about three cells high and three cells wide (Fig. 7, 12E). In the root tips of *Dendrobium fimbriatolabellum, Sarcanthus fuscomaculatus, Phalaenopsis amabilis* and *Thrixspermum saruwatarii* broad promeristems are found (Figs. 3, 5, 6, 8, 12C, 12F). The cells in the extreme promeristems of *Arundina chinensis, Dendrobium fimbriatolabellum, Eria arisanensis, Phalaenopsis amabilis* and *Sarccolabium formosanum* are somewhat rectangular with their short axis perpendicular to the root axis, as seen in the longitudinal section whereas that in other species, such as *Sarcanthus* sp. and *Thrixspermum* sp. they appear as polygonal and more isodiametric in shape. Apparently the new cell walls in the latter species are laid down in a rather irregular orientation—other than being parallel or perpendicular to the root axis.

Two-group celled type. Only one species—*Bulbophyllum uraiense* is found belonging to this promeristem type (Fig. 9; Table 1). The boundary between the cap initial or cap cells and root proper is sharp even at the extreme region of the promeristem (Fig. 9B). But the boundary between the tissues in the root proper, such as velamen, cortex and vascular cylinder is obscure. All of these tissues share an initial group of cells, or they have a common origin which is located next to the cap initial. The cells in the cap initial or calyptrogen consist of more conspicuous nuclei and arranged in a more compact pattern than those in the initial cells of the root proper. The initial cells of the root cap and the young cap cells are arranged in longitudinal files whereas the filing pattern is not distinct in the initial cells of root proper.

Four-group celled type. The meristematic region of *Dendrobium flaviflorum* has four groups of district initial cells. They are the cap initials (calyptrogen), velamen initials (protoderm), corticals (periblem) and vascular initials (plerome). The cell walls between the root proper and cap cells are deeply stained, resulting in very

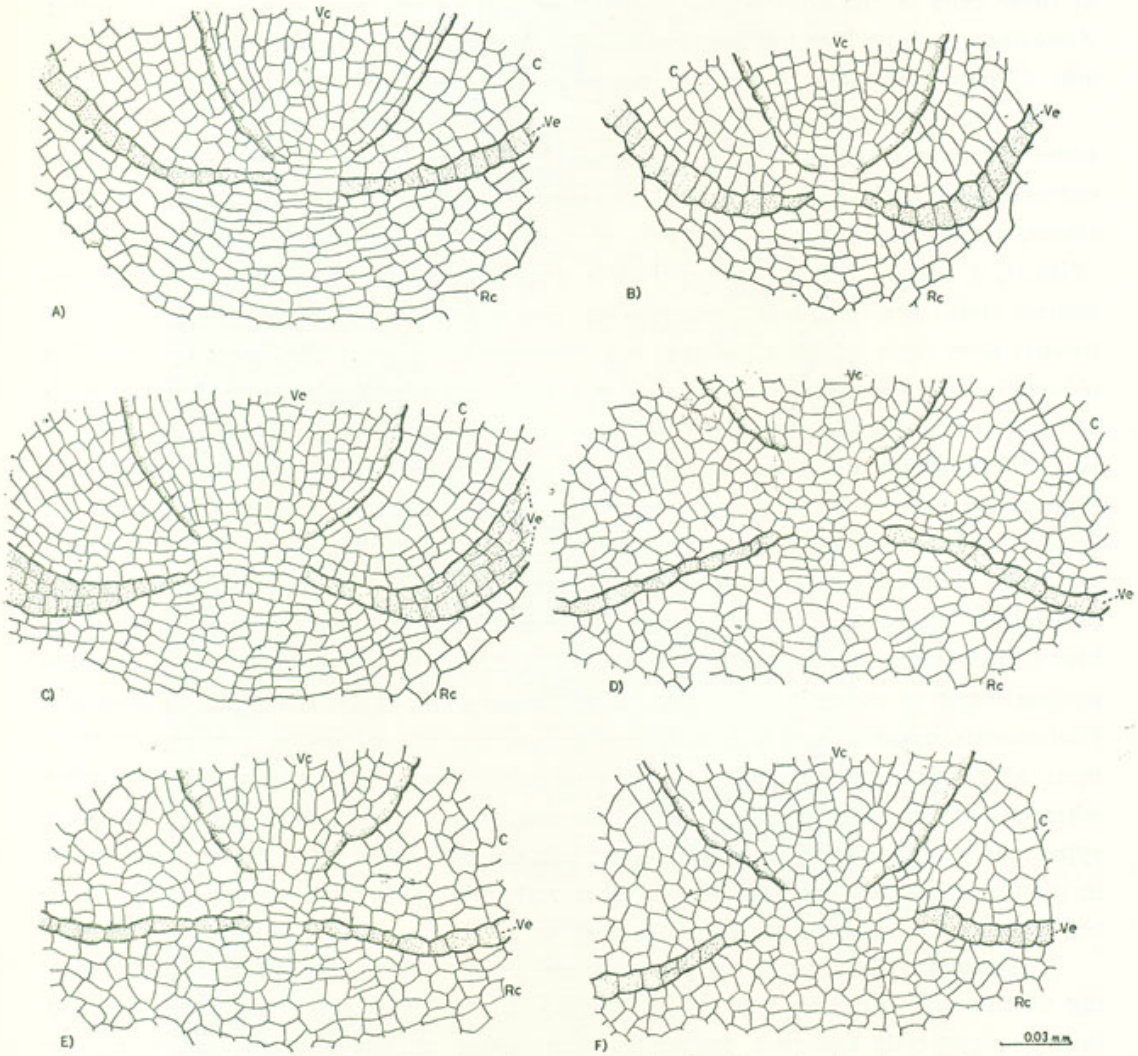


Fig. 12. Illustrations showing the various types of cell orientation in the root meristems, all of them have only one group of initial cells in their promeristems.

A) *Arundina chinensis* Bl.
B) *Eria arisanensis* Hay.
C) *Dendrobium fimbriatolabellum* Hay.
D) *Sarcanthus fuscomaculatus* Hay.
E) *Sarccolabium formosanum* Hay.
F) ***Thrixspermum saruwatarii*** (Hay.) Schltr.

distinct shallow W-shape line with its deepest points located between the protoderm and calyptrogen (Fig. 10). The innermost cell layer of calyptrogen which is located in contact with velamen initials, is more vacuolated than the velamen initials. The initial cells of velamen, which are located between the cap initials and cortical initials are arranged horizontally in one layer, since they divide anticlinally in this region. The periclinal division of young velamen cells can only be found in the

axial cells immediately next to the distal points of the two dips in the W-shaped line. The cells divide predominantly anticlinally at later stages. Immediately above the uni-layered velamen initials, there are three layers of cortical initials. Their meristematic activity contributes to the cells of cortex which includes the exodermis, endodermis and cortex proper. The cells in the stele apex belong to the stele initials. These cells are smaller in comparison with the initial cells in the other histogens and are more chromophilic.

Five-group celled type. In the root tip of *Haraella odorata*, root cap, velamen, exodermis, cortex-endodermis and stele have their own independent initials (Fig. 11). The boundaries between each initial are not as distinct as that in the root of *Dendrobium flaviflorum* but each initial can still be identified from the cell patterns shown in the median longitudinal sections (Fig. 11B). The boundary between root cap and root proper forms a slightly W-shape line. The new walls formed in these initial cells are predominantly anticlinal in cap initials; periclinal in velamen, exodermis, cortex-endodermis initials; and both anticlinal and periclinal in stele initials. There is one layer of cells in velamen initials and exodermal initials, and two layers in cortex-endodermis initials.

II. Root cap

The root cap is conspicuous in all the species examined. Most of them have about 15–25 layers of cells in the front of promeristematic regions. The shape of the young cap cells are more or less similar to the embryonic cells in the distal part of promeristem in the root which is the one-celled group type; and similar to the cells in the cap initials in the root which have an independent origin. (Fig. 2–11).

In most species, the new walls formed in the young cap cells which are located close to the promeristem divide both periclinally and anticlinally, whereas they form mainly anticlinal walls in the old cap cells which are located in the outer part of the root cap. Therefore they are arranged in a layered pattern covering the root tip and constantly slough off from the outermost layer. But in the cap cells of *Eria*, the intermediate directions of new cell walls are conspicuous, they do not follow either an exact anticlinal or an exact periclinal direction (Fig. 4B).

Chloroplasts are not found in the root cap cells of *Dendrobium fimbriatolabellum*, *D. flaviflorum*, *Eria* and *Bulbophyllum* (Figs. 3, 10, 4, 9). Chloroplasts can be seen in the remaining species. They are abundant in all the cap cells of *Sarccolabium* even in the cells of promeristem (Fig. 7); distributed in all the cap cells except in the cells very close to the promeristem of the roots of *Arundina* and *Phalaenopsis* (Figs. 2, 5); present only in the older part of the cap cells in *Sarcanthus* and *Thrixspermum* (Figs. 6, 8); not abundant but are distributed in all the cap cells of *Haraella* (Fig. 11). The nuclei are distinct and always keep their shape even in the old sloughing off cells which are highly vacuolated and losing their original figures.

III. Velamen

The velamen ranges from one to nine cells thick and is present in all the species examined (Table 1). Chiang (1970) observed that the number of cell layers in velamen of *Dendrobium kwashotense* (another orchid from Taiwan) was affected by the media, or its substrates on which the roots grew. In order to avoid this error caused by environment, more than ten roots of each spccies were measured in the present investigation; and all of them were collected from plants which were in the same stage of development. The protoderms of *Eria* and *Bulbophyllum* undergo only anticlinal divisions to form one layered velamens. (Figs. 13C, 14D). *Dendrobium* has rather thick velamens. *D. fimbriatolabellum* has six and *D. flaviflorum* has nine rows (Figs. 13B, 15A). In *Phalaenopsis* and *Haraella* (Figs. 13D, 15B) the velamen is two layered; in *Sarccolabium* and *Thrixspermum* three (Figs. 14B, 14C); and in *Sarcanthus* about four (Fig. 14A). In these species with multilayered velamens, the periclinal divisions occur slightly behind the apical meristems in the protoderms. Of these some cells are slightly folded over each other. The process of differentiation in velamen cells is similar to that which occurs in the root of *Dendrobium kwashotense* (Chiang, 1970). During the course of early development of the root tissues, the vacuolation occurs last in the velamen cells. Therefore the cytoplasms of young velamen cells are denser in comparison with the other tissues of the same level of development. There are no intercellular spaces in the velamen. All the cells are compactly arranged. They bear no root hairs in most species; but in the roots of *Arundina chinensis, Eria arisanensis* and *Bulbophyllum uraiense* most of the velamen cells tend to protrude on the outside of root forming the root hair-like structures in all the directions (Figs. 13A, 13C).

The velamen cells lose all the protoplasmic contents when the other tissues of the roots (such as pith, exodermal and cortical cells) still retain their cell contents in the same level of development. The cells in velamens of most species are elongated with their long axes parallel with root axes. But the velamen cells of *Bulbophyllum uraiense, Haraella odorata* and the outermost layers of the many layered velamens are shorted or somewhat isodiametric.

The velamen cells regularly have secondary walls. The outer tangential walls of the uniseriate velamen and the outer tangential walls of the outermost layer of the multiseriate velamen are always thinner; and thicken progressively toward the center of the root. Several different patterns of seconday walls are found in the velamen cells. There are numerous small irregular openings in *Bulbophyllum* (Fig. 16h), much like a sac with many pores in all directions. The secondary walls of velamen cells in the multiseriate velamens may be deposited in only one way, or in several different patterns. In *Dendrobium fimbriatolabellum* and *D. flaviflorum* only one type of wall pattern is formed (Fig. 16b, 16i). They are reticulate, forming a cross thread-like thickening in all directions (Fig. 16b, 16i). The other

multiseriate velamens have more than one type of wall thickening (Table 1). They always have thinner walls with larger openings in the outer layer, or thick walls with smaller openings toward the inside of the roots. (Fig. 16). Endophytic fungi and algae are present in the cells of the velamens in all roots examined. Generally, mycorrhizal hyphae or algal filaments are more abundant in the root hairs and the outer layers of the velamens of the multiseriate type. They are less abundant in the inner layers.

IV. Cortex

The cortex in all these species can be divided into three different regions: the uni-layered exodermis, or the outermost layer enclosing all the root tissues except the velamen; the many-layered cortex proper, or the middle tissue; and the one-layered endodermis, or the innermost layer surrounding the central stele (Figs. 13–15). As mentioned in the previous section, these three regions may be derived from the same initial cells which gives rise to other tissues or may come from independent initial cells, as in *Dendrobium flaviflorum* and *Haraella odorata* (Table 1).

Exodermis. The exodermis in all the plants observed in this investigation appear as a one celled layer which in most of the species constantly consist of two kind of cells: long cells and short cells, or exodermal passage cells. As in some other orchid roots (Chiang, 1970), the long cells and short cells are arranged in vertical rows and regularly interposed between each other (Fig. 2–11). During the course of tissue differentiation from the apical meristem to the upper part of the root, the cells in the cortex proper are the first to vacuolate, and the long cells in the exodermis are the second to vacuolate. Sometimes the vacuolation of long cells and of cortex proper cells occur at about the same time. Because of the vacuolation in the long cells in their early stage and their peculiar arrangement in the root tissues, the exodermis is recognizable even in the region very close to the meristem. The vacuolation in exodermal passage cells occur at a rather late stage. With the exception of that in *Phalaenopsis*, the exodermal long cells are extensively elongated with their long axes parallel with the root axes, and the exodermal passage cells (short cells) are more or less isodiametric as seen in a longitudinal section. The exodermal long cells can not be distinguished from the short cells by their size in transverse sections, except in the stage when the short cells still retain their thin walled nature and when the long cells are coated by secondary walls. The arrangement of the long and short cell pattern is not apparent in the exodermis of *Phalaenopsis*. But the exodermis of *Paraenopsis* is also very easy to recognize because of its thickened walls, and the enlargement and vacuolation of its cells in the very early stages of development in the region near the meristem (Fig. 5A).

Both exodermal long cells and passage cells have thick secondary walls in the mature roots. The deposition of the secondary wall in the long cells occurs earlier than that in the passage cells. The secondary thickening is laid down first on the

outer tangential wall and than spreads along the transverse and radial wall towards the inner tangential wall. Therefore, in some sections, the exodermal cells show that the outer tangential, radial and transverse walls are occupied by the thick secondary walls whereas the inner tangential walls (the walls in contact with the cortex proper) still remain very thin. The nuclei are still conspicuous in both long and short cells which have become highly vacuolated and have developed thick walls.

The relationship between the cellular structure of exodermal cell and the media, on which the root grow, has not been studied in present investigation. In *Dendrobium kwashotense* the wall structure of exodermal cell is affected by the substrate (Chiang, 1970).

Cortex proper. All the cells in the cortex are parenchymatous. As seen in the transverse sections, most of the cortex is occupied by large cells except the layers which are located next to the exodermis and to the endodermis (Figs. 13–15). Cortex proper in the mature root is the only tissue which contains intercellular spaces; and is the only tissue which remains parenchymatous even in very old parts where the rest of the tissues have become sclerified.

Chloroplasts are constanly present in the cells of the cortex proper of all species, and are conspicuous in the extreme promeristems in most of the species examined. The cell layers in the cortex proper in the radial direction range from 4 (*Eria* and *Bulbophyllum;* Figs. 13C and 14D) to 25 layers (*Sarcanthus;* Fig. 14A). It is difficult to trace the relationships between the thickness of the root and thickness of the cortex proper or thickness of vascular stele and layers of the velamen from the data provided in Table 1.

Of the ten species examined, all of them have raphid-containing idioblasts in the cortical cells. The cortex proper is the only tissue in the root which contains raphid-containing idioblasts. Most of the species develop raphids very early in the regions where they are close to the root promeristems. They usually occur in the outer layers of the cortex proper rarely in the inner layers, sometimes in the cell layer next to the exodermis (Fig. 15D). The raphid is formed within a membrane in its young stage (Fig. 15C), but the membrane is usually destroyed in the older stage. In comparison with the remaining cells in the cortex proper, the size and the density of the cytoplasm which surrounds the raphid does not show any peculiarity in the most plants. But in *Dendrobium flaviflorum* and *Phalaenopsis*, the raphid is constantly surrounded by a extensively chromophilic substances (Figs. 15D, 15E).

Endodermis. Endodermis which forms the innermost sheath of the cortex is conspicuous in the mature roots in all the plants (Figs. 13–15) because of their thickened walls. The course of development or differentiation of endodermal cells are quite similar to that which occurs in the roots of the other orchids, *e.g.*,

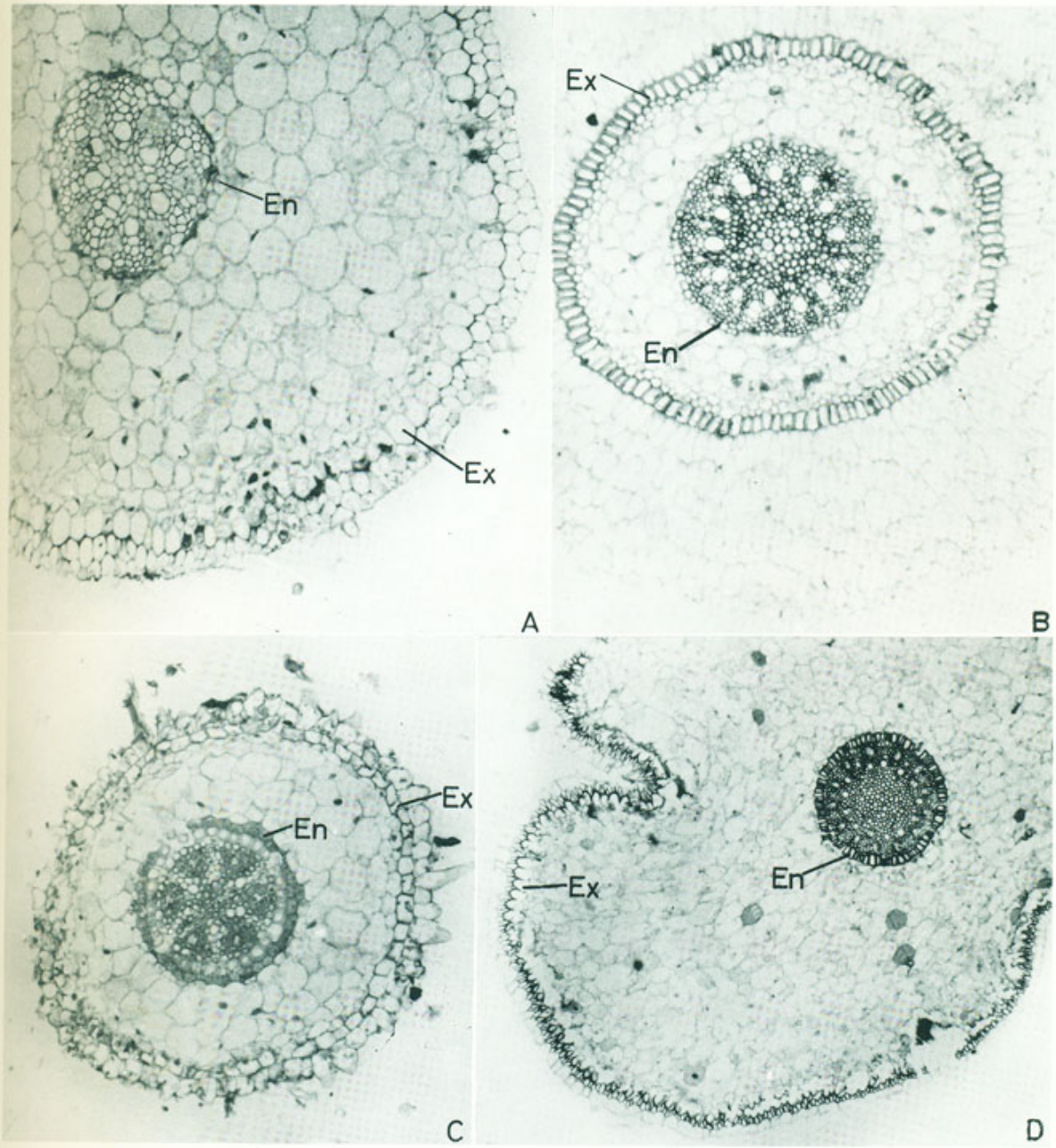


Fig. 13. Photographs showing the transverse views of the roots in the mature parts.
Fig. 13A. *Arundina chinensis*, ×97.
Fig. 13B. *Dendrobium fimbriatolabellum*, ×97.
Fig. 13C. *Eria arisanensis*, ×97.
Fig. 13D. *Phalaenopsis amabilis*, ×38.

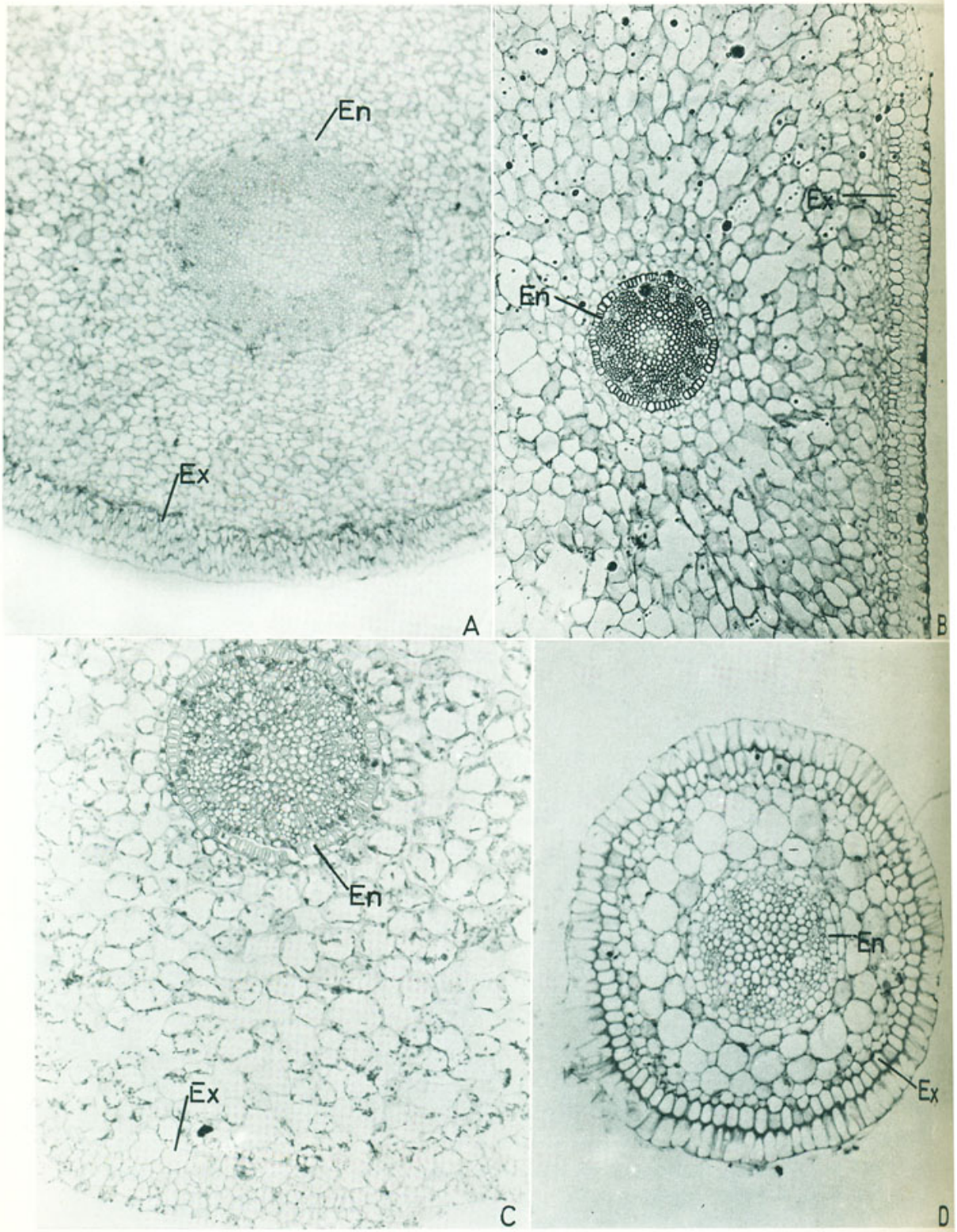


Fig. 14. Photographs showing the transverse views of the roots in the mature parts.
Fig. 14A. *Sarcanthus fuscomaculatus*, ×38.
Fig. 14B. *Sarccolabium formosanum*, ×97.
Fig. 14C. *Thrixspermum saruwatarii*, ×97.
Fig. 14D. *Bulbophyllum uraiense*, ×97.

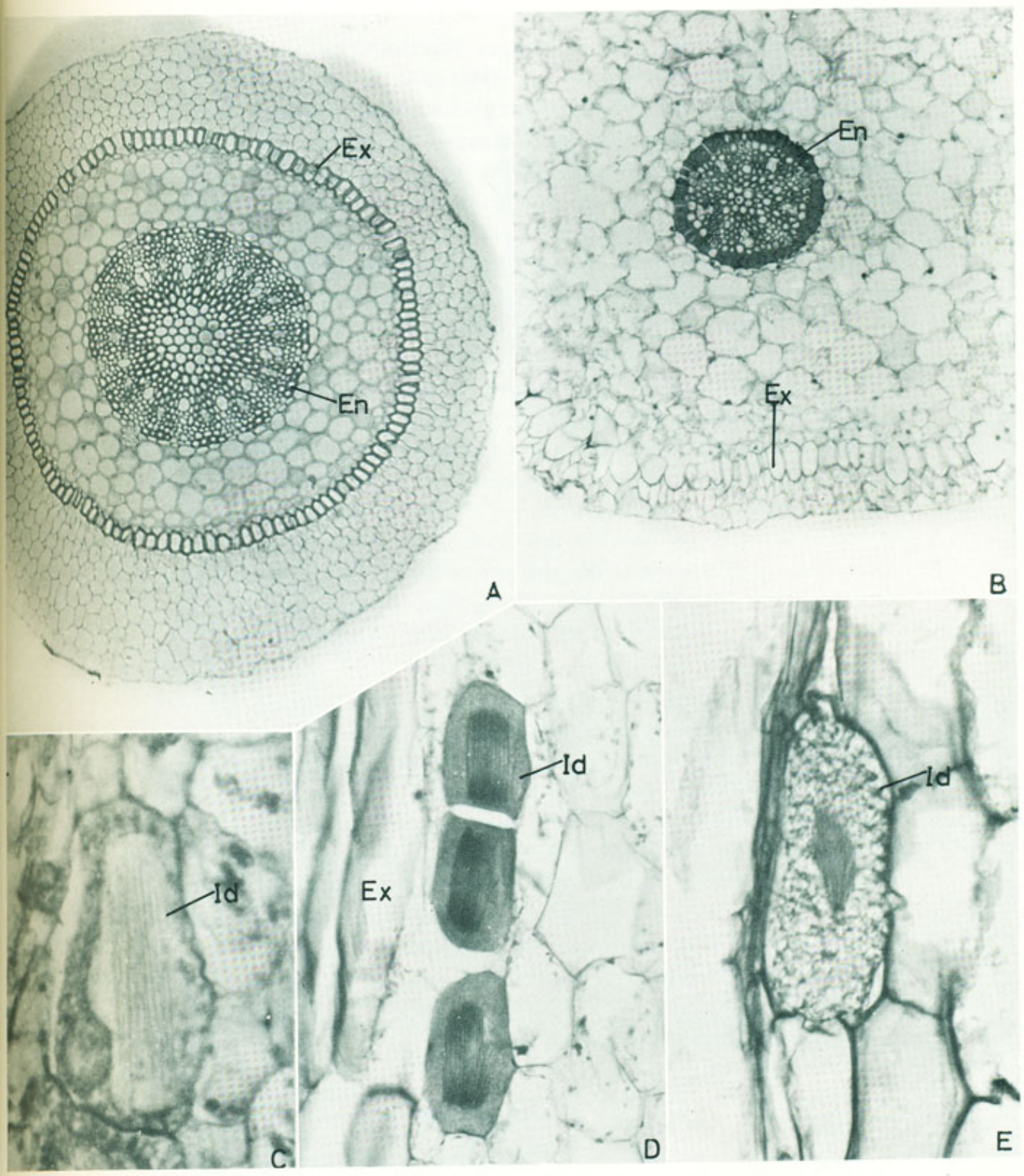


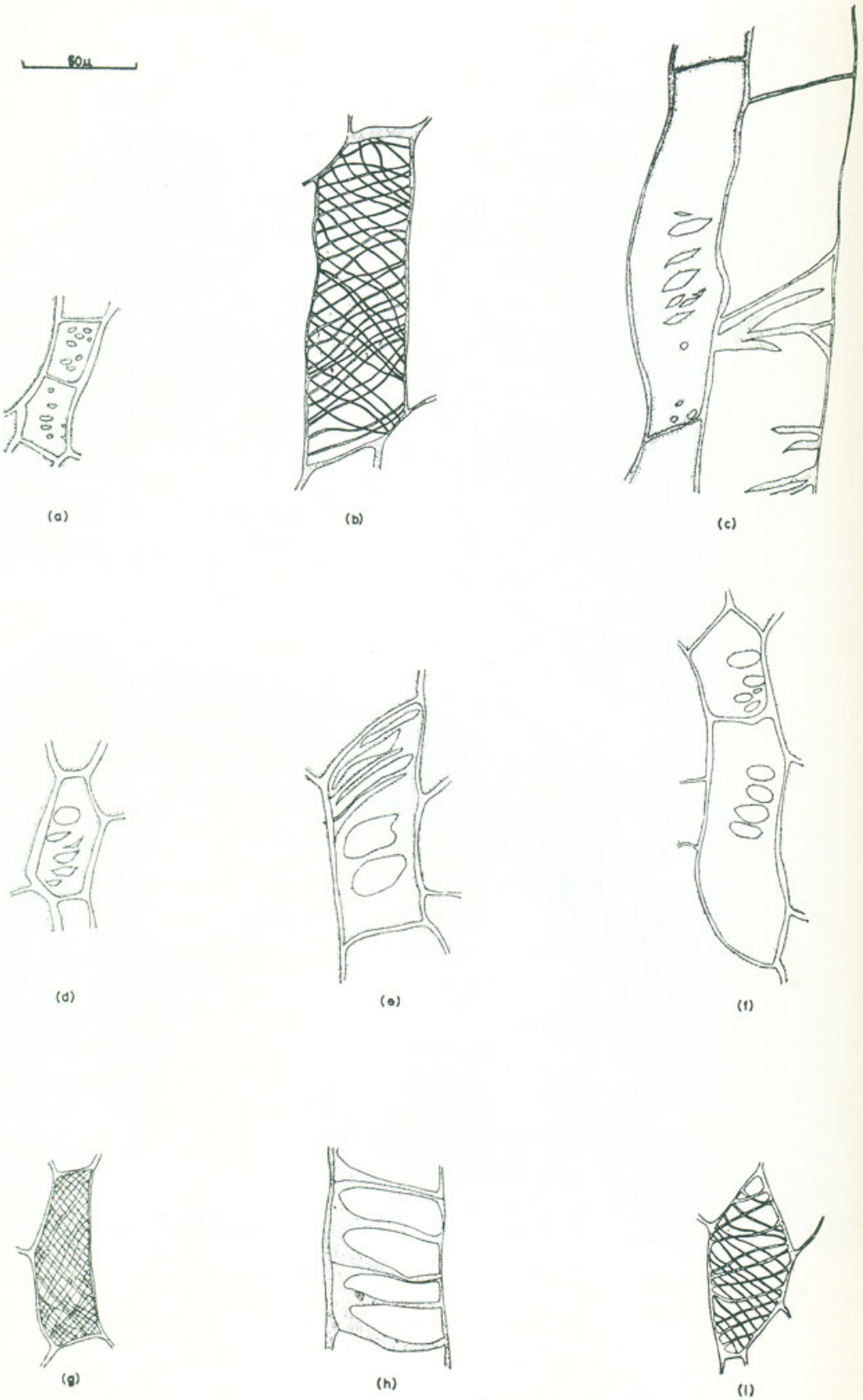
Fig. 15A. Transverse section of the root of *Dendrobium flaviflorum* through the mature part, ×97.

Fig. 15B. Transverse section of the root of *Haraella odorata* through the mature part, ×97.

Fig. 15C. Young idioblast in the root of *Thrixspermum*. Note the presence of a conspicuous nucleus, cytoplasm and the raphid, ×500.

Fig. 15D. Longitudinal section through the mature root of *Phalaenopsis*, showing three idioblasts which contain raphids surrounded by dense cytoplasms, ×250.

Fig. 15E. Longitudinal section through the mature root of *Dendrobium flaviflorum*, showing idioblast which contains raphid surrounded by dense cytoplasm, ×500.


50μ
(a)
(b)
(c)
(d)
(e)
(f)
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(i)