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Leaf architecture in some Euphorbiaceae

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Abstract

The present study deals with the leaf architectural study of 44 species distributed over 20 genera of the Euphorbiaceae to provide comprehensive account on the leaf architecture of Euphorbiaceae and its taxonomic significance. The leaves are simple except in *Anda* and *Hevea* where leaves are 3-5 foliate. The leaf shape, apex, base, number of areoles and vein endings entering the areoles are species specific. Major venation pattern is pinnate-craspedodromous, pinnate-camptodromous with brochidodromous, weak brochidodromous, festooned brochidodromous, eucamptodromous and reticulodromous secondaries and actinodromous. The highest degree of vein order is up to 6º. Quantitative parameters like the numbers of secondary veins, areoles and vein endings per unit area have using analyzed. The veinlets terminations are mostly conventional tracheids or occasionally dilated. The presence of bundle sheath is common around 1º to 5º veins. Leaf architectural characteristics such as presence of major venation categories, nature of marginal ultimate venation, areoles, presence or absence of bundle sheath and type of leaf margins are found to the helpful in delimiting the taxa study.

Key words: Leaf architecture, taxonomy, Euphorbiaceae.

Leaf architecture including venation pattern has been studied in 20 genera and 44 species of the Euphorbiaceae. Though the study of leaf architecture is more than a century old, due importance was not given to it in the systematic studies of the dicotyledons. However, the work of Hickey[5,6] gave a new impetus and precision to the subject. Hickey and Wolfe[7] and Melville[10] based most of their conclusions on a survey of dicotyledonous and angiospermous leaves respectively. A perusal of the past literature revealed that studies on leaf architecture in Euphorbiaceae are almost negligible[1,2,4,8,9,11,13]. Therefore, the present investigation has been carried out to provide a detailed account on the same besides its evaluation for taxonomic purpose.

The plant materials were collected from various places like Bangalore, Castlerock (Goa), Waghai Botanical garden and Thrissur (Kerala). The leaves of the material fixed in acetic alcohol are cleared in a supersaturated solution of chloral hydrate for 2 or 3 days. However, the leaves of the herbarium material are first boiled in 5% sodium hydroxide for a few minutes and then kept in 10% potassium hydroxide at 30ºC for 2-3 days. Permanent Canada balsam mounts of the cleared leaves are prepared after dehydration in alcohol and staining them with alcoholic Kores stamp pad purple ink Rao *et al.*[12]. In those taxa with compound leaves, the middle leaflets of a mature leaf are selected and the leaflet is referred to as leaf. The terms described are adapted from Hickey[5] and Hickey and Wolfe[7].

Morphological description :

Leaves simple, unlobed, 3-lobed, pinnately lobed or palmate; alternate, opposite or subopposite; the leaves ovate, elliptic, obovate or oblong; margin entire dentate or undulate; apex acute, acuminate, mucronate, rounded or attenuate; base rounded, truncate, decurrent, peltate or cordate; texture herbaceous, coriaceous or chartaceous.

In all the taxa studied, the venation is unicostate and multicostate reticulate and may be differentiated into a number of size classes. The veins of first, second and third categories are considered under the major venation pattern and the veins of the subsequent categories – the minor venation pattern that forms the reticulum. The species wise qualitative leaf features are given in the Table 1a and 1b.

Major venation pattern :

Major venation pattern is pinnate-craspedodromous, pinnate-camptodromous with brochidodromous, weak brochidodromous, festooned brochidodromous, eucamptodromous and reticulodromous secondaries and actinodromous.

In pinnate craspedodromous type single primary vein originate from base of the leaf lamina and traverse towards its apex. The thickness of the primary vein gradually decreases from base to the apex. The primary vein gives rise to secondary veins on either side in opposite, sub-opposite or alternate fashion. Secondaries after originating from the primary are traverse towards the margin. If the secondaries directly terminate at the margin the venation pattern is simple craspedodromous. Such pattern is observed in *Phyllanthus acidus* and *Vernicia fordii* (Plate I, Figs. 1-2). Secondaries branch just inside the margin, with one arm terminating at the margin and the other join the super-adjacent secondary. This is called semicraspedodromous found in *Acalypha ciliata*, *A. fruticosa*, *A. hispida* and *Baliospermum* (Plate I, Figs. 3-5). In *Agrostistachys indica* semicraspedodromous venation having one additional set of loops outside the branch that joins the supra-adjacent secondary this is called festooned semicraspedodromous (Plate I, Fig. 6). In pinnate camptodromous type secondaries do not terminate at the margin, but join together in a series of prominent arches and forms brochidodromous type. It is seen in *Aporosa*, *Breynia nivosa*, *B. retusa*, *Croton*, *Euphorbia fulgens*, *E. indica*, *E. milii*, *Glochidion*, *Hevea*, *Jatropha integerrima*, *Mallotus nudiflorus*, *M. philippensis*, *Pedilanthus*, *Phyllanthus* airy-*shawii*, *P. debilis*, *P. indofischeri*, *P. polyphyllus*, *P. reticulatus*, *P. urinaria*, *Putranjiva* (Plate I, Figs. 7-9 and Plate II, Figs. 1-3). If the arches of secondaries are not prominent it is weak brochidodromous type found in *Anda*, *Euphorbia neriifolia* and *E. umbellata* (Plate II, Fig. 4). Primary loops having a set of secondary loops outside and forms festooned brochidodromous type in *Flueggea leucopyrus* and *F. virosa* (Plate II, Fig. 5). When secondaries upturned and gradually diminishing apically inside the margin, connected to the supra-adjacent secondaries by a series of cross veins without forming prominent marginal loops, such eucamptodromous type is found in *Phyllanthus maderaspatensis* and *P. virgatus* (Plate II, Fig. 6). If the secondaries losing their identity towards the leaf margin by repeated branching into a vein reticulum the venation pattern is reticulodromous. It is observed in *Euphorbia heterophylla* and *E. tirucalli* (Plate II, Fig. 7).

In actinodromous type three or more primary veins diverging radially from a single point. The position of the first point of primary vein radiation is at the base (basal). Ramification of the lateral actinodromous veins covering at least 2/3 of the blade area (perfect) and actinodromous veins reaching at the margin (marginal). Such pattern is observed in *Chrozophora prostrata*, *C. rottleri*, *Jatropha curcas*, *J. gossypiifolia*, *J. multifida*, *J. podagrica*, *Manihot* and *Tragia* (Plate II, Figs. 8-9).

Primary vein:

The primary vein (1°) is the thickest vein of the leaf/leaflets and its thickness decreases gradually towards the apex and it gives off other degree veins on either side. The primary vein is stout to moderate or weak. It runs straight or bends into a small curve in the lamina. The primary veins are simple and remain unbranched.

Secondary veins:

The secondary veins (2°) arises on either side of the primary vein in alternate fashion and sometime opposite manner, which diverge uniformly at a moderate acute angle from the primary vein and extend towards the margin bending in a smooth or abrupt curve. The secondaries are present more on one side of the primary vein in leaves with oblique base. The number of secondary veins varies within the same species. The angle of divergence of the secondary veins is acute wide, acute moderate or acute narrow and varies from species to species and even within the same species from base to apex. In *B. retusa, J. podagrica*, the basal secondary veins are acute wide. Some secondary veins become more acute wide at the apical of lamina in *A. ciliata, Euphorbia indica, Euphorbia tirucalli, Flueggea leucopyrus, Glochidion, Phyllanthus airy-shawii, P. debilis, P. indofischeri, P. polyphyllus,* and *P. urinaria* (Plate II, Figs. 2-3). The secondaries may or may not show branching into two towards tip. These are interconnected by supra adjacent secondaries.

The inter secondaries are present running parallel or nearly so to the secondaries as in *Breynia nivosa, B. retusa*, *Euphorbia fulgens, E. umbellata, Fluggea leucopyrus, F. virosa, Glochidion, Jatropha gossypiifolia, J. integerrima*, *Phyllanthus maderaspatensis* and *Putranjiva* (Plate I, Fig. 7 and Plate II, Figs. 4, 6).

Agrophic veins which are comb like complex of veins comprised of a lateral 1° or 2° secondaries with two or more exmedial 2° veins that travel roughly parallel courses towards the margin present in *Acalypha ciliata, A. fruticosa, A. hispida, Baliospermum, Croton, Jatropha integerrima, Mallotus nudiflorus, M. philippensis* and *Vernicia* (Plate I, Figs. 2-5, 8 and II, Fig. 1). In *Vernicia* they are compound and straight and simple and looped in others.

Tertiary veins:

The next higher order veins the tertiaries (3°) arising from the secondaries and are of RR, AR, AO, AA, RO types. They form either ramified or percurrent and random reticulate pattern.

Minor venation pattern:

The veins of the next order originating from the tertiaries and those of the same size originating from secondaries and even primary constitute the quaternary (4°) veins and those originating from these and those of equal size from the lower order are the quinternaries (5°). The highest order veins are identified up to 6°. In *Aporosa*, it is up to 6°. In *Agrostistachys, Anda, Baliospermum, Croton, Euphorbia fulgens, E. heterophylla, E. indica, E. milii, E. neriifolia, E. tirucalli, E. umbellata, Flueggea leucopyrus, F. virosa, Hevea, Mallotus nudiflorus, Mallotus philippensis and Vernicia*, it is upto 5° and in rest of the genera investigated it is upto 4°. The numerical data on the venation pattern are charted in Table-2.

The freely ending ultimate veins are called veinlets. The number of veinlets entering an areole also varies from species to species and within the same species.

The marginal venation:

The marginal ultimate venation is incomplete in *Acalypha ciliata, A. fruticosa, Agrostistachys, Breynia nivosa, B. retusa, Chrozophora prostrata, C. rottleri, Croton, Euphorbia fulgens, E. heterophylla, E. indica, E. milii, E. neriifolia, E. tirucalli, E. umbellata, Flueggea leucopyrus, Jatropha curcas, J. gossypiifolia, J. integerrima, J. multifida, J. podagrica, Manihot, Pedilanthus, Phyllanthus airy-shawii, P. debilis, P. indofischeri, P. maderaspatensis, P. polyphyllus, P. reticulatus, P. urinaria, P. virgatus, Putranjiva* and *Tragia* (Plate III, Figs. 2, 7- 8).

It is fimbriate in *Anda, Baliospermum, Mallotus nudiflorus, Phyllanthus acidus* and *Vernicia* (Plate III, Figs. 5 - 6, 9) and looped in *Acalypha hispida, Aporosa, Flueggea virosa, Glochidion, Hevea* and *Mallotus philippensis*.(Plate III, Figs. 1, 3-4).

Areoles:

The areoles are the smallest areas of the leaf tissue, which are bounded by the thinnest branches of the veins, mostly either with quaternary or quinternaries. The areoles are mostly imperfect e.g. *Acalypha hispida, Agrostistachys, Anda, Baliospermum, Breynia, nivosa, B. retusa, Croton, Euphorbia fulgens, E. indica, E. milii, E. neriifolia, E. tirucalli, Flueggea leucopyrus, F. virosa, Glochidion, Hevea, Jatropha curcas, J. gossypiifolia, J.*

integerrima, J. multifida, J. podagrica, Manihot, Pedilanthus, Phyllanthus debilis, P. indofischeri, P. polyphyllus, P. virgatus, Putranjiva, Tragia and Vernicia.(Plate IV, Fig. 11). The areoles are well developed in *Aporosa, Mallotus nudiflorus, M. philippensis* and *Phyllanthus acidus* (Plate IV, Fig. 6). The areoles are incomplete in *Acalypha fruticosa, Euphorbia heterophylla, E. umbellata, Phyllanthus airy-shawii, P. maderaspatensis, P. reticulatus, and P. urinaria*. (Plate IV, Fig. 12). The areoles are absent in *Chrozophora prostrata* and *C. rottleri*. The size and shape of the areoles are variable. The shape is generally quadrangular, triangular, pentagonal and polygonal rarely circular, triangular or irregular. The size of the areoles also varies. The areoles generally contain terminal vein endings. In *Euphorbia heterophylla*, the areoles are empty, very few areoles contain vein endings (Plate IV, Fig. 10). The vein endings end blindly in the mesophyll. In several cases, loop formation is observed e.g. *Agrostistachys, Anda, Baliospermum, Breynia nivosa, B. retusa, Croton, Euphorbia fulgens, E. heterophylla, E. indica, E. milii, E. neriifolia, E. tirucalli, E. umbellata, Flueggea virosa, Jatropha gossypiifolia, J. podagrica, Mallotus nudiflorus* (Plate IV, Fig. 3). Vein endings may be simple or branched. The simple vein endings may be linear or curved. The branched ones divide dichotomously once, twice or three times. The branches may be symmetrical or asymmetrical.

Vein endings:

The vein terminations show variations and include conventional and dilated trachieds. They are either linear, isodiametric, spindle shaped or T shaped (Plate IV, Fig. 5). They are uniseriate, biseriate, multiseriate and juxtaposed in arrangement. The trachieds in groups or clusters are observed as in *Aporosa, Euphorbia* and *Mallotus* (Plate IV, Figs. 4, 9). The uniseriate super imposed trachieds occur in *Euphorbia tirucalli*. (Plate IV, Fig. 8).

Isolated vein endings - uniseriate, bi-seriate or multiseriate - are observed in some plants with terminal trachieds lying free. Isolated trachieds are also of common occurrence in a few plants e.g. *Acalypha hispida* (Plate IV, Fig. 2). Extension cells are parenchymatous, which adjoin a vein with an isolated trachieds as observed in *Acalypha hispida*.

Bundle sheath:

Bundle sheath is very well developed parenchymatous anisodiametric cells on all the grades of veins and vein endings in *Euphorbia indica, E. heterophylla* and *E. umbellata* whereas in *E. tirucalli*, and *Phyllanthus maderaspatensis* its associations ranges from secondary (2°) vein to quaternary (4°) vein (Plate IV, Fig. 7).

Sclerids:

These elements are ramiform with short arms or processes and are scattered throughout the leaf on either side of veins in *Euphorbia umbellata* and *Fluggea virosa*.

Crystals:

Calcium oxalate crystals lie on either side of primary veins in *Acalypha fruticosa* and *A. hispida, Chrozophora* and *Flueggea leucopyrus* (Plate IV, Fig. 1).

The leaves mostly simple except in *Anda* and *Hevea* where leaves are 3-5 foliate. Further the simple leaves are either unlobed or with 3-5 lobes. In *Jatropha multifida* the leaf is pinnately lobed.

During the course of present studies nine types of venation pattern encountered. The venation types observed are pinnate-craspedodromous (simple, semi and festooned-semi), pinnate-camptodromous with brochido-dromous, weak brochidodromous, festooned brochidodromous, eucamptodromous and reticulodromous secondaries and actino-dromous. The actinodromous pattern is common in lobed leaves. Unlobed leaves show pinnate craspedodromous or pinnate campto-dromous types.

Sehgal and Paliwal[13] have concluded that the venation pattern in *Euphorbia* species is uni, bi and tri veined on the basis of number of strands entering the base of the petiole or base of the leaf and serves as the origin for the higher order venation. They found tri - veined type in majority of species. Aldhebiani and Jury[1] also show one-veined, three-veined to those with four or more veins in *Euphorbia* species and predominant type is three veined. In present studies, however, *Euphorbia* species have one-veined venation type. The present observations are in accordance with those of Sehgal and Paliwal[13] and Aldhebiani and Jury[1] except that the predominant type is tri-veined.

Dehgan and Webster[2] described the venation in *Jatropha* species is actinodromous and brochidodromous - semicraspedodromous in lobed and ovate-lanceolate to narrowly lanceolate leaf respectively. In present investigation *Jatropha integerrima* have pinnate leaves with pinnate-brochidodromous venation whereas other species have palmately lobes leaves with actinodromous venation. Nwokocha *et al.*[11] in their study on leaf architecture of *Jatropha* species have also recorded actinodromous venation type. Therefore, the present investigation supports to above mentioned work.

Hickey[5] stated that, “artificial” or paraphyletic families like Euphorbiaceae have several basic patterns of leaf architecture. Later Hickey and Wolfe[7] designated that the Euphorbiaceae members having ‘Dilleniid’ leaf type possesses actinodromous venation. Levin[9], based on his studies on systematic foliar morphology of Phyllanthoideae (Euphorbiaceae) described the venation is pinnate, brochidodromous to eucamptodro-mous, a few species cladodromous or reticulodromous. However, the presently investigated plants also show the occurrence of above mentioned venation types.

Hickey[5] classified the marginal ultimate venation into looped, fimbriate and incomplete patterns. In the present investi-gation marginal ultimate venation exhibit great uniformity in majority of the plants, it is incomplete. *Anda*, *Baliospermum*, *Mallotus nudiflorus*, *Phyllanthus acidus* and *Vernicia* show fimbriate margins. Looped marginal venation occurs only in *Acalypha hispida*, *Aporosa*, *Flueggea virosa*, *Glochidion*, *Hevea* and *Mallotus philippensis* and this character makes this taxon stand apart from the other species investigated.

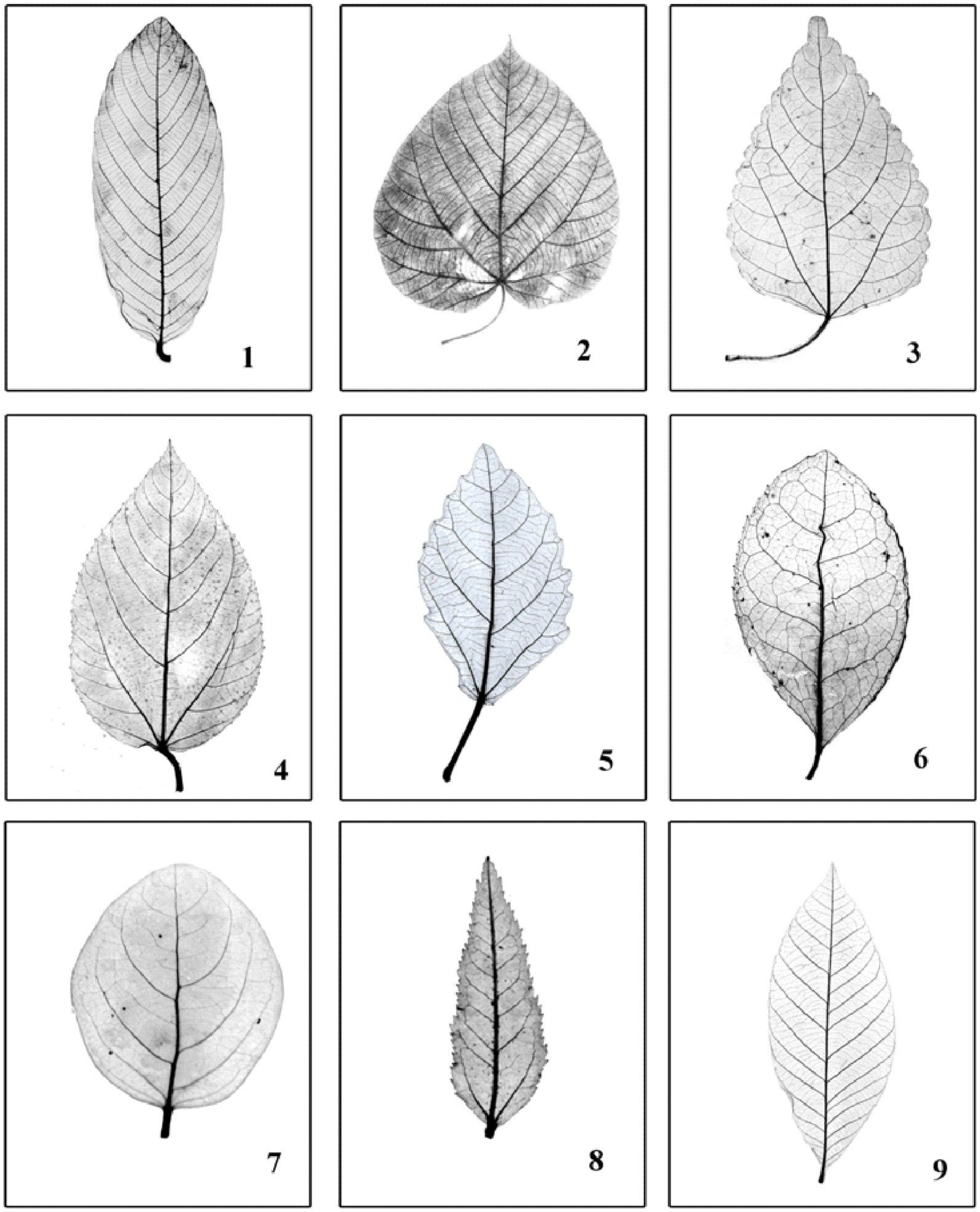

Photo Plate – I. Cleared leaves

1. *Phyllanthus acidus*, 2. *Vernicia fordii*, 3. *Acalypha fruticosa*, 4. *Acalypha hispida*, 5. *Baliospermum solanifolium*, 6. *Agrostistachys indica*, 7. *Breynia nivosa*, 8. *Croton bonplandianus*, 9. *Hevea brasiliensis*

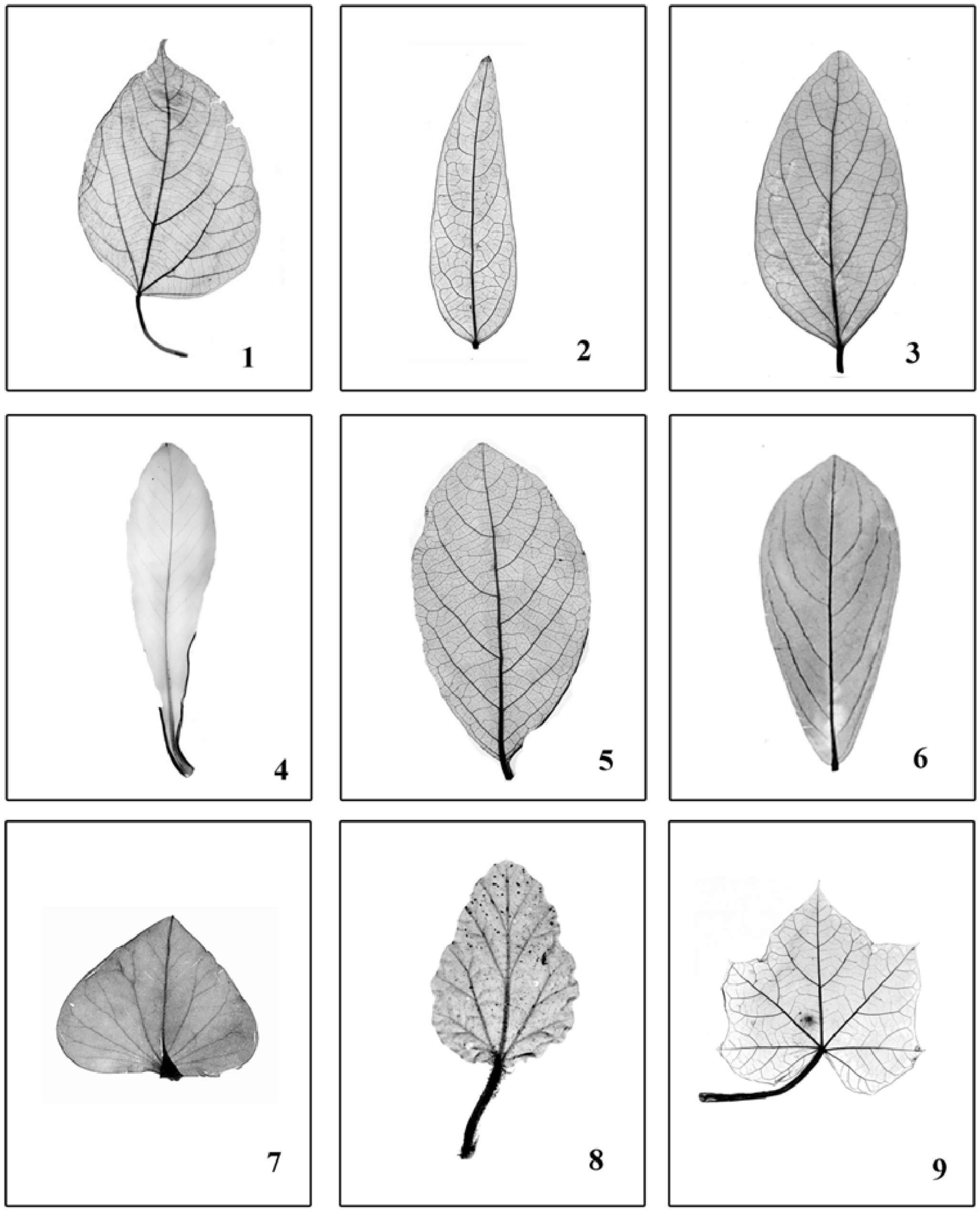

Photo Plate – II. Cleared leaves

1. *Mallotus nudiflorus*, 2. *Phyllanthus indo-fischeri*, 3. *Phyllanthus polyphyllus*, 4. *Euphorbia umbellata*, 5. *Flueggea virosa*, 6. *Phyllanthus maderaspatensis*, 7. *Euphorbia heterophylla*, 8. *Chrozophora prostrata*, 9. *Jatropha curcas*

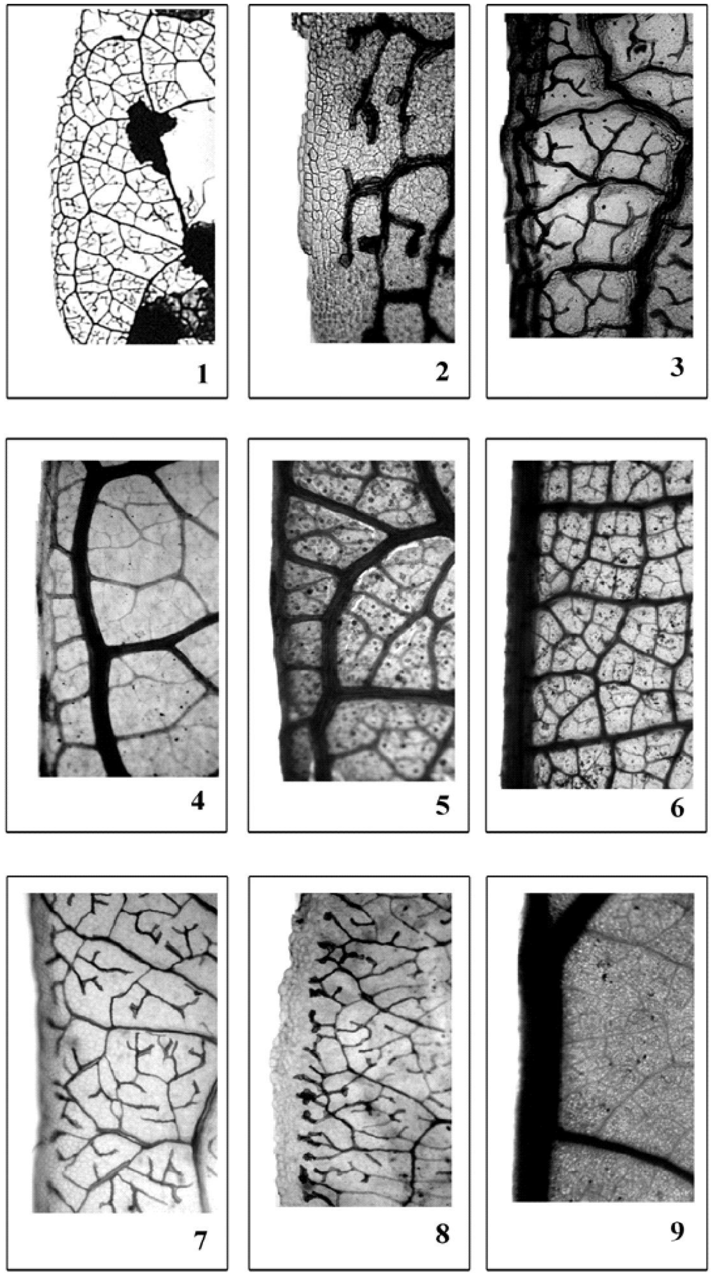

Photo Plate – III. Laminar margins

1. *Aporosa lindleyana*, 2. *Euphorbia neriifolia*, 3. *Flueggea virosa*, 4. *Hevea brasiliensis*, 5. *Mallotus nudiflorus*, 6. *Phyllanthus acidus*, 7. *Phyllanthus polyphyllus*, 8. *Phyllanthus virgatus*, 9. *Vernicia fordii*

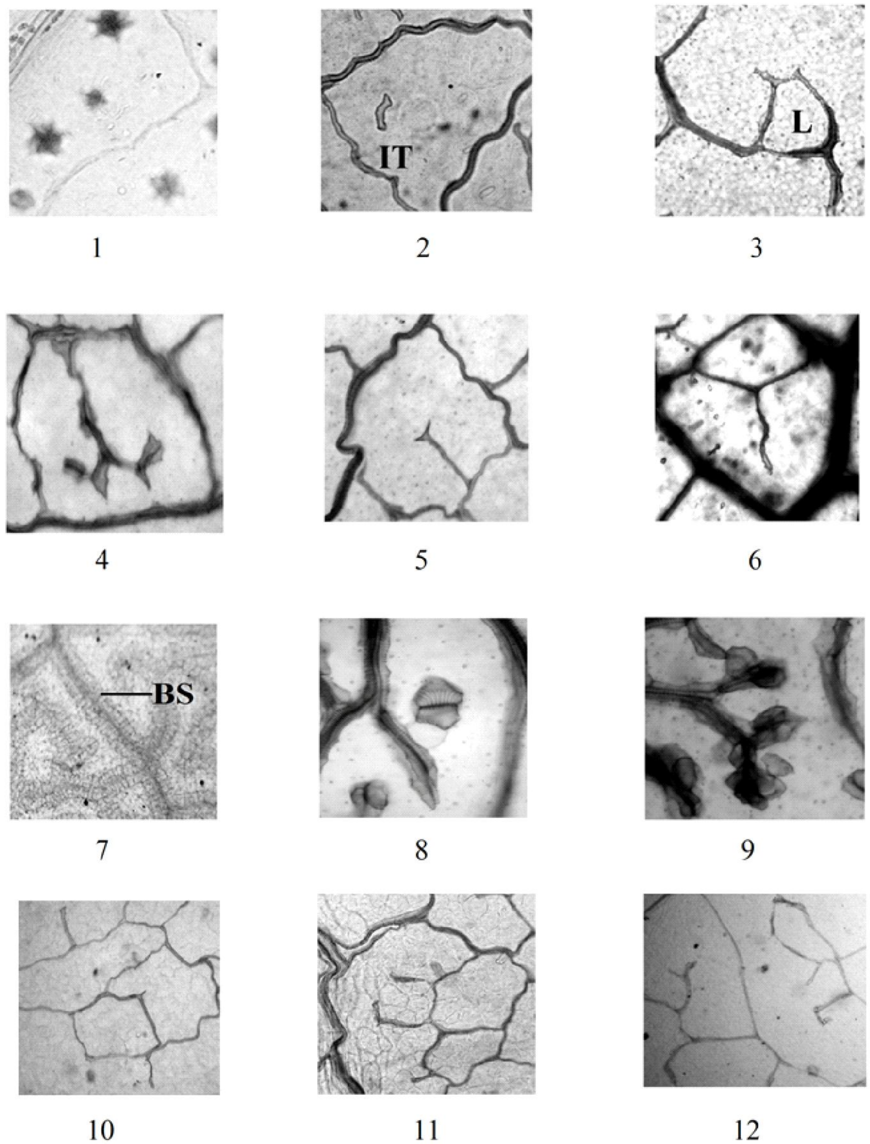

Photo Plate – IV

1. *Acalypha ciliata* – Showing abundant crystal, 2. *Acalypha hispida* – Showing isolated tracheids, 3. *Breynia nivosa* – Showing loop formation, 4. *Euphorbia neriifolia* – Showing branched tracheids, 5. *Phyllanthus debilis* – Showing 'T' shaped tracheids, 6. *Phyllanthus acidus* – Showing areoles well developed, 7. *Euphorbia indica* – Showing bundle sheath, 8. *Euphorbia tirucalli* – Showing uniserriate super imposed tracheids, 9. *Euphorbia tirucalli* – Showing cluster tracheids at tip of veinlet, 10. *Euphorbia heterophylla* – Showing empty areoles, 11. *Tragia plukenetii* – Showing imperfect areoles, 12. *Euphorbia umbellata*- Showing incomplete areoles

Abbreviation used: IT – Isolated tracheids, L – Loop formation, BS – Bundle sheath

Table 1a Showing species-wise leaf feature and venation pattern

Sr. No.	Name of plant	Leaf	Leaf attachment	Leaf/ leaflet shape	Base shape	Apex shape	Margin type	Lobation	Texture	Lamina balance
1	*Acalypha ciliata*	Simple	Alternate	Ovate-lanceolate	Rounded	Acuminate	Serrate	Unlobed	Herbaceous	Symmetrical
2	*Acalypha fruticosa*	Simple	Alternate	Ovate	Truncate to Rounded	Acuminate	Crenate to dentate	Unlobed	Herbaceous	Symmetrical
3	*Acalypha hispida*	Simple	Alternate	Ovate	Rounded	Attenuate	Serrate	Unlobed	Herbaceous	Symmetrical
4	*Agrostistachys indica*	Simple	Alternate	Wide elliptic	Obtuse	Obtuse	Serrate	Unlobed	Coriaceous	Asymmetrical
5	*Anda gomesii*	Palmately compound	Alternate	Ovate	Rounded	Acute	Entire	Unlobed	Herbaceous	Symmetrical
6	*Aporosa lindleyana*	Simple	Alternate	Wide elliptic	Obtuse	Acute	Entire	Unlobed	Coriaceous	Asymmetrical
7	*Baliospermum solanifolium*	Simple	Alternate	Elliptic	Obtuse	Acute	Sinuate-toothed	Unlobed	Herbaceous	Asymmetrical
8	*Breynia nivosa*	Simple	Alternate	Wide elliptic	Rounded	Obtuse	Entire	Unlobed	Thinly coriaceous	Symmetrical
9	*Breynia retusa*	Simple	Alternate	Wide elliptic	Rounded	Rounded	Entire	Unlobed	Thinly coriaceous	Symmetrical
10	*Chrozophora prostrata*	Simple	Alternate	Wide ovate	Obtuse	Rounded	Undulate	Unlobed	Herbaceous	Asymmetrical
11	*Chrozophora rottleri*	Simple	Alternate	Wide ovate	Decurrent -truncate	Acute or obtuse	Undulate	Tri-lobed	Herbaceous	Asymmetrical
12	*Croton bonplandianus*	Simple	Alternate	Ovate-lanceolate	Obtuse	Acuminate	Serrate	Unlobed	Herbaceous	Asymmetrical
13	*Euphorbia fulgens*	Simple	Whorled	Elliptic-suborbiculate	Eccentric Peltate	Obtuse	Entire	Unlobed	Herbaceous	Symmetrical
14	*Euphorbia heterophylla*	Simple	Opposite	Very wide ovate	Truncate	Acute	Entire	Unlobed	Herbaceous	Asymmetrical
				Narrow ovate	Decurrent	Mucronate	Entire	Unlobed	Herbaceous	Asymmetrical
15	*Euphorbia indica*	Simple	Opposite	Elliptic-oblong	Obliquely rounded	Acute	Entire or dentate	Unlobed	Herbaceous	Asymmetrical
16	*Euphorbia milii*	Simple	Alternate	Obovate - oblanceolate	Decurrent	Mucronate	Entire	Unlobed		Asymmetrical
17	*Euphorbia neriifolia*	Simple	Alternate	Obovate - oblanceolate	Acute	Rounded	Entire	Unlobed	Herbaceous	Symmetrical
18	*Euphorbia tirucalli*	Simple	Alternate	Narrow oblong	Decurrent	Acute	Entire	Unlobed	Herbaceous	Symmetrical
19	*Euphorbia umbellata*	Simple	Alternate	Obovate - oblanceolate	Decurrent	Acute	Entire	Unlobed	Herbaceous	Asymmetrical

20	*Flueggea leucopyrus*	Simple	Alternate	Obovate-orbiculate	Obtuse	Rounded	Entire	Unlobed	Coriaceous	Asymmetrical
21	*Flueggea virosa*	Simple	Alternate	Elliptic or obovate	Acute	Acute	Entire or crenulate	Unlobed	Coriaceous	Symmetrical
22	*Glochidion hohenackeri*	Simple	Alternate	Narrow oblong elliptic	Decurrent	Acute	Entire	Unlobed	Thinly coriaceous	Symmetrical
23	*Hevea brasiliensis*	Palmately compound	Alternate	Elliptic	Decurrent	Attenuate	Entire	Unlobed	Coriaceous	Asymmetrical
24	*Jatropha curcas*	Simple	Alternate	Broadly ovate	Deeply cordate	Acuminate	Entire or undulating	Palmately lobed into	Chartaceous	Symmetrical
								3 or 5		
25	*Jatropha gossypiifolia*	Simple	Alternate	Broadly ovate	Shallowly Cordate	Acuminate	Serrated or serrulate, minutely toothed with glandular tips with regular spacing	Palmately or digitately lobed into 3 or 5	Chartaceous	Symmetrical
26	*Jatropha integerrima*	Simple	Alternate	Narrow obovate or elliptic or fiddle-shaped or they may have three sharp pointed lobes	Acute	Acuminate	Entire with subulate	Palmately lobed	Chartaceous	Symmetrical
27	*Jatropha multifida*	Simple	Alternate	Orbicular or broadly ovate	Deeply cordate	Attenuate	Incised with alternatingly arranged leaf projections or pointed segments	Pinnatisect or Palmately divided into 9 or 11 segments	Cariaceous	Symmetrical
28	*Jatropha podagrica*	Simple	Alternate	Orbicularly ovate	Peltate	Acuminate	Sinuate	Palmately lobed into 3 or 5	Cariaceous	Symmetrical
29	*Mallotus nudiflorus*	Simple	Opposite to subopposite	Ovate	Rounded	Acuminate	Sub entire	Unlobed	Coriaceous	Asymmetrical

30	*Mallotus philippensis*	Simple	Alternate	Ovate or broadly elliptic	Rounded	Mucronate	Entire or coarsely toothed	Unlobed	Coriaceous	Symmetrical
31	*Manihot esculenta*	Simple	Alternate	Ovate-orbicular	Slightly peltate	Attenuate	Entire	Palmately lobed	Herbaceous	Symmetrical
32	*Pedilanthus tithymaloides*	Simple	Alternate	Wide elliptic	Decurrent	Acute	Entire	Unlobed	Herbaceous	Asymmetrical
33	*Phyllanthus acidus*	Simple	Alternate	Narrow -oblong	Obtuse	Acute	Entire	Unlobed	Coriaceous	Symmetrical
34	*Phyllanthus airy-shawii*	Simple	Alternate	Elliptic to obovate	Acute	Acuminate	Entire	Unlobed	Herbaceous	Symmetrical
35	*Phyllanthus debilis*	Simple	Alternate	Elliptic or obovate	Obtuse	Acuminate	Entire	Unlobed	Herbaceous	Symmetrical
36	*Phyllanthus indofischeri*	Simple	Alternate	Lanceolate	Rounded	Acuminate	Entire	Unlobed	Herbaceous	Symmetrical
37	*Phyllanthus maderaspatensis*	Simple	Alternate	Obovate - oblanceolate	Cuneate	Obtuse	Entire	Unlobed	Herbaceous	Symmetrical
38	*Phyllanthus polyphyllus*	Simple	Alternate	Narrow ovate	Broadly convex	Acute	Entire	Unlobed	Herbaceous	Asymmetrical
39	*Phyllanthus reticulatus*	Simple	Alternate	Oblong-elliptic	Rounded	Obtuse	Entire	Unlobed	Herbaceous	Asymmetrical
40	*Phyllanthus urinaria*	Simple	Alternate	Linear-oblong	Acute	Acute	Entire	Unlobed	Herbaceous	Symmetrical
41	*Phyllanthus virgatus*	Simple	Alternate	Narrow obovate	Acute	Mucronate	Entire	Unlobed	Herbaceous	Asymmetrical
42	*Putranjiva roxburghii*	Simple	Alternate	Elliptic -oblong	Obtuse	Acuminate	Distantly serrulate	Unlobed	Coriaceous	Asymmetrical
43	*Tragia plukenetii*	Simple	Alternate	Ovate-lanceolate or oblong	Obtuse	Acute	Entire or serrate	Palmately three partite	Herbaceous	Symmetrical
44	*Vernicia fordii*	Simple	Alternate	Broadly ovate	Cordate	Acuminate	Entire or crenate	Unlobed	Herbaceous	Symmetrical

Table 1b

Sr. No.	Name of plant	Nature of the midvein on adaxial side	Primary vein size	Secondary veins, angle of divergence	Predominant tertiary vein origin angle	Marginal ultimate venation	Venation pattern
1	*Acalypha ciliata*	Elevated	Massive, curved	Acute narrow	RR, AO	Incomplete	Semi-craspedodromous
2	*Acalypha fruticosa*	Elevated	Moderate, straight	Acute moderate	RR, AO	Incomplete	Semi-craspedodromous
3	*Acalypha hispida*	Elevated	Weak, straight	Acute moderate	RR	Looped	Semi-craspedodromous
4	*Agrostistachys indica*	Grooved	Moderate, straight	Acute wide	AO, RA	Incomplete	Semi-craspedodromous
5	*Anda gomesii*	Grooved	Stout, curved	Acute wide	RO, AO	Fimbriate	Weak brochidodromous
6	*Aporosa lindleyana*	Elevated	Massive, straight	Acute wide	AR, RR	Looped	Brochidodromous
7	*Baliospermum solanifolium*	Elevated	Moderate, curved	Acute narrow	AA, RR, RA	Fimbriate	Semi-craspedodromous
8	*Breynia nivosa*	Slightly elevated	Massive, straight	Acute wide	AA, RR	Incomplete	Brochidodromous
9	*Breynia retusa*	Slightly elevated	Massive, straight	Acute moderate	AA	Incomplete	Brochidodromous
10	*Chrozophora prostrata*	Elevated	Massive, curved	Acute narrow	AA	Incomplete	Actinodromous
11	*Chrozophora rottleri*	Elevated	Stout, curved	Acute narrow	AA	Incomplete	Actinodromous
12	*Croton bonplandianus*	Grooved	Massive, curve	Acute moderate	AR	Incomplete	Brochidodromous
13	*Euphorbia fulgens*	Slightly elevated	Stout, straight	Acute moderate	AR, OO	Incomplete	Brochidodromous
14	*Euphorbia heterophylla*	Grooved	Massive, curved	Acute narrow	OA, RA	Incomplete	Brochidodromous
15	*Euphorbia indica*	Slightly elevated	Massive, straight	Acute moderate	AO, OA	Incomplete	Brochidodromous
16	*Euphorbia milii*	Slightly elevated	Massive, straight	Acute moderate	AO	Incomplete	Brochidodromous
17	*Euphorbia neriifolia*	Slightly elevated	Massive, curved	Acute narrow	AA	Incomplete	Weak brochidodromous
18	*Euphorbia tirucalli*	Slightly elevated	Massive, curved	Acute moderate	RA, AA	Incomplete	Reticulodromous
19	*Euphorbia umbellata*	Slightly elevated	Stout, curved	Acute moderate	AR,	Incomplete	Weak brochidodromous
20	*Flueggea leucopyrus*	Elevated	Massive, straight	Acute moderate	RR, AR	Incomplete	Brochidodromous
21	*Flueggea virosa*	Elevated	Stout, straight	Acute moderate	AR, RR	Looped	Brochidodromous
22	*Glochidion hohenackeri*	Slightly elevated	Massive, curved	Acute wide	AR, RR, RO	Looped	Brochidodromous
23	*Hevea brasiliensis*	Grooved	Moderate, straight	Acute moderate	RR, RA, AR	Looped	Brochidodromous
24	*Jatropha curcas*	Slightly elevated	Weak, straight	Acute moderate	AR, AA	Incomplete	Actinodromous
25	*Jatropha gossypiifolia*	Elevated	Weak, straight	Acute moderate	AR, AA	Incomplete	Actinodromous

26	*Jatropha integerrima*	Grooved	Stout, straight	Acute wide	AR	Incomplete	Brochidodromous
27	*Jatropha multifida*	Elevated	Weak, straight	Acute narrow	RA, AA	Incomplete	Actinodromous
28	*Jatropha podagrica*	Elevated	Stout, straight	Acute wide	AO, RA, RR	Incomplete	Actinodromous
29	*Mallotus nudiflorus*	Elevated	Weak, curved	Acute moderate	RR	Fimbriate	Brochidodromous
30	*Mallotus philippensis*	Slightly elevated	Weak, straight	Acute moderate	AO	Looped	Brochidodromous
31	*Manihot esculenta*	Slightly elevated	Weak, straight	Acute moderate	RO, AO, AR	Incomplete	Actinodromous
32	*Pedilanthus tithymaloides*	Grooved	Moderate, straight	Acute wide	AA	Incomplete	Brochidodromous
33	*Phyllanthus acidus*	Slightly elevated	Moderate, straight and curved	Acute moderate	AA, RR, AO	Fimbriate	Simple craspedodromous
34	*Phyllanthus airy-shawii*	Elevated	Massive, curved	Acute wide	RO, RA	Incomplete	Brochidodromous
35	*Phyllanthus debilis*	Slightly elevated	Massive, curved	Acute moderate	AA	Incomplete	Brochidodromous
36	*Phyllanthus indofischeri*	Slightly elevated	Massive, straight and curved	Acute moderate	RO, RR	Incomplete	Brochidodromous
37	*Phyllanthus maderaspatensis*	Slightly elevated	Weak , straight	Acute moderate	AA	Incomplete	Eucamptodromous
38	*Phyllanthus polyphyllus*	Slightly elevated	Massive, curved	Acute narrow	AR, RR	Incomplete	Brochidodromous
39	*Phyllanthus reticulatus*	Slightly elevated	Stout, straight	Acute moderate	AR	Incomplete	Brochidodromous
40	*Phyllanthus urinaria*	Elevated	Massive, stout	Acute narrow	AR	Incomplete	Brochidodromous
41	*Phyllanthus virgatus*	Elevated	Massive, straight	Acute moderate	AR, RO	Incomplete	Eucamptodromous
42	*Putranjiva roxburghii*	Elevated	Stout, straight	Acute moderate	AA	Incomplete	Brochidodromous
43	*Tragia plukenetii*	Elevated	Massive, curved	Acute narrow	RR	Incomplete	Actinodromous
44	*Vernicia fordii*	Elevated	Massive, curved	Acute narrow	AA, RR	Fimbriate	Simple craspedodromous

Abbreviations:

AA — Acute acute; AO — Acute obtuse; AR — Acute right; AO — Acute obtuse; OA — Obtuse acute; RA — Right acute; RO — Right obtuse; RR — Right right

Table-2. Numerical data on the venation pattern

Sr. No.	Name of plant	Leaf area in mm^2	No. of 2^o Veins along one side of mid-rib	Angle between $1^o + 2^o$ veins	No. of areoles per mm^2	Veins endings termination	Highest vein order (^{o})
1	*Acalypha ciliata*	0114.00	07	35^o -45^o	08.00	5	4^o
2	*Acalypha fruticosa*	1690.00	05	50^o - 60^o	03.80	4	4^o
3	*Acalypha hispida*	3373.00	09	45^o - 60^o	09.60	5	4^o
4	*Agrostistachys indica*	2150.00	07	60^o - 65^o	02.20	7	4^o - 5^o
5	*Anda gomesii*	1426.00	16	60^o - 70^o	04.80	5	5^o
6	*Aporosa lindleyana*	2506.00	10	60^o - 65^o	04.80	8	6^o
7	*Baliospermum solanifolium*	1554.00	07	50^o -60^o	09.40	4	5^o
8	*Breynia nivosa*	0291.30	06	50^o - 70^o	02.20	4	4^o
9	*Breynia retusa*	0072.00	08	45^o - 50^o	05.00	5	4^o
10	*Chrozophora prostrata*	0128.00	03	40^o - 45^o	06.40	3	3^o - 4^o
11	*Chrozophora rottleri*	0634.60	03	30^o - 40^o	08.60	2	3^o - 4^o
12	*Croton bonplandianus*	0133.33	11	50^o - 60^o	09.40	4	5^o
13	*Euphorbia fulgens*	0460.00	08	55^o - 60^o	02.40	5	5^o
14	*Euphorbia heterophylla*	0072.00	02	40^o - 45^o	01.60	4	5^o
		0198.00	09	40^o - 45^o	02.20	4	5^o
15	*Euphorbia indica*	0132.20	08	45^o - 50^o	03.80	2	5^o
16	*Euphorbia milii*	0234.00	08	50^o -60^o	03.80	6	5^o
17	*Euphorbia neriifolia*	0192.00	06	30^o - 40^o	08.20	6	5^o
18	*Euphorbia tirucalli*	0018.66	09	50^o - 60^o	07.80	5	5^o
19	*Euphorbia umbellata*	1530.00	12	35^o - 50^o	02.00	3	5^o
20	*Flueggea leucopyrus*	0288.00	06	40^o - 60^o	09.20	3	4^o - 5^o
21	*Flueggea virosa*	0846.00	08	40^o - 60^o	11.80	4	5^o
22	*Glochidion hohenackeri*	0448.00	07	50^o - 70^o	06.40	4	4^o
23	*Hevea brasiliensis*	2432.00	21	50^o - 55^o	03.80	4	4^o - 5^o
24	*Jatropha curcas*	1904.00	06	40^o - 45^o	09.40	7	4^o
25	*Jatropha gossypiifolia*	0526.60	11	50^o - 55^o	12.60	5	3^o - 4^o
26	*Jatropha integerrima*	0858.60	12	50^o - 60^o	05.60	6	3^o - 4^o
27	*Jatropha multifida*	2193.30	10	30^o - 40^o	06.60	5	3^o - 4^o
28	*Jatropha podagrica*	8700.00	09	60^o - 70^o	05.40	6	4^o
29	*Mallotus nudiflorus*	5846.00	06	40^o - 60^o	06.60	6	5^o
30	*Mallotus philippensis*	4070.00	10	40^o -55^o	09.00	7	5^o
31	*Manihot esculenta*	4806.00	13	50^o - 70^o	31.60	6	4^o
32	*Pedilanthus tithymaloides*	1708.00	10	50^o - 55^o	02.80	6	4^o
33	*Phyllanthus acidus*	3010.00	18	40^o - 50^o	09.80	2	4^o
34	*Phyllanthus airy-shawii*	0052.40	05	50^o - 70^o	02.80	2	4^o
35	*Phyllanthus debilis*	0032.26	06	50^o - 60^o	06.00	2	4^o
36	*Phyllanthus indofischeri*	0192.20	08	40^o - 60^o	07.00	2	4^o
37	*Phyllanthus maderaspatensis*	0089.33	07	35^o - 50^o	01.00	2	4^o
38	*Phyllanthus polyphyllus*	0300.00	06	35^o - 40^o	07.80	3	4^o
39	*Phyllanthus reticulatus*	0100.00	06	35^o - 50^o	03.60	4	4^o
40	*Phyllanthus urinaria*	0070.00	10	25^o - 40^o	02.00	3	4^o
41	*Phyllanthus virgatus*	0036.66	05	35^o - 45^o	26.80	3	3^o - 4^o
42	*Putranjiva roxburghii*	2085.30	12	50^o - 60^o	05.60	4	4^o
43	*Tragia plukenetii*	0442.00	08	30^o - 35^o	14.20	4	4^o
44	*Vernicia fordii*	1256.60	10	40^o - 50^o	05.00	3	4^o - 5^o

The areoles formation is mostly either with quaternary or quinternaries in all the taxa investigated. The areoles are variable in size and shape but imperfect in many species. They are well developed in certain taxa, e.g. *Aporosa*, *Mallotus nudiflorus*, *M. philippensis* and *Phyllanthus acidus*. The areoles are incomplete in *Acalypha fruticosa, Euphorbia heterophylla*, *E. umbellata*, *Phyllanthus airy-shawii*, while in *Chrozophora prostrata* and *C. rottleri* areoles are absent. The areoles may show veinlets and free vein endings. Sometimes areoles are devoid of veinlets as in *Euphorbia heterophylla* wherein most of the areoles are empty. The free vein endings end blindly in the mesophyll. In most of the plants, these have terminal tracheids, which may be uniseriate, biseriate or in groups. The free vein endings, isolated tracheids and extension cells are observed in a few plants. Foster[3] used the term tracheary idioblasts for dilated enlarged terminal tracheids at the vein endings, while the tracheoidal idioblasts are those that lie free and disjunct the areoles. Herbst[4], have reported the occurrence of isolated veins in *Euphorbia forbesii*. Sehgal and Paliwal[13] described the tracheidal elements lying free in the areole as 'free vein ending'. But there is no clear cut distinction between isolated veins, isolated free vein endings and isolated tracheids.

Sehgal and Paliwal[13] proposed a correlation between the loop formation in areoles and number of vein endings in species of *Euphorbia*. According to them, loop formation is a common feature in the areoles where there are few vein endings or none, the present study favours the above correlation as most of the taxa studied e.g. *Agrostistachys*, *Anda*, *Baliospermum*, *Breynia nivosa*, *B. retusa*, *Croton*, *Euphorbia fulgens*, *E. heterophylla*, *E. indica*, *E. milii*, *E. neriifolia*, *E. tirucalli*, *E. umbellata*, *Flueggea virosa*, *Jatropha gossypiifolia*, *J. podagrica*, *Mallotus nudiflorus* show loop formation where the areoles have less vein endings. Nwokocha *et al.*[11] also reported loop formation in the species of *Jatropha*.

Presence of bundle sheath is a diagnostic character in the presently investigated taxa. Bundle sheath is very well developed with parenchymatous anisodiametric cells on all the grades of veins and vein endings in *Euphorbia heterophylla*, *E. umbellata* and *Pedilanthus* whereas in *E. tirucalli*, and *Phyllanthus maderaspatensis* its associations ranges from secondary (2°) vein to quaternary (4°) vein. Kakkar and Paliwal[8] have recorded a conspicuous parenchymatous bundle sheath termed as 'ornamented' is present around the veins of all categories in *Euphorbia thymifolia*. Aldhebiani and Jury[1] also reported it on midrib and secondary veins in some species of *Euphorbia*. Webster *et al*.[14] noted jacketed venation in *Chamaesyce*. Levin[9] also recorded parenchymatous bundle sheath on higher order veins in majority of plant species of Phyllanthoideae (Euphorbiaceae).

Occurrence of sclerids around the veins is common in *Euphorbia umbellata* and *Fluggea virosa*. Crystals are present on the sides of primary veins in *Acalypha fruticosa*, *A. hispida*, *Chrozophora* and *Flueggea leucopyrus*.

The characters such as types of venation, marginal ultimate venation, bundle sheath, nature of areoles, tracheoids etc. can be employed for the taxonomic delineations of the taxa studied.

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