CHAPTER - IV

Non-self-supporting (climbing) plants are unique and are distributed all over in the flowering plants and gymnosperms (like *Ephedra* and *Gnetum*). They may be spreading on ground, climbing, or twining around the supporting objects or grows among other plants as scramblers. They have adopted various strategies to climb over the supporting object by modifying the aerial organs like leaves, petioles, rachis, and axillary buds etc. into tendrils, sticky roots, or hook like structure. Such modification was not only observed in the aerial organs but they also showed alterations in their mechanical architecture as compared to self-supporting species. The major and notable changes observed include their narrow stem diameter as compared to self-supporting plants. If compared with tree habit, they possess approximately similar leaf area for harvesting the sunlight. Besides this, several modifications may be observed in the mechanical and conducting tissues like reduced ratio of xylem fibres, abundance of unlignified parenchyma, increased vessel diameter (Figure 1A, B). Though not all the climbing members but most of them were characterized by the presence of wide and tall rays (Figure 1C-E), many of them also showed formation of successive cambia while others possessed regular growth pattern i.e., their stem diameter increase by the activity of a single ring of vascular cambium (Figures 2, 3) but showed development of intra-and interxylary phloem (Figure 4A-F). In some of the species stem outline (conformation) in transverse view also changes from circular to various shapes like lobbed, flattened, or irregular. Therefore, present study is aimed to understand the histological significance of these modifications for the successful adaptation towards the climbing habit.

4.1). ***Stem conformation (outline) in transverse view:***

In transverse view, structural outline is one of the important features to study the mechanical architecture, ecology, and adaptation towards the climbing habit. Stem outline also indicates the strategy of secondary growth by which they reach the canopy of the supporting trees/objects. As compared to the self-supporting plants, non-self-supporting plants like vines, herbaceous climbers, and woody liana possess narrower stem. Due to their narrow stems and reduced mechanical tissue, they use various other strategies so that they can facilitate climbing on the supporting objects/hosts by promoting the extension growth. Initially, when the individual plants are young, all the species studied in the present investigation showed circular stem conformation in transverse view. With the increase in age and stem diameter, stem outline in transverse view in some members changed into various shapes other than circular (Table 2).

Variation in the stem shape was achieved by differential activity of the vascular cambium or by forming the successive cambia. In such species, vascular cambium at certain regions showed unequal deposition of the secondary xylem and phloem that led to the formation of lobbed outline. In contrast, some species like *Rhynchosia pyramidalys* (Fabaceae), *Tetrastigma bracteolatum* and *Cayratia trifoliata* (Vitaceae) and sometimes in *Turbina corymbosa* (Convolvulaceae) showed development of crescent-shaped segments of the successive cambia on two opposite lateral sides (Figure 5A-D). Flat stems were also observed in the *Cocculus pendulus* (Menispermaceae) due to variation in the cambial behaviour and development of a greater number of crescent shaped cambia only on one side within the same individual. In this species is characterized by the presence of the successive cambia. The stem portion that is growing at right angle to the ground showed oval to circular outline of the stem (Figure 1C). As the stem changes orientation i.e., parallel to the ground, it gradually becomes flat due to the initiation of successive cambia only on the lower side of the stem (Figure 1D). In *Hewittia malabarica* stem, certain segments of vascular cambium either cease to divide or deposit relatively less secondary xylem as compared to the adjacent alternating portions of the cambium; thus, resulting into variously lobbed stems (Figure 5E, F). Further, it also showed formation of neo-formed vascular cylinders external to the regular phloem, which consequently leads to lobbed nature of the stems (Figure 5F). Alteration in the stem outline of these species is a constant and conserved feature and not associated with stem constriction in response to increased pressure and stem diameter of climbing species and supporting host. Similarly, in *Cissus quadrangularis*, four segments of the cambium either ceased to divide and deposit relatively less quantity of the xylem (Figure 5G) while alternating segments deposited the secondary xylem regularly and consequently led to the development of quadrangular and lobbed outline of the stem (Figure 3F).

In species with flat stems, the secondary xylem produced by the cambium showed significant variations in the arrangement of xylem rays and distribution of vessels on proximal and distal sides of the stem (Figure 5G, H). Visually, vessels were relatively fewer in number and narrower in diameter on the side of the stem that does not form successive cambia (Fig. 5G). In *Rhynchosia*, stems became flat like ribbon due to development of crescent shaped successive cambia on the opposite side of the stem (Figure 5A, C). Occasionally, development of such crescent shaped cambia and flat stem was also observed in *Turbina corymbosa* (Figure 5D). The structure and arrangement of the xylem elements differ on the adaxial and abaxial (Figure 6A) side of the stem. On the adaxial (i.e., facing supporting object and opposite to it) side of the stem, rays run nearly parallel to each other (Figure 6B) the xylem rays on the abaxial side of the stem became more radiating (i.e., distance increases between adjacent rays) with the increasing distance from pith towards cortex (Figures 6B, C). In contrast, rays in the xylem formed by the crescent shaped successive cambium remained regular like the secondary xylem of other eudicots with circular stems (Figure 6D). They were uni-multiseriate and thick walled when passing through the lignified portion of the xylem and thin-walled (non-lignified) when passing through the bands of thin-walled axial parenchyma cells. The Secondary xylem formed by the successive cambia showed a relatively higher number of wide vessels that were intermixed with radial multiples of narrow vessels on the distal side of the stem than in the regular vascular cambia (Figure 6D). Details of these growth patterns are described in detail in the respective section.

Though, not all but several non-self-supporting species showed deviation in their regular (i.e., normal, which is observed in most of the eudicots) way of primary and secondary growth. Therefore, for the sake of convenience, present study is categorized into two parts:

i) Regular and variant primary growth and,

ii) Regular and variant secondary growth.

The primary growth in all the investigated species of eudicots (Bignoniaceae, Convolvulaceae, Fabaceae, Loganiaceae, Menispermaceae, Polygalaceae, Polygonaceae, Ranunculaceae, Sapindaceae and Vitaceae), Diascoriaceae (monocots) and *Gnetum* (Gnetaceae) and *Ephedra* (Ephadraceae) from the gymnosperms starts in a regular way as observed in most cases. Besides *Campsis radicans* (Bignoniaceae) and members of the Apocynaceae and Convolvulaceae (pl. see Table 1) also showed simultaneous development of primary intraxylary phloem.

4.2). *Structure of young stem and initiation of primary growth*:

In all the species studied, the young stems were circular in outline and were composed of single layered, oval to circular or barrel shaped thin-walled parenchymatous epidermis (Fig. 7A-D). In *Cayratia auriculata*, an epidermis was multilayered (2-3 cell layered) and showed presence of grooves like sunken stomata (Figure 7E). An epidermis was covered with thin cuticle which becomes relatively thick in subsequent internodes (Figure 7E). In a certain species like *Campsis radicans*, members of the Apocynaceae and the Convolvulaceae, the epidermis also contains stalked, multicellular and rosettes of the glandular and e-glandular trichomes (Figure 7F). The epidermis was followed by one to several cells wide hypodermis that was composed of oval to polygonal thin-walled cells. Unlike other species, in *Cayratia auriculata* the hypodermis was distinct and composed of radially elongated cells (Figure 7E). The hypodermis was followed by several cells wide cortex that was composed of compactly arranged oval to polygonal, isodiametric, thin-walled parenchyma cells with or without intercellular spaces (Figure 7A-D, F) in most of the species investigated. However, it was made up of small cells intermixed with large ones (Figure 7E). Cortex also contains continuous ring or tangentially small segments of pericyclic fibres (Figure 7C, D). Increase in stem thickness resulted in the fragmentation of these pericycle fibres rings. Isolated or groups of randomly distributed sclereids (*Campsis radicans*, *Strychnos bredemeyeri*) or laticifers were common in the members of the Convolvulaceae, (Figure 7B) Apocynaceae and Asclepiadaceae. An endodermis or pericycle is made up of thin walled isodiametric or tangentially elongated barrel, shaped and compactly arranged parenchymatous endodermis and pericycle while in some of the species like *Turbina corymbosa, Valaris solanacea, Strychnos bredemeyeri, Beaumontia jerdoniana, Campsis radicans*, the pericycle was indistinct. Though, the endodermis and pericycle appear indistinct (Figure 7A, B, E), they can be discerned by the presence of pericyclic fibres. On the inner side of the pericycle, a distinct circular band of promeristem that was characterized by the darkly stained, thin-walled cells with conspicuous nucleus gave rise to procambium (Figure 8A). A central portion of the young stem was occupied by the parenchymatous pith. In subsequent internodes a cluster of the external protophloem and protoxylem began to differentiate in 4-7th visible internode. Several vascular bundles that were composed of one to two protoxylem elements and cluster of three to four protophloem elements on either side of the procambium initiated in the subsequent internodes (Figure 7A, B). These vascular elements become distinctly visible with enlarging metaxylem elements in the 7-9th internodes (Figure 8B, C). Subsequently, small segments of interfascicular cambium initiated between adjacent vascular bundles and formed a complete the ring of vascular cambium (Figure 7C). This newly initiated vascular cambium was functionally bidirectional to deposit the secondary xylem centripetally and phloem centrifugally (Figure 7A, C). The centrally located pith consists of thin-walled parenchyma cells that may be isodiametric or irregular in shape and size. Species like *Beaumontia jerdomiana* (Apocynaceae), *Dicranostyles ampla*, *Hewittia malabarica* (Convolvulaceae), *Leptadenia reticulata, L. pyrotechnica* (Asclepiadaceae, Apocynaceae), *Maripa nicaraguensis*, *Turbina corymbosa* (Convolvulaceae), *Vallaris solanacea* and *Wattakaka volubilis* (Apocynaceae) showed the presence of interxylary phloem at the pith margin (Figure 8B, 9A).

As the secondary growth progressed further, increase in stem diameter exerted a pressure on the epidermis and ring of pericyclic fibres. In 8-10 mm thick stems, sub-epidermal cells divide periclinally and showed initiation of phellogen, which produce several cells wide periderm (Figure 8D-F). In *Rhynchosia pyramidalys* it shows dark staining due to the deposition of tannin (Figure 8F) while in *Dicranostyles ampla* and *Maripa nicaraguensis*, the cork cells/periderm produced by the phellogen were thick-walled and lignified (Figure 9B-D). Inner tangential and radial walls of these cork cells were unevenly thickened tangential walls which showed typical 'U' shaped thickening (Fig. 9C, D).

4.2.1). *Regular and Variant Primary Growth*

In all the species investigated primary growth started in regular way but some of them showed development of intraxylary phloem as the primary variants. In the members of the Fabaceae, Menispermaceae and Vitaceae, isolated or groups of 2-4 strands of regular protophloem (sieve elements) began to differentiate from the procambial initials in the 4-6th visible inter node (Figures 7A, 8C, 9A). In the subsequent internodes (particularly in the members of the Menispermaceae and Vitaceae) the procambium became conspicuous i.e., fascicular regions (Figure 7C) while alternating regions became interrupted by small segments of parenchymatous thin-walled cells. In due course, these cells became meristematic and gave rise to interfascicular cambium (Figures 7C, 9E) and interconnect the fascicular segments of the cambium to establish a complete ring of the vascular cambium (Figures 7E; 9F). At this stage, stem was composed of several collateral vascular bundles comprising of external protophloem, protoxylem and strands of few internal protophloem elements in the 7-9th internode (Figures 7A; 9F). Protoxylem was composed of xylem parenchyma and few elongated vessel elements. These protoxylem elements were characterized by annular and helical thickening with simple perforation plates on slightly oblique to transverse end walls.

4.2.2). *Development of the intraxylary phloem*:

Besides regular primary growth, *Campsis radicans* (Bignoniaceae), *Strychnos bredemeyeri* and *S. andamanensis* (Loganiaceae) and the members of the Apocynaceae and Convolvulaceae showed simultaneous differentiation intraxylary protophloem on the inner side of the protoxylem elements (Table 1). The presence of intraxylary (internal) phloem on the pith margin or within pith (Figures 8B, C; 9A) i.e., of protoxylem is the characteristic feature and is observed in all the species of the family Apocynaceae, Convolvulaceae and the Loganiaceae investigated in the present study. Formation of intraxylary (primary) was either simultaneous or takes place after the development of protoxylem elements. In members of the Convolvulaceae (Table 1), differentiation of primary intraxylary protophloem occurred simultaneously to that of regular protophloem (Figures 8B, 9A). However, in *Beaumontia jerdomiana* (Apocynaceae) and *Maripa nicaraguensis* (Convolvulaceae), development of intraxylary phloem was delayed and started only after the deposition of the protoxylem (Figures 7A; 8B, C). At this stage, it is intricate to distinguish whether their origin is from the procambial derivatives or from the pith cells. In the present study all the members showed development of intraxylary phloem on the pith margin except *Beaumontia jerdomiana* (Apocynaceae), in which several intraxylary phloem islands differentiate significantly away from the pith margin (Figure 10A, B). In contrast, *Campsis radicans* (Bignoniaceae) its development was observed only after the initiation of the secondary growth (Figure 10C-F).

4.2.3). ***Gross structure of the secondary xylem*:**

Once the complete ring of the vascular cambium was established, it deposited secondary xylem centripetally and secondary phloem centrifugally. In all the species studied, the secondary xylem was diffuse porous with indistinct growth rings (Figures 11A-I, 12A-I), except *Campsis radicans, Cocculus pendulus, Dalbergia volubili, Maripa nicariguensis, Serjania mexicana, Valaris solanacea, Vitis vinifera, Ephedra karumanchiana* and semi-distinct in *Wattakaka volubilis* (Figure 11 A-I, 12A-I). The secondary xylem composed of vessels, xylem fibres and axial and ray parenchyma cells (Figure 1A-D). The presence of wide as well as narrow (fibriform) vessels i.e., vessel dimorphism is a common feature among all the species investigated from the family Convolvulaceae. Wide vessels were oval to circular in outline, mostly solitary in *Dalbergia volubilis, Hewittia malabarica, Serjania mexicana, Leptadenia pyrotechnica, L. reticulata, Strychnos bredemeyeri*, (Figures 11A, D, H; 12A-F, I) while tangential and radial multiples intermixed with solitary vessels was common in species like *Beumontia jerdoniana* (Figure 11C), *Rhynchosis pyramidylis*, *Phaseolus lunatus*, and members of the family Vitaceae (Figures 6B, D; 11C) while small and narrow vessels were arranged in clusters or group of three to several narrow vessels in *Campsis radicans*, *Canavalia virosa*, *Pruereria tuberosa*, *Serjania mexicana*, *Vallaris solanacea* and *Wattaka volubilis* (Figure 12G). All the species investigated showed presence of simple perforation plate on transverse end walls. Details of the structure of the secondary xylem are described under separate section.

4.2.4). ***Transition from self-supporting to climbing habit*:**

During the self-supporting stage, when the growing shoots were searching for the support, the stems were stiff in *Arrabidaea candicans* (Bignoniaceae), *Beaumontia jerdoniana*, *Dicranostyles ampla*, *Entada rheedi*, *Maripa nicaraguensis*, *Serjania mexicana* and *Strychnos bredemeyeri*, *S. andamanensis* (Figures 13A, B; 11G; 12C). At this stage, the secondary xylem was exclusively composed of abundance fibres, oval to relatively narrow vessels and rays while lignified, thick-walled axial parenchyma formed sheath around the vessels. In tangential view, rays were mostly uni- to biseriate, while multiseriate rays were observed rarely at this stage (Figure 13D-F). However, herbaceous vines and other members like *Canavalia gladiata*, *C. virosa*, *Cissampelos pareira*, *Phaseolus lunatus*, *Pueraria tuberosa* lack such transition of the secondary xylem, which may be due to their weak stems. Once the growing shoots find their host for support, the structure of the secondary xylem changed unexpectedly and it showed typical features of the lianescent habit (Figure 13A-C; G-I). After the shift from the self-supporting stage, the vessel elements became uniformly distributed, their diameter and frequency increased significantly (Figure 13A-C; G-I). The occurrence of narrow lumened vessels intermixed with wide vessels was observed frequently in most of the species studied. Progressively ray width and number of unlignified, thin-walled parenchyma cells were also increased.

4.3). Regular and Variant Secondary Growth

4.3.1). *Regular secondary growth*:

During the initiation of secondary growth, depending on species investigated in the present study, several conjoint collateral vascular bundles (in the members of Apocynaceae, Bignoniaceae, Convolvulaceae, Fabaceae, Loganiaceae, some members of Menispermaceae, Polygalaceae and Sapindaceae) while 5-10 vascular bundles (some members of Menispermaceae, Polygonaceae, Ranunculaceae and Vitaceae) were interconnected by interfascicular cambium and formed a complete cylinder of vascular cambium. The interfascicular cambium was initiated by acquiring the meristematic character in the parenchyma cells positioned between adjacent vascular bundles (Figures 9E, F; 2A-E; 3A-C, E; 14A). The newly initiated interfascicular cambium interconnects with the fascicular segment of the cambium and resulted in the establishment of the complete ring of the vascular cambium. However, in *Coccinia grandis* and other members of the Cucurbitaceae, the vascular bundles are arranged in two rings, the first ring was composed of 5-7 vascular bundles that were separated by significantly wide medullary rays. With the increase in age, a second ring of the vascular bundles initiated alternating to the already existing bundles (Figure 15A, B). At this stage interfascicular cambium initiated to form the complete cylinder of the vascular cambium (Figures 14F; 15C). As mentioned earlier that the cambium is functionally bifacial and produce the secondary xylem centripetally and the phloem centrifugally. However, in some species deposition of the secondary xylem and phloem was not uniform; rather in smaller segments of the cambium, cell division activity and deposition of the secondary occurred in relatively lesser amount while other portion continued regularly. Such uneven deposition of cambial derivatives resulted in loss of circular arrangement of the stem and became various in shapes in transverse view (Figure 3F).

4.3.2). *Stem conformation (outline) in transverse view*:

In most of species, the fully grown stems were oval to elliptic or circular in outline in transverse view (Figures 2A-E, 3A-F; 5A-F; Table 1). In species like *Hewittia malabarica*, *Phaseolus lunatus*, *Turbina corymbosa*, *Cissus quadrangularis* they were variously lobed. In these species, small sectors of the cambium ceased or became relatively less active, which resulted in formation of furrows. These depressions gradually became deeper with the increase in age and consequently led to the formation of lobbed nature of the stem (Figure 3F). Number of lobes varies from species to species and it may be a conserved character for some species like *Argyreia boseana, Cissus quadrangularis* which showed trilobed and lobbed quadrangular nature respectively in all the investigated samples (Figures 3F; 15D). In contrast, some species like *Rhynchosia pyramidalys*, *Tetrastigma bracteolatum* and occasionally in some samples of *Turbina corymbosa* (Figures 2D; 5A-D), cambial activity retards permanently on two opposite sides (i.e., facing to supporting object and its opposite side) while it showed elevated activity of the vascular cambium on alternating lateral sides. Most of the time, such species with flat stem showed formation of crescent shaped successive cambia only on the opposite lateral sides. Therefore, stems became much more tangentially flattened. Among the species investigated, *Serjania circumvallata* is unique and showed polystelic conditions, in which three or more stele develop external to the centrally located main stele and form a trilobed stem (Figure 15E). Details of the development of the successive cambia are elucidated in detail in the section on development of successive cambia. Another interesting example was observed in case of *Cocculus pendulus* (Menispermaceae) growing in wild at Zaria Mahadev near Chotila. The entire population showed unique behaviour of stem flattening. *C. pendulus* is perennial woody liana in which the stem that was vertically oriented showed circular outline of the stem with eccentric rings of the successive xylem rings. However, the curved branches or the main stems of the individual showed significant alteration in the stem shape and it became flat due to the development of eccentric and crescent shaped successive cambia only on the lower side of the stem (Figure 2C, D).

4.3.3). *Development of lianescent characteristics of the secondary xylem*:

The main alterations in the stem particularly composition in the secondary xylem occurs only after the initiation of climbing habit. These modifications include change in the mechanical tissues and development of the variant secondary growth in the climbing species. Though, not all but most of the climbing species show modifications in the mechanical architecture, which comprised reduced number of xylem fibres, abundance of thin-walled unlignified parenchyma (Figure 1A, B), vessel dimorphism (Figure 15F), wide and tall rays (Figures 16A-C), development of xylem in plates or development of unusual (variant) secondary growth (Figure 12I). Variant secondary growth includes formation of the successive cambia (Figures 1A-E; 5A-D; 12H-I), development of the intra-and interxylary phloem (Figure 4A-F), phloem wedges etc. (Figure 16D, E). Many climbing species like *Cissampelos pareira*, *Cissus repanda*, *C. quadrangularis*, *C. rotundifolia*, *Ampelosisus latifolia*, *Cayratia auriculata*, *Dalbergia volubilis*, *Tinospora cordifolia*, *T. sinensis*, *Vitis vinifera*, *Wattakaka volubilis* and several other species increase their stem diameter with a single vascular cambium throughout their lifespan (Figures 3C-F; 11D; 12E). These species although showed regular secondary growth, the secondary xylem was characteristically composed of climbing habit. In contrast, some of the species like *Campsis radicans*, *Combretum coccinium*, *C. ovalifolium*, *Darbergia volubilis*, *Wattakaka volubilis* (Figures 11D; 12E; 16A, C) are woody lianas but they do not show any lianescent features that are characteristic to climbing habit. The species showing variations in the secondary xylem after the initiation of climbing habit are elucidated as follows:

4.3.4). *Formation of the secondary xylem in plates*:

Irrespective of regular secondary growth or presence of successive cambia, in certain species, the secondary xylem in transverse view appeared as arranged in radial plates of axial elements alternating with few to several cells wide multiseriate rays (Figures 16A-C, F; 17B, C). Species that showed presence of the successive cambia (described under separately title “formation of successive cambia”) also retain arrangement of the secondary xylem as radial plates of axial elements include members of the Menispermaceae (i.e., *Anamirta cocculus*, *C. laurifolius*, *Cocculus hirsutus, C. pendulus, Cyclea peltata , Diploclisia glaucescens, Pachygone ovata, Tiliacora racemosa*) while other members (like *Coscinium fenestratum, Cissampelos pareira, Stephania japonica, Tinospora cordifolia* and *T. sinensis*) possessed single ring of the vascular cambium even in the thick stems. Though, there is slight variation, members like *Cissus repanda*, *C. quadrangularis*, *Tetrastigma bracteolatum, Vitis vinifera* (Vitaceae) and member of Cucurbitaceae (*Zanonia indica*) showed presence of the secondary xylem in plates.

During the primary growth and in the beginning of the secondary growth, the above-mentioned species, the vascular bundles were distinct and broadly separated with each other due to presence of wide medullary rays (Figures 7C; 9E; 14B, C). As the growth progressed further, additional vascular bundles initiate in between the existing vascular bundles (Figure 15A, C). These bundles were slightly external to the already existing vascular bundles; thus, giving an appearance like their arrangement in two rings (Figure 15A, C). As the secondary growth progressed, these bundles were subsequently adjusted in a single ring by increasing the stem diameter. At this stage also the secondary retained the width of the medullary rays to maintain the arrangement axial elements in plates (Figure 15B).

Members of the Menispermaceae like *Anamirta cocculus*, *Cocculus hirsutus*, *C. laurifolius*, *C. pendulus*, *Cyclea peltata, Diploclisia glaucescens, Pachygone ovata, Tiliacora racemosa* show presence of successive cambia (Figure 2A-E). In all the successive cambia, initially the radial plates of axial xylem elements develop opposite to the medullary rays (Figure 12I) but subsequent growth and readjustment resulted in aligning the rays in the same plain of previous xylem rings in the same radial plan (Figure 17A.). Beside medullary rays, development of secondary rays was also observed in radial plates of the xylem but these rays were uni-biseriate while 3-4 cells wide rays were observed occasionally (Figure 17B, C). Therefore, it became difficult to spot them in low magnification or in macroscopic view.

4.3.5). ***Abundance of parenchyma* (*both axial and ray*)**:

Formation of abundant parenchyma is one of the adaptive features that is credited to the climbing habit. In the present study several species (Acanthaceae: *Thunbergia grandiflora*; Fabaceae: *Canavalia gladiata*, *C. virosa*, *Entada rheedii*, *Phaseolus lunatus*, *Pueraria tuberosa*; Vitaceae: *Ampelocisus latifolia*, *Cayratia auriculata*, *C. trifolia*, *Cissus rependa*) belonging to different families showed the presence of unlignified, thin-walled parenchyma cells that composed major portion of the stems (Figure 17D-F). As the secondary growth progressed, first few secondary xylem elements were thick-walled and lignified and thereafter differentiating xylem was mostly composed of unlignified thin-walled parenchyma except vessels and fibres were the lignified elements (Figure 17D, F). Vessels mostly solitary, large in diameter while xylem fibres (sometimes tracheids) either formed a sheath around the vessels or tangential bands external to-or on the inner side of the vessel (Figure 17D, F). In some cases, narrow vessels co-occurred with wide vessels and formed cluster around them or arranged in radial multiples (Figure 17D).

4.3.6). ***Variant secondary growth***:

In general, in most of the seed plants (including eudicots and gymnosperms) several conjoint collateral vascular bundles interconnect by forming interfascicular cambium and establish a complete cylinder of the vascular cambium. This cambium remains functional throughout the life span and deposit secondary xylem internally and phloem externally. Such pattern of secondary growth is termed as regular secondary growth. However, in small segment of seed plants, such pattern of secondary growth deviates from the above type and stem diameter increases in various ways is referred as variant secondary growth. It includes formation of successive cambia, functionally inverse cambia, development of inter-and intraxylary phloem, proliferation of axial and ray parenchyma cells, development of phloem wedges and lobbed stems etc. following ways of variant secondary growth are observed in present study which are described in detail:

4.3.7). *Formation of successive cambia*:

In several species, irrespective to the habit (self-supporting or non-self-supporting; stem thickness was increased by forming successive cambial rings. In the present study, members of the Convolvulaceae, Fabaceae, Mensipermaceae, Sapindaceae and Vitaceae were selected to investigate for their development. The tissue responsible for the development of successive cambia differed among the species investigated and they may develop from: i) pericyclic parenchyma or pericyclic derivatives, ii) dilating ray cells, iii) the cortical parenchyma cells and iv) the xylem parenchyma cells formed in the beginning of every successive cambium. The later type i.e., formation of successive cambia from the xylem parenchyma was unique, which formed xylem externally and phloem internally (i.e., functionally inverse) and henceforth referred as functionally invers cambia. Development of successive cambia from each category is elucidated as follows:

4.3.7.1). *Initiation of successive cambia from pericyclic parenchyma or derivatives*:

In the members of the Convolvulaceae like *Antigonon leptopus*, *Cyratia trifoliata*, *Dicranostyles ampla*, *Maripa nicaraguensis*, *Moutabea gentry*, *Tetrastigma bracteolatum* and *Turbina corymbosa,* development of the successive cambia was observed in 6 to 10 mm thick stems. In these species, parenchyma cells external to the crushed protophloem (on the inner side of isolated or group of 2-3 pericyclic fibres that are considered as demarcating the pericycle and endodermis) acquired meristematic character by repeated cell divisions and formed few cells wide radial files of tangentially flattened cells appearing like cambium (Figure 18A-G). Several such small segments of the cambium initiated throughout the circumference of the stem (Figure 19A). These newly initiated segments of the cambium showed bifacial differentiation the secondary xylem internally and phloem externally (Figure 19B). After the production of few xylem derivatives by these small segments of the cambium, unlignified cells (interfascicular parenchyma) present between these newly initiated cambial segments underwent dedifferentiation and interconnect these cambial segments to form a complete cylinder of the first successive cambium. Subsequent successive cambia followed similar pattern of their initiation from the parenchyma cells located external to the phloem formed by the previous cambium.

4.3.7.2). *Initiation of neo-formed vascular cylinders from dilating phloem ray parenchyma*:

As the stem diameter increased in 9-11 mm thick stems of *Hewittia malabarica*, *Phaseolus lunatus* and *Turbina corymbosa*, ray parenchyma cells of the external phloem showed dilation due to tangential increase in their width (Figure 19C). Subsequently, isolated or groups of dilating ray cells became meristematic (Figure 19D). These meristematic cells formed oval to circular or elliptic to circular neoformed vascular cylinders by differentiating bidirectionally i.e., the secondary xylem and phloem on either side (Figures 19E; 20A-C). If compared with other members of the Convolvulaceae, these vascular cylinders fail to interconnect; therefore, they formed discrete vascular cylinders that were encircled by a ring of the vascular cambium (Figure 20C). Development of such neo-formed vascular cylinders most often resulted in lobbed nature of the stem (Figures 5E, F; 20D). Orientation of these vascular cylinders varies from species to species or within species. They may be obliquely, radially, or irregularly oriented to the main axis of the stem (Figures 19D, E; 20C).

However, in 15-20 mm thick stems of *Hewittia malabarica* and *Phaseolus lunatus*, phloem parenchyma cells positioned between outer and inner successive cambia or neo-formed vascular cylinders became meristematic and showed development of similar type of vascular strands (Figure 20E, F). Like external phloem ray vascular cylinders, these neo-formed vascular strands within the secondary xylem were irregularly oriented and the cambium associated with them was functionally bidirectional. The secondary xylem of these neo-formed vascular cylinders was composed of vessels (both, fibriform and narrow), fibres, axial parenchyma, and uni- to biseriate rays. Rays were heteromorphic and composed of vertically upright ray cells while the phloem was composed of sieve elements, companion cells, axial and ray parenchyma cells.

4.3.7.3) *Initiation of successive cambia from cortical parenchyma*:

As mentioned earlier in Menispermaceae, (like *Anamirta cocculus*, *Cocculus hirsutus, C. laurifolius*, *C. pendulus*, *Cyclea peltata*, *Diploclisia glaucescens, Pachygone ovata* and *Tiliacora racemosa*) and *Rhynchosia pyramidalys* increased their stem diameter by forming successive cambia. Unlike members of the Convolvulaceae, the first successive cambium initiated from the parenchyma cells of the cortex instead of pericyclic derivatives. Development of the first successive cambium was observed external to the pericyclic fibre caps in 7-9 mm thick stems (Figure 21A-C). The thin-walled parenchyma cells few cells external to the pericyclic fibres became meristematic, divided repeatedly, and formed small segments of 3-4 cells wide radial bands of cambial cells. Newly initiated cambium (fascicular segments) was functionally bidirectional and produce secondary xylem centripetally and phloem centrifugally (Figure 12I). Subsequent successive cambia initiated in similar fashion but originate the parenchyma cells external to the earlier formed cambium (Figure 21D-F). Prior to the initiation of the subsequent successive cambium, some of the cells external to the phloem produced by the previous cambium began to differentiate into pitted sclerenchyma with thick lignified walls before deposition of any xylem and phloem derivatives and not the fibres (Figure 21D-F). Subsequently, several such segments of the cambium (fascicular) initiated that differentiated secondary xylem and phloem as mentioned above (Figure 21E). All these segments were interconnected by the wide ray cambium and formed the complete ring of the successive cambium in *Anamirta cocculus*, *Cocculus pendulus*, *Cocculus hirsutus, Cyclea peltata*, *Diploclisia glaucescens*, *Pachygone ovata* and *Tiliacora racemosa*. In contrast, those species showing eccentric growth, a crescent shaped cambia formed only on one side of the stem; thus, resulting into oval to elliptic or flat conformation of the stem as in *C. pendulus* (Figure 2D). As compared to circular stems, rays in the elliptic to flat stems with eccentric rings showed presence of narrow rays. Quantity of the secondary xylem produced by each successive cambium varies from species to species but on an average, it ranges between 5-10 mm.

4.3.7.4). *Development of functionally inverse cambia*:

In the thick stem of *Argyreia elliptica*, *Canavalia gladiata*, *C. virosa*, *Entada rheedii, E. gigas*, *Dicranostylis ampla*, *Phaseolus lunatus*, *Turbina corymbosa* and *Hewittia malabarica* segments of the cambium initiate in the earlier formed secondary xylem (Figures 20F; 22A, B). Species like *A. elliptica*, *D. ampla*, *T. corymbosa* and *H. malabarica* were characterized by the presence of successive cambia and the inverse cambia develop from the parenchyma cells between successive rings of the xylem. However, *Canavalia gladiata*, *C. virosa*, *Entada rheedii*, *E. gigas* and *P. lunatus* differ from the above species by having a single ring of the vascular cambium. In these later mentioned species, earlier formed unlignified parenchyma underwent proliferation and became meristematic, divided repeated and formed small segments of the cambium arranged in radial files (Figure 22C-F). Interestingly, these newly initiated cambial segments may be functionally unidirectional or bidirectional and produced its derivatives in inverse fashion. Bidirectional segments deposited secondary xylem facing externally and phloem facing towards pith (Figure 22A, B, F) while unidirectional segments formed only phloem derivatives centripetally (Figures 22C-E; 23A, B). Structure of the secondary xylem and phloem formed by the functionally regular and inverse cambium remained similar.

In contrast, some of the samples of *Argyreia elliptica* showed a case of autapomorphy i.e., it showed formation of xylem strands that were exclusively composed of fibres, narrow (fibriform) vessels and lignified parenchyma cells without phloem elements (Figure 23C, D). These strands of the fibres were formed in the parenchyma cells sandwiched between successive rings of the xylem and phloem of the previous cambium (Figure 23C). These parenchyma cells underwent repeated cell division, became meristematic and differentiated into thick-walled xylem strands that showed absence of phloem. They were often surrounded with 1-3 flattened meristematic cells arranged in radial like cambial cells (Figure 23D). Several such isolated strands initiated throughout the parenchymatous ring external to the phloem and external xylem ring.

4.3.8). *Proliferation of xylem rays and formation of ray cambium*:

Species like both species of *Canavalia*, *Hewittia malabarica*, *Phaseolus lunatus*, *Pueraria tuberosa* and *Turbina corymbosa* are characterized by the presence of large and several cells wide multi-seriate rays. In the thick stems, earlier formed ray cells and axial parenchyma adjacent to rays showed dedifferentiation and proliferation (Figure 22E, F). Cells of the wide rays along with the adjacent axial parenchyma next to the pith acquired meristematic character and showed production of several new cells. Proliferation of these cells and their differentiation developed pressure on the xylem located external to pith, which led to the detachment of lignified tissue (i.e., protoxylem, metaxylem and secondary xylem), caused a natural fracture (Figures 23E; 24A, B, E). Consequently, it led to the interruption and detachment of pith and secondary xylem and the proliferating cells intrude into pith portion (Figures 23E; 24A, B, E). With the passage of time, marginal ray cells underwent repeated cell division (Figures 24C, D; 25A-C) and became meristematic (hereafter referred as ray cambium). These cells exclusively deposited the sieve elements and parenchyma cells. In *Hewittia malabarica*, continuous production of the secondary phloem from the ray cambium contributed significantly in further disruption of xylem cylinder external to the pith portion (Figures 25A, B). In the thick stems, some of the samples also showed presence of the secondary xylem produced from the ray cambium (Figures 25C-E). Proliferations of these parenchyma cells gradually extend centrifugally and connect the pith to the cortex. With the advancement of the secondary growth, proliferation of axial, ray, and pith parenchyma along with the activity of internal cambium that produced intraxylary phloem and secondary xylem makes it intricate to find out the origin of the source of proliferating parenchyma (Figure 25D, E). Simultaneous proliferation of parenchyma cells and production of phloem from the internal cambium also plays important role in the fragmentation and disruption of the pith in these species.

4.3.9). *Development of interxylary phloem*:

Interxylary phloem strands are the sieve elements, companion cells and associated parenchyma that are develop within the secondary xylem (Figure 4A-C). In the present study, development of such phloem was observed in *Canavalia virosa*, *C. gladiata*, *Entada rheedii*, *Hewittia malabarica*, *Leptadenia reticulata*, *L. pyrotechnica*, *Phaseolus lunatus*, *Pueraria tuberosa*, *Strychnos bredemeyeri*, *Thunbergia grandiflora* and *Turbina corymbosa* (Figures 11I, 12B, D; 13H; 22C, D). From the above-mentioned species, ontogeny of interxylary phloem formation in *Strychnos bredemeyeri* and *S. andamanesis* differs from *Leptadenia reticulata* and *L. pyrotechnica* while other species showed totally different type of interxylary phloem development from the genus *Strychnos* and *Leptadenia*.

In *Strychnos bredemeyeri* and *S. andamanesis*, formation of interxylary phloem began in the young stems after the development of 3-5 mm of secondary xylem. At this stage the cambium was functionally regular like most of the eudicots and produce secondary xylem centripetally and secondary phloem centrifugally (Figure 26A). After a short period of regular cambial activity, at several places inward development of secondary xylem by small segment of the cambium was ceased temporarily whereas remaining sectors of the cambium continued the cambial activity in regular fashion (Figure 26B). Therefore, the sector of cambium that ceased to divide temporarily gets detached from functionally regular portion of the cambium and formed depression (Figure 26B). A coalescent cambial segment initiated from the phloem parenchyma cells located external to the furrow (Figure 26C, D) and connects the disjunct sectors of the cambium. Establishment of new cambial segments restored a complete ring of the cambium. Newly formed coalescent cambial segment deposit secondary xylem internally and secondary phloem externally which enclosed the ceased segments of the cambium within the secondary xylem (Figure 26E). Formation of such isolated strands led in the formation of phloem patches within the secondary xylem. In thick stems show several interxylary phloem islands enclosed in the secondary xylem (Figure 4C). The small sectors of the cambial associated with each phloem patch remained active for the substantial period. Deposition of phloem by such cambial segments led to crushing of earlier formed non-conducting phloem elements (Figure 26F).

In contrast, formation of interxylary phloem in *Leptadenia* differed from the above said case. The vascular cambium of climbing species of *Leptadenia* (*L. reticulata*) and self-supporting species (*L. pyrotechnica*) divided and differentiated bidirectionally and deposited the secondary xylem and secondary phloem like other eudicots (Figure 27A). After the establishment of vascular cambium and development of few xylem derivatives, small segments of the vascular cambium at several places began to produce thin-walled and unlignified parenchyma towards xylem side instead of thick-walled lignified elements. Along with the differentiation of unlignified derivatives and unlignified parenchyma, some of the cells also differentiated into sieve elements (Figure 27B, C). Subsequently, after a short period, the cambium regained its normal activity and began to produce lignified xylem derivatives internally (Figure 27E). Such behaviour of cambium i.e., production of unlignified parenchyma along with sieve elements followed by differentiation of lignified elements resulted in the inclusion of sieve elements and unlignified parenchyma islands within the lignified xylem elements. Such a repeated behavior of small segments of the vascular cambium caused formation of numerous interxylary phloem islands embedded within the secondary xylem (Figure 28A). Initially these interxylary phloem islands possessed few sieve elements but as the secondary growth advanced, more number of parenchyma cells from these islands dedifferentiated and gave rise to additional sieve tube members (Figure 28B). All the parenchyma islands produced by the vascular cambium did not produce sieve elements rather they were exclusively composed of thin-walled unlignified parenchyma cells and showed absence of sieve elements (Figure 28C). Parenchyma islands that lack sieve elements also showed formation of sieve elements at a later stage of the secondary growth. In all these species addition of sieve elements at a later stage of secondary growth exerted a pressure and consequently led to crushing of earlier formed but non conducting sieve elements.

Formation of the interxylary phloem in *Canavalia virosa*, *C. gladiata*, *Entada rheedii*, *Hewittia malabarica*, *Jacquemontia paniculata*, *Phaseolus lunatus*, *Pueraria tuberosa,* and *Turbina corymbosa* differed from the above-mentioned types. In all these species, stem diameter increases with a single ring of the vascular cambium that formed the secondary xylem and phloem in regular position like other eudicots. The secondary xylem of these species was composed of abundance of unlignified and thin-walled parenchyma cells (Figures 17D-F; 21C-F). With the advancement of the secondary growth, these parenchyma cells underwent dedifferentiation to become meristematic and redifferentiated into sieve elements (Figure 28E). In thick stems of *Canavalia virosa*, *C. gladiata* and, *P. lunatus*, earlier formed axial and ray parenchyma showed radial or tangential elongation followed by repeated cell divisions in various angles. In certain pockets, proliferation of these parenchyma literally formed small segments of meristematic cells looking like cambium (Figure 28F). These cells became the source of subsequent deposition of the interxylary phloem.

4.3.10). *Development of intraxylary phloem and intraxylary phloem cambium*:

Intraxylary phloem or internal/medullary phloem are strands of phloem that are composed of sieve elements, companion cells and axial parenchyma cells that are formed at the margin of the pith. In the present study, formation of such phloem was recorded in *Beaumontia jerdomiana*, *Campsis radicans*, *Dicranostyles ampla*, *Hewittia malabarica*, *Jacquemontia paniculata*, *Leptadenia reticulata*, *L. pyrotechnica*, *Maripa nicaraguensis*, *Strychnos bredemeyeri*, *Turbina corymbosa*, *Vallaris solanacea*, and *Wattakaka volubilis* (Figures 4D, F; 8B; 10E, F; 26A). Development of intraxylary phloem occur on the inner margin of the protoxylem (in other words at the pith margin) from the beginning of the primary growth (Figures 8B; 26A). Details of intraxylary proto-phloem is already described above in the section “Regular and variant primary growth.” Additional phloem derivatives differentiated subsequently from the adjacent pith cells. As the stem time passes, parenchyma cells positioned between the protoxylem and proto-intraxylary phloem underwent dedifferentiation and resulted in the commencement of small meristematic segments of the cambia (Figures 10E, F; 29A). Henceforth referred as intraxylary phloem cambium. These arcs of intraxylary phloem cambium became unsuccessful to establish a complete ring. In the thick stems of *C. radicans*, *H. malabarica*, *J. paniculata*, *S. bredemeyeri*, *S. andamanesis*, *T. corymbosa* and *V. solanacea*, these segments of the intraxylary phloem cambium were initially unidirectional (Figure 29A-C) but subsequently it became bidirectional and deposited the secondary xylem centrifugally and phloem centripetally (Figure 29E, F). The secondary xylem formed by these cambia was composed of both wide and narrow vessels, fibres and parenchyma (both axial and ray) cells (Figures 4E; 29E, F). Similarly, the intraxylary phloem was composed of sieve elements, companion cells and axial and ray parenchyma cells (Figure 29C, E). Non-conducting phloem was characterized by heavy accumulation of callose followed by collapsed and obliterated sieve elements (Figure 29C, F).

4.3.11). ***Development of phloem wedges (furrowed xylem) and lobbed stems***:

Furrowed xylem also referred as phloem wedges is one of the widespread cambial variants documented in several flowering plants. The occurrence of the furrowed xylem/phloem wedges are mostly recorded in climbing species, which is characteristic and unique feature of some families. Members of the Bignoniaceae (particularly tribe Bignonieae) are characterized by the presence of such phloem wedges (Figure 30A, B). Besides the family Bignoniaceae, development of phloem wedges was also recorded in *Jacquemontia paniculata*, *Serjania mexicana* (Sapindaceae) and *Turbina corymbosa* (Figures 16E; 30A-D). In the young stems (2-4 mm thick stems) of *Arrabidaea candicans* development of phloem wedges began as four small segments of the vascular cambium at equidistance. In these segments, cell division activity ceased towards the xylem side (Figure 30E) while phloem formation was increased as compared to the adjacent interwedges (Figure 30A). A similar way of phloem wedges development was also observed in *Serjania mexicana*. However, it differs from the above case in having three to five phloem wedges, which subsequently increase with the increase in age of the plants. In 15-20 mm thick stems, the number of wedges increased up to 11 in (Figure 30D). Unlike members of the tribe

Bignonieae, the tangential width of all these phloem wedges in *J. paniculata* and *S. mexicana* was not uniform. In *J. paniculata* they may be "U" or "V" shaped while in *S. mexicana,* they were unequal in their width (Figure 30C).

Unlike above-mentioned species, formation of furrowed xylem in *Turbina corymbosa* number of wedges/furrows are not fixed. In *J. paniculata* and *Vitis quadrangularis*, small segments of the cambium ceased to produce the secondary xylem internally while elevated production of phloem observed externally (Figure 30E). Such behaviour of the cambium does not affect the outline shape of the stem in transverse view (Figure 16E). In contrast, in *Turbina corymbosa*, *Argyreia boseana* and *Hewittia malabarica* segments of the cambium were either slow or deposited relatively less quantity of xylem that was composed of unlignified and thin-walled parenchyma (Figure 30F). The secondary xylem produced by functionally regular segments showed uniform distribution of the vessels while the secondary xylem formed by functionally slow portion of the cambium was found to be devoid of wide vessels mostly composed of fibres. Therefore, the stem became trilobed (Figure 15D). Besides furrowed xylem and differential activity of the vascular cambium, lobbed stems may also develop due to formation of neoformed vascular bundles in species like *H. malabarica* and *T. corymbosa.* Neoformed vascular cylinders fail to interconnect to form a complete cylinder (Figure 5E, F). Therefore, increase in size of these vascular cylinders remains restricted to certain portion of the stem; thus, resulting into lobbed nature of the stem. Initiation of neoformed vascular cylinders is described earlier in the section "Initiation of successive cambia from dilating phloem parenchyma".

4.4). *Serjania circumvallata* Radlk. and ***S. mexicana*** (L.) Willd.**: A special case of variant growth:**

As compared to other members investigated in this study, a unique pattern of primary and secondary growth was observed in *S. circumvallata*. Among three species (*S. circumvallata*, *S. mexicana* and *Cardiospermum helicacabum*) of Sapindaceae investigated here, all three represent different growth trajectories. Among them, *C.*

helicacabum showed regular secondary growth (Figure 31A) like most eudicots while *S. circumvallata* and *S. mexicana* showed primary and secondary variant growth respectively.

Thick stems of *S. mexicana* showed formation of neo-formed vascular cylinders. In 2-3 mm thick stems, parenchyma cells positioned external to the phloem wedges (Figure 31B) and on the inner margin of the pericyclic fibres underwent repeated cell divisions to form radial files of the meristematic cells and initiated small sectors of cambia (Figure 31C-F). The thick stem samples available to us showed several such small cylinders of cambial cylinders (Figure 31B). Functionally, these newly formed cambial cells were bifacial and produced the secondary xylem internally and phloem externally. Therefore, neo-formed vascular cylinders initially appeared as oval to circular or elliptic in outline (Fig. 31E). Afterward they extend tangentially or fuse with adjacent vascular cylinders to form a small sector of the newly formed cambia (Figures 31B; 32A, B). Unlike successive cambia, these neo-formed vascular cylinders were completely encircled from all sides by a ring of cambium (Figure 32A, B). Hence, these newly formed cambial segments look like an oval to circular or elliptic strands of conducting elements of the xylem and phloem positioned external to the phloem formed by the previous vascular cambium.

Serjania circumvallata differs from the above species which showed development of polystelic condition or also referred as multiple cylinders (Figure 32C, D). It represents the case of multiple procambium that was active at more than 3-6 locations and formed 3-6 neo-formed vascular cylinders (Figure 32D). Development of these multiple cylinders was slightly delayed in comparison to the main stem (Figure 32E, F). Initiation of these vascular cylinders occurred only after the formation of few xylem derivatives after the initiation of the secondary growth (Figures 32E, F; 33A). The cells located on the inner margin of the pericycle fibre ring underwent repeated divisions to form distinct procambium and began to differentiate into protoxylem and protophloem elements as discrete strands (Figure 33A, B). It extends gradually and forms a complete ring of vascular cambium and resulted in the formation of vascular cylinder enclosing pith with few cells (Figure 33C-E). The vascular cambium of the neo-formed vascular cylinder encircled the xylem cylinders in relatively thick stems (Figure 33D, E). This cambium was functionally bifacial and deposited xylem centripetally and phloem centrifugally. Structurally, the secondary xylem and phloem formed in these vascular cylinders remained similar to that of main cylinder. The secondary xylem was diffuse porous with indistinct growth rings (Figure 33F). Increase in stem thickness and diameter of the newly formed vascular cylinders exerted a pressure on the parenchyma cells situated between the adjacent cylinders led to their crushing (Figure 34A, B). The secondary xylem of both (i.e., main and neo-formed vascular cylinder) was composed of wide, relatively narrow and fibriform vessels (Figure 34C). Wide vessels were mostly solitary with simple perforation plate on their terminal ends while radial or tangential multiples of 2-3 vessel elements were very rare (Figure 33F). In contrast, relatively narrow vessels the central cylinder was frequently arranged in the radial multiples of 3-17 or more vessels (Figure 34D). The xylem rays were more or less homocellular (sometimes intermixed with procumbent or upright ray cells) mostly uni-biseriate (Figure 34E, F).

4.5). *Structure of secondary xylem:*

The gross structures of secondary xylem of various species are discussed below among their respective families, with dimensional details for all species provided in table 3.

4.5.1). *Apocynaceae*:

In all the members *viz. Beaumontia jerdoniana*, *Leptadenia pyrotechnica* and *L. reticulate while* it is distinct in *Vallaris solanacea* and *Wattakaka volubilis*, the secondary xylem was diffuse-porous with indistinct growth rings. However, *L. pyrotechnica* and *L. reticulata* also showed presence of interxylary phloem islands distributed randomly throughout the secondary xylem (Fig. 12B). All the species were characterised by the presence of intraxylary phloem at the pith margin. It was composed of vessels (both wide and fibriform), fibres, tracheids, axial and ray parenchyma cells. Wide vessels were arranged mostly in radial multiples and possess a simple perforation plate on their transverse to slightly oblique end walls. It became difficult to distinguish narrow (fibriform) vessels in transverse section, due to their exceptionally narrow lumen diameter like xylem fibres. *Beaumontia jerdoniana* showed vessel restriction owing to the restriction of the vessels differentiation from to certain fusiform cambial cells in small segments. While remaining portion of the secondary xylem showed absence of wide vessels (Fig. 11 C). A similar kind of vessel-less area was also been observed in *Leptadenia* and *Vallaris solanacea* (Fig. 12 B, E). The alternate bordered pits on the lateral walls of both fibriform and wide vessels were oval-oblong to elliptic or oblong in all the species investigated. Xylem rays were non lignified in outer conducting secondary xylem while lignified and thick walled in inner xylem part, vertically upright, heterocellular, uni- to biseriate or rarely multiseriate were observed in all the species. The occurrence of radially oriented laticifers in the secondary xylem rays was observed frequently in all the species studied. They were slightly larger than the ray cells and frequently showed formation of anastomosing network. Axial parenchyma scanty paratracheal and sometime formed incomplete sheath around the vessel in *Vallaris solanacea, Leptadenia pyrotechnica*, *L. reticulate* and *Wattakaka volubilis*, while they were scarce in *Beaumontia jerdoniana.* In thick stems, pith cells undergo obliteration while some of the cell underwent lignification and become thick walled. At this stage stem, quantifiable amount of of intraxylary phloem was observed in all species investigated. Dimensional details of secondary xylem of all these members are provided in the Table 3.

4.5.2). *Bignoniaceae*:

The structure of the secondary xylem of *Arrabidaea candicans* and *Campsis radicans* altered significantly after for the initiation of climbing habit. The secondary xylem was ring porous with distinct growth rings in *A. candicans* (Figure 30B) and *C. radicans* (Figure 11D). Wide vessels were oval to oblong, solitary or in a group of two to three and associated with clusters of two to several narrow vessels while arrow vessels were arranged in clusters and formed distinct patches of radial multiples or various shapes and dimensions and possess a simple perforation plate on their transverse to slightly oblique end walls. Inter vessel walls showed alternate oval to polygonal bordered pits. Both the species were characterised by the presence of distinct phloem wedges. Xylem rays were mostly uni-triseriate, heterocellular with 2–4 upright to square marginal ray cells. Perforated ray cells are a common feature and observed frequently in both the species. Dimensional details of secondary xylem of all these members are provided in the Table 3. Fibre tracheids with alternate bordered pits on their lateral walls. In thick stems of *C. radicans* was completely replaced by the secondary intraxylary phloem and intraxylary phloem developed from the intraxylary cambium. The dimensional details of the secondary xylem are given in table 3.

4.5.3). *Convolvulaceae*:

Structurally, the secondary xylem in the mature stems of *Hewittia malabarica* and *Turbina corymbosa* remained more or less similar while *Dicranostyles ampla* and *Maripa nicaraguensis* shared similar features. The secondary xylem was diffuse porous with indistinct growth rings in *H. malabarica, T. corymbosa* and *Jacquemontia paniculata* while *D. ampla* and *M. nicaraguensis* showed presence of growth rings. It was composed of fibriform and wide vessels, tracheids; fibres, ray and scanty vasicentric axial parenchyma cells (Figure 11G). Wide vessels were exclusively solitary in *D. ampla* and *M. nicaraguensis* while solitary and in tangential multiples of two to three in *H. malabarica* and *T. corymbosa* (Figure 5H). Vessels possess transverse to slightly oblique perforation plate with oval to circular bordered pits on their tangential vessel walls. Fibriform vessels were characterised by narrow lumen diameter with sub- to terminal perforation plate is observed in all the investigated species. Patches of thin-walled axial parenchyma embedded within the lignified secondary xylem is observed in *H. malabarica* and *T. corymbosa* while absent in *D. ampla* and *M. nicaraguensis*. Vessel associated parenchyma cells were thick walled, un-lignified and of the scanty paratracheal in *D. ampla* and *M. nicaraguensis* and scanty vasicentric in *H. malabarica* and *T. corymbosa*. Xylem fibres were characterised by the presence of distinct bordered pits (i.e., fibre tracheids) and they were the longest cell types among the derivatives of the secondary xylem. Rays were mostly uni- to biseriate in *H. malabarica,* D. *ampla, M. nicaraguensis* and *J. pentantha* while tall and multiseriate rays were also observed in *T. corymbosa*. They were heterocellular with vertically upright ray cells. The occurrence of intraxylary phloem and intraxylary cambium was characteristic to all the species. I thick stems, pith was occupied by deposition of intraxylary phloem. The dimensional details of the secondary xylem are given in table 3.

4.5.4). *Cucurbitaceae*:

Zanonia indica is a monotypic species of Cucurbitaceae increased its stem diameter with a single ring of the vascular cambium. Initial growth although remains similar to other cucurbits but thick stems showed arrangement of axial elements in plates due to the presence of wide and multiseriate medullary rays (Figure 16F). The secondary xylem consisted wide and narrow vessel elements, ray large, wide and heterocellular and axial parenchyma and fibres. Wide vessels were mostly solitary, oval to circular, in outline while narrow vessels were solitary (Figure 16F). Thin walled and non-lignified axial parenchyma cells formed in small patches distributed randomly in within the secondary xylem. Rays were several cells wide and heterocellular. The dimensional details of the secondary xylem are given in table 3.

4.5.5). *Fabaceae*:

In *Canavalia gladiata, C. virosa, Dalbergia volubilis*, *Entada rheedii* and *Pueraria tuberosa*, the secondary xylem was formed by the regular vascular cambium while *Phaseolus lunatus* and *Rhynchosia pyrimidalis* showed formation of successive rings of the secondary xylem. The secondary xylem was diffuse porous with indistinct growth rings. The secondary xylem of *Canavalia gladiata, C. virosa, Entada rheedii* and *Pueraria tuberosa*, showed abundance of unlignified parenchyma (Figure 1B&C, 17D-F). However, in *D. volubilis* (Figure 11F) it was characterised by lignified elements while parenchyma patches and successive cambia was found absent. *R. pyramidalis* showed crescent shaped successive rings of xylem. The secondary xylem was composed of vessels (both wide and narrow), tracheids, fibres, tracheids, axial and ray parenchyma cells. Wide vessels mostly solitary, oval to circular, narrow vessels in radial multiples of 2–9 vessels in all the species investigated. Dimensional details of the secondary xylem elements are mentioned in Table 3.

In thick stem of *Canavalia gladiata, C. virosa, Entada rheedii* and *Pueraria tuberosa* thin walled, non-lignified axial parenchyma embedded within the xylem became meristematic ad differentiate into interxylary phloem derivatives. In *R. pyrimidalis* secondary xylem produced by the regular cambium showed considerable variations in the arrangement of xylem rays and distribution of vessels on proximal and distal sides of the stem. Visually, vessels were relatively fewer in number and narrower (25–211 µm) in diameter on the proximal side of the stem that does not form successive cambia on its outer side (Figure 6A-D). Usually the vessels formed during initial growth were narrower in tangential diameter, which gradually increase with increase in thickness of stem or once attaining to the climbing stage (Figure 6A-D). . Rays were exclusively uniseriate in *D. volubilis* while uni to bi-seriate and rarely tri-seriate in *Canavalia* and *Entada* rheedii and *Rhynchosia pyramidalis*. In *Phaseolus lunatus* and *Pueraria tuberosa*, rays were tri-seriate..

4.5.6). *Loganiaceae*:

In *Strychnos bredemeyeri* and *S. andamanensis*, the secondary xylem was diffuse porous and growth rings were indistinct (Figure 13H, 12D). It was composed of tracheids, vessels, fibres with bordered pits (i.e. fibre tracheid), axial and ray parenchyma cells. As a straggling shrub, the young stems grow erect and susequetly it shifts to the climbing habit. At both stages, they showed remarkable difference in the structure and composition of secondary xylem (Figure 13H) and explained earlier under “xylem structure during transition from self-supporting to climbing habit. Dimensional details of the secondary xylem elements are mentioned in Table 3.

4.5.7). *Menispermaceae*:

In Menispermaceae, Anamirta cocculus (L.) Wight & Arn., *Cocculus pendulus* (J.R. Forst & G. Forst) Diels, (including C. hirsutus and C. laurifolius), Diploclisia glaucescens (Blume) Diels, Pachygone ovata (Poir.) Diels and Tiliacora racemosa Coleb) showed the presence of successive rings of the xylem alternating with the phloem. In contrast, Cissampelos pareira L., Coscinium fenestratum Colebr., Cyclea peltata (Lam.) Hook.f. & Thomson, Stephania japonica (Thunb.) Miers., Tinospora cordifolia (Willd.) Miers and T. sinensis (Lour.) Merr., showed a single ring of the secondary xylem even in thick stems. The secondary xylem was diffuse porous with indistinct growth rings in both, i.e., species with successive cambia and species with single ring of the secondary xylem (Figure 2A-E, 3A). In all the species, axial elements of the xylem were arranged in radial plates that were separated by thin-walled wide rays.. The secondary xylem was composed of vessels, tracheids, fibre tracheids with distinct wide rays. In all the species, vessels were mostly solitary rarely in group of two or three (Figure 17A, B & C), with simple perforation plate on transverse to slightly oblique end walls. Axial parenchyma diffuse or diffuse in aggregate and scanty paratracheal. Rays were mostly tall, heterocellular with marginal sheath cells. Rays in the successive xylem rings were exceptionally wide and tall and their height and width varies from species to species (Table 3). Ray cells may be thin or thick walled and both the types of ray cells were observed within the same species e.g., in *Cocculus pendulus, Cyclea peltata Diploclisis glaucoscens, Pachygone ovata* and *Tiliacora racemosa*. Marginal ray/sheath cells often showed presence of rhomboidal crystals in *Anamirta cocculus, Cocculus pendulus*. Massive accumulation of crushed and non-conducting phloem was observed in the innermost successive cambium of all the species investigated (Figure 17A).

4.5.8). ***Polygalaceae*****:**

A single representative of the family *Moutabea gentry* has been investigated. The stem was composed of successive rings of the secondary xylem alternating with the phloem rings (Figure 19B). The secondary xylem was diffuse porous with distinct growth rings present. Vessels mostly solitary and rarely in tangential multiples of two were observed. Narrow vessels were rare or absent. Vessels oval to circular or oblongs with transverse to obliquely oriented perforation plates and alternate bordered pith on their lateral walls. Axial parenchyma formed the sheath around the vessels. Rays uni to bi-seriate while multiseriate rays were observed rarelyThe dimensional details of the secondary xylem are given in table 3.

4.5.9). *Polygonaceae:*

Antigonon leptopus (Polygonaceae) icreased their stem thickness by forming successive xylem rings. The first ring of xylem formed by the regular vascular cambium was diffuse porous with indistinct growth rings. It was composed of vessels (both wide and fibriform), fibres, ray and axial parenchyma. Wide vessels were solitary while radial or tangential multiples of vessels were observed occasionally (Figure 11A, B). Most of the radial or tangential multiples were formed by narrow vessels and they were intermixed with wider ones. The paratracheal axial parenchyma were vasicentric and thick walled and formed a sheath around the vessels. Rays mostly uniseriate while medullary rays were several cells wide. Unlignified pith cells in the young stems showed lignification in the thick stems. Dimensional details of the secondary xylem elements are mentioned in Table 3.

4.5.10). Sapindaceae:

In the present study three species of Sapindaceae (*viz. Cardiospermum helicacabum*, *Serjania circumvallata* and *S. mexicana*) were investigated. All three species showed significant variations in the xylem structure and composition. *Cardiospermum helicacabum* showed regular growth pattern like other eudicots. Initially, *Serjania maxicana* (Figure 13A) showed regular growth but subsequently it started forming phloem wedges as recorded for the tribe Bignonieae. In thick stems, formation of successive cambia (neoformed vascular cylinders was observed (Figure 18E). In contrast, *Serjania circumvallata* showed polystelic condtion i.e., forms 3-5 vascular cylinders simultaneous to regular vascular cylinder along with primary growth (Figure 32C & D, 33D-F). Secondary xylem was diffuse porous in both the species with indistinct growth rings in both species i.e., *S. mexicana* S. *circumvallata*. Co-occurrence of wide and narrow vessels was common in both the species (Figure 13C & 33F). The wide vessels were circular, tangentially oval to elliptic in outline and mostly solitary while narrow lumened vessels formed radial multiples of several cells (Figure 13C & 33F). Besides wide and narrow vessels, the formation of exceptionally narrow vessels was also observed (Figure 13C & 33F). Rays were heterocellular, mostly uniseriate, thick-walled, and lignified in both the species. The dimensional details of the secondary xylem are given in table 3.

4.5.11). *Vitaceae*:

The secondary xylem diffuse porous, growth rings indistinct in all the species (*viz. Ampelocissus latifolia, Cayratia auriculata, Cissus quadrangularis* (Quadrangular in stem outline, Figure 3F), *Cissus repanda, Cissus rotundifolia*) except *Cayratia trifolia* and *Tetrastigma bracteolatum* (Figure 5A & B), which showed successive xylem rings.. Vessels exclusively solitary and wide in *Cayratia auriculata, Cissus quadrangularis, C. rependa* and *C. rotundifilia,* while wide as well as narrow vessels with radial multiples in *Cayratia trifolia, Tetrastigma bracteolatum* and *Vitis vinifera.* Vessel circular to elliptic in all species investigated. In *Cissus rotundifolia* and *Tetrastigma bracteolatum* they were polygonal and angular with transverse to oblique perforation plates. Abundance of axial parenchyma was observed in *Ampelocissus latifolia, Cayratia auriculata, Cayratia trifolia, Cissus repanda* and *Cissus rotundifolia* while in *Cissus quadrangularis* and *Vitis vinifera* no such pattern was observed. In all the species rays were multiseriate and heterocellular. In *Vitis viniferara* ray parenchyma cells are lignified. Pith contains circular non lignified parenchyma cells with inter cellular spaces in all the species studied. The dimensional details of the secondary xylem are given in table 3.

4.5.12). *Gymnosperms*:

Three different species of gymnosperms *viz*. *Ephedra foliata*, *Ephedra karumanchiana* (Ephedraceae) and *Gnetun ula* (Gnetaceae). Both *E. foliata* and *Ephedra karumanchiana* showed a single ring of the secondary xylem (Figure 35E) while *G. ula* possessed successive xylem rings (Figure 12H, 35B). The secondary xylem was diffuse porous with distinct growth rings in *Ephedra* while it was indistinct in *G. ula*(Figure 35D). Wide vessels oval to circular in outline and solitary while narrow vessels were solitary or in radial multiples. Unlike other gymnosperms, both Ephedra and Gnetum showed presence of vessels (both narrow and wide) As the characteristic of gymnosperms, the tracheids were present in all three species investigated. Fibre tracheids and axial parenchyma cells were observed in *Gnetum* while in case of *Ephedra* only vessels and tracheids were present in secondary xylem (Figure 12H, 35B). Rays uni to biseriate, rarely multiseriate in species of *Ephedra* while they were multiseriate and heterocellular. Pith cells lignified and thick walled with intercellular spaces in all three species investigated. The dimensional details of the secondary xylem are given in table 3.

Table 2: Anatomical peculiarities in the secondary growth of the species investigated.

Sr. No.	**Family**	**Name of the taxon**	**Stem outline**	**Type of growth**			
				Difference in self and climbing stage	Intraxylary Phloem	Interxylary Phloem	Successive cambia
1	Apocynaceae	*Beaumontia jerdoniana*	Circular	Y	Y	N	N
2		*Leptadenia reticulata*	Circular	N	Y	Y	N
3		*Leptadenia pyrotechnica*	Circular	N	Y	Y	N
4		*Vallaris solanacea*	Circular	Y	Y	N	N
5		*Wattakaka volubilis*	Circular	N	Y	N	N
6	Bignoniaceae	*Arrabidaea candicans*	Circular	Y	N	N	N
7		*Campsis radicans*	Circular	N	Y	N	N
8		*Cardiospermum helicacabum*	Circular	N	N	N	N
9	Convolvulaceae	*Dicranostyles ampla*	Circular to triangular	Y	Y	N	Y
10		*Hewittia malabarica*	Circular-elliptic; variously lobbed	N	Y	Y	Y
11		*Jacquemontia*	Circular-elliptic	N	Y	Y	N

		paniculata					
12		*Maripa nicaraguensis*	Circular to triangular	Y	Y	N	Y
13		*Turbina corymbosa*	Flat, highly irregular, and variously lobbed	N	Y	Y	Y
14	Cucurbitaceae	*Zanonia indica*	Circular	N	N	N	N
15	Fabaceae	*Canavalia gladiata*	Circular	N	N	Y	N
16		*Canavalia virosa*	Circular	N	N	Y	N
17		*Dalbergia volubilis*	Circular	N	N	N	N
18		*Entada gigas*	Circular to variously lobbed	Y	N	Y	N
19		*Entada rheedii*	Circular to variously lobbed	Y	N	Y	N
20		*Phaseolus lunatus*	Circular	N	N	Y	N
21		*Pueraria tuberosa*	Circular	N	N	Y	N
22		*Rhynchosia pyramidalis*	Flat, ribbon like	N	N	Y	Y
23	Loganiaceae	*Strychnos bredemeyeri*	Circular	Y	Y	Y	N
24		*Strychnos andamanensis*	Circular	Y	Y	Y	N
25		*Anamirta cocculus*	Circular	N	N	N	Y
26		*Cissampelos pareira*	Circular	N	N	N	N

27	Menispermaceae	*Cocculus hirsutus*	Circular	N	N	N	Y
28		*Cocculus laurifolius*	Circular to elliptic	N	N	N	Y
29		*Cocculus pendulus*	Circular to elliptic	N	N	N	Y
30		*Coscinium fenestratum*	Circular	N	N	N	N
31		*Cyclea peltata*		N	N	N	Y
32		*Diploclisia glaucescens*	Circular	N	N	N	Y
33		*Pachygone ovata*	Circular	N	N	N	Y
34		*Stephania japonica*	Circular	N	N	N	N
35		*Tiliacora racemosa*	Circular	N	N	N	Y
36		*Tinosporia cordifolia*	Circular	N	N	N	N
37		*Tinospora sinensis*	Circular	N	N	N	N
38	Polygalaceae	*Moutabea gentry*	Circular to elliptic	N	N	N	Y
39	Polygonaceae	*Antigonon leptopus*	Circular, irregularly lobbed	N	N	N	Y
40	Sapindaceae	*Serjania circumvallata*	Tri-lobed, Compound xylem	N	N	N	N
41	Sapindaceae	*Serjania mexicana*	Circular	Y	N	N	Y
42		*Ampelocissus latifolia*	Circular	N	N	N	N
43		*Cayratia auriculata*	Circular	N	N	N	N
44		*Cayratia trifolia*	Circular to elliptic	N	N	N	Y

45	Vitaceae	*Cissus quadrangularis*	Square to quadrangular	N	N	N	N
46		*Cissus repanda*	Circular	N	N	N	N
47		*Cissus rotundifolia*	Circular	N	N	N	N
48		*Tetrastigma bracteolatum*	Flat, ribbon like	N	N	N	Y
49		*Vitis vinifera*	Circular	N	N	N	N

Gymnosperms

50	Gnetaceae	*Gnetum ula*	Circular to elliptic	N	N	N	Y
51	Ephedraceae	*Ephedra karumanchiana*	Circular	N	N	N	N
52		*Ephedra foliata*	Circular	N	N	N	N

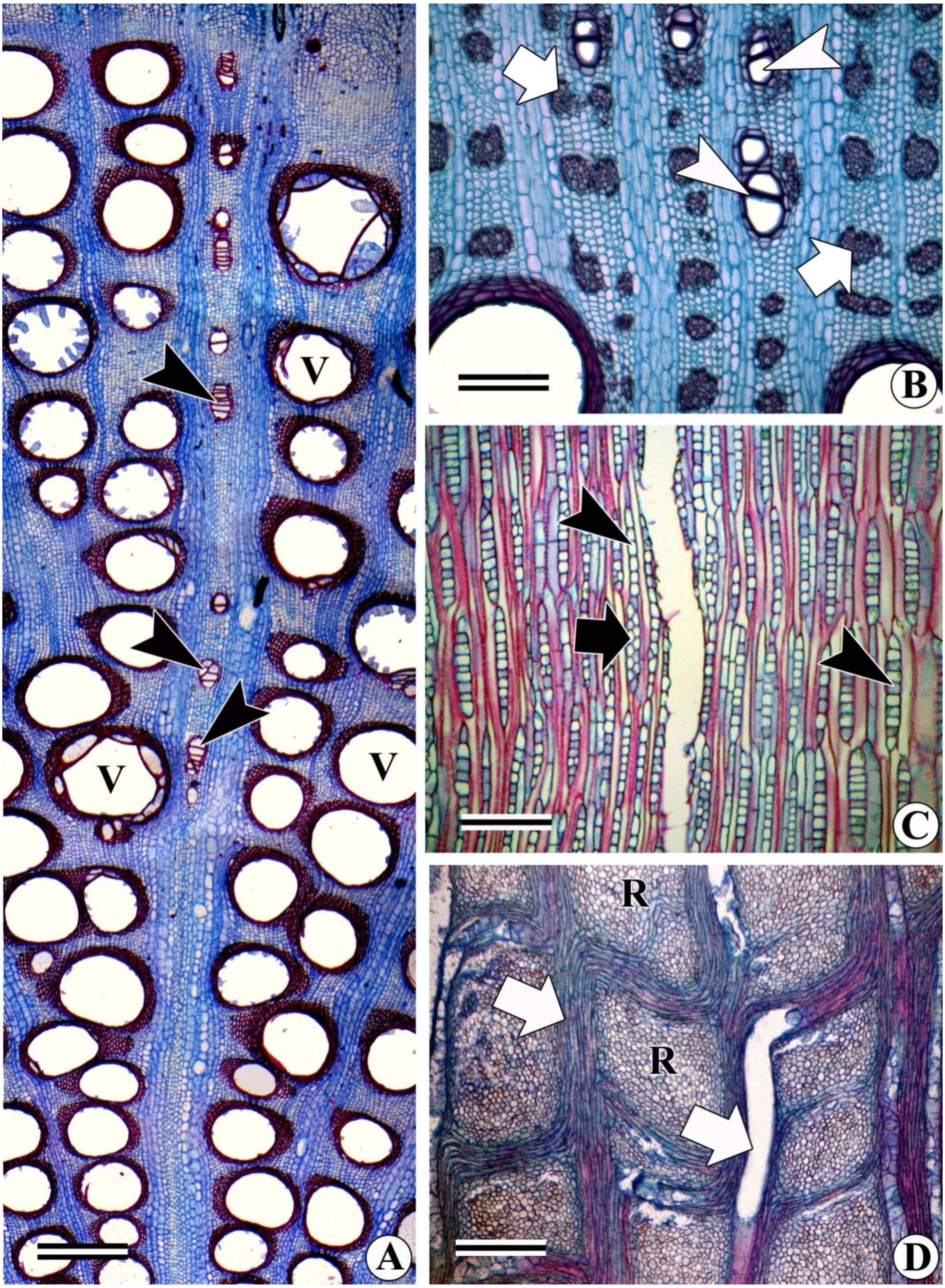

Figure 1

Figure 1: Transverse (A & B) and tangential longitudinal (C &D) views of mature stems of various species showing the structure of secondary xylem.

A: Mature stem of *Cissus rependa*showingtypical structure of secondary xylem characteristic to the climbing habit. Note the amount of unlignified axial parenchyma (stained with astra blue), wide(V) and narrow vessels (arrowheads).

B:Structure of secondary xylem of mature stem of *Pruereria tuberosa* showing the large vessels (arrowheads), patches of xylem fibres (arrow) and amount of parenchyma cells.

C: Mature stem of *Wattakaka volubilis* showing structure of xylem and storied arrangement of the uniseriate rays(arrowheads) while biseriate rays are almost nil.

D: Exceptionally tall and multiseriate rays in the xylem of *Anamirta Cocculus*. Norte the width of rays (R). Arrowhead showing narrow plates of axial elements (vessels and fibres).

Scale bars: A& D = 500 µm; B & C = 200 µm.

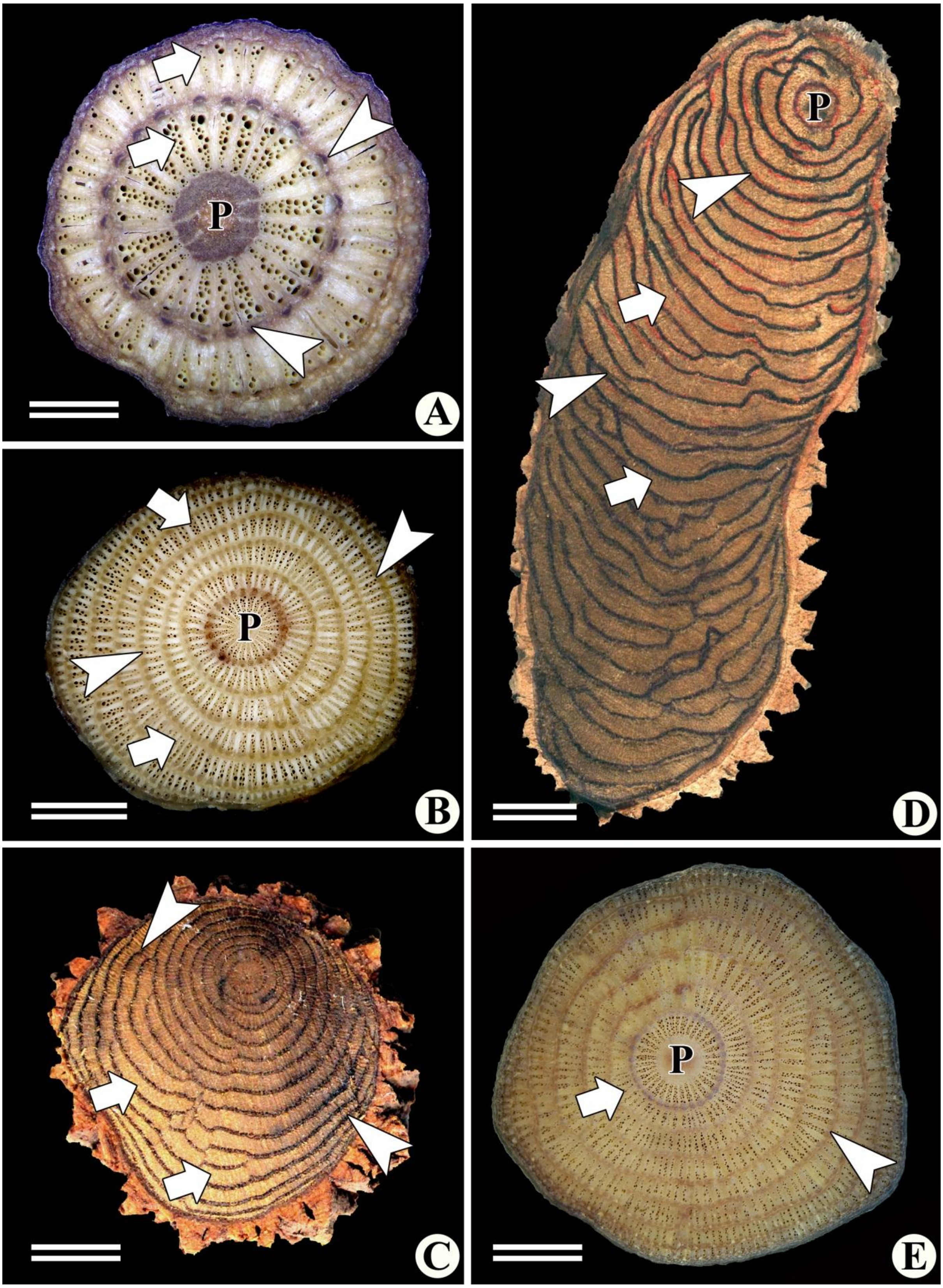

Figure 2

Figure 2: Macromorphological outline conformation of stems of some members of the family Menispermaceae composed of multiple rings of xylem (arrows) and phloem (arrowheads). Note that the outline of stem.

A: *Anamirta cocculus*. B: *Diploclisia glauscence*. C: *Cocculus pendulus*. D: *C. pendulus*. E: *Tiliacora racemosa.*
Abbreviation: P = pith

Scale bars: A: 5 mm; B: 3 mm; C: 2 mm; D: 10 mm; E: 15 mm.

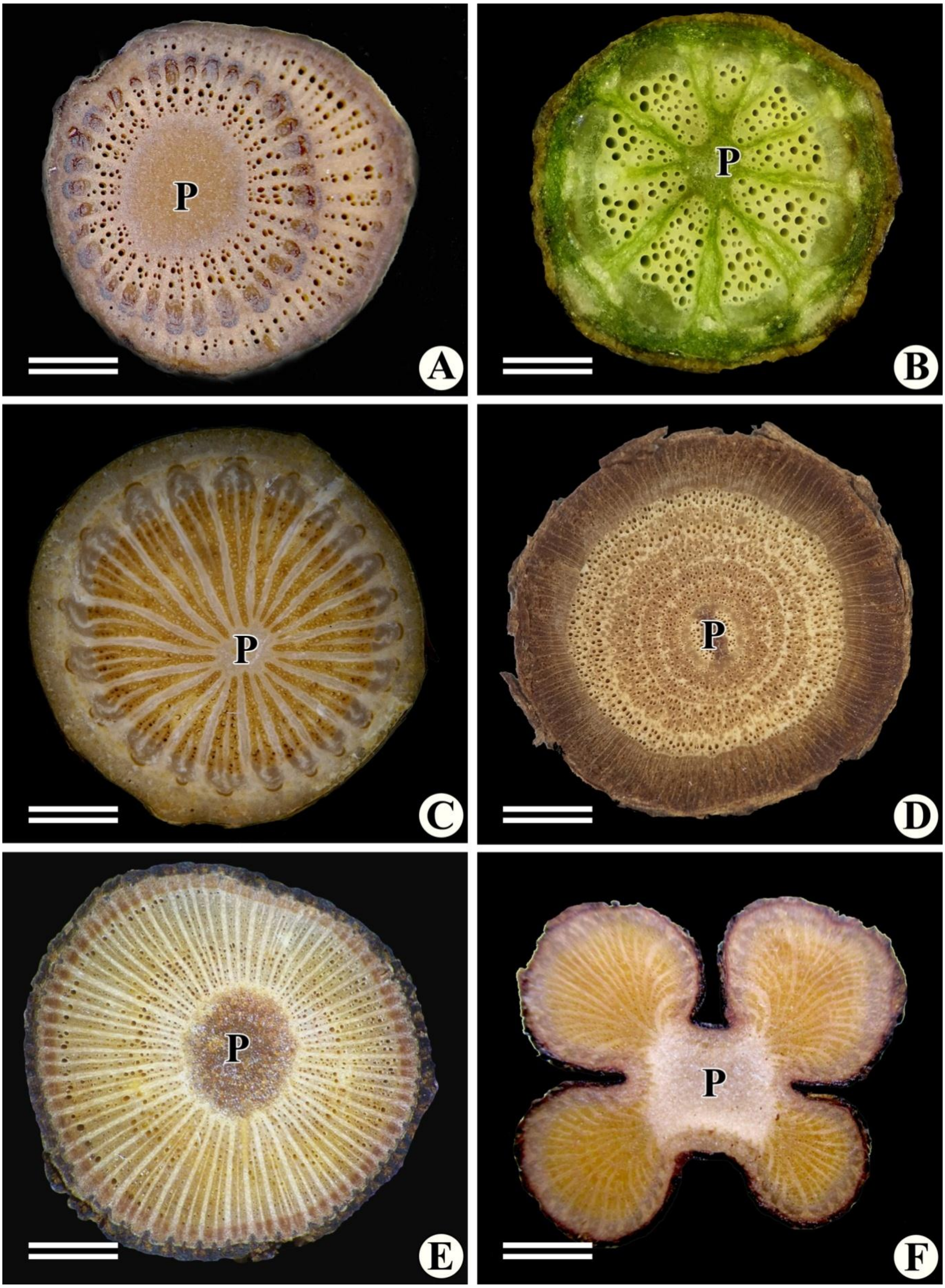

Figure 3

Figure 3: Macromorphological views of mature stems of species viz. *Pachygone ovata* (A); *Cissampelos pareira* (B); *Tinospora cordifolia* (C); *Campsis radicans* (D); *Coscinium fenestratum* (E); *Cissus quadrangularis* (F) showing the various growth patterns (i.e., successive rings of xylem and phloem in *P. ovata,* regular growth in *C. pareira* (B); *T. cordifolia* (C); *C. radicans* (D); *C. fenestratum* and lobbed nature *C. quadrangularis*.

Abbreviation: P = pith

Scale bar: A & D: 3mm; B: 2mm; C, E & F: 5mm

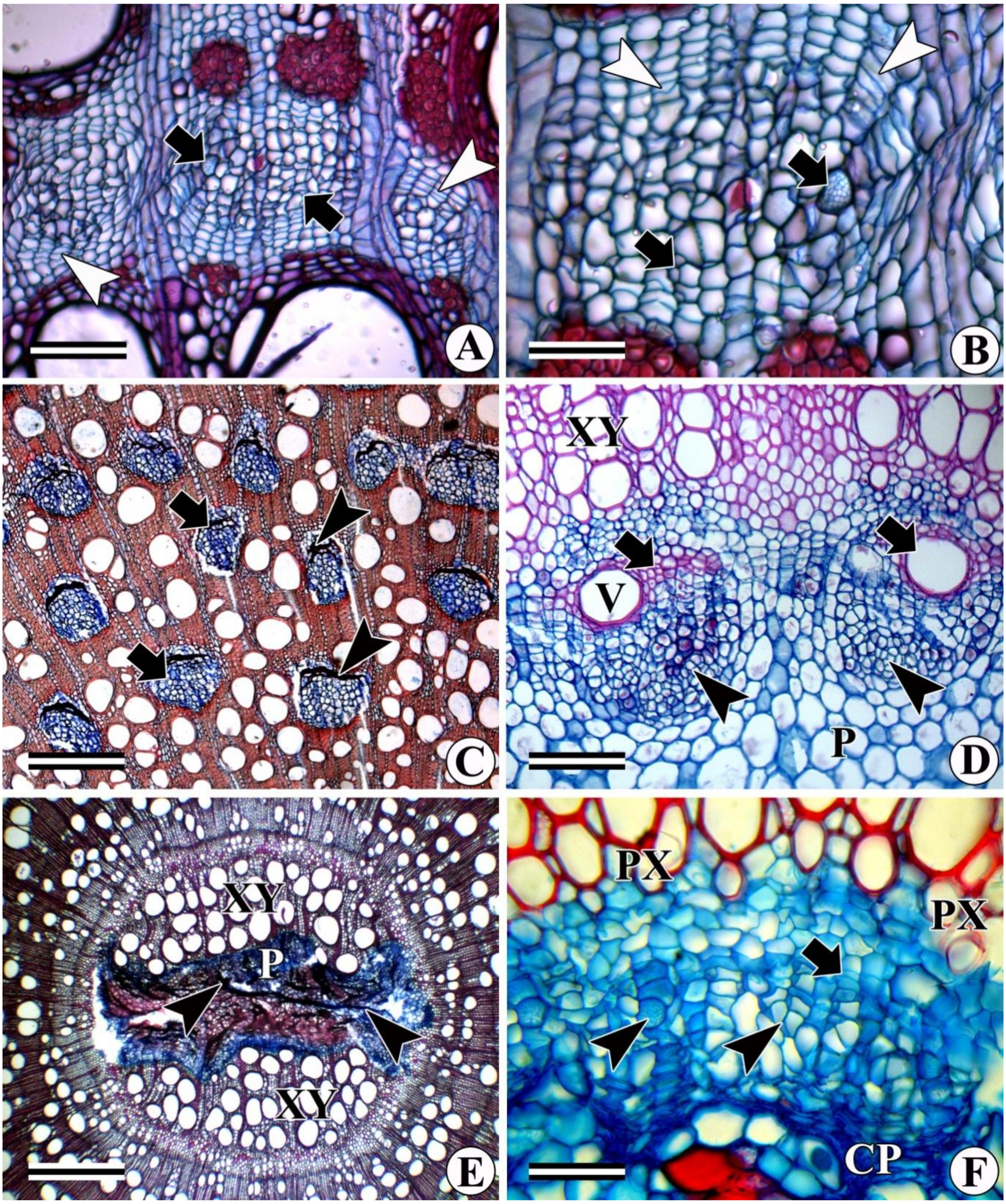

Figure 4

Figure 4: Transverse view of young and mature stem of different species showing the presence of interxylary and intraxylary phloem.

A: Mature stem of *Canavalia visrosa* showing dedifferentiation of unlignified parenchyma and formation of phloem (arrows) island within the secondary xylem. Note that the meristematic cells like cambium that encircles the island (arrowheads). Note the presence of fibre islands (F) within parenchymatous xylem.

B: Enlarged view of the Figure 4A showing the sieve tube elements (arrowheads) and the cambium (arrowheads) that encircles the phloem island.

C: Mature stem of *Strychnos andmanesis* showing the included phloem islands (arrows). Note the crushed phloem (arrowheads).

D: Relatively young stem of *Campsis radicans* showing bidirectional nature of internal /intraxylary phloem cambium. Arrows indicates the secondary xylem while arrowheads show the secondary intraxylary phloem produced by the internal cambium.

E: Mature stem of *C. radicans* showing intraxylary phloem (IP) and secondary xylem (XY) formed by the internal/intraxylary phloem cambium. Note the pith portion of the thick stem is completely occupied by the secondary xylem (XY) and phloem (P). Note the crushed pith cells (arrowheads).

F: Marginal portion of pith in mature stem of *Leptadenia pyrotechnica* showing protoxylem (PX), intraxylary phloem (arrowheads), the intraxylary cambium (arrow), and non-conducting crushed phloem (CP).

Abbreviations: P = pith, PX = protoxylem, XY = secondary xylem, V= vessel

Scale bars: A, D & F: 100 µm; B: 50 µm; C: 200 µm; E: 500 µm

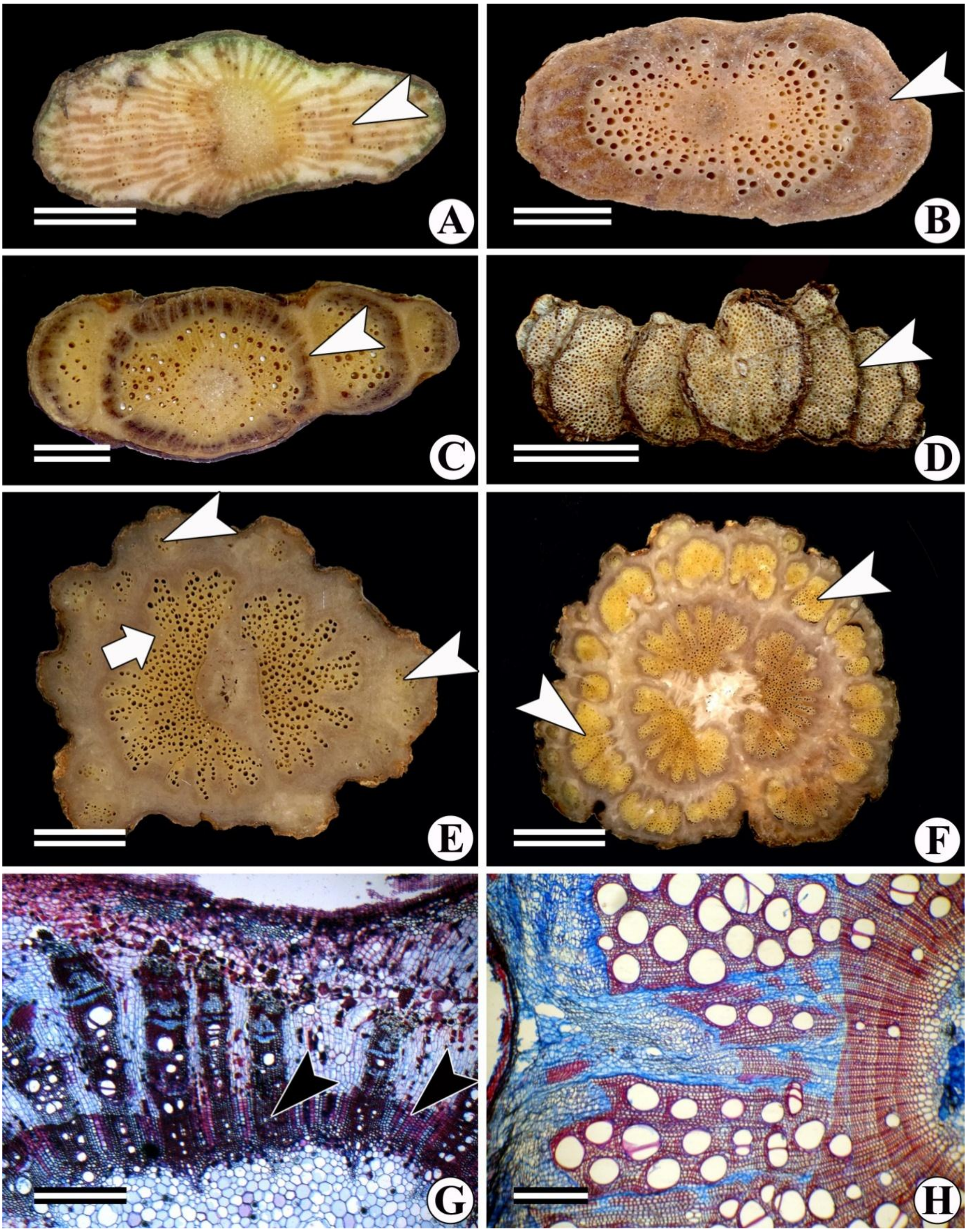

Figure 5

Figure 5: Macro-morphology (A-F) of the stem and structure of the secondary xylem in transverse view (G-H). Development of successive cambia leading to formation of flat stem in:

A: *Tetrastigma bracteolatum*. B: *Cayratia trifolia.* C: *Rhynchosia pyramidalis.* D: *Turbina corymbosa* due to initiation of crescent-shaped successive cambia (arrowheads) on the distal part of the stem. Note the absence of successive cambia on proximal part of the stem resulting in an elongated stem shape.

E) Relatively thick stem showing irregular outline of the stem due to formation of neo-formed vascular cylinders (arrowheads) and phloem wedges in *Hewittia malabarica*. Arrow indicates uneven activity of the cambium forming phloem wedges.

(F) Fully grown mature stem showing several neo-formed vascular cylinders (arrowheads).

G: Transverse view of the secondary xylem of *Tetrastigma bracteolatum* thick stem, showing a portion of stem that fails to develop successive cambia; note the pattern of vessel distribution (arrowheads).

H: Transverse view of secondary xylem of *Turbina corymbosa* showing a portion of stem that fails to develop successive cambia; note the pattern of vessel distribution.

Scale bars: A: 5 mm; B: 4 mm; C: 2mm; D: 15 mm; E: 2.5 mm; F: 10 mm; G & H: 500 µm.

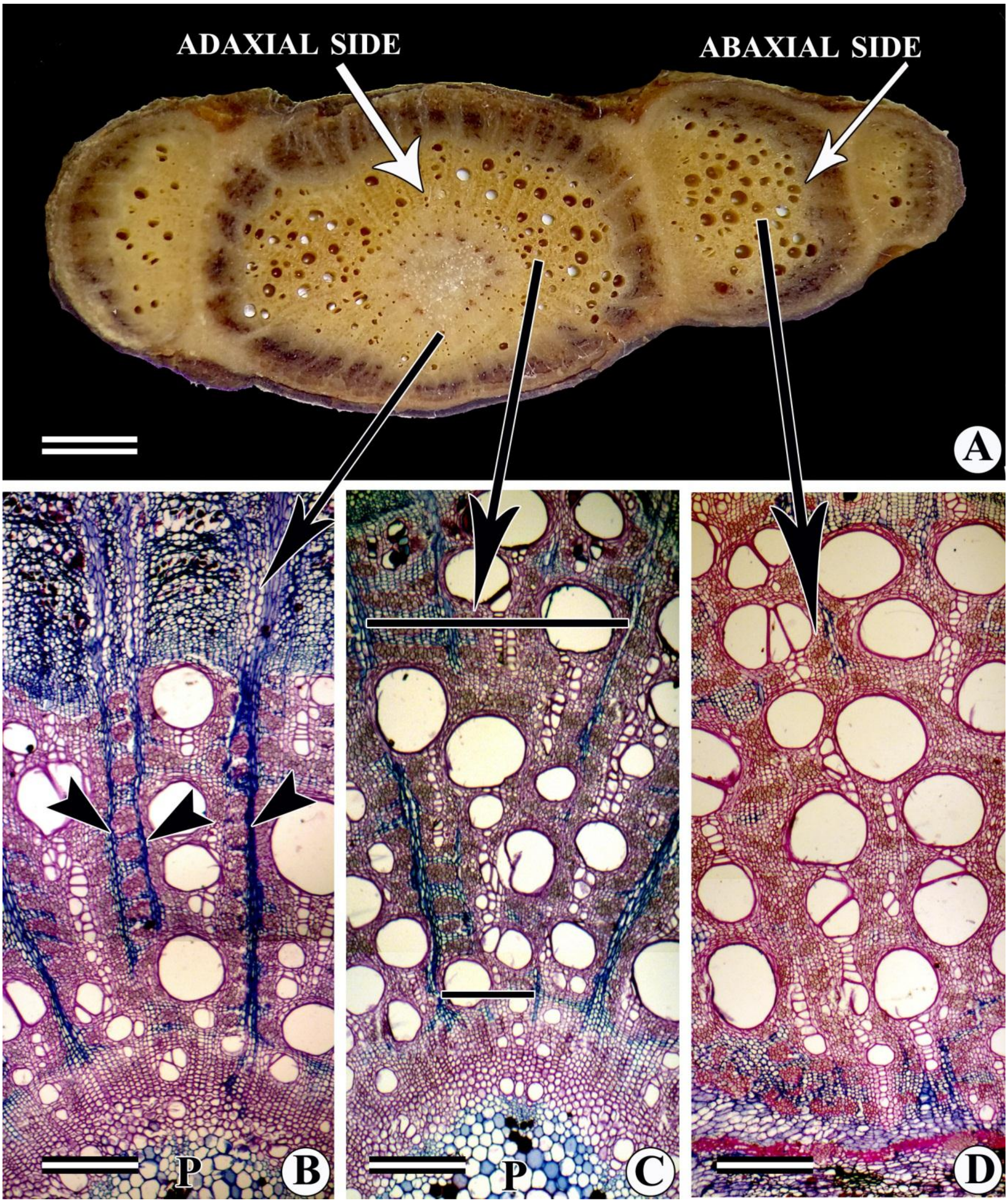

Figure 6

Figure 6: Transverse view of *Rhynchosia pyramidalis* stems showing structure of secondary xylem.

(A): Macro-morphology of the stem showing flat stem. Note that arrows indicate the various regions of the stem for which the internal structures are shown in subsequent image.

(B): Structure of the secondary xylem on the adaxial side of the stem. Note the multiseriate rays arranged more or less parallel to each other (arrowheads). *Abbreviation*s: P = Pith.

(C): Structure of the secondary xylem on abaxial side of the stem. Note the increasing distance between adjacent rays from pith (P) towards periphery of the stem (solid lines).

(D): Structure of the secondary xylem produced by successive cambium. Note that the rays are mostly uni-biseriate and difficult to distinguish in transverse view.

Scale bars: A: 2 mm; B, C & D; 200 µm.

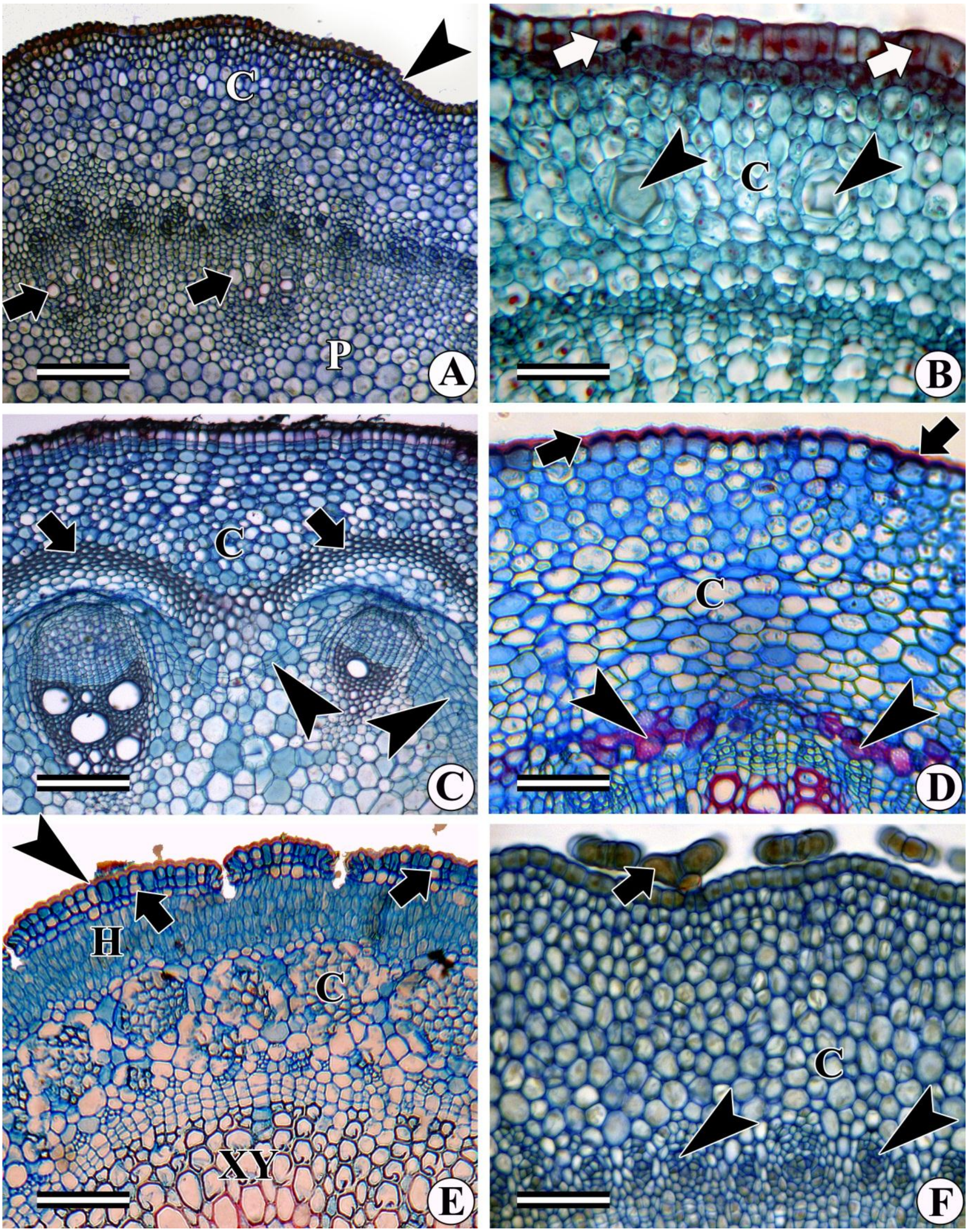

Figure 7

Figure 7: Transverse view of young stems of various species showing the structure of young stem and primary tissues.

A: Young stem of *Campsis radicans* showing initiation of the cambium, primary xylem and primary phloem. Arrowhead shows epidermis, cortex (C), differentiating metaphloem, metaxylem (arrow), cambium (C) and pith (P).

B: Transverse view of young stem of *Turbina corymbosa* showing the secretory ducts in the cortex (arrowheads). Arrows indicates epidermis and primary phloem.

C: Young stem of *Tiliacora racemosa* showing the tangential ring of pericyclic fibre cap (arrows) over the phloem only. Arrows indicates the initiation of interfascicular cambium, which connects with the fascicular to form complete ring of vascular cambium.

D: Young stem of *Strychnos bredemeyeri* showing epidermis, cuticle (arrows), cortex (C), phloem and xylem. Arrowheads indicate isolated perivascular sclereids. Note that endodermis and pericycle are indistinct.

E: Young stem of *Cayratia auriculata* showing the thick cuticle (arrowhead), multi-layered epidermis (arrow), sunkem stomata. Note that the hypodermal (H) cells are compactly arranged and radially elongated.

F: Young stem of *Campsis radicans* showing glandular trichome (arrow) on epidermis, cortex (C) and differentiating protophloem (arrowheads).

Scale bars: A, D & E: 100 µm; B & F: 50 µm; C: 200 µm.

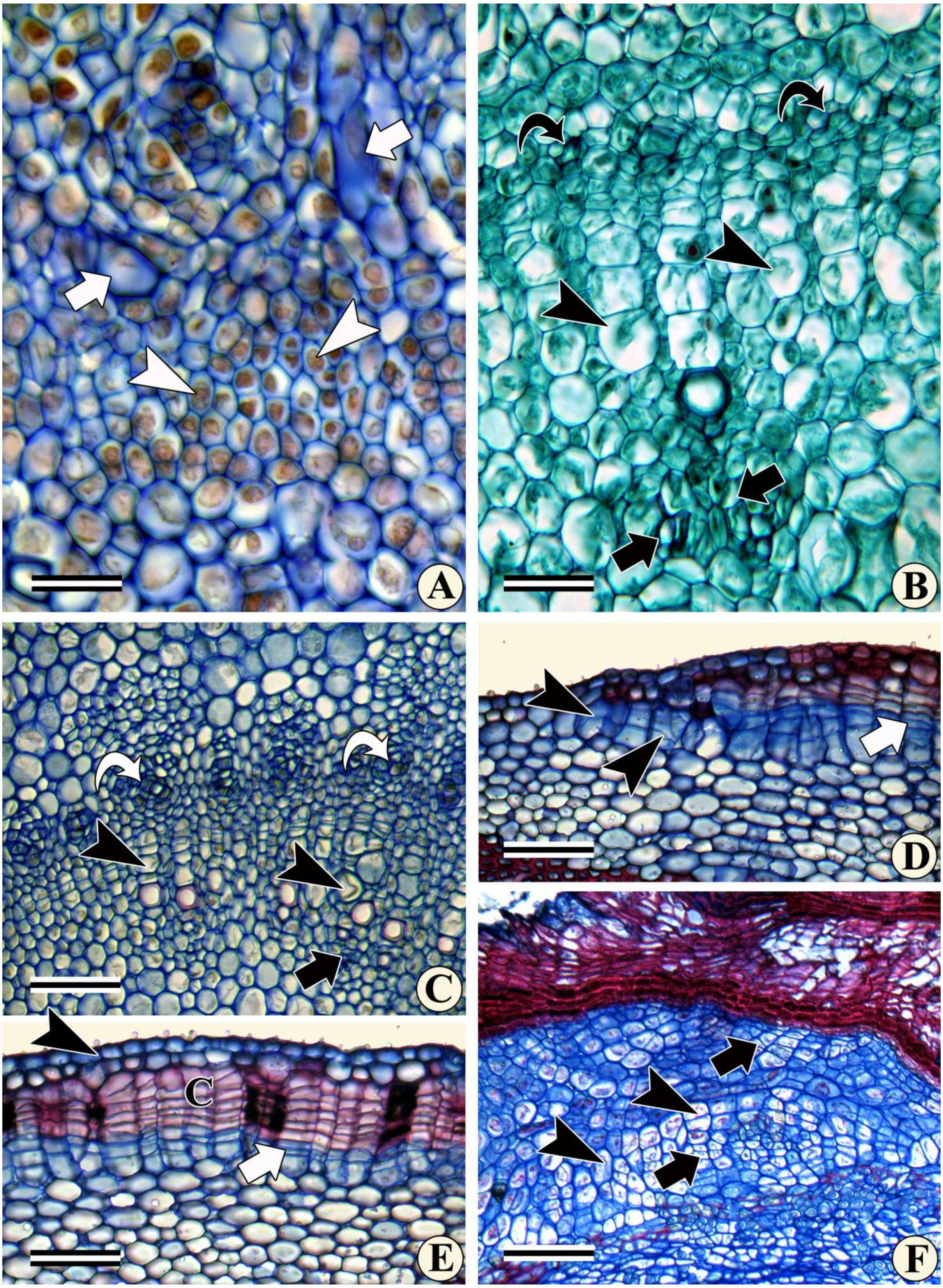

Figure 8

Figure 8: Transverse view of young stems of various species showing the structure of young stem and primary tissues.

A: Young stems of *Beaumontia jerdoniana* (Apocynaceae) showing initiation of procambium. Note the distinct nucleus in the meristematic cells (arrowheads) in 4th visible internode and arrow indicates the laticiferous ducts.

B, C: Differentiating and enlarging metaxylem elements (arrowheads) from 7th to 9th visible internode of *Leptadenia reticulata* (B) and *Beaumontia jerdoniana* (C). Arrows indicate intraxylary phloem while curved arrows indicate regular protophloem in 7th to 9th visible internodes.

D: Young stem of *Anamirta cocculus* showing the initiation of phellogen i.e., cork cambium (arrow). Note the enlarging sub-epidermal cells (arrowheads) and periclinal divisions.

E: Relatively enlarged view of figure 8E showing well-developed cork cambium (arrow) and enlarging sub-epidermal cells (arrowhead).

F: Young stem of *Rhynchosia pyramidalis* showing initiation of successive cambium (arrows) from the cortical parenchyma cells. Note the swelling of cortical parenchyma (arrowheads). *Abbreviation*: C = cork

Scale bars: A: 20 µm; B: 100 µm; C, D, E & F: 50 µm.

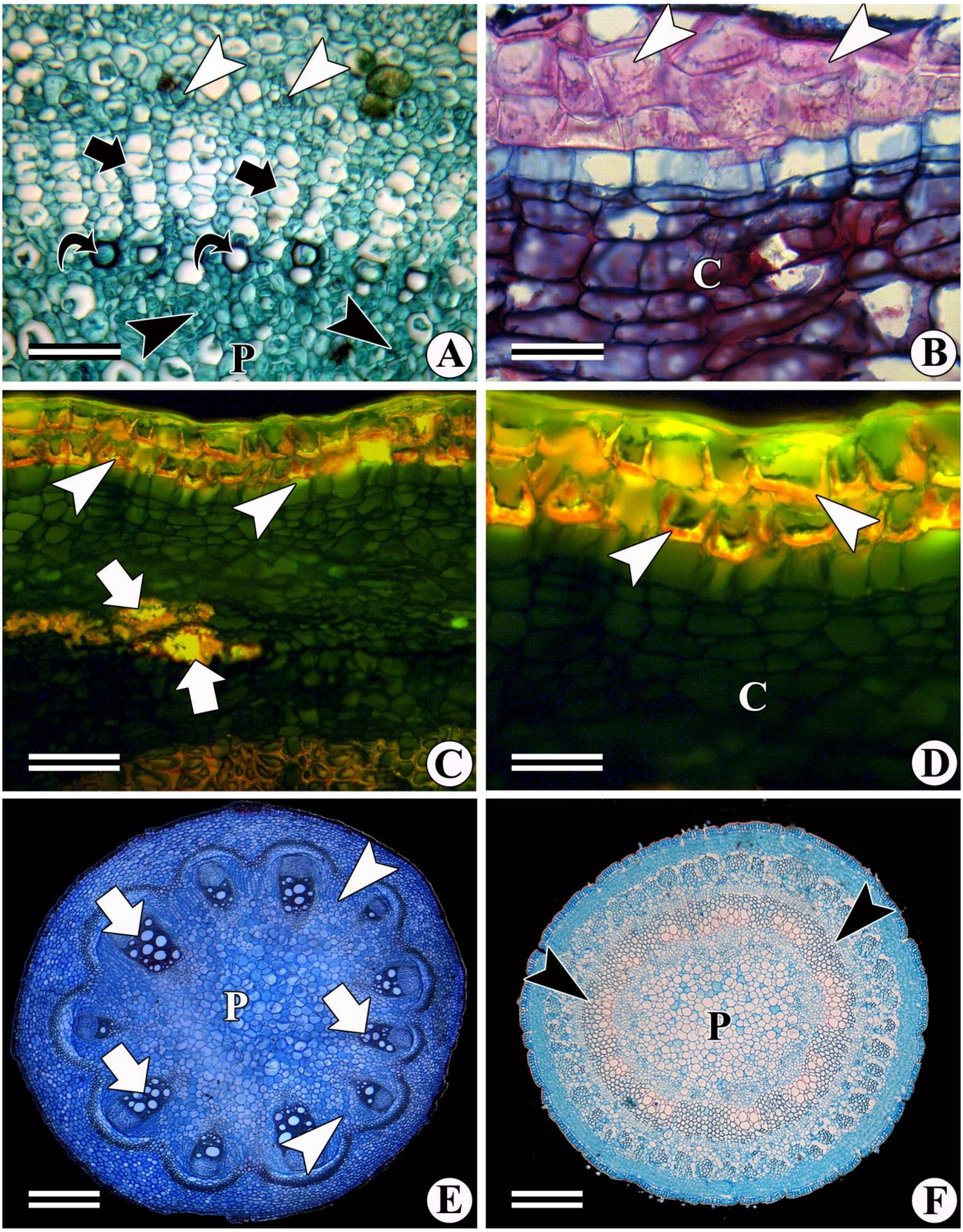

Figure 9

Figure 9: Transverse view of young stems of *Leptdenia reticulata* shows the initiation of internal phloem while *Dicranostyles ampla* and *Maripa nicaraguensis* showing various stages of growth.

A: Young stem of *Leptdenia reticulata* at 4th - 6th visible internode showing the development of primary internal phloem (black arrowheads) at pith margin. Note the differentiating xylem (arrows) from the procambium. Note the regular phloem (white arrowheads) and protoxylem (curved arrow).

B: *Dicranostyles ampla* stems observed under bright field (B), phase contrast microscope (C, D). Young (8 mm thick) stem showing lignified cork (arrowheads) cells.

C: Unevenly thickened and lignified cork cells (arrowheads) under phase contrast microscope in *Maripa nicaraguensis*.

D: Enlarged view of figure 9C showing ‘U’ shaped deposition of lignin in *Maripa nicaraguensis*. Note the auto-fluorescence of cork cells (arrowheads) and group of sclereids (arrows) indicating lignin deposition.

E: Young stem of *Stephania japonica* showing the arrangement of vascular bundles (arrows). Note that the vascular bundles are separated by the wide interfascicular regions (arrowheads).

F: Young stem of *Cayratia auriculata* showing several vascular bundles that form a complete ring of vascular cambium (arrowheads).

Scale bars: A: A & D: 50 µm; B: 20 µm; C: 100 µm; E & f: 500 µm

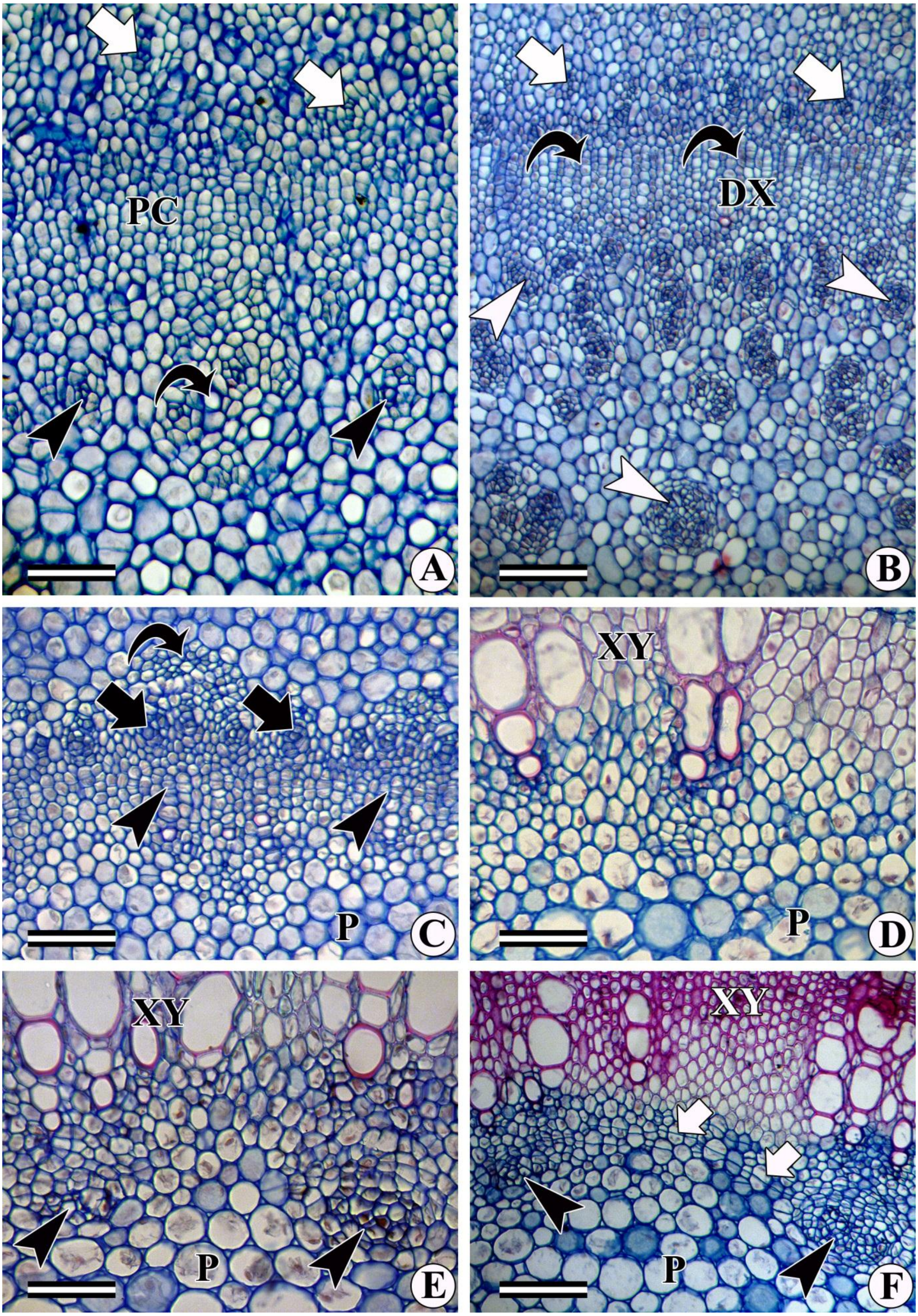

Figure 10

Figure 10: Transverse view of young stems showing the formation and initiation of primary intraxylary phloem (A-D), secondary intraxylary phloem and initiation of intraxylary phloem cambium (internal cambium).

A: Young stems of *Vallaris solanacea* showing initiation of procambium from the pro-meristem. Arrow indicates differentiation of regular external phloem while arrowheads indicating intraxylary phloem. Note the differentiating protoxylem element (curved arrow). *Abbreviation*: PC = procambium

B: Initiation of intraxylary (internal) phloem development (arrowheads) in the young stems of *Beaumontia jerdoniana*. Arrowhead indicates regular external phloem while arrowheads show intraxylary phloem islands. Note that the intraxylary phloem islands are scattered deep into the pith. Curved arrows showing procambium. *Abbreviation*: DX = differentiating protoxylem

C: Initiation of procambium (arrowheads) in *Campsis radicans*. Arrows indicate regular external protophloem. Note the absence of intraxylary phloem on the pith margin.

D: Relatively thick stem of *C. radicans* showing absence of intraxylary phloem on the pith margin. *Abbreviation*: P = pith, XY = secondary xylem.

E: Relatively thick stem showing initiation of intraxylary secondary phloem development (arrowheads) in 10th internode in *C. radicans*.

F: Initiation of internal/intraxylary phloem cambium in the 11th internode of the *C. radicans* (arrows). Arrowheads indicate intraxylary phloem.

Scale bars: A, C & E: 50 µm; B, D & F: 100 µm.

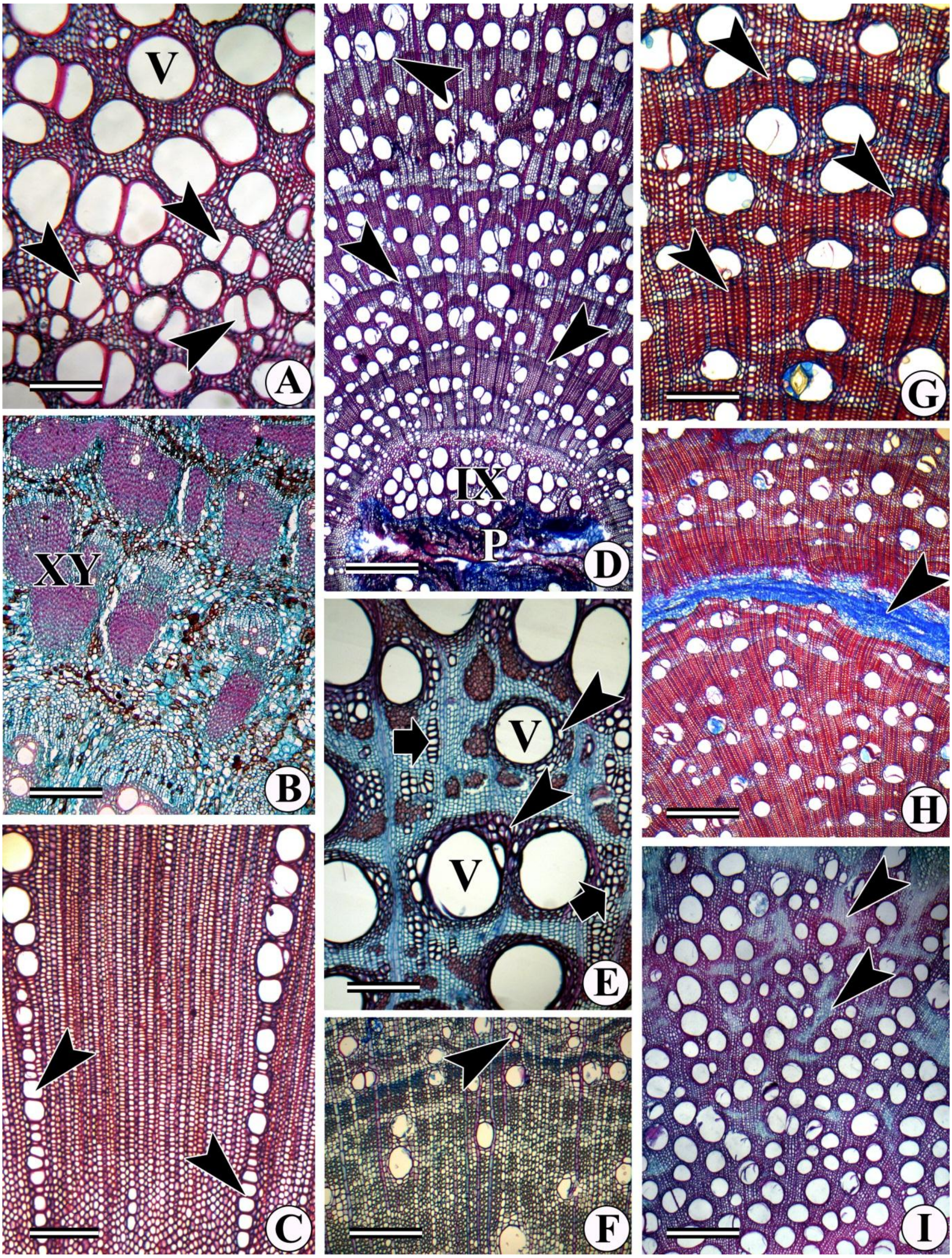

Figure 11

Figure 11: Structure of the secondary xylem in transverse view in mature stems of different species.

A: Structure of the secondary xylem formed by the vascular cambium of *Antigonon leptopus* showing solitary and radial/tangential or diagonal multiples of vessels (arrowheads).

B: Structure of the secondary xylem formed by the successive in *Antigonon leptopus*. Note the absence of vessels.

C: Secondary xylem of *Beaumontia jerdomiana* showing radial multiples of vessels (arrowheads) while in other portion of the xylem, wide vessels are either absent or formed less in number.

D: Mature stem of *Campsis radicans* showing the structure of secondary xylem in fully growth thick stems. Arrows showing distinct growth rings. Note the quantity of secondary xylem (IX) formed by intraxylary phloem cambium. P intraxylary phloem (crushed) in pith region.

E: Structure of the secondary xylem in fully grown stem of *Prureria tuberosa* showing abundant parenchyma forming large patches. Note the wide vessels are solitary (V) encircled by lignified derivatives (arrowheads) while narrow vessels were arranged in radial multiples (arrows).

F: Structure of the secondary xylem in *Dalbergia volubilis* showing solitary vessels. Note that the marrow vessels forming a cluster (arrowhead) or arranged in radial multiples.

G: Structure of secondary xylem of *Dicranostyles ampla* in the climbing stage. Note the vessel frequency and vessel associated parenchyma cells. Arrowheads indicate growth rings.

H: Structure of the secondary xylem of *Maripa nicaraguensis*. Arrowhead shows a phloem formed from the successive ring of the cambium.

I: Structure and composition of the secondary xylem of *Hewittia malabarica.* Note the oval to circular solitary vessel islands of unlignified parenchyma (arrowheads) distributed randomly.

Scale bars: A: 250 µm; B, C, E & F: 200 µm; D, H & I: 500 µm; G: 50 µm.

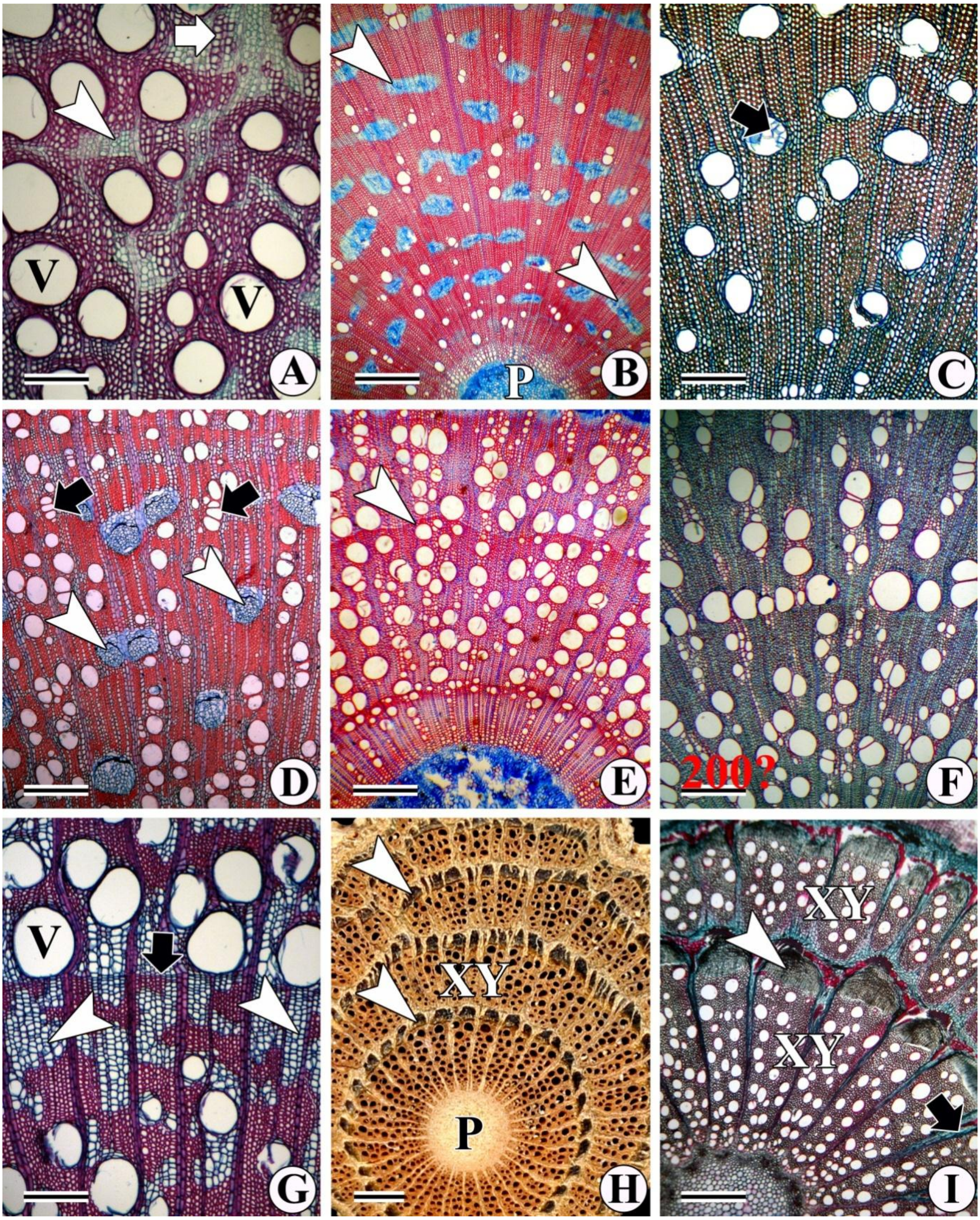

Figure 12

Figure 12: Transverse view of stems of different species showing structure of the secondary xylem.

A: Enlarged view of *Hewittia malabarica* showing unlignified parenchyma island (arrowhead) and vessel distribution and uni-biseriate rays. Note wide (V) and narrow vessels (arrows). *Abbreviation*: V = vessels.

B: *Leptadenia pyrotechnica* secondary xylem composed of phloem islands (arrowheads), distribution of vessels and absence of growth rings.

Abbreviation: P = pith.

C: Structure and composition of the secondary xylem of *Maripa nicaraguensis*. Note the distribution of parenchyma and undetectable uniseriate rays. Arrow indicates vessel occluded with tyloses.

D: *Strychnos andamanensis* showing the included phloem islands embedded within the secondary xylem (arrows). Note that the solitary vessels. Arrowheads indicates vessels in radial multiples.

E: Structure of the secondary xylem in thick stems of *Vallaris solanacea* . Arrowheads indicate distinct growth rings.

F: Mature stem of *Wattakaka volubilis* showing indistinct growth rings and the structure of secondary xylem. Wide vessels are solitary or in a group of two and narrow vessels are in radial multiples.

G: Structure and composition of the secondary xylem of *Campsis radicans* showing wide solitary vessels (V) while narrow vessels form radial multiples/cluster (arrowhead). Note the distinct growth ring (arrowhead).

H: Macro-morphological view of *Gnetum ula* stem showing successive rings of the secondary xylem (XY) and phloem (arrowheads). *Abbreviation*: P = pith.

I: Relatively thick stem of *Diploclisia glaucoscens* showing successive xylem rings (XY). Note the radial plates of axial elements separated by medullary rays (arrow).

Scale bars: A & G: 200 µm; B, D, E, F, H & I: 500 µm; C: 50 µm.

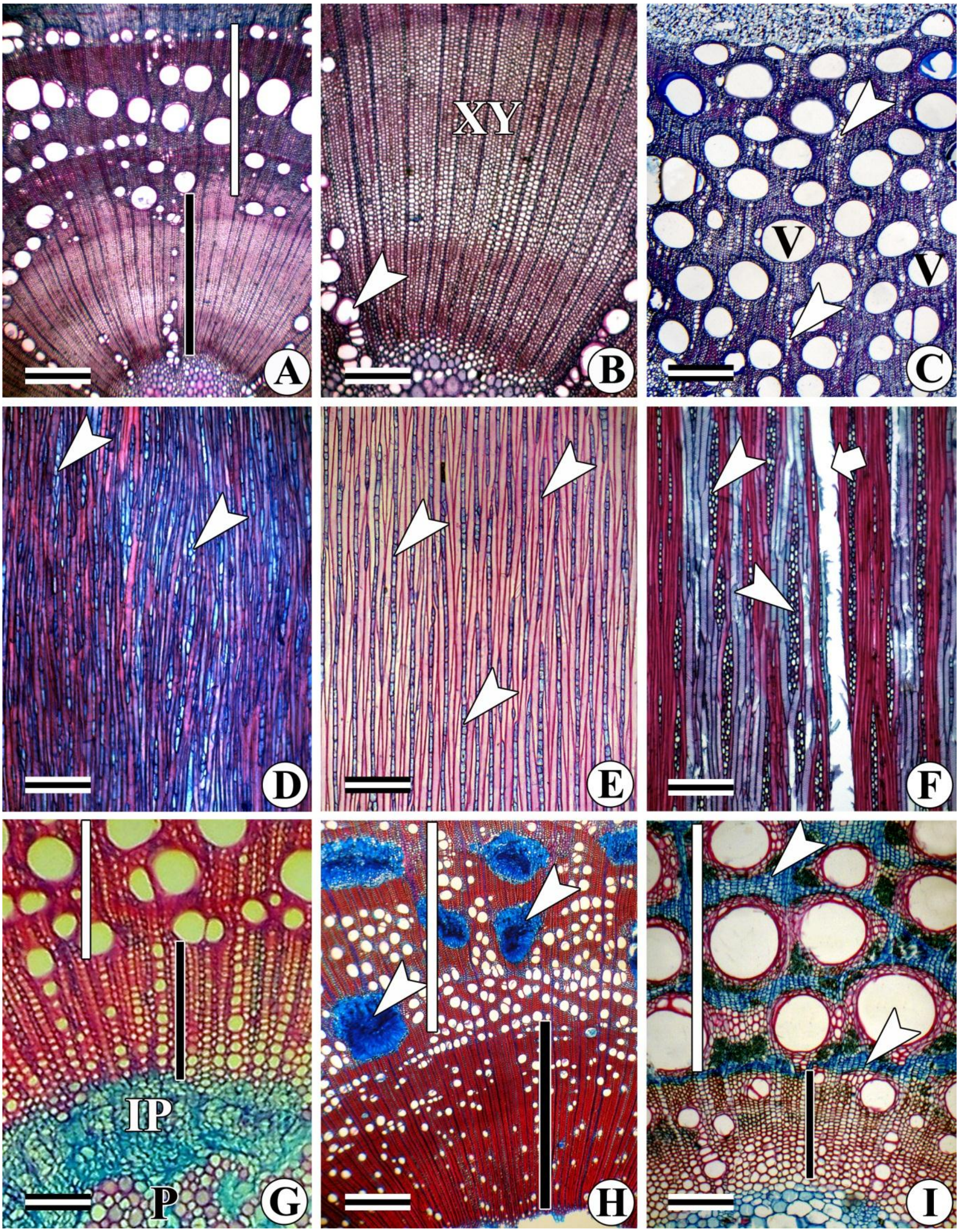

Figure 13

Figure 13: Transverse (A, B, C, G, H and I) and tangential longitudinal (D, E & F) structure of xylem which are formed during self-supporting phase and climbing phases.

A: Structure of the secondary xylem in *Serjania mexicana* showing alteration during the self-supporting habit (vertical black line) and after the initiation of climbing habit (vertical white line). Note the radial rows of vessels (arrowheads) and composition of the xylem at both the growth phases.

B: Enlarged view of panel 13A showing the secondary xylem (SX) formed during the self-supporting phase is devoid of wide vessels. Arrowhead indicates vessels arranged in radial multiples.

C: Structure of the secondary xylem of *Serjania mexicana*. Note that wide vessels are mostly solitary (V) while narrow vessels form radial multiples (arrowheads).

D: Tangential longitudinal view of the secondary xylem of *Dicranostyles ampla*. Note the uni- to biseriate rays (arrowheads) composed of vertically upright ray cells.

E: Structure of xylem of *Beaumontia jerdoniana* in tangential longitudinal plane, section passing through a stem portion lacking wide vessels. Note the exclusively uniseriate and very rarely biseriate rays (arrowheads).

F: Tangential longitudinal view of the secondary xylem of *Campsis radicans* showing multiseriate and tall rays (arrowheads) and vessel column (arrow)

G: Structure of the secondary xylem of *Leptadenia reticulata*. Note the difference in the xylem formed during self-supporting (black vertical line) and climbing habit (white vertical line). *Abbreviation*s: IP = intraxylary phloem, P = pith.

H: *Strychnos bredemeyeri* stem showing structure and composition of the secondary xylem. Arrowheads indicate interxylary phloem. Note the difference in the xylem formed during self-supporting (black vertical line) and climbing habit (white vertical line).

I: Transverse view of *Canavalia virosa* stem showing secondary before climbing (black line) and after climbing (while line) habit. Note the vessel diameter and increase in number of parenchyma (arrowheads) cells after the initiating of climbing condition.

Scale bars: A, C & H: 500 µm; B, D, F, G, I: 200 µm.

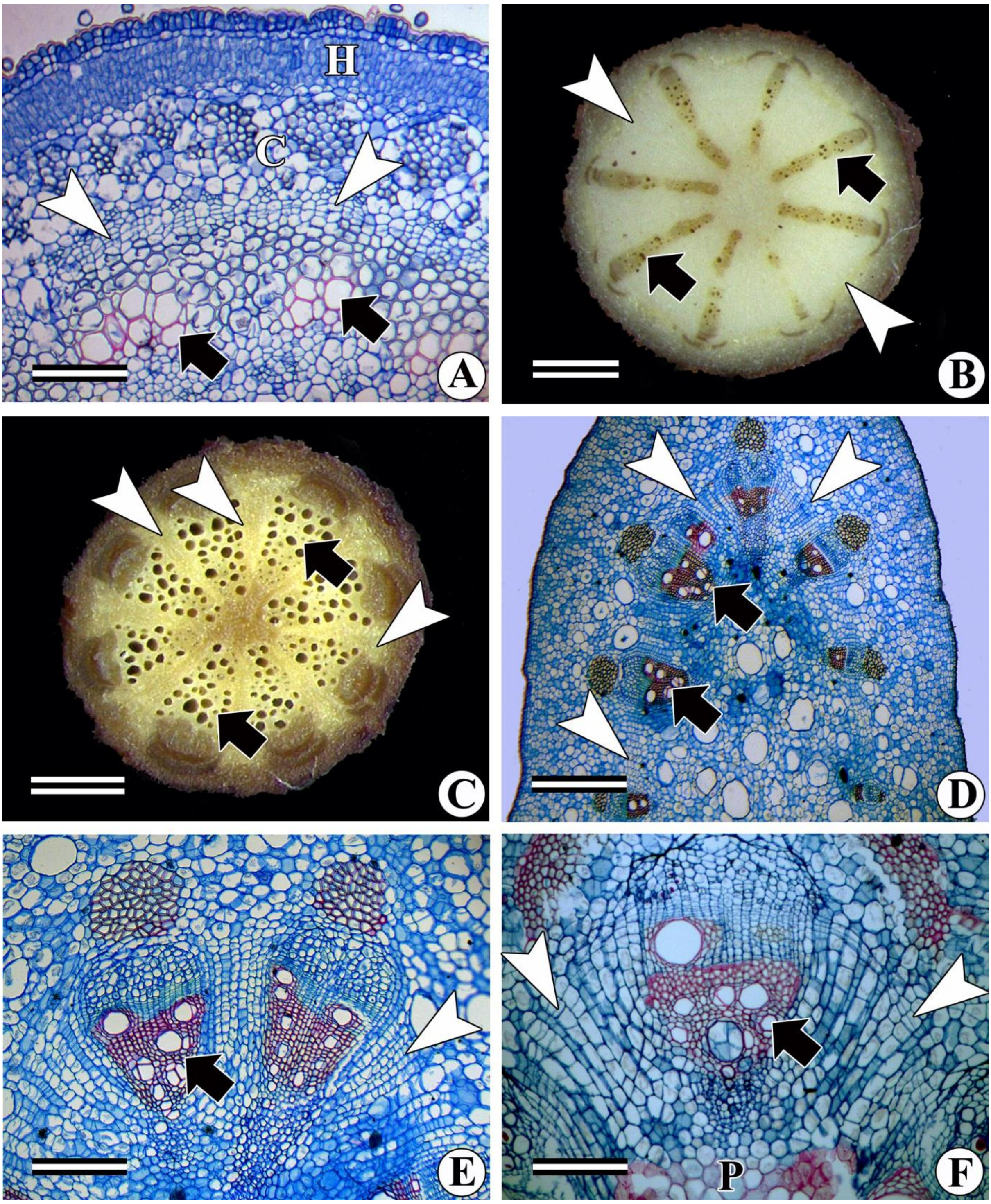

Figure 14

Figure 14: Transverse views young stems of various species showing the structure of xylem tissue.

A: Young stem of *Cayratia auriculata* showing the formation of complete ring of vascular cambium by connecting the fascicular and interfascicular cambium (arrowheads). Also note the layers of epidermis, elongated hypodermal cells (H) and cortical (C) parenchyma cells. Arrows indicate protoxylem elements.

B & C: Young stem of *Tinospora sinensis* (B) and *Cissampelos parerii* (c) showing widely separated vascular bundles (arrows) and interfascicular portion of the vascular cambium (arrowheads).

D: Young stem of *Cissus quadrangularis* showing the development of primary vascular tissue (arrows) from the fascicular cambium. Note the wide interfascicular region of the cambium (arrowheads).

E: Magnified view of young stem of *Cissus quadrangularis*. Note the structure and development of conducting elements of xylem and phloem.

F: Establishment of vascular cambium in *Zanonia indica*. Note the initiation of interfascicular cambium (arrowheads) on both side of the vascular bundle (arrow) to form a complete ring. *Abbreviation*: P = pith

Scale bars: A: 100 µm; B: 1.5 mm; C: 2 mm; D: 500 µm; E, F: 200 µm.

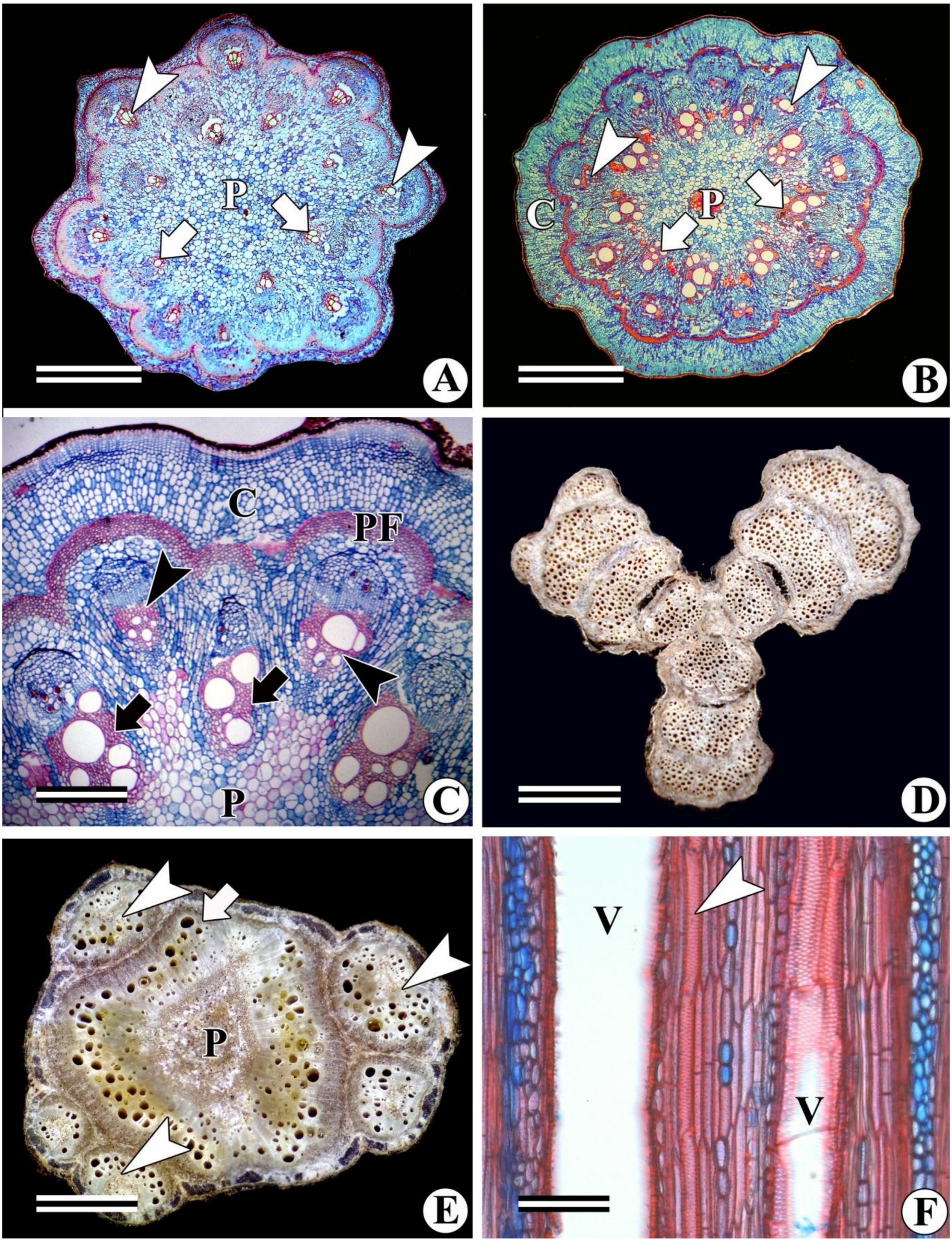

Figure 15

Figure 15: Transverse view young and mature stems of different species showing the structure of secondary xylem and outline conformation of the stem.

A & B: Young stem of *Zanonia indica* showing the formation of vascular bundles. Note that vascular bundles are arranged inn two rings. The second ring (arrowheads) initiates external to- and alternate to previous ring (arrows). *Abbreviation*: P = pith.

C: Enlarged view of *Zanonia indica* young stem showing the alternate vascular bundles (arrows and arrowheads). Note the absence of inner phloem of the vascular bundle. *Abbreviations*: C = cortex, PF = pericycle fibres, P = pith

D: Macro-photo of fully grown stem of *Argyereia eliptica* showing the tri-lobed stem in outline due to cessation of cambial activity at certain regions.

E: Macro-photo of *Serjania circumvallata.* Stem showing the polystele condition, characteristic to several Serjania species. Arrowheads indicate external stele while arrow shows central cylinder.

F: Longitudinal view of *Rhynchosia pyrimidalis* showing the vessel dimorphism. Arrow indicates the wide (V) and narrow (arrowhead) vessels. Note the uniseriate and multiseriate rays. *Abbreviation*: V = vessels.

Scale bars: A & B: 1 mm; C: 500 µm; D & E: 3.5 mm; F: 150 µm.

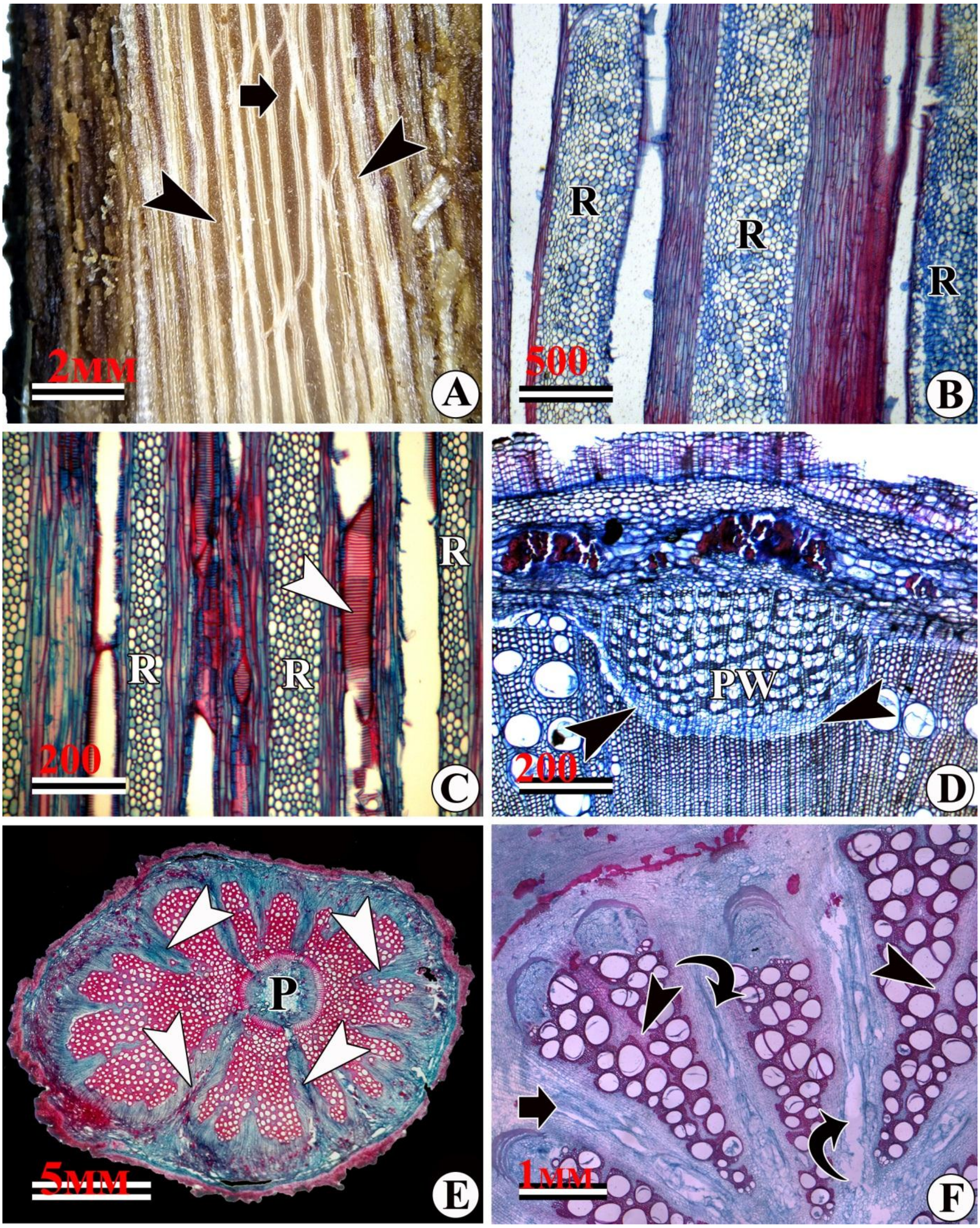

Figure 16

Figure 16: Transverse and tangential longitudinal views mature stems of various species showing the structure of secondary xylem and outline of the stem.

A: Macro-morphological tangential longitudinal view of thick stem of *Anamirta cocculus* showing the exceptionally tall rays (arrow & arrowheads). Note that some of the rays are exceptionally tall (arrowheads) crossing beyond the wood block.

B & C: Tangential longitudinal view of stem of *Anamirta cocculus* (B) *Vitis vinifera* (C) showing multiseriate and tall rays.

D: Mature stem of *Arrabidaea candicans* in transverse view showing the phloem wedge (PW). Arrowheads showing the vascular cambium and xylem boundary. *Abbreviations*: PW, phloem wedge.

E: Macromorphological view of fully grown mature stem of *Jacquemontia paniculata* showing the stem outline and phloem wedges (arrowheads).

F: *Zanonia indica* showing the secondary xylem in plates. Arrow indicates wide ray, curved arrow indicates obliteration of ray parenchyma cell due to cavitation or marginal ray cell dilation and arrowheads indicates the splitting of xylem plate and development of new ray.

Scale bars: A: 2 mm; B: 500 µm; C, D, F: 1 mm.

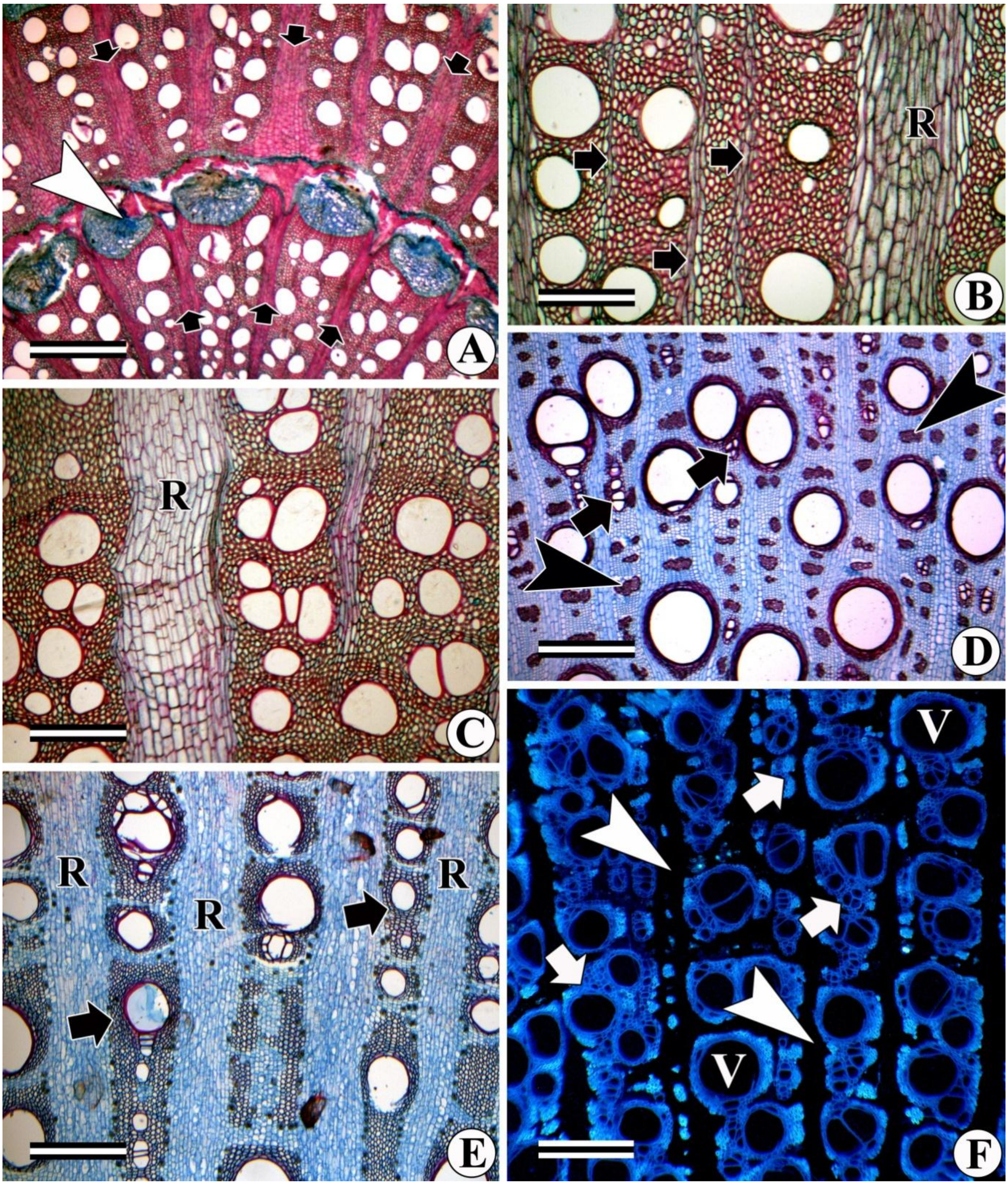

Figure 17

Figure 17: Transverse views of mature stems showing structure and composition of the secondary xylem in different species.

A: Mature stem of *Diploclisia glaucoscens* showing the successive cambial rings and secondary xylem arranged in radial plates. Note that the medullary rays are more or less continuing in successive xylem rings (arrows). Arrowhead indicates phloem formed by previous cambial ring and crushing of the earlier formed phloem.

B & C: Magnified view of secondary xylem of *Cocculus pendulus* (B) and *Cocculus hirsutus* (C) showing the multiseriate ray (R). Arrows indicates the initiation of secondary rays with the increase in stem thickness. Note the distribution of axial parenchyma cells.

D: Structure of the secondary xylem in *Prureria tuberosa*. Note the parenchyma abundance (blue stained cells) while the xylem fibres form small islands (arrowheads). Arrows indicates the narrow vessels and tracheids or fibre tracheids are forming a sheath around wise vessels.

E: *Cissus rependa* showing abundant unlignified parenchyma abundance and wide rays (R) that separates the axial elements of the secondary xylem in radial plates.

F: Secondary xylem of *Phaseolus lunatus* seen under fluorescence microscope. Bright blue fluorescence (arrows) indicates lignified axial elements while dark black background (arrowheads) shows unlignified parenchyma due to lack of fluorescence.

Scale bars: A & G: 200 µm; B, C, E & F: 200 µm; D: 50 µm.

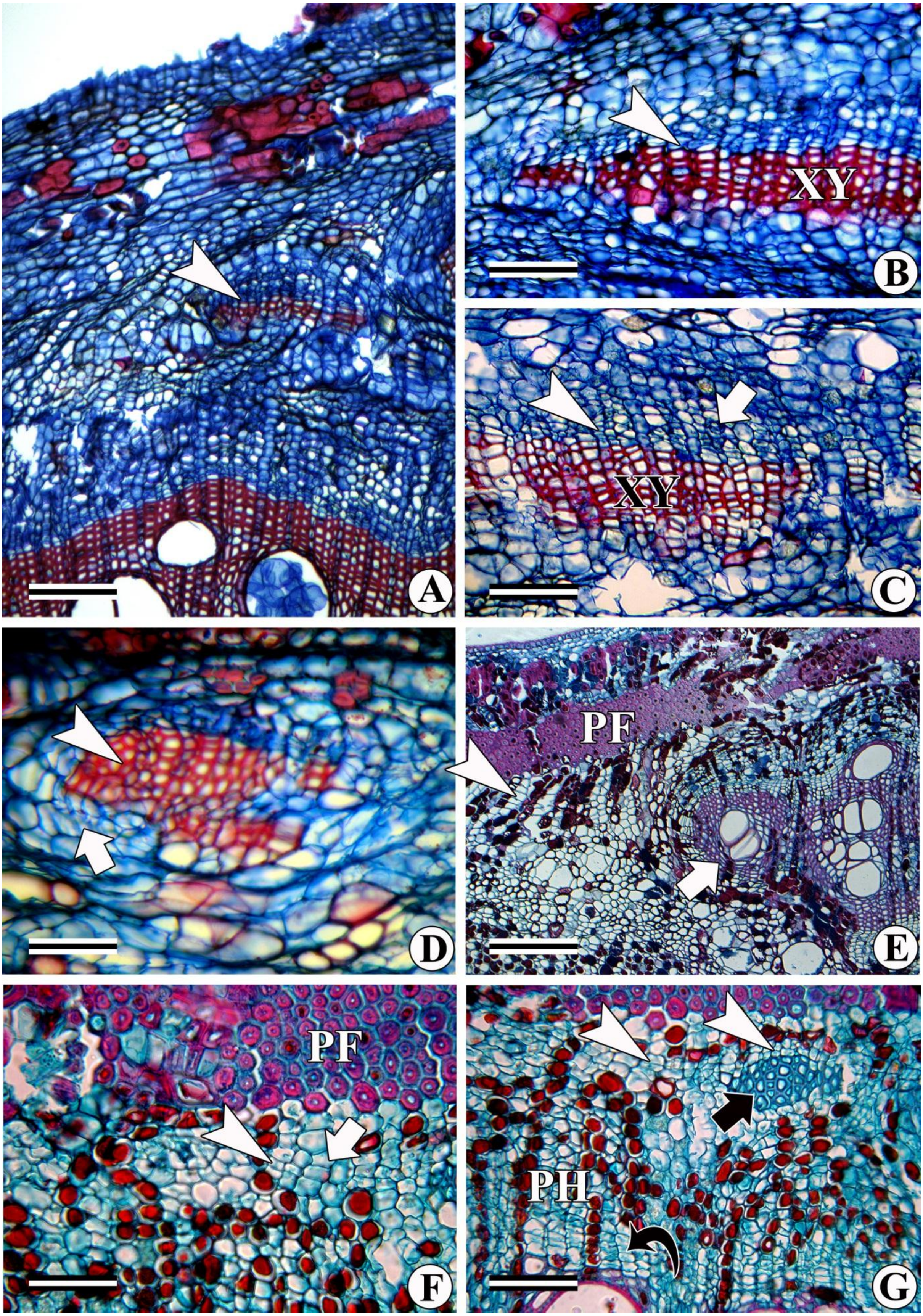

Figure 18

Figure 18: Transverse views of mature stems of various species showing the initiation of successive cambium in *Maripa nicaraguensis* (A–C), *Turbina corymbosa* (D), *Serjania mexicana* (E) and *Antigonon leptopus* (F, G).

A: Initiation of first ring of successive cambium (arrowhead) external to the phloem formed by regular vascular cambium (B).

B: Enlarged view of Figure 18A, showing small segment of the cambium (arrowhead) initiated external to the phloem formed by the regular vascular cambium. Note the xylem (XY) and phloem formed from it.

C: Differentiation of the secondary xylem (XY) and secondary phloem (arrow) from the newly initiated cambium (arrowhead).

D: Development of successive cambium (arrow) in *Turbina corymbosa.* Note the secondary xylem (XY) formed by newly initiated successive cambial segment (arrowhead) in conjunctive tissue.

E: Stem portion external to the phloem wedge showing radial arrangement of newly initiated cambial cells (arrowhead) in *Serjania mexicana.* Arrowhead indicates newly formed vascular cylinder from the successive cambium. *Abbreviation*: PF = pericycle fibre

F: Initiation of cambium (arrowhead) in *Antigonon leptopus.* Note the expansion of the parenchyma cells (arrow) that divide tangentially to initiate of first ring of successive cambia. *Abbreviation*: PF = pericycle fibres.

G: Newly initiating cambium (arrows) in *Antigonon leptopus* showing recently differentiated xylem element (arrowhead). Note the functional phloem (Ph) formed by regular vascular cambium (curved arrow).

Scale bars: A, G: 200 µm; B, C, E, and F: 100 µm; D: 50 µm.

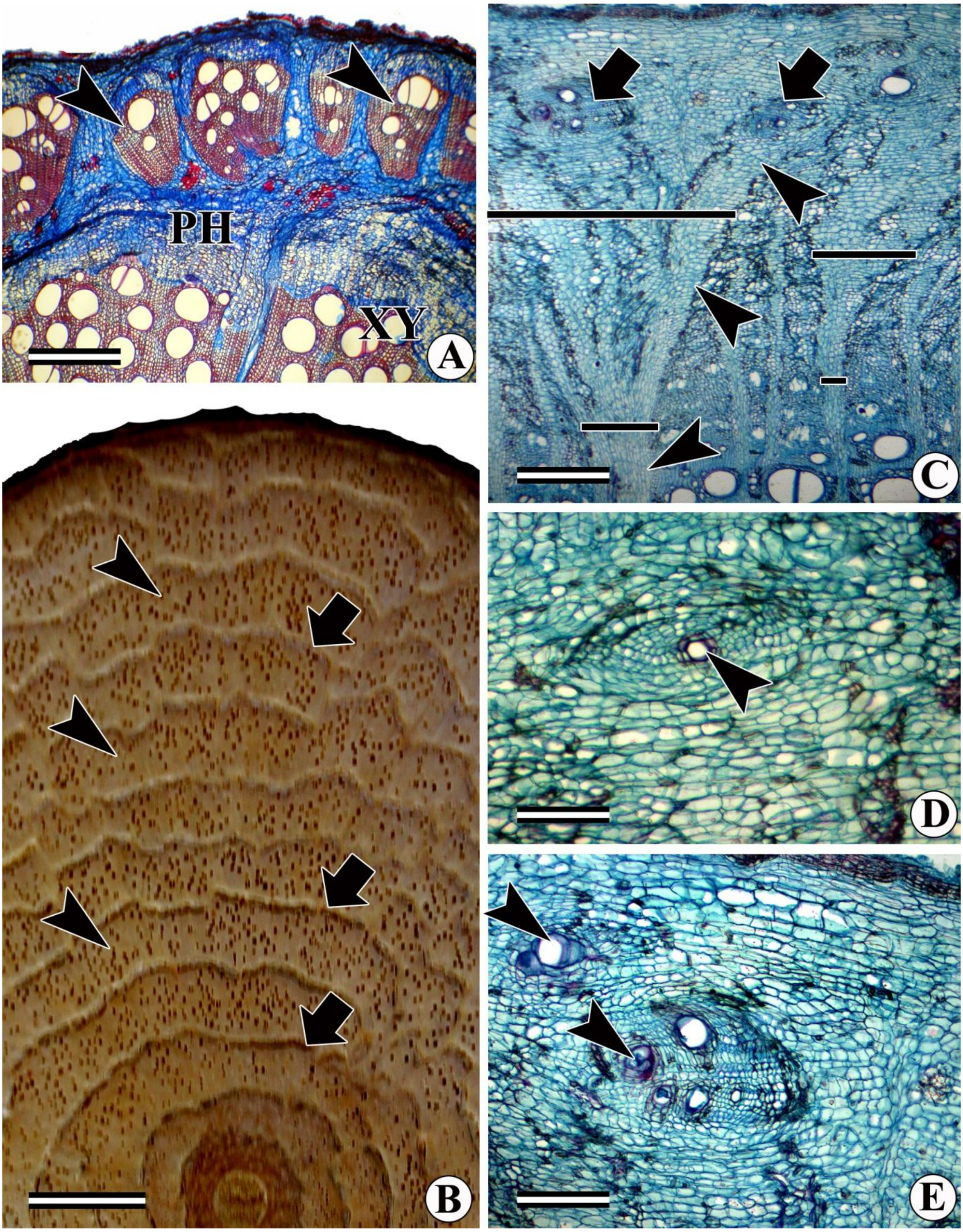

Figure 19

Figure 19: Transverse view of relatively mature stems of different species showing ray dilation and initiation of successive cambium.

A: Development of small cambial segment leading to formation of vascular bundle-like arrangement (arrowheads) of vascular tissues *Turbina corymbosa*. *Abbreviation*s: PH = phloem & XY = xylem formed by the regular vascular cambium.

B: Microphotograph of *Moutabea gentry* fully grown stem showing several successive xylem (arrowheads) and phloem rings (arrows).

C: Mature stem of *Phaseolus lunatus* showing the dilation (horizontal lines) and proliferation of phloem rays. Note that these ray cells dedifferentiated to meristematic cells and formation of vascular tissue (arrows). Arrowheads indicate dilating ray. Note the tangential increase in width of the ray.

D & E: Magnified view of Figure 19B showing the differentiation of xylem and phloem (arrowheads) from the newly formed vascular cambium.

Scale bars: A: 500 µm; B: 10 mm; C: 500 µm; D: 100 µm; E: 200 µm.

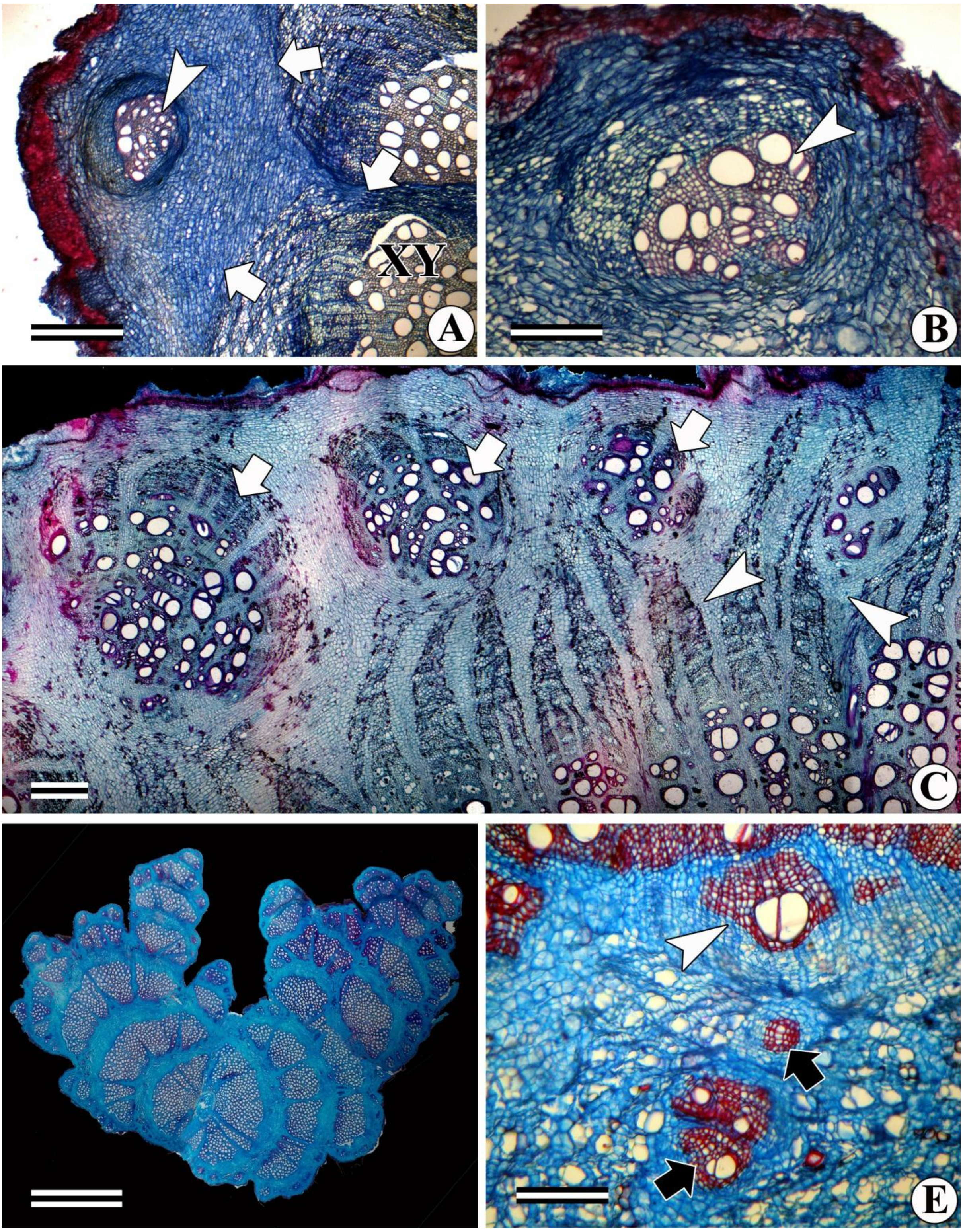

Figure 20

Figure 20: Transverse views of mature stems of various species showing the initiation of regular successive cambium and formation of inverse cambium and lobed stem outline.

A & B: Dilation of phloem rays (arrows), dedifferentiation of ray cells and initiation of neo-formed vascular cylinders (arrowhead) in *Hewittia malabarica.* Note the tangential widening of phloem rays (arrows) in figure 20A due to dilation while figure 20B is enlarged view of one of the neoformed vascular cylinder.

C: Various stages of neo-formed vascular cylinders (arrows) in dilating rays of *Phaseolus lunatus.* Note that the tangential widening of dilating rays (arrowheads).

D: Variously lobed stem formed in response to formation of successive cambia (i.e., neoformed vascular cylinders) in *Turbina corymbosa*.

E: Formation of new vascular bundle (arrow) due to dedifferentiation of phloem parenchyma between two successive xylem rings of *Turbina corymbosa* stem. Arrowhead indicates functionally inverse cambium and xylem deposited from it.

Scale bars: A & C: 500 µm; B & E: 200 µm; D: 5 mm.

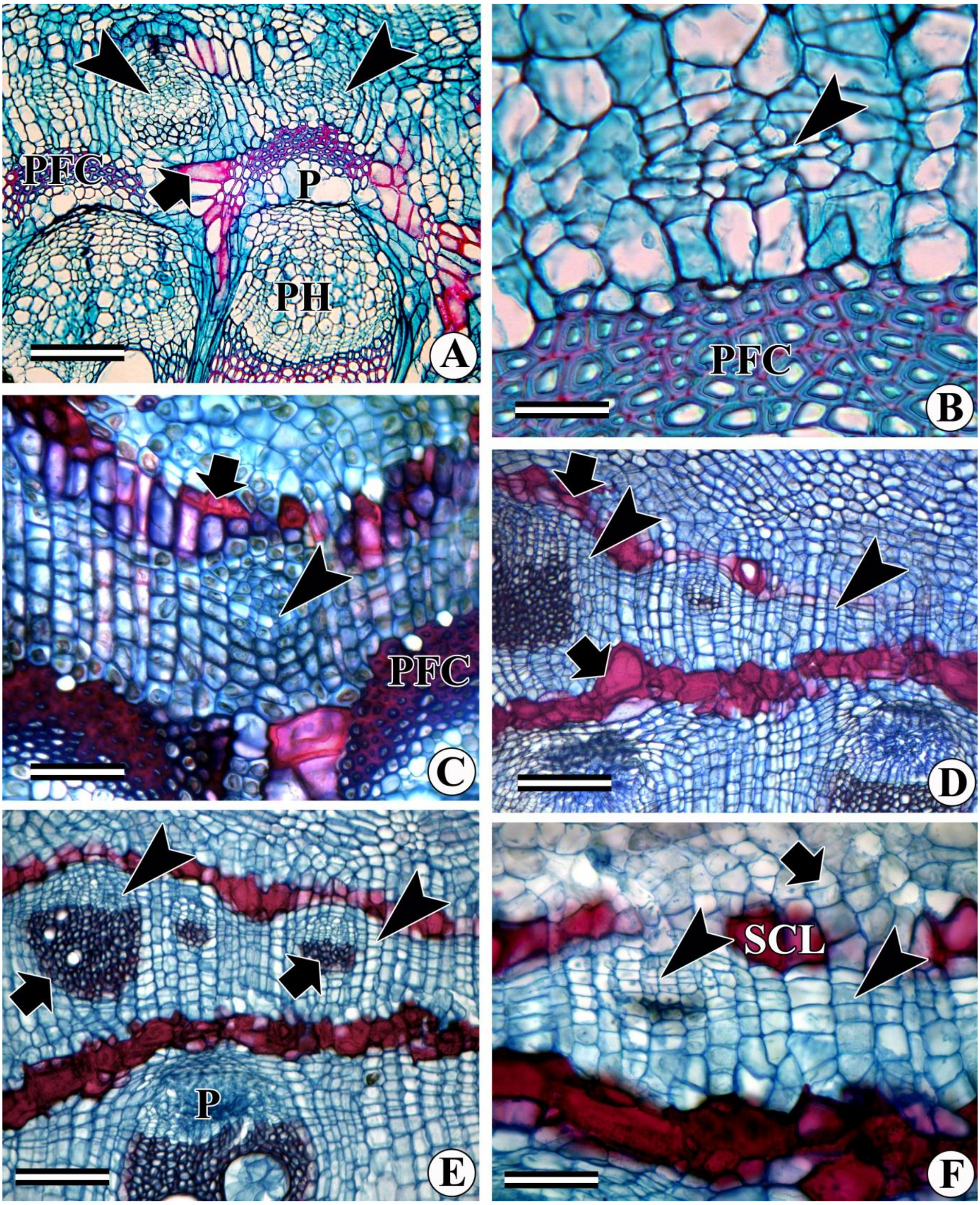

Figure 21

Figure 21: Transverse view of young stem of members of Menispermaceae showing initiation of successive cambium.

A: Young stem of *Cocculus laurifolius* showing initiation of first successive ring of cambium (arrowheads). Arrow shows sclereids. *Abbreviations*: P = phloem formed by the regular vascular cambium, PFC = pericyclic fibre cap, P = pericycle cells.

B: Enlarged view of *Cocculus laurifolius* showing initiation of cell division (arrowhead) in the cortical parenchyma cells. *Abbreviations*: PFC = pericyclic fibre cap

C: Initiation of first successive cambium in *Pachygon ovata* showing initiation of first successive cambium (arrowhead). Arrow indicates differentiating sclerenchyma external to newly initiating cambium. *Abbreviations*: PFC = pericyclic fibre cap.

D: Initiation of successive cambium (arrowheads) in *Anamirta cocculus*. Arrows indicate sclerenchyma layer external to the phloem formed by previous cambium.

E: Enlarged view of the young stem showing newly initiating successive cambium in *Anamirta cocculus* (arrowheads). Arrows showing differentiating xylem from the newly initiated cambium. *Abbreviation*: P = phloem.

F: Enlarged view of newly initiating successive cambium (arrowhead) in *Diploclisia glaucoscens*. Arrow indicates dividing cortical cells that differentiate into sclerenchyma ring. *Abbreviation*: SCL = sclerenchyma.

Scale bars: A, D, E = 200 µm, B = 50 µm, C, F = 100 µm.

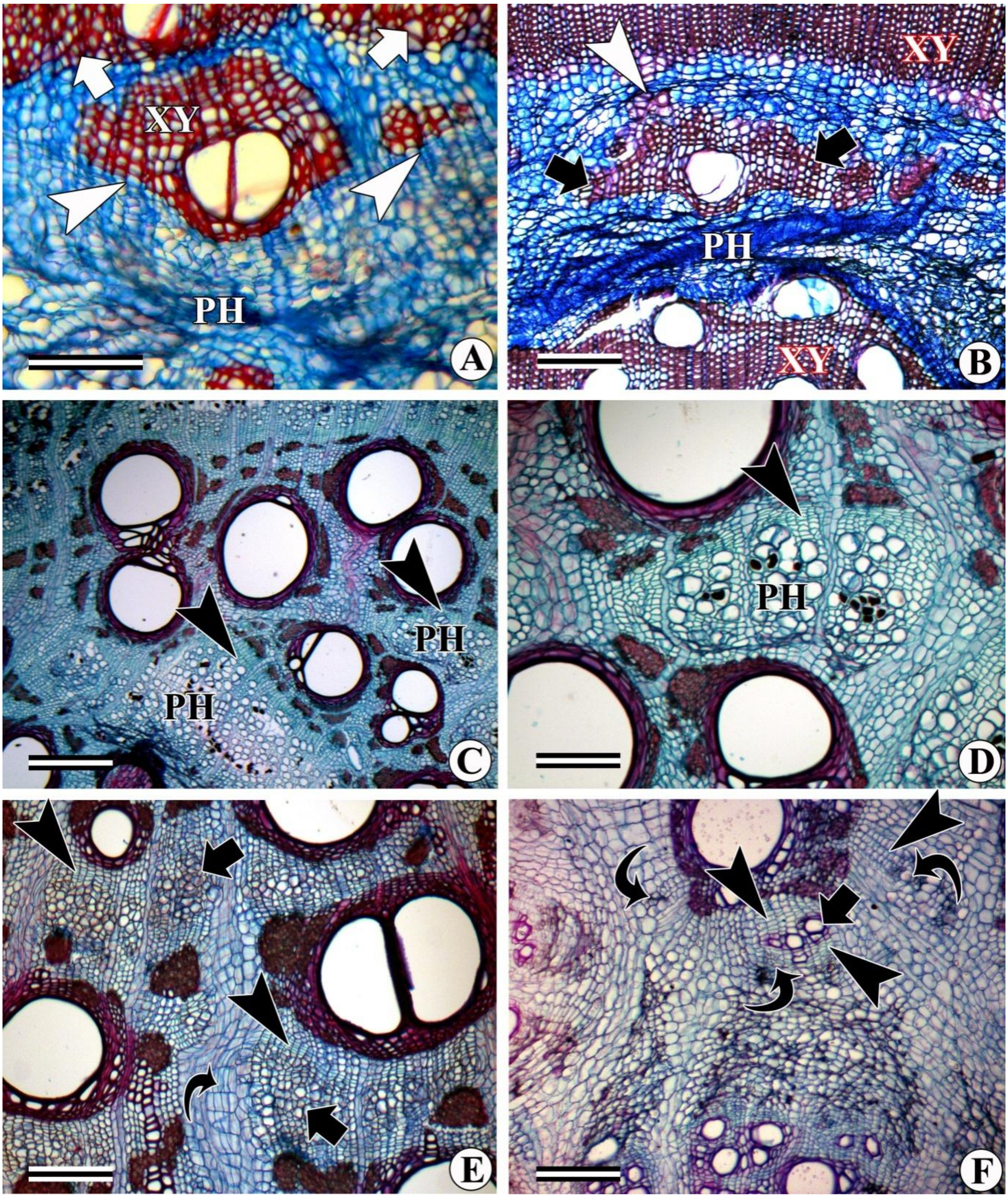

Figure 22

Figure 22: Transverse views of mature stems of various species showing the formation of inverse cambium and their derivatives.

A: Enlarge view of Figure 20E showing the portion of functionally inverse cambium (arrowheads) that produce the secondary xylem on the outer side and phloem towards the centre. Arrows indicate the xylem formed by the functionally regular cambium. *Abbreviations*: PH = crushed phloem, XY = xylem formed from functionally inverse cambium.

B: Xylem deposited by functionally inverse cambium (arrows) in *Dicranostylis ampala* XY is the secondary xylem formed by the functionally regular cambium while PH is the crushed phloem formed by the functionally regular cambium. Arrowhead indicates the junction between the xylem formed by functionally regular and inverse cambium.

C: Gross structure of the *Entada rheedii* stem showing dedifferentiation and initiation of inverse cambia (arrowheads) and phloem (PH) formed deposited by them in the parenchymatous ground mass.

D: Enlarged view of Figure 22C, showing functionally inverse cambium (arrowhead). Note that functionally inverse cambium exclusively deposit phloem elements.

E: Transverse view of the earlier formed secondary xylem of *Canavalia virosa* showing several interxylary phloem islands (arrows) formed by the functionally inverse cambia (arrowheads). Note that even marginal ray cells show meristematic nature (curved arrow).

F: Xylem portion of *Phaseolus lunatus* showing initiation of inverse cambium (arrowheads) showing phloem (curved arrow) and secondary xylem (arrow).

Scale bars: A & B: 100 µm; C: 500 µm; D, E & F: 200 µm.

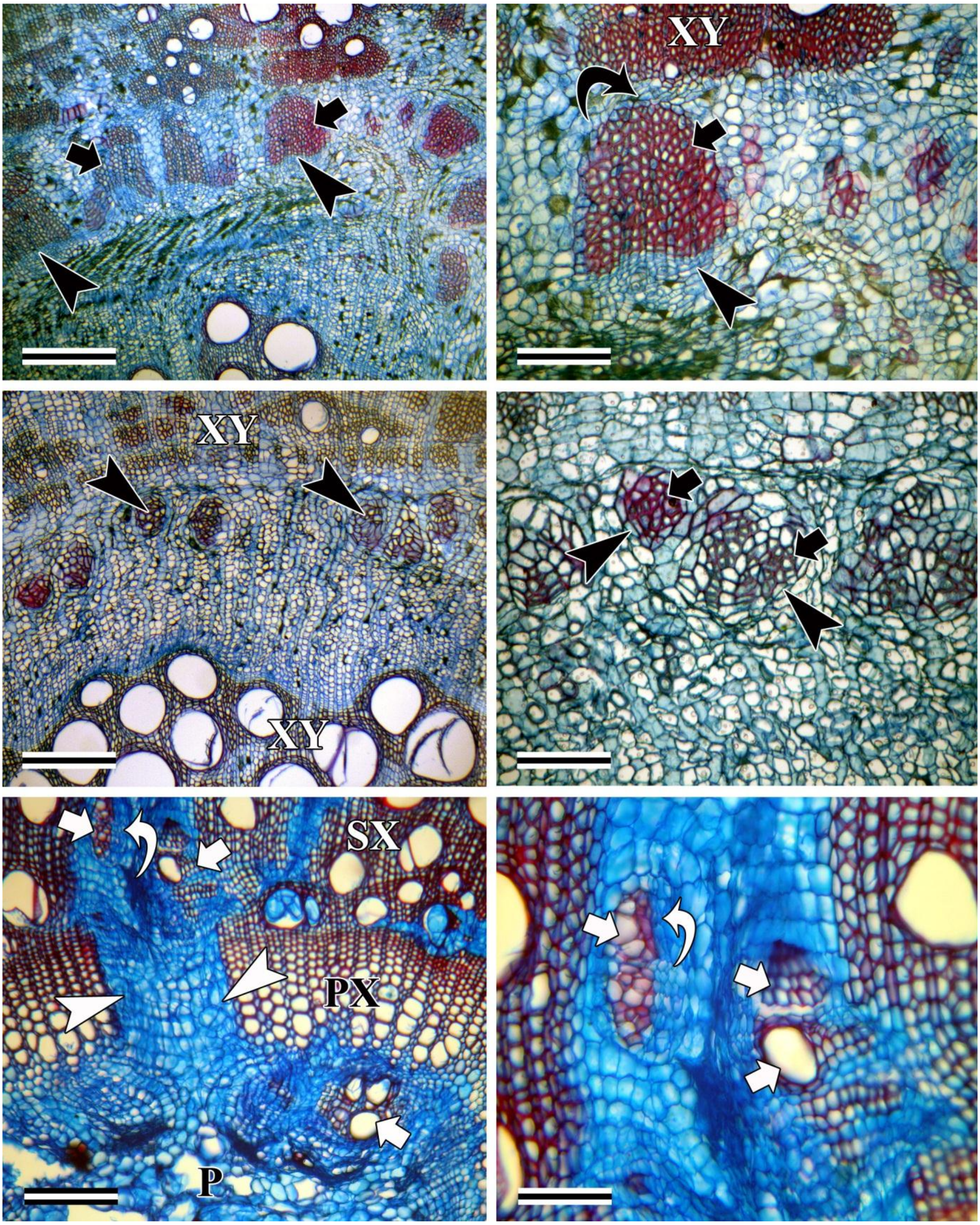

Figure 23

Figure 23: Structure of the inversely oriented secondary xylem in the mature stem and development xylem strands.

A: Formation of functionally inverse cambia (arrowheads) from parenchyma cells located between successive rings of xylem and phloem. Arrow indicates the xylem produced by functionally inverse cambium produce xylem outside (arrow). Note the absence of vessels in the earlier formed secondary xylem.

B: Enlarged view of figure 23A showing the structure and composition of the secondary xylem (arrow) formed by the inverse cambium (arrowhead). Note the absence of wide vessels and junction zone (curved arrow) between xylem formed by functionally regular and inverse cambium.

C: Thick stem showing several strands exclusively composed of fibres (arrowheads) i.e., lignified xylem elements. These strands initiate in between adjacent successive rings of xylem rings. XY indicates xylem of adjacent successive rings..

D: Enlarged view of figure 23C showing the structure of lignified xylem strands lacking phloem (arrow). Note the radially arranged meristematic cells in a radial file (arrowhead).

E: Thick stem showing the breakage in the earlier formed xylem ring due to ray parenchyma proliferation of (arrowheads). Note the dedifferentiation of marginal ray cells, development of ray cambium (curved arrow) and formation of vascular tissue (arrows) from the proliferating cells. *Abbreviation*: P = pith, PX = protoxylem, SX = secondary xylem.

F: Enlarged view of figure 23E showing the initiation of ray cambium (curved arrow). Arrows indicate the secondary xylem and secondary phloem formed by the ray cambium.

Scale bars: A, C & E: 500 µm; B & D: 200 µm; F: 100 µm.

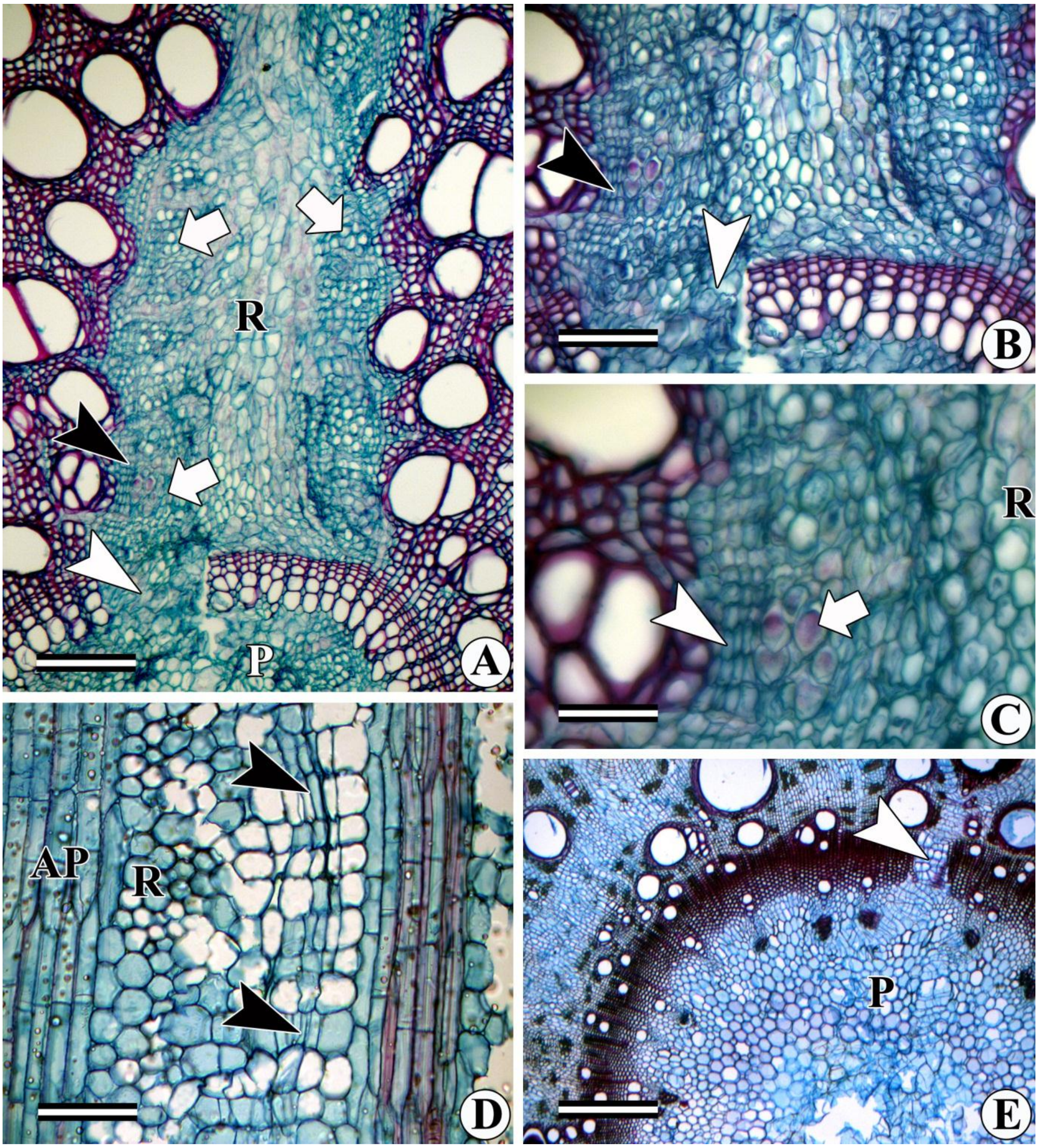

Figure 24

Figure 24: Transverse (A-C, E) and tangential longitudinal (D) view of mature stems and proliferation of ray parenchyma cells.

A: Fully grown stem of *Hewetia malabarica* showing the proliferation of phloem wedge parenchyma (white arrowhead) and rupture of the initially formed xylem ring (arrow). Black arrowhead indicates the cambium initiated from marginal parenchyma and the secondary phloem (arrows). *Abbreviation*: P = pith, R = ray

B: Relatively enlarged view of plate figure 24A showing the formation of radially oriented ray cambium (black arrowhead) producing the phloem (arrow) elements. Also note the rupture in the primary xylem tissue (white arrowhead).

C: Enlarged view of figure 23B showing ray cambium (arrowhead) and phloem elements deposited from the ray cambium (arrow). *Abbreviation*: R = ray

D: Tangential longitudinal views of *Pruereria tuberosa* stem showing initiation of ray cambium (arrowheads) in multiseriate ray. Note the formation of ray cambium. Also note the storied condition of xylem elements. *Abbreviation*s: AP = axial parenchyma, R = ray

E: Thick stem of *Canavalia virosa* showing splitting of xylem ring (arrowhead). Note the difference in deposition of xylem formed before and after the initiation of climbing habit.

Scale bars: A: 200 µm; B & D: 100 µm; C: 50 µm; F: 500 µm.

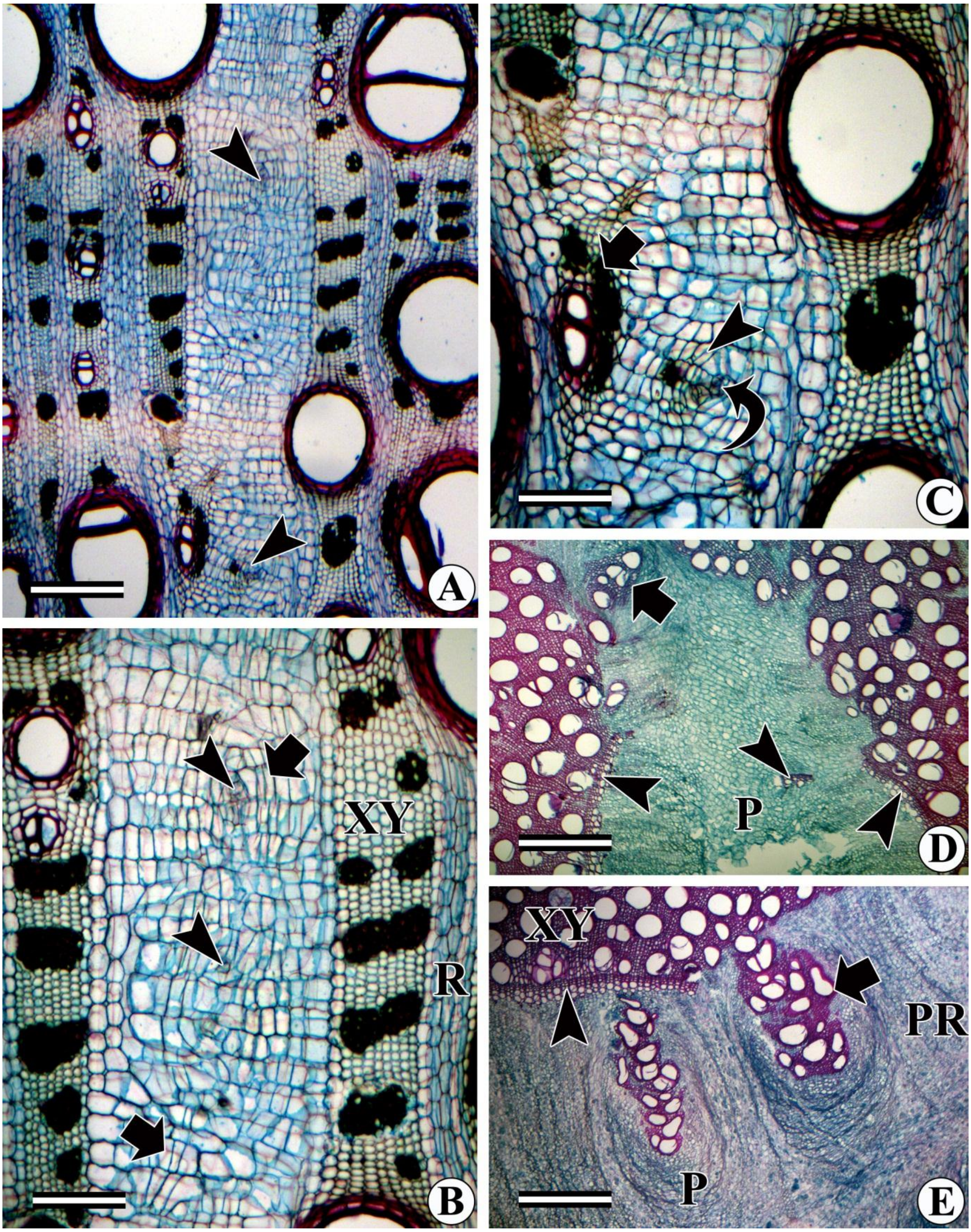

Figure 25

Figure 25: Transverse views of the secondary xylem of the fully grown climbing species showing the proliferation of xylem rays and formation ray cambium.

A: Dedifferentiation of ray cells and initiation of ray cambium (arrowheads) in wide rays of earlier formed xylem in *Prureria prurins*. Note the abundance of unlignified parenchyma.

B: Enlarged view of figure 25A showing initiation of ray cambium (arrows). Arrowhead indicates sieve element formed by the one of the ray cambial cell.

C: Enlarged view of figure 25A showing initiation of ray cambium (arrowhead). Arrow indicates xylem formed by the ray cambial cells. Curved arrow indicates differentiating sieve element

D: Xylem ray parenchyma proliferation in *Hewittia malabarica* stem showing formation of interxylary phloem and xylem (arrow). Note that the pith is completely fragmented. Arrowheads indicate protoxylem at the pith margin.

E: Stem showing internal cambium, intraxylary phloem development in *Hewittia malabarica*. Note that the quantity of xylem (arrowhead) and phloem (IP) formed by the internal cambium.

Scale bars: A, B & D: 500 µm; C, E & F: 250 µm.

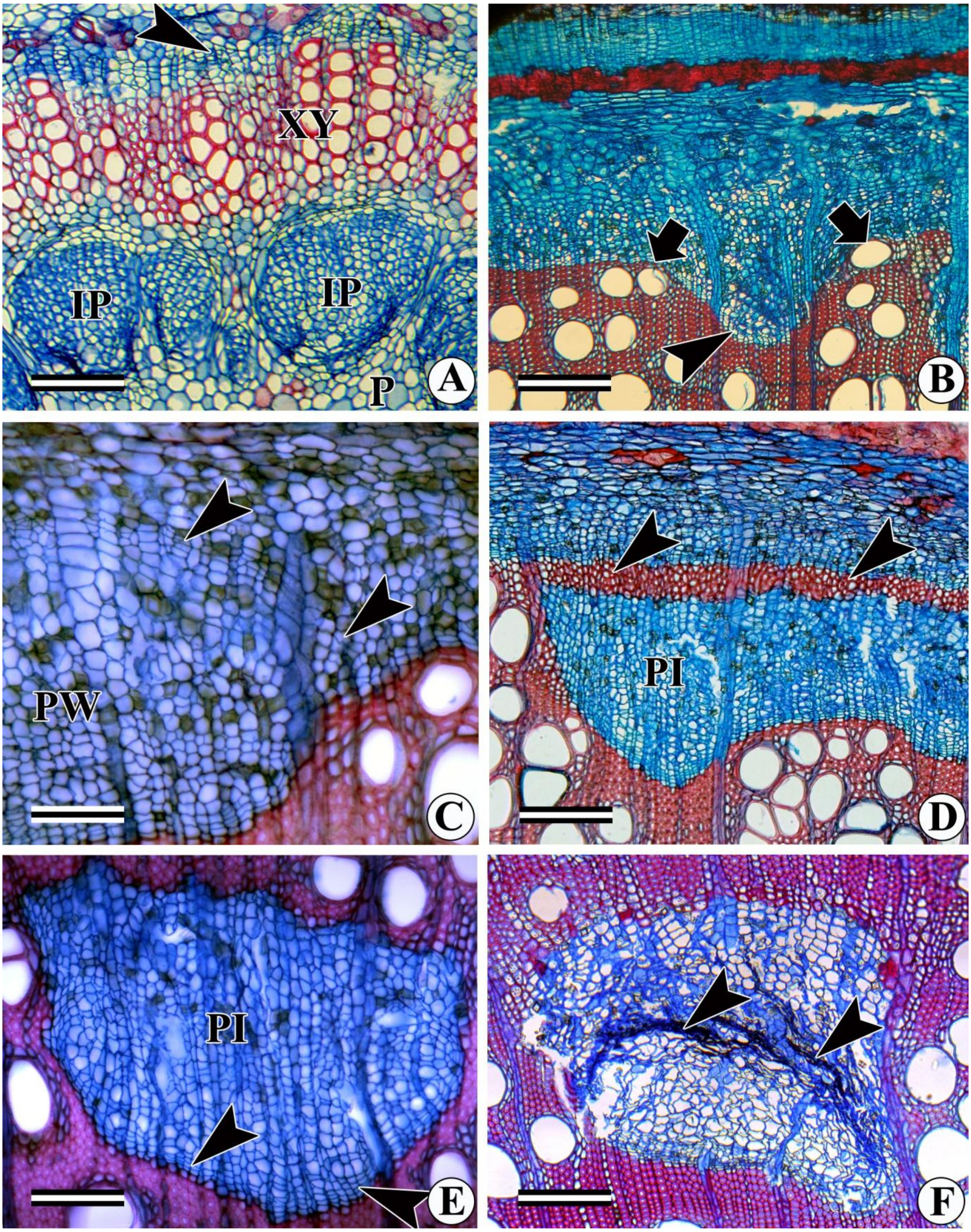

Figure 26

Figure 26: Transverse views of mature stems of various species showing the initiation and formation of included phloem.

A: Young stem of *Strychnos bredemeyeri* showing secondary xylem (XY), regular phloem (arrowhead) and intraxylary phloem (IP).

B: Initiation interxylary phloem island formation in of *Strychnos bredemeyeri*. Note the cessation of cell division and formation of secondary xylem by small segment of the cambium (arrowhead) while adjacent portion of the cambium continue to produce xylem normally (arrows). Note the formation of phloem wedge.

C: Mature stem of *Strychnos bredemeyeri* showing wedge (PW) formed in response to increased phloem production and cessation of xylem production in small segments of cambium. Note the initiation of cambial segment (arrowheads).

D: Bidirectional differentiation of xylem (arrowheads) and phloem by newly initiated cambium external to the phloem wedge. Note that the phloem in the wedge gets enclosed within the xylem to form phloem island (PI)

E: *Strychnos bicolor* showing one of the interxylary phloem islands (PI) embedded within the secondary xylem. Note the cambium (arrowheads) on the inner margin of the phloem islands.

F: Structure of phloem islands in *Strychnos bredemeyeri* stem in transverse view showing crushed phloem (arrowheads) formed at the time of phloem island formation.

Scale bars: A & D: 250 µm; B: 500 µm; C: 100 µm; E & F: 200 µm.

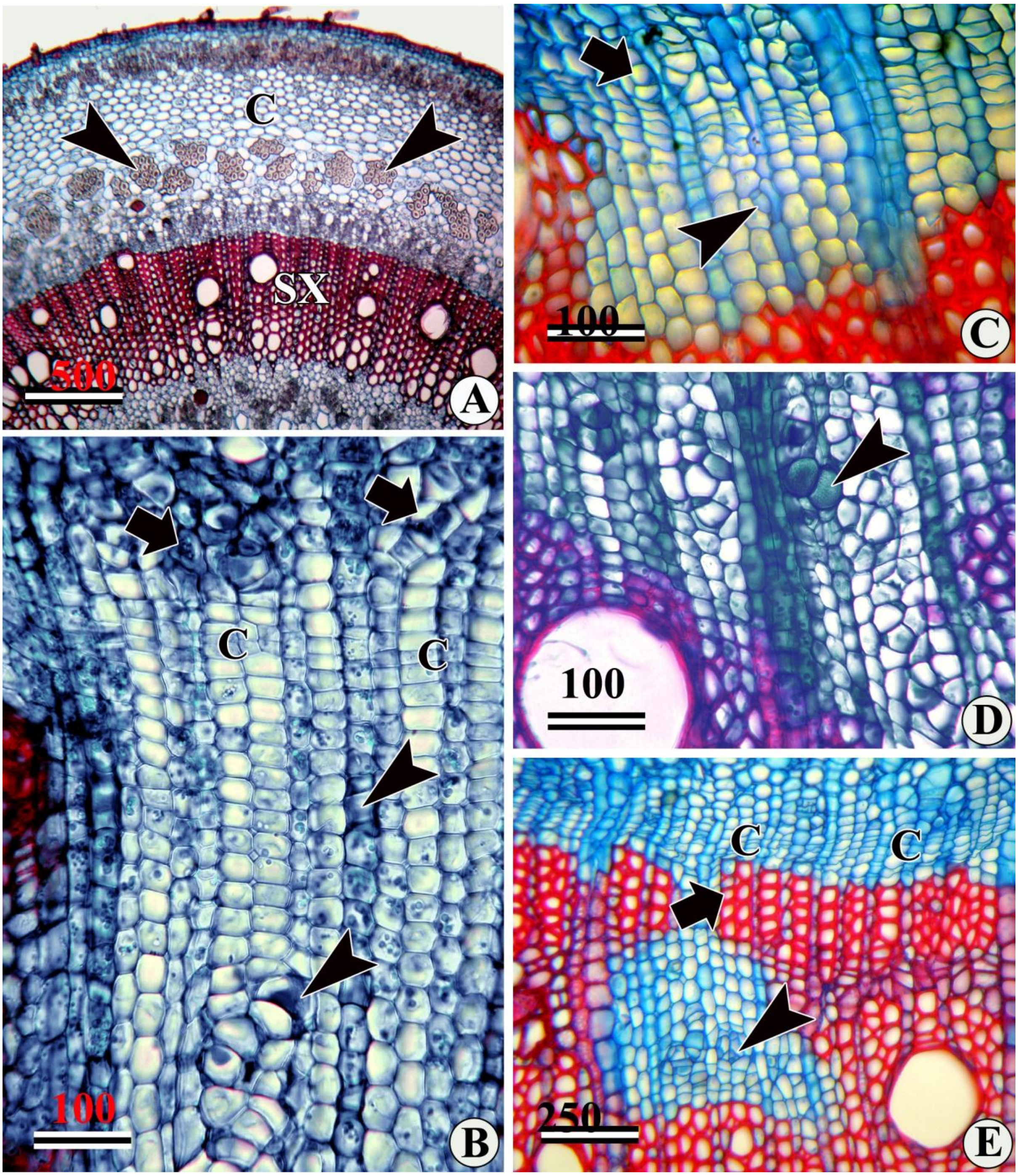

Figure 27

Figure 27: Transverse views of mature stems of *Leptadenia pyrotechnica* (A, C, E) and *Leptadenia retuculata* (B, D) showing the initiation of interxylary/included phloem in mature stem.

A: Structure of young stem showing the epidermis, cortex (C), and secondary xylem (SX). Arrowheads indicate pericyclic fibres.

B: Internal differentiation of sieve elements (arrowhead) by the vascular cambium (C). Arrows indicate regular external phloem. Note the difference in sieve tube element diameter between external and included phloem.

C: Bidirectional differentiation of cambium producing phloem elements on the inner (arrowhead) and the outer (arrow) side of the cambium. Note the differentiating sieve tube elements with companion cell (arrowhead) while arrows show external normal phloem.

D: Distribution of included phloem in mature stem. Arrowhead indicates fully differentiated sieve tube elements.

E: Secondary xylem formed after the formation of the phloem island (arrow). Arrowhead indicates sieve elements in the phloem island. *Abbreviation*: C = cambium

Scale bars: A: 500 µm; B, C & D: 100 µm; E: 250 µm.

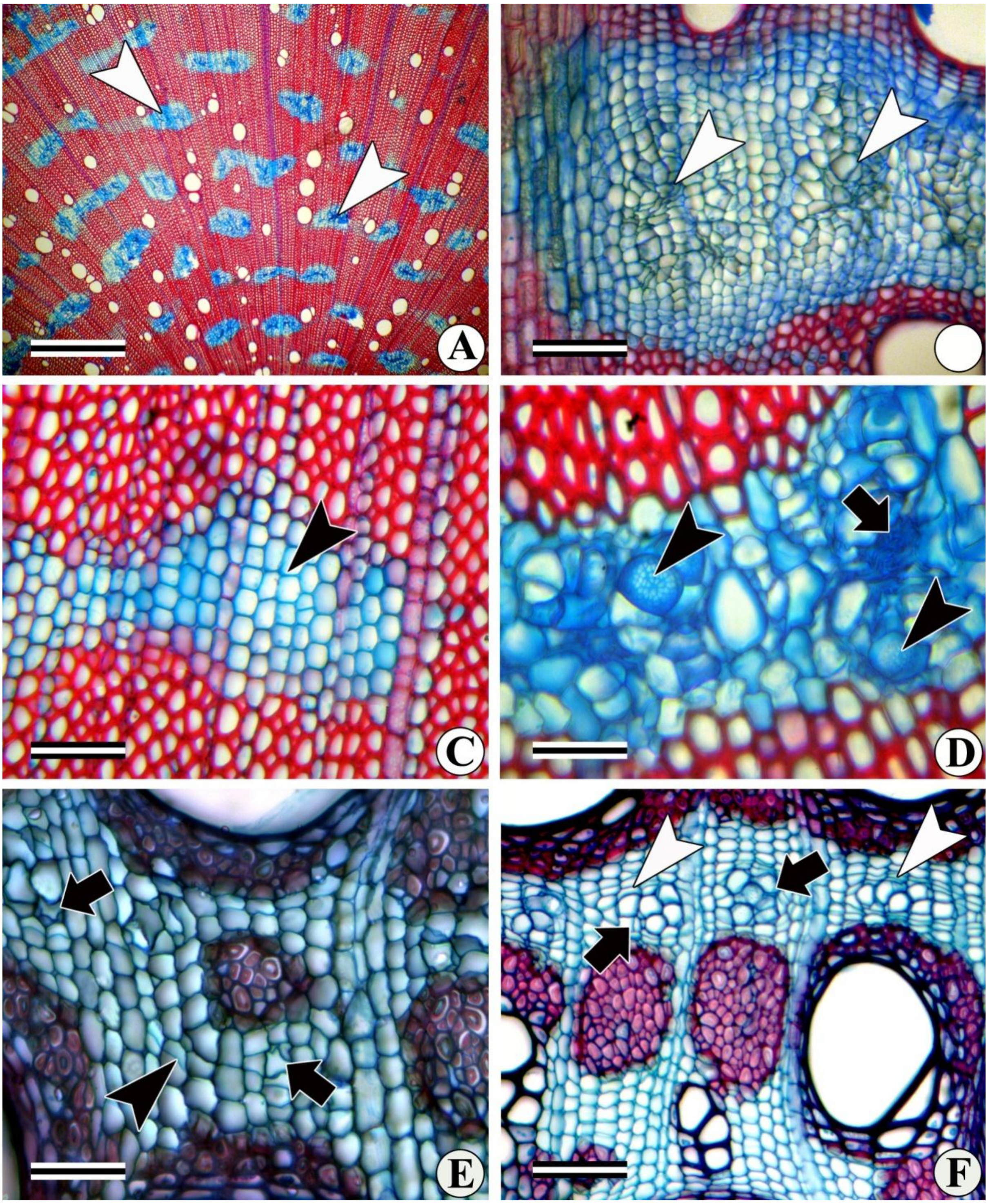

Figure 28

Figure 28: Transverse views of fully grown stems of *Leptadenia pyrotechnica* (A, C, D), *Canavalia gladiate* (E) and *Canavalia virosa* (F) showing the various stages of included phloem development.

A: Structure and composition of the secondary xylem in thick stem of *Leptadenia pyrotechnica*. Arrowheads show phloem islands distributed randomly in the secondary xylem.

B: One of the earlier formed phloem (arrowhead) island embedded within secondary xylem of *Leptadenia reticulata*.

C: Some of the parenchyma islands (arrowhead) in *Leptadenia pyrotechnica* are devoid of interxylary phloem.

D: Earlier formed interxylary phloem islands showing conducting sieve tube elements with open sieve pores (arrowhead). Arrow indicates non-conducting phloem in *Leptadenia reticulata*

E: In mature stem of *Canavalia gladiata* showing dedifferentiation into meristematic cell and formed the sieve tube elements and companion cells (arrows). Note the dividing parenchyma cells (arrowhead).

F: dedifferentiation of unlignified parenchyma into cambium like meristem (arrowheads) and newly formed sieve tube elements (arrows) in *Canavalia virosa*.

Scale bars: A: 500 µm; B: 200 µm; C - E: 50 µm; F: 100 µm.

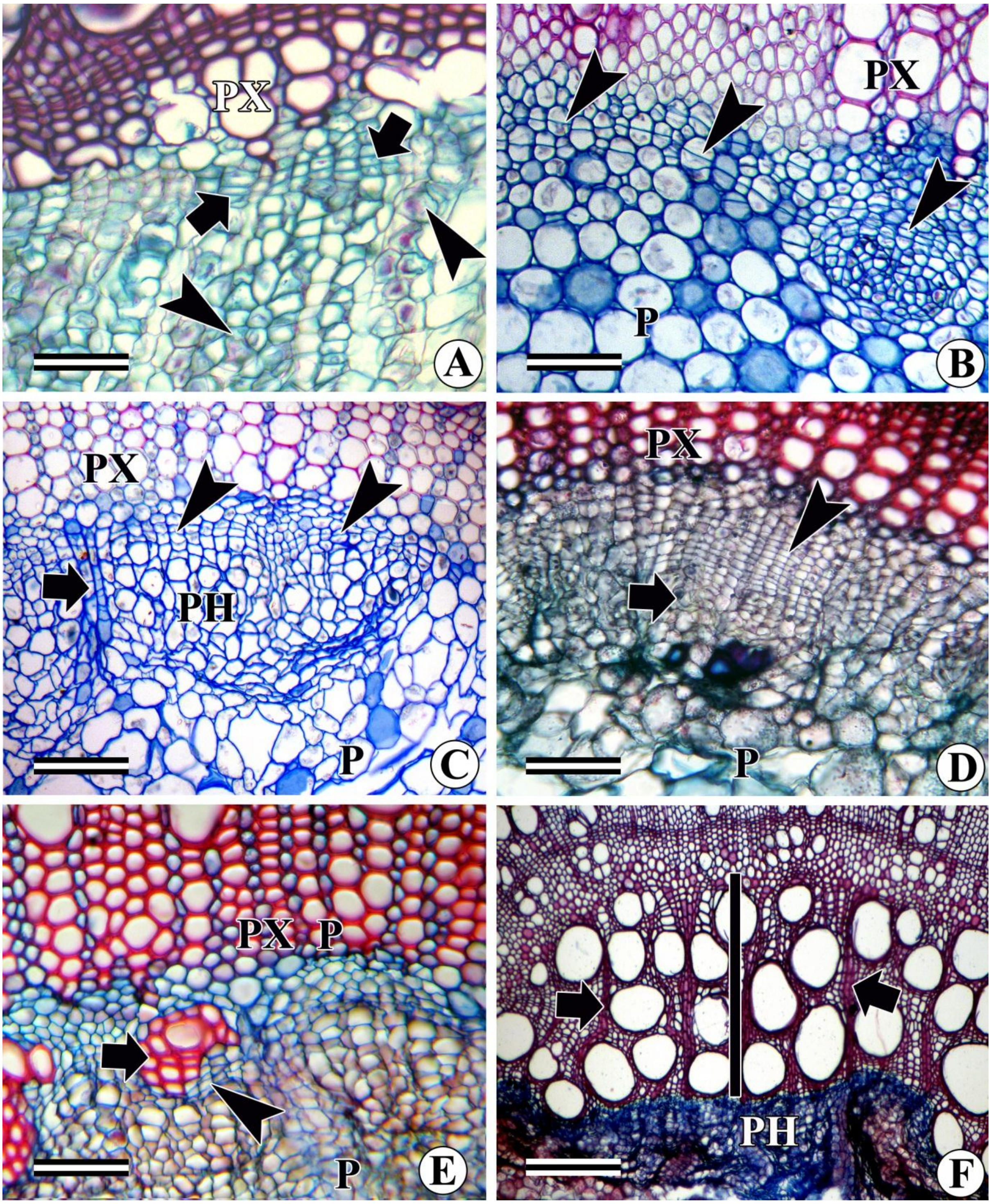

Figure 29

Figure 29: Transverse views of mature stems of different species showing the development of intraxylary phloem cambium and their derivatives.

A: Pith portion of *Leptadenia pyrotechnica* in thick stem showing protoxylem (PX), intraxylary phloem (arrowheads), the intraxylary phloem cambium (arrow).

B: Pith margin of *Campsis redicans* showing the initiation of cell division and establishment of internal/intraxylary phloem cambium (arrowheads). *Abbreviation*: P = pith, PX = protoxylem.

C: Stem section of fully grown *Maripa nicaraguensis* showing the well-developed internal cambium (arrowhead) on pith margin. Note the internal phloem and phloem rays (arrow). *Abbreviation*: P = pith, PX = protoxylem.

D: Well established internal/intraxylary phloem cambium (arrowhead) and phloem elements deposited from it. *Abbreviation*: P = pith, PX = protoxylem.

E: Bidirectional nature of internal/intraxylary phloem cambium (arrowhead) in *Vallaris solanaceae* showing formation of xylem (arrow) and phloem. *Abbreviation*: P = pith, PX = protoxylem.

F: Central portion of the thick stem of *Campsis redicans* showing pith is completely occupied by intraxylary secondary xylem (vertical line) and phloem (PH). Note the crushed pith cells and rays (arrowheads).

Scale bars: A, D & E: 100 µm; B: 50 µm; F: 500 µm.

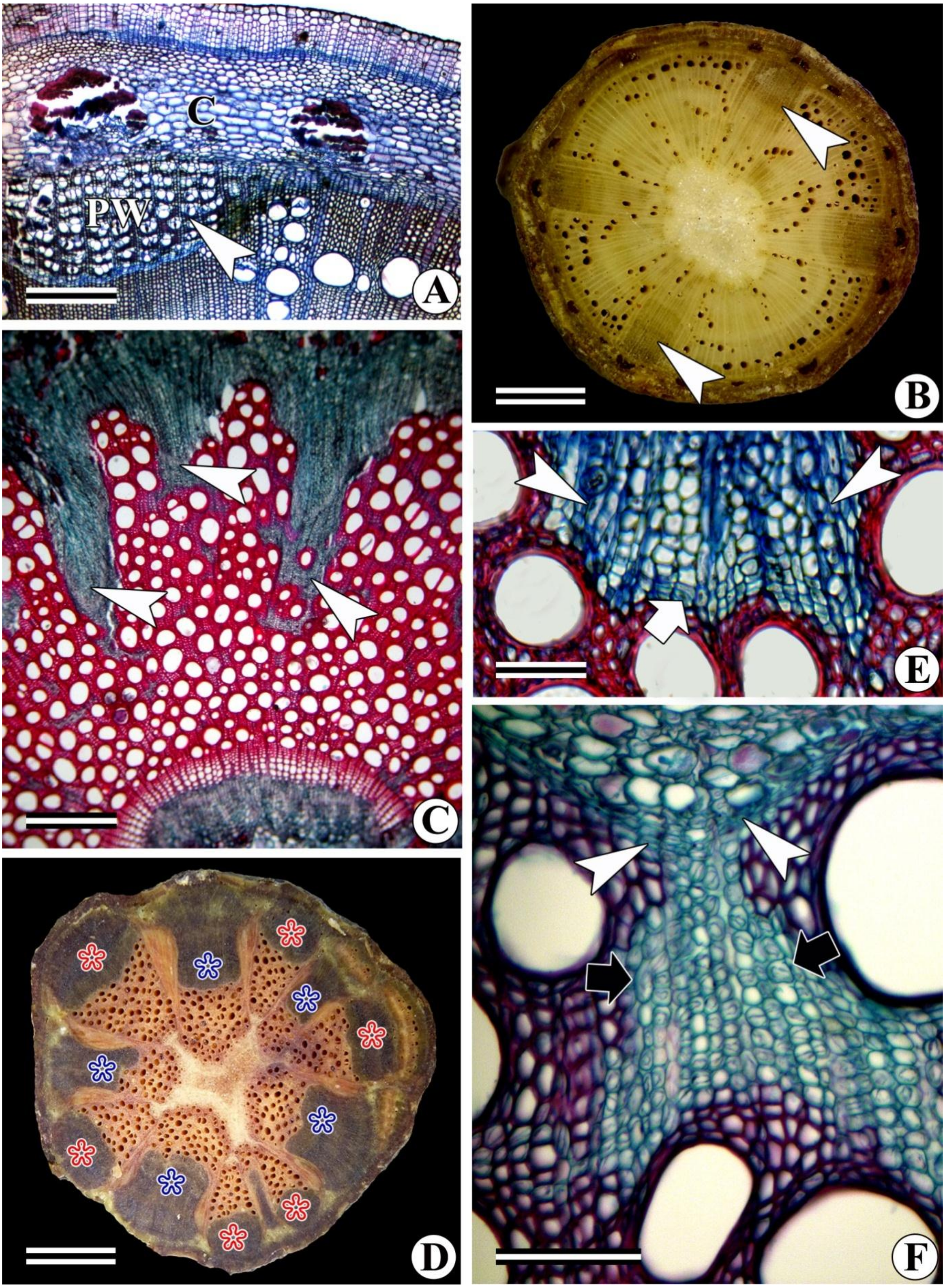

Figure 30

Figure 30: Transverse view of mature stems of some species showing the formation of phloem wedges.

A: Formation of phloem wedge (arrowhead) in *Arrabidaea candicans*. Arrowhead indicates the phloem wedge embedded in the secondary xylem.

Abbreviation: C = Cortex, PW = Phloem wedge.

B: Macro morphological view of young stem of *Arrabidaea candicans* showing the four phloem wedges (arrowheads).

C: Mature stem of *Jaquemontia paniculata* in transverse view showing phloem parenchyma wedges (arrowheads).

D: Thick stem of *Serjania mexicana* showing phloem wedges (asterisks). Initially formed phloem wedges with blue asterisks while later formed phloem wedges shown with red asterisks.

E: Phloem wedges in *Jacquimontia paniculata* showing phloem wedges (arrowheads). Note the position of the cambium (arrow).

F: Phloem wedge in the young stem of *Hewittia malabarica* showing parenchyma wedge (arrows). Arrowhead indicate segment of the cambium that is lagged.

Scale bars: A & F: 200 µm; B: 2 mm; C & D: 500 µm; E: 50 µm.

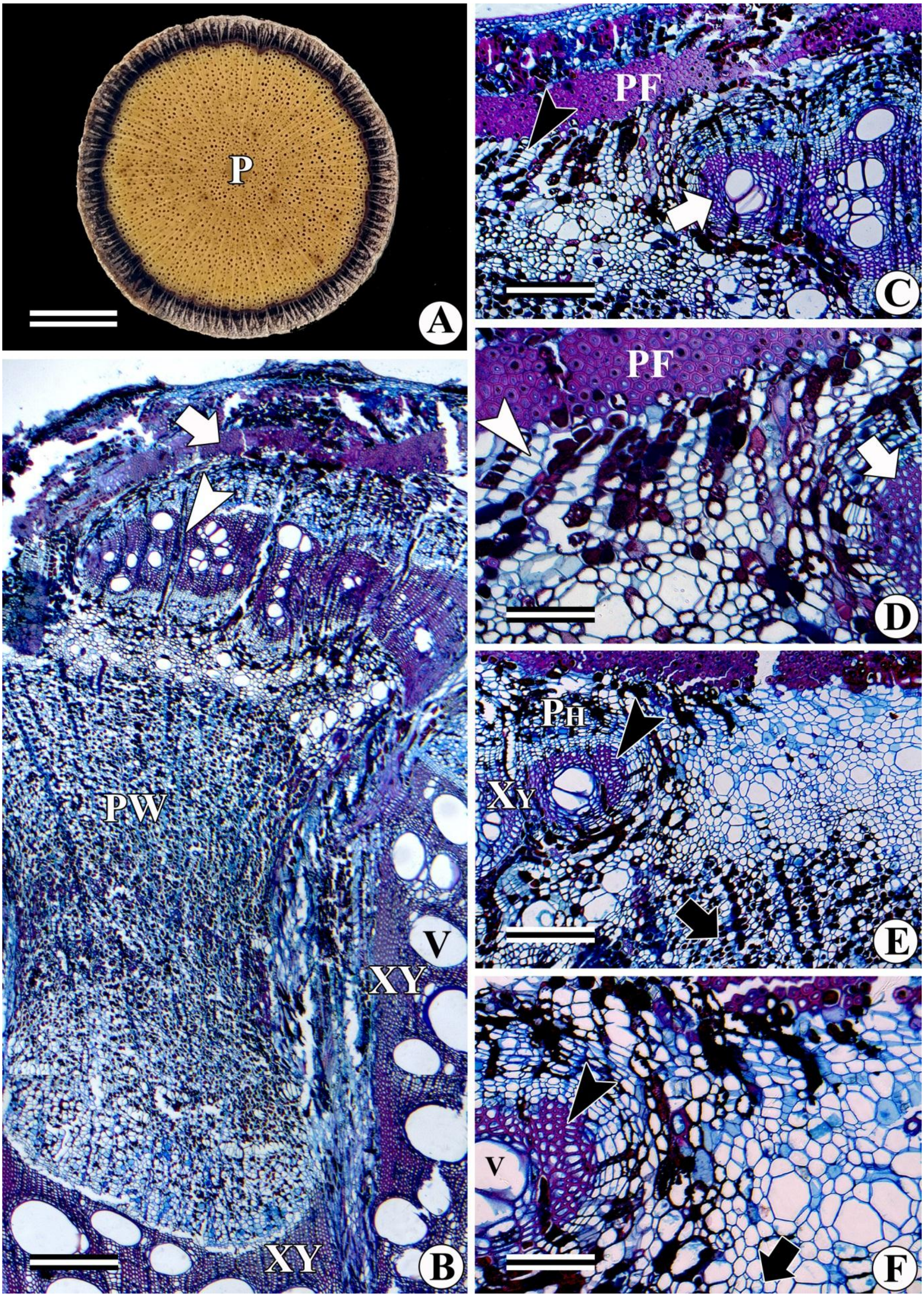

Figure 31

Figure 31: Transverse views of mature stems of *Cardiospermum helicacabum* showing regular secondary growth (A) and *Serjania mexicana* showing development of neo-formed vascular cylinders (B – F).

A: Macro morphological view of mature stems of *Cardiospermum helicacabum*; Note the regular secondary structure and absence of compound xylem. *Abbreviation*: P = pith.

B: Fully grown, mature stem showing structure of the secondary xylem (XY), one of the phloem wedges (PW) and newly originating successive cambium (arrowhead). Note the diameter solitary vessels (V).

C: Initiation of successive cambium from phloem parenchyma cells (arrowhead). Arrow indicates the newly formed secondary xylem and phloem by the successive cambium. Note the tangential band of pericyclic fibres (PF).

D: Enlarged view of panel C showing radial files of meristematic cells indicating initiation of successive cambium (arrowhead). Arrow indicates newly formed vascular cylinder. *Abbreviation*: PF pericyclic fibres.

E: Part of the neo-formed vascular cylinder (arrowhead) showing secondary xylem and phloem. Arrow indicates presence of tannin in phloem parenchyma formed by the regular vascular cambium. Note the bifacial cambium of neo-formed vascular cylinder showing xylem (XY) and phloem (PH) formed from it.

F: Enlarged view of figure 31E showing neo-formed vascular cylinder (arrowhead) and phloem parenchyma (arrow) formed by the previous cambium.

Abbreviation: V = vessel.

Scale bars: A: 5 mm; B & E: 200 µm; C & F: 100 µm; D: 50 µm.

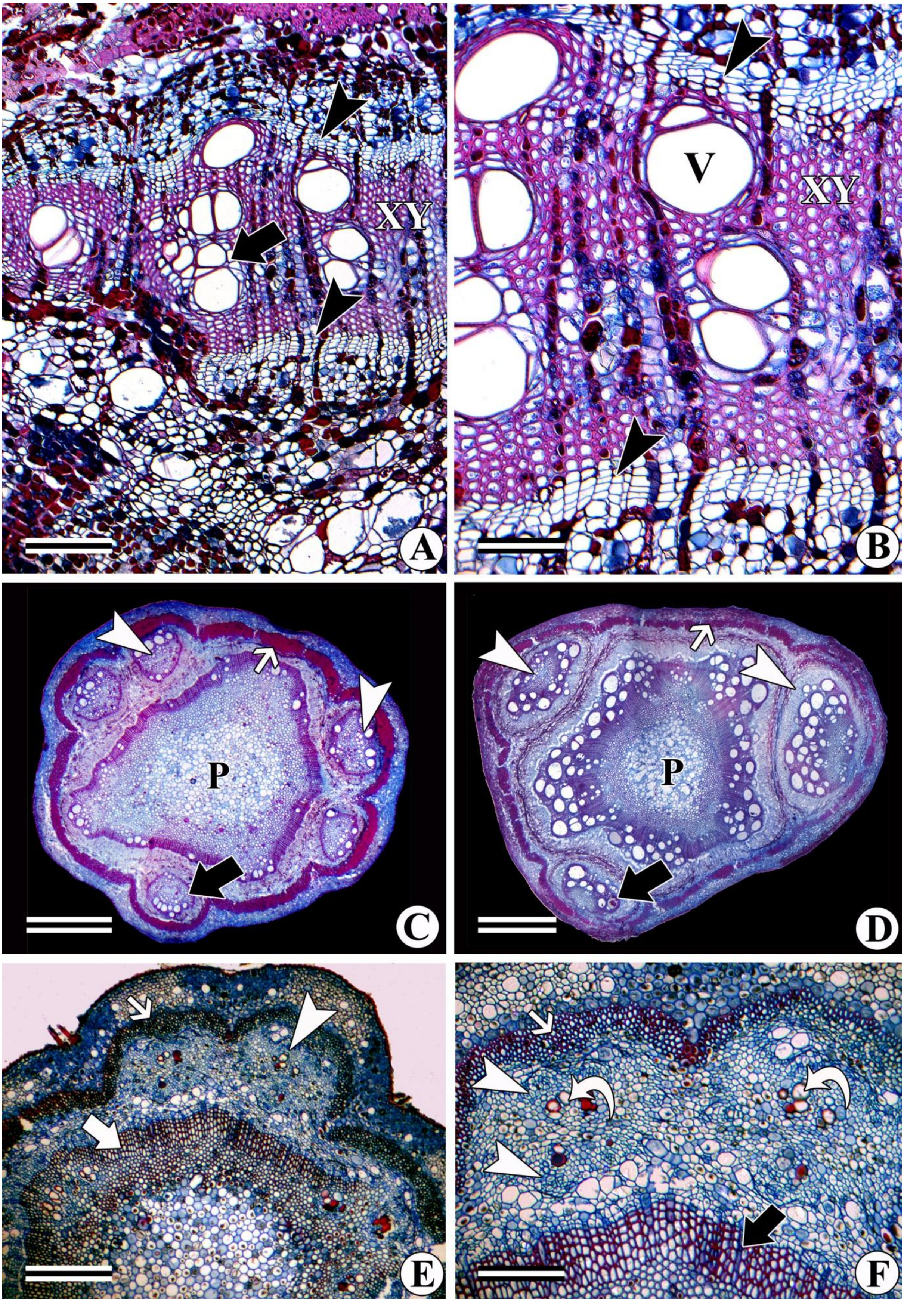

Figure 32

Figure 32: Transverse views of *Serjania mexicana* mature (A & B) and young stem of *S. circumvallata* (C - F).

A: Part of the neo-formed vascular cylinder showing a structure of secondary xylem (XY). Arrowheads showing cambium that encircles the xylem while arrow showing cluster of vessels.

B: Enlarged view of figure 32A showing structure and composition of xylem (XY) formed by the successive cambium. Arrowheads show cambium on either side of the xylem.

C: Relatively young stem showing development of neo-formed vascular cylinders. Note the single vascular cylinder (arrow).

D: Merging of two neo-formed vascular cylinders in relatively thick stem. Arrowheads indicate merged cylinders as shown in figure 32C. Note the single vascular cylinder (arrow).

E: Initiation of new vascular cylinders on the inner side of the pericycle fibre (small arrow) ring. Arrow indicates the differentiating xylem elements from cambial segments. Arrowhead indicates differentiating protoxylem in neo-formed vascular cylinder while arrow shows xylem formed by the vascular cambium of the main vascular cylinder. Note the quantity of xylem formed in main vascular cylinder and newly forming vascular cylinders.

F: Enlarges view of figure 32E showing developmental of new vascular cylinder. Arrowheads indicate the cambial segments forming the primary vascular tissues. Arrowheads showing differentiating protoxylem while curved arrow indicates protoxylem elements. Note the amount of xylem produced by the main vascular cambium (arrow).

Scale bars: A & E: 200 µm; B & F: 100 µm; C & D: 500 µm.

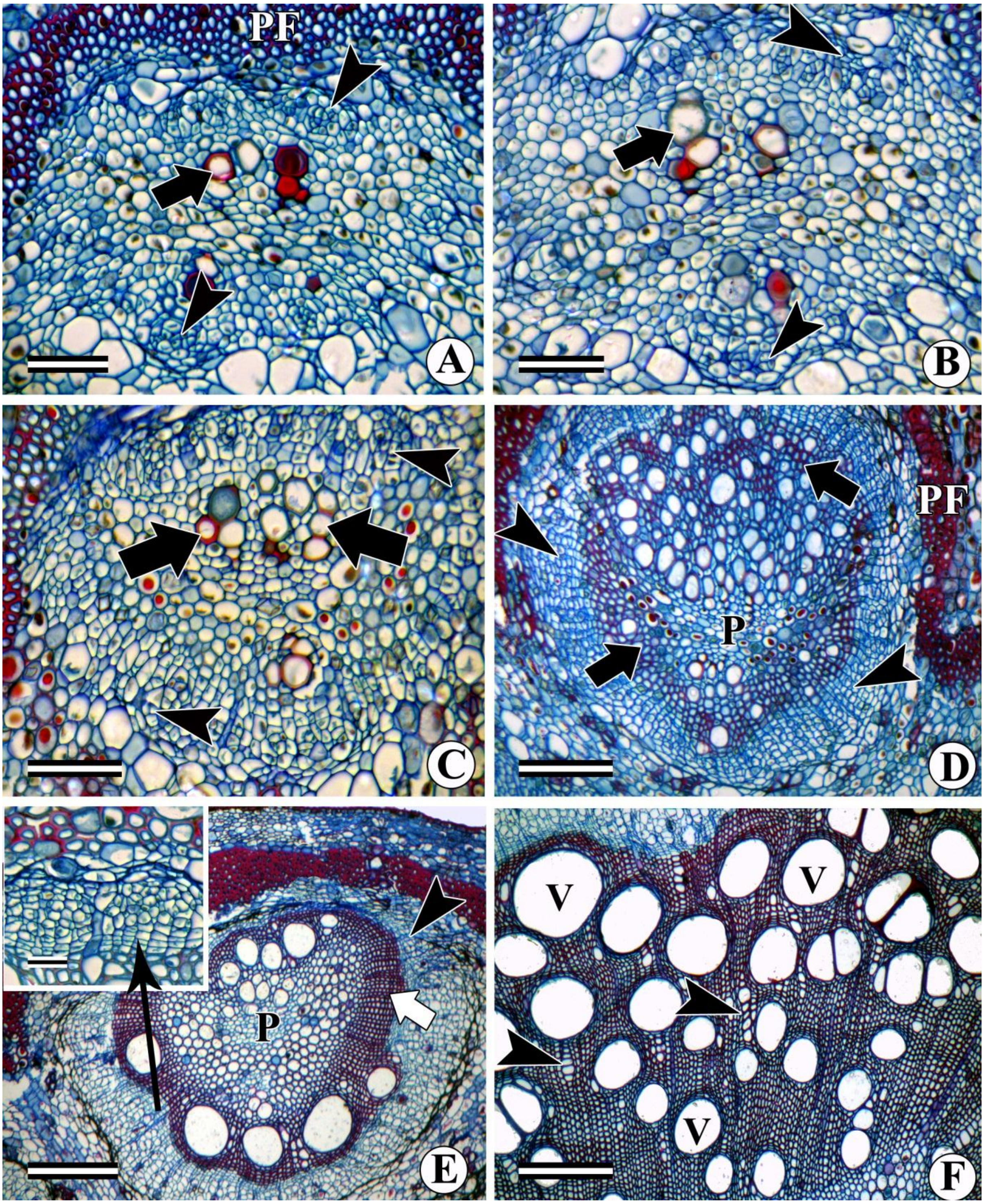

Figure 33

Figure 33: Transverse views of young (A - C, G) and mature (D – F) stems of *Serjania circumvallata* showing the Stages of development of compound xylem lobes.

A-C: Various developmental stages of neo-formed vascular cylinder formation showing differentiating protoxylem (arrow/s) and protophloem (arrowheads) on the inner side of pericycle fibre (PF) band.

D, E: Cambium extends to form a complete ring around the secondary xylem (arrows) and secondary phloem ring external to the cambium (arrowheads). Note the enlarged view on left side of small segment of the vascular cylinder in figure 33E showing the cambial cells arranged in radial files. Note the central pith (P).

F: Structure of the secondary xylem of fully grown vascular cylinder. Note the large diameter solitary vessels (V) radial files of narrow vessels (arrowheads).

Scale bars: A - C: 50 µm; D: 100 µm; E & F: 200 µm; G: 25 µm.

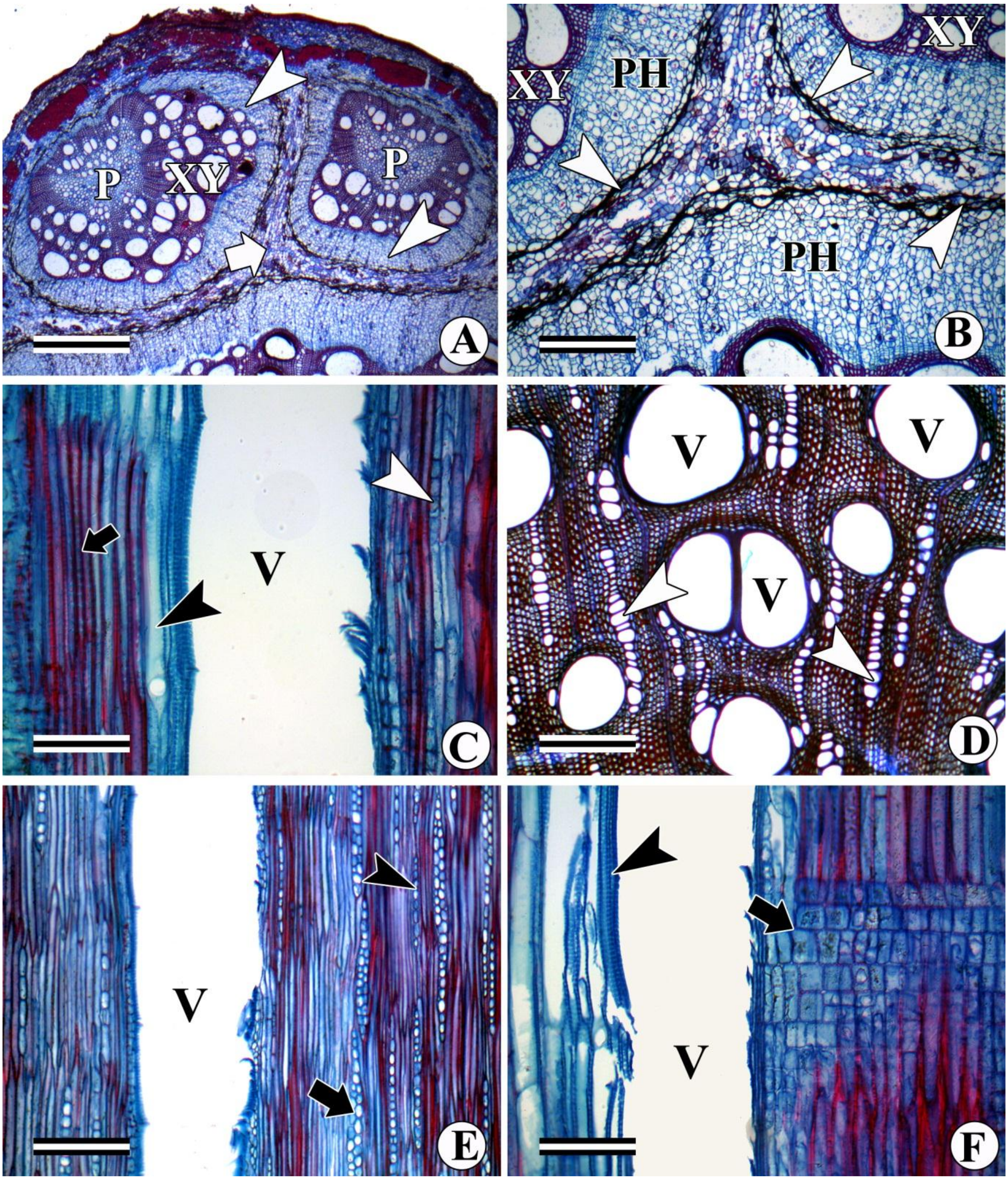

Figure 34

Figure 34: Structure of the secondary xylem and phloem in transverse (A, B & D) and tangential longitudinal (C, E & F) views of mature stems of *Serjania circumvallata*.

A: Structure and composition of neoformed vascular cylinder in relatively thick stem showing quantifiable amount of the secondary xylem (XY) and phloem (arrowheads). Arrow indicates crushed parenchyma between central and adjacent vascular cylinders. *Abbreviation*: P = pith.

B: Enlarged view of figure 34A showing the region between the neo-formed vascular cylinders and the main vascular cylinder. Note the crushing of parenchyma cells (arrowheads) due to exerting pressure from the enlarging of the neo-formed vascular cylinders.

C: Structure of the secondary in mature stem showing the wide vessel (V), fibriform vessels (black arrowhead). Arrow indicates fibre tracheid while white arrowhead indicates the uniseriate ray.

D: Structure of the secondary xylem in mature stem showing wide and solitary vessels (V) while arrowheads show radial multiples.

E: Structure of the secondary xylem showing wide vessel (V). Note uniseriate (arrowhead) and biseriate (arrow) ray.

F: Structure of the secondary xylem showing ray parenchyma cells. Arrowhead indicates the ray parenchyma cells, vessel (V) and fibriform vessel (arrowhead).

Scale bars: A: 500 µm; B, D & E: 200 µm; C & F: 100 µm.

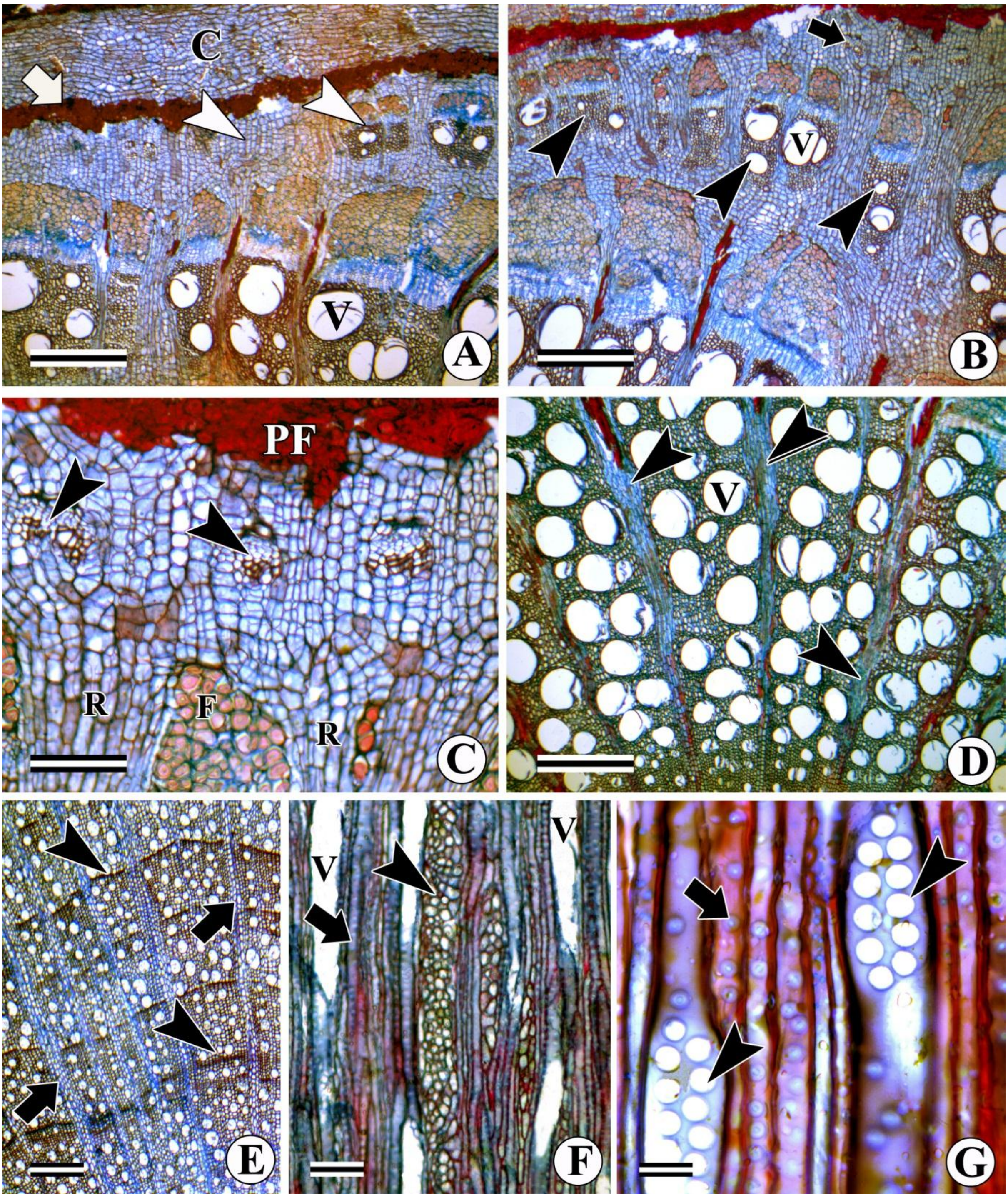

Figure 35

Figure 35: Transverse (A-D & E) and tangential longitudinal (F & G) sections of *Gnetum ula* (A-D & F) and *Ephedra foliata* (E & G) stem. Showing initiation of successive cambia and structure of secondary xylem.

A: Initiation of successive cambium (arrowheads) from the cells located on the inner side of the pericycle (arrow). C represents the cortex and V vessel.

B: Initiation of deposition of the secondary xylem from the newly initiated successive cambium (Arrowheads). Arrow indicates the initiation of new cambial segment. *Abbreviation*: V = vessel.

C: Enlarged view of figure 35B showing the initiation of cambial segments just below the pericycle (PF) from phloem parenchyma cells. *Abbreviation*s: R = phloem ray, F = phloem fibres.

D: Structure of the secondary xylem with solitary vessels (V) and indistinct growth rings and diffuse porous wood. Arrowheads represent multiseriate rays.

E: Structure of the secondary xylem with diffuse porous wood with distinct growth rings (arrowheads) while arrows indicate multiseriate rays.

F: Secondary xylem in tangential longitudinal view showing the multiseriate rays (arrowhead), vessel elements (V) and tracheids (arrows).

G: Enlarged view of secondary xylem showing vessel with perforation (arrowhead) while arrow indicates the bordered pits on the lateral walls.

Scale bars: A, B, D & E: 500 µm; C & F: 200 µm; G: 50 µm.

Table 3: Dimensional details of vessel elements (both wide and narrow), fibres, fibre tracheids and xylem rays.

Table 3.1: **Apocynaceae**

Sr. No	Species name	Wide vessel element		Narrow vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Beaumontia jerdoniana*	413.16 ±14.23 (397–442)	118.47 ±6.21 (118–148)	498.48 ±10.81 (478–518)	30.78 ±3.74 (28–33)	501 ±32.54 (598–683)	16.83 ± 1.44 (12–30)	--	698 ±20.13 (665– 732)
2	*Leptadenia reticulata*	319±11.21 (267–371)	118±3.52 (95–146)	775±10.38 712–838	33±0.79 (28–38)	551±11.69 (318–784)	36±0.91 14–58	--	821±11.85 (709–911)
3	*Leptadenia pyrotechnica*	280±10.33 (233–321)	110±3.66 (89–135)	730±11.25 (644–810)	26.3±0.99 (22–33)	641±13.59 (416–866)	42±0.881 (16–62)	--	856±10.85 (788–921)
4	*Vallaris solanacea*	320±6.85 (297–366)	126±4.35 (89–168)	348±3.63 (309–388)	28±0.93 (22–37)	651±23.93 (431–871)	21±3.92 (12–29)	--	689±16.28 (633–772)
5	*Wattakaka volubilis*	269±7.02 (228–310)	188±4.36 (109–268)	356±2.85 (298-414)	41±0.89 (25–58)	213±4.58 138–289	18±3.02 (12–26)	--	587±14.89 (485–689)

Table 3.2: **Bignoniaceae**

Sr. No	Species name	Wide vessel element		Narrow vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Arrabidaea candicans*	263±4.86 (210-317)	219±4.63 (198-240)	355±3.91 (298-412)	19.5±2.11 (13-26)	320±4.14 (250-390)	30±3.11 (10-50)	--	768±8.48 (689-848)
2	*Campsis radicans*	248.8±5.48 (218-277)	138±5.88 (121-178)	271.5±6.55 (238-296)	26±3.65 (20-41)	423±27.87 (238-685)	37±8.14 (24-53)	--	646±12.47 (624-748)
3	*Cardiospermum helicacabum*	288±4.48 (251-318)	237±4.38 (189-285)	338±3.71 (281-458)	39±2.87 (28-50)	298±3.44 (237-428)	29±2.10 (13-48)	--	685±6.51 (592-748)

Table 3.4: **Convolvulaceae**

Sr. No	Species name	Wide vessel element		Narrow vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Dicranostyles ampla*	342±7.64 (280-368)	245±6.73 (109-346)	--	--	253±9.71 (130-383)	93±11.03 (35-136)	--	889 ± 9.73 (943-1168)
2	*Hewittia malabarica*	218±9.43 (137–268)	179±10.13 (148–257)	536±7.41 (485–613)	27±2.21 (19–32)	121±9.85 (213-236)	141±16.53 (11-319)	--	659± 11.0 (584–698)
3	*Jacquemontia paniculata*	239±8.42 (187-310)	204±6.87 (141-276)	453±11.09 (382-510)	83±0.85 (53-113)	394±16.48 (213-887)	219±18.56 (13-463)	--	734±10.76 (603-894)
4	*Maripa nicaraguensis*	307±8.23 (238–343)	121±8.43 (90–188)	--	--	119±6.43 (148-298)	74±8.37 (24-121)	--	712 ± 9.33 (645–881)
5	*Turbina corymbosa*	270±10.70 (178-310)	221±8.61 (144-292)	--	--	381±12.09 (177-1011)	189±1.39 (16-374)	--	785±11.65 (654-933)

Table 3.5: **Cucurbitaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Zanonia indica*	172±6.82 (109-228)	272±15.55 (178-485)	--	--	2174±18.46 (1879-2469)	378±11.53 (281-476)	--	885±18.77 (504-1297)

Table 3.6: **Fabaceae**

Sr. No	Species name	Wide vessel element		Fibriform/Narrow vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		

1	*Canavalia gladiata*	170.28±11.72 (119–267)	286.44±14.34 (208–386)	219±11.90 (129–277)	68.64±5.98 (40–99)	249±12.15 (159-348)	89±8.30 (12-171)	1175±44.34 (901–1544)	400.62±16.25 (327–515)
2	*Canavalia virosa*	194±8.92 (183-211)	223±9.53 (182-259)	244±3.85 (218-264)	47±0.90 (38-61)	253±1.05 (146-356)	78±1.23 (13-147)	--	365±1.61 (248-481)
3	*Dalbergia volubilis*	216±1.25 (187-249)	93±0.67 (69-119)	--	--	253±1.34 (197-314)	7±0.23 (6-9)	341±1.21 (287-394)	--
4	*Entada gigas*	162±3.40 (118-204)	282±3.51 (199-364)	272±4.54 (203-343)	41±0.97 (31-49)	228±2.29 (158-297)	8±0.23 (6-9)	--	684±4.89 (467-897)
5	*Entada rheedii*	151±1.98 (107-197)	259±2.67 (187-329)	254±3.58 (227-286)	43±2.81 (34-54)	232±1.51 (141-319)	7±0.21 (5-9)	--	668±8.90 (419-919)
6	*Phaseolus lunatus*	257±6.59 (213-304)	287±3.89 (189-388)	243±1.38 (129-359)	63±1.08 (38-86)	272±8.59 (237-309)	272±6.61 (51-491)	--	773±6.57 (498-1087)
7	*Pueraria tuberosa*	327.36±17.90 (207–475)	274.56±8.72 (208–327)	228±12.23 (158–317)	70.62±4.30 (49–99)	302±2.86 (248-354)	282±4.74 (447-514)	3270±119.97 (2812–4138)	687±31.98 (465–881)
8	*Rhynchosia pyramidalis*	267±9.80 (217–297)	186 ± 7.32 (152–216)	334 ± 8.07 (311–385)	39 ± 3.32 (29–52)	457 ± 9.77 (416–584)	24 ± 2.35 (17–49)	1669 ± 17.91 (1494– 1772)	--

Table 3.7: **Loganiaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Strychnos bredemeyeri*	431±16.08 (188–633)	123±2.33 (99–149)	--	--	409±17.14 (267–653)	33±1.07 (25–45)	1089±21.60 (723–1197)	--
2	*Strychnos andamanensis*	416±24.02 (227–544)	58±3.52 (40–84)	--	--	384±16.18 (257–589)	29±0.90 (22–39)	688±24.64 (534–940)	--

Table 3.8: **Menispermaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Anamirta cocculus*	449±4.93 (327-614)	191±3.05 (119-267)	--	--	1922±39.05 (1639-2328)	707±20.16 (475-950)	1122±7.91 (881-1465)	--
2	*Cissampelos pareira*	180±2.05 (158-237)	115±1.89 (99-129)	--	--	1410±23.53 (1306-1520)	419±21.27 (285-523)	771±4.01 (508-923)	--
3	*Cocculus hirsutus*	284±1.72 (181-361)	124±1.13 (119-189)	--	--	2391±12.07 (1785-4197)	192±10.11 (92-408)	978±6.18 (646-1281)	--
4	*Cocculus laurifolius*	259±9.20 (232-287)	101±11 (50-153)	--	--	2287±14.41 (1841-2753)	298±10 (255-345)	878±7.18 (619-1318)	--
5	*Cocculus pendulus*	299±1.93 (168-376)	134±1.10 (109-178)	--	--	2642±10.07 (1900-4275)	173±11.05 (95-356)	1032±6.14 (664-1362)	--
6	*Coscinium fenestratum*	451±10.38 (336-633)	150±19.33 (109-237)	--	--	3042±14.57 (2375-3943)	234±16.17 (95-451)	955±4.00 (717-1257)	--
7	*Cyclea peltata*	275±12.93 (251-359)	120±11.48 (54-317)	--	--	441±20.26 (238-693)	178±13.83 (113-233)	22±4.45 (12-31)	--
8	*Diploclisia glaucescens*	485±2.20 (336-584)	189±2.75 (129-247)	--	--	3490±19.92 (2423-4703)	184±6.63 (119-261)	1184±3.67 (935-1455)	--
9	*Pachygone ovata*	339±1.94 (208-525)	132±1.32 (109-158)	--	--	3658±17.28 (2375-6223)	165±9.45 (71-238)	1054±2.01 (704-1455)	--
10	*Stephania japonica*	252±12.11 (139-396	54±3.61 (30-89)	--	--	3808±17.59 (3217-4376)	291±12.33 (91-498)	589±16.76 (446-812)	--
11	*Tiliacora racemosa*	363±1.69 (237-252)	201±1.46 (168-277)	--	--	3402±16.58 (2517-4275)	249±13.23 (95-428)	918±2.00 (746-1386)	--
12	*Tinosporia cordifolia*	249±1.16 (208-297)	133±1.79 (99-158)	--	--	3954±19.08 (2717-4331)	229±13.48 (108-389)	1344±4.02 (732-2118)	--

13	*Tinospora sinensis*	257±11.85 (62-337)	31±5.38 (10-79)	--	--	3888±18.85 (2687-4273)	231±11.53 (110-393)	678±12.33 (532 - 799)	--

Table 3.9: **Polygalaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Moutabea gentry*	443±6.38 389-508	195±8.43 (139-258)	--	--	447±8.33 (366-533)	33±1.03 (11-53)	749±4.17 567-866	--

Table 3.10: **Polygonaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Antigonon leptopus*	179±6.93 (100–244)	160±12.21 (77–333)	248±5.49 (199–299)	31±1.34 (17–44)	154±6.49 (112–211)	20±1.02 (16–44)	386±10.15 (255–488)	--

Table 3.11: **Sapindaceae**

Sr. No	Species name	Wide vessel element		Narrow vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Serjania circumvallata*	167±2.81 (103-235)	83±1.03 (62-108)	--	--	165±2.11 (123-209)	21±0.15 (12-31)	--	609±9.513 (518-687)
2	*Serjania mexicana*	259±3.45 (208-307)	316±2.88 (247-376)	334±2.91 (278-389)	72±4.15 (58-92)	264±7.21 (214-311)	29±2.14 (18-39)	--	719±8.21 (648-785)

Table 3.12: **Vitaceae**

Sr. No	Species name	Wide vessel element		Fibriform vessel element		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Ampelocissus latifolia*	335±38.57 (257-416)	150±47.61 (79-257)	--	--	--	163±10.61 (61-267)	--	540±12.27 (396-624)
2	*Cayratia auriculata*	191±8.80 (129-257)	415±18.69 (288-514)	--	--	--	89±1.09 (28-148)	--	799±19.74 (584-1009)
3	*Cayratia trifolia*	412±0.93 (228-485)	163±9.46 (179-267)	--	--	--	71±5.62 (21-119)	--	730±19.57 (485-901)
4	*Cissus quadrangularis*	270±51.98 (178-327)	134±26.58 (89-198)	--	--	--	168±2.01 (124-209)	--	449±58.28 (356-544)
5	*Cissus repanda*	408±10.51 (288-495)	362±10.10 (208-604)	--	--	---	435±8.09 (339-526)	--	745±16.91 (495-910)
6	*Cissus rotundifolia*	306±55.48 (208-426)	50±9.70 (30-70)	--	--	--	197±4.67 (120-278)	--	460±73.34 (336-643)
7	*Tetrastigma bracteolatum*	340±12.47 (238-454)	324±5.22 (287-366)	--	--	--	256±6.60 (118-388)	--	588±21.15 (455-762)
8	*Vitis vinifera*	513±86.19 (366-673)	102±36.21 (40-178)	--	--	--	98±0.28 (44-149)	--	763±17.52 (584-891)

Table 3.13: **Gymnosperm**

Sr. No	Species name	Vessel element		Tracheid		Xylem Ray		Libriform Fibre length	Fibre tracheid length
		Length	Diameter	Length	Diameter	Height	Width		
1	*Gnetum ula*	359-502	94-254	--	--	--	83±1.06 (48-114)	--	698-891
2	*Ephedra foliata*	--	--	547±5.98 (465-631)	48±1.09 (39-59)	464±8.68 (192-741)	67±0.89 (41-91)	--	--
3	*Ephedra karumanchiana*	--	--	558±3.89 (438-681)	42±0.78 (32-48)	404±3.67 (178-629)	59±0.81 (27-88)	--	--