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LEAF VENATION ARCHITECTURE IN SOME AMARANTHACEAE

K. Narmada, S.R. Shanmukha Rao* and S. Padmini

Plant Anatomy & Taxonomy Laboratory, Department of Botany, Sardar Patel College, Padmaraonagar, Secunderabad – 500 025, India
*Corresponding author's e-mail: rshanmukh@hotmail.com

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ABSTRACT

In the present investigation, we have studied the leaf venation architecture (foliar venation characteristics) of eighteen taxa belonging to Amaranthaceae. The study suggests that that the following characters: major venation pattern, marginal venation, number of vein-lets per sq. mm, thickness of primary vein, number of 2^0 veins, nature of areole formation, highest vein order and terminal tracheids are quite helpful in the identification of the taxa belonging to plant family Amaranthaceae. Further, based on our detailed observations we hereby propose a key for the identification of taxa investigated.

Key-words: Amaranthaceae, Brochidodromous, Eucamptodromous, Leaf venation architecture, Pinnate camptodromous, Taxonomy.

INTRODUCTION

Many previous toxononic studies have emphasized the importance of leaf architecture in dicotyledons (Hickey 1973, Hickey & Wolfe 1975, Levin 1986, Ellis et al. 2009, Shanmukha Rao & Srinivas Rao 2015, Sita Ratnam & Shanmukha Rao 2015). The leaf venation patterns show remarkable diversity and species specificity (Fujita & Mochizuki 2006, Sack & Scoffoni 2013). Importance of leaf venation architecture has also been recognized across the domain of plant biology and ecology such as: distribution and productivity of ecosystems, and applications in palaeobiology, agriculture and technology (Sack & Scoffoni 2013). Previous studies on the leaf architecture of Amaranthaceae have been confined to a few species that too with few general features (Handro 1964, 1967, Larocha 1973, Banerjee 1980, Fisher & Evert 1982, Gavilians 1983, Shanmukha Rao & Narmada 1994, Fank-de-Carvalho & Graciano-Ribeiro 2005). Thus, in the present study we have investigated (in detail) foliar venation characteristics (leaf venation architecture) of eighteen taxa representing ten genera that include *Celosia argentea* L. var. *argentea* L., *C.argentea* var. *cristata* (L.) Kuntze, *C.polygonoides* Retz., *Achyranthes aspera* L., *A.bidentata* Bl., *Aerva sanguinolenta (L.)* Bl., *Amaranthus blitum* L., *Amaranthus caudatus* L., *Pupalia lappacea* (L.) *Juss.*var.*velutina* (Moq.) Hook.f, *Tricuriella. monsoniae* (L.f.) Bennet, *Alternanthera bettzickiana* (Regel) Voss, *A.dentata* Moench, *A.paronychioides* St. Hil., *A.philoxeroides* Mart., *Brayulinea densa* Small, *Iresine herbstii* Hook., *Iresine lendeni* Van Houtte, and *Tidestromia lanuginosa* (Nutt.) Standl, belonging of Amaranthaceae.

MATERIAL AND METHODS

All the taxa studied in the present investigation have been collected from various locations (refer Table 1,

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Table 1. Foliar venation characteristics in the Amaranthaceae.

S. No.	NAME OF THE TAXON	Source / Locality	Venation pattern	Nature of primary vein	NO.of 2^{0} veins on either side of midrib	Range of angle between 1^{o} & 2^{o}	Predominant tertiary vein origin angle	Highest degree of venation	No.of areoles per sq.mm	No. of veinlets entering in areoles per sq.mm	Vein endings per sq.mm
1	*Celosia argentea* L. var.*argentea* L.	Hyderabad	mixed brochido-duomous	massive	4-6	acute	RR.RO	5^{0}	9.4	3.3	10.8
2	*C.argentea* var. *cristata* (L.) Kuntze	Hyderabad	mixed brochido-duomous	stout	8-10	acute	RR.AR	6^{0}	2.0	0.9	5.2
3	*C.polygonoides* Retz.	Ananthapur	mixed brochido-duomous	massive	4-6	acute	RR,RA	6^{0}	5.5	3.5	9
4	*Achyranthes aspera* L.	Hyderabad	weak brochido-dromous	weak	6-8	acute	AA,AR,RR	6^{0}	3.5	0.7	3.7
5	*A.bidentata* Bl.	Tiruchira-palli	mixed brochido-duomous	moderate	4-5	acute	RR.AR	6^{0}	1	0.5	1.8
6	*Aerva sanguinolenta (L.)* Bl.	Gujarat	weak brochido-dromous	weak	4-5	acute	RR,.RO	5^{0}	15.8	4.4	11.6
7	*Amaranthus blitum* L.	Hyderabad	weak brochido-dromous	moderate	6-8	acute	RR,AR	5^{0}	3.1	1.5	8.8
8	*Amaranthus caudatus* L.	Hyderabad	eucampto-dromous	massive	10-12	acute	RR,AR	6^{0}	5.7	2.8	13
9	*Pupalia lappacea* (L.) *Juss.*var.*velutina* (Moq.) Hook.f	Hyderabad	weak brochido-dromous	stout	10-12	acute	RR.AR	6^{0}	1.5	1.1	6.6
10	*Tricuriella. monsoniae* (L.f.) Bennet	Hyderabad	simple brochido-dromous	massive	–	acute	–	3^{0}	0.64	0	4
11	*Alternanthera bettzickiana* (Regel) Voss	Hyderabad	mixed brochidodromous	stout	5-6	acute	AO,AR	5^{0}	1.1	1.4	6.9
12	*A.dentata* Moench	Hyderabad	mixed brochido-dromous	stout	6-8	acute	AA.RR	5^{0}	1.2	0.2	2.1
13	*A.paronychioides* St. Hil.	Tiruchira-palli	mixed brochido-dromous	stout	5-6	acute	AR,RR	5^{0}	2.2	0.8	7.8
14	*A.philoxeroides* Mart.	Hyderabad	simple brochido-dromous	stout	8-10	Acute	AR.RR	5^{0}	1.7	0.8	4.8
15	*Brayulinea densa* Small	Gothenberg	simple brochido-dromous	weak	3-4	acute	RA.RR	5^{0}	8.1	5	13.4
16	*Iresine herbstii* Hook.	Hyderabad	mixed brochidodromous	moderate	5-6	acute	RR.RA	5^{0}	0.4	0.1	1.6
17	*Iresine lendeni* Van Houtte	Hyderabad	mixed brochido-dromous	moderate	5-6	acute	RR.RA	5^{0}	0.4	0	1.5
18	*Tidestromia lanuginosa* (Nutt.) Standl	Gothenberg	simple brochido-dromous	stout	3-4	acute	AR.RA	5^{0}	9.4	8	19

Note: Marginal ultimate venation is fiimbriate in all the taxa except *Celosia polygonoides* which shows an incomplete margin.

this article). Mature leaves were cleared following Thakur (1988) and Narmada & Shanmukha Rao (1994). For the terminology of venation we follow Hickey & Wolfe (1975), Levin (1986) and Narmada & Shanmukha Rao (1994).

RESULTS AND DISCUSSION

Leaf pattern(s)

The plants belonging to family Amaranthaceae have simple alternate or simple opposite leaves. The leaves of Amaranthaceae are highly variable in shape, apex and base with the leaf margin being entire and the texture being chartaceous or membranous.

Venation pattern(s)

Previous studies on the leaf architecture of Amaranthaceae have been confined to major venation patterns that too limited to a few species. According to these studies, the venation patterns observed were pinnate camptodromous (Handro 1964, 1967), festooned brochidodromous (Banerjee 1980), eucamptodromous (Fisher & Evert 1982) and/or simple, weak and mixed brochidodromous (Shanmukha Rao & Narmada 1994). In the present study, we observe that the Pinnate camptrodromous (= secondary veins not terminating at the margin) is the main venation pattern in the Amaranthaceae as has been noted in previous works (Shanmukha Rao & Narmada 1994). In addition, we also witness that Brochidodromous (= secondaries joined together in a series of prominent arches) and eucamptodromous (= secondaries upturned and gradually diminishing apically without forming prominent marginal loops) patterns of the camptrodromy.

On the basis of studies on foliar morphology of Phyllanthoideae, Levin (1986) recognized brochidodromy into two i.e., simple brochidodromous (= festooned brochidodromous of Hickey and Wolfe 1975) and weak brochidodromous patterns (= ascending brochidodromous of Hickey & Wolfe 1975). In the former, secondary loops end abruptly and are accompanied by outer loops. These loops are formed by the well differentiated secondary, tertiary and quaternary veins whereas in the weak brochidodromous pattern, the secondary loops are accompanied by additional loops that gradually decease in size and merge into tertiary loops. In the present investigation, simple as well as weak brochidodromous patterns have been observed (Table 1). Further, a new pattern called mixed brochidodromous pattern, recognized earlier (Shanmukha Rao & Narmada 1994) has also been observed in the present study (Table 1). A mixed brochidodromous pattern is unique in the sense that it shows both simple and weak brochidodromous patterns in the same leaf with the proximal part of the leaf showing weak brochidodromous while the distal part showing simple brochidodromous patterns. This pattern is named as mixed brochidodromous under pinnate camptodromous type (Shanmukha Rao & Narmada 1994). Interestingly, in the present investigation, nine taxa out of eighteen show a mixed brochidodromous pattern while four taxa display simple as well as weak brochidodromous patterns (Table 1). Further, we observe that eucamptodromy is exclusive to *Amaranthus caudatus* (Table 1).

Considering the patterns of major venations, Primary vein (1^0) is the thickest vein of the leaf. It is usually straight. Based on the thickness, the primary vein is characterized as massive, stout, moderate or weak; however, the thickness of the primary vein decreases gradually towards the apex. Secondary veins (2^o) range in number from 3-12 on either side of the primary vein and uniformly diverge at a moderate acute angle from the primary vein. Apart from the two taxa *Trichuriella monsoniae* and *Alternanthera bettzickiana* where intersecondaries were found to be completely absent, these veins occur frequently in all the other taxa observed in the present investigation. Where present, the intersecondaries are intermediate in thickness between the veins of second and third order and arise from the primary vein. They are of composite nature and interspread among the secondary veins. Their length is shorter than that of the secondary veins and their course is parallel to the secondary veins. Tertiary veins (3^0) are generally characterized into three types i.e., ramified, reticulate and percurrent (refer Hickey 1973). In the present investigation on Amaranthaceae, the latter two types have been observed. The leaves of the majority of the taxa studied in the present work show percurrent pattern, however, leaves of four taxa (*Alternanthera bettzickiana, A. paronychioides, Iresine lendeni* and *Tridestromia lanuginosa*) show random reticulate pattern while that of three taxa (*Amaranthus caudatus, Alternanthera philoxeroides* and *Brayulinea densa*) depict an orthogonal reticulate pattern (refer Table 1, this article).

Considering the observations on minor venations within Amaranthaceae taxa studied here, the quaternary veins (4^0) are always thin and their course is found to be orthogonal. We also observe that the quaternary veins form areoles in some of the taxa studied (refer Table 1, this article). The 5^0 and 6^0 veins constitute the highest order of venation in majority of the taxa studied and form aeroles (Table 1). However, in *Trichuriella monsoniae*, veins are recognizable only up to tertiary veins (Table 1). Areoles are formed with quaternaries (Plate 1D), or 6^o veins with the shape of the areoles being either quadrangular (Plate 1D, G, H), pentagonal or polygonal (Plate1G, H). In addition, the areoles are well developed (Plate 1G, H), incompletely developed (Plate1D) or imperfectly developed. Further, loop formation is commonly observed in all the taxa studied in the present work. We also note that the variations in the shape and size of the areoles, number of veinlets per areole are not confined to different taxa but are also observed in the same leaf (i.e, within same taxon). In the present study we found no correlation between the size of areole and number of veinlets and vein endings per areole. Considering veinlets, simple (linear or curved) (Plate 1H,E,D) as well as once or twice branched veinlets are observed and appear to be taxonomically insignificant. Isolated tracheids have been observed in *Alternanthera paronychioides* (Plate1A) and *A. bettzickiana*. The isolated tracheids lie in areoles and completely surrounded by bundle sheath cells.

Interestingly, in the context of vein termination patterns, the cells terminating the veins are found to show considerable variation and following Tucker's (1964) characterization of veinlet terminations as tracheoidal elements, conventional tracheids, dilated tracheids, reticulate walled tracheids, terminal sclereids and secretary cells, we observe that conventional and dilated tracheids are present in the Amaranthaceae taxa studied in the present investigation. Conventional tracheids are witnessed in *Celosia argentea* var. *argentea, C.argentea* var. *cristata, C. polygonoides, Achyranthes aspera, A. bidentata* and *Iresine lendeni*, whereas dilated tracheids are present only *in Aerva sanguinolenta, Trichuriella monsoniae, Brayulinea densa, Tridestromia lanuginosa and Pupalia lappacia*. The remaining taxa show both the conventional as well as dilated tracheids. The dilated tracheids are known to be useful in the storage of water (Haberlandt 1914, Pant & Bhatnagar 1977) or providing mechanical support (Mohan & Inamdar 1984). The dilated tracheids vary greatly in their shape. They are linear, isodiametric or ovate. Further, they are uniseriate, biseriate, juxtaposed, superposed or multiseriate. In the present investigation, tracheids in groups or clusters have been observed in *Alternathera paronychioides* while dilated tracheids associated with veins have been observed in *Tidestromia lanuginosa and Pupalia lappacea*.

In the present work, we also observe that the majority of the taxa studied show fimbriate margin (= higher vein orders fused into a vein running just inside the margin), except *Celosia polygonoides* that has an incomplete ultimate venation (refer Table 1, this article). We believe that this character is useful in segregating this member from the rest of the taxa studied here and thus has been used in the key proposed in the present work (further refer section "taxonomic importance", this article).

It should be noted that Sphaerocrystals are associated with all the degrees of veins in *Celosia argentea* var. *argentea* (Plate 1I) however, in *Celosia polygonoides*, they have been observed along with primary, secondary and tertiary veins.

Bundle sheath encircles the primary as well as lateral veins in all the taxa except *Achyranthes aspera* and *A. bidentata*. It is also distinctly observed in the leaf architectural preparations but appears to be indistinct in *Celosia argentea* var. *argentea, C. argentea* var. *criatata, C. polygonoides, Iresine lendeni* and *I. herbstii*.

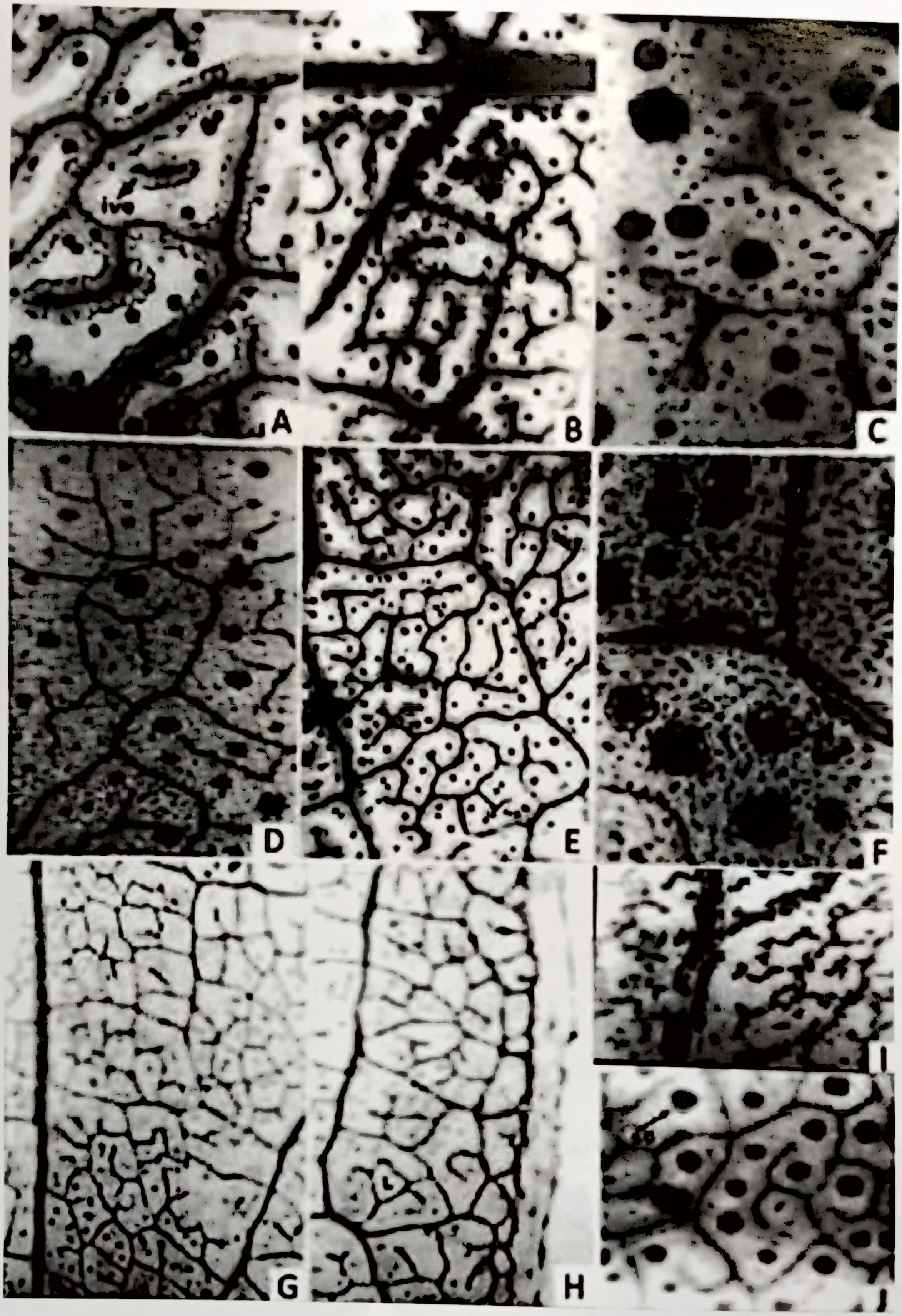

PLATE 1

A. *Alternanthera paronychioides*, isolated vein endings, x144. **B.** *A. paronychoides*, primary vein stout, x58. **C.** *Amaranthus blitum*, multiseriate dilated tracheids, x190. **D.** *Alternanthera bettzickiana*, Y' shaped vein ending, x58. **E.** *Alternanthera polygonoides*, polygonal areoles, x45. **F.** *Pupalia lappacea* var. *velutina*, veins associated with dilated tracheids, x189. **G.** *Aerva sanguinolenta*, areoles with quaternaries and well developed, x60. **H.** *Aerva sanguinolenta*, Marginal ultimate venation fimbriate, x58. **I.** *Celosia argentea var.argentea*, sphaerocrystals in association with veins, x54. **J.** *Amaranthus caudatus*, 'T' shaped veinlet, x 98.

Taxonomic importance

The present study on the leaf venation architecture of the eighteen taxa belonging to Amaranthaceae (refer Table 1, this article) suggests that the following characters: major venation pattern, marginal venation, number of vein-lets per sq. mm, thickness of primary vein, number of 2^0 veins, nature of areole formation, highest vein order and terminal tracheids are quite helpful in the identification of the taxa belonging to this plant family. Therefore, based on the above observations (refer section "results and discussion", this article) we hereby propose a key for the identification of the Amaranthaceae.

1. Venation pattern pinnate eucamptodromous ... *Amaranthus caudatus*
1. Venation pattern pinnate brochidodromous
2. Venation pattern pinnate simple brochidodromous or weak brochidodromous
3. Venation pattern simple brochidodromous
4. Higher vein order 3^0... *Trichuriella monsoniae*
4. Higher vein order 5^0
5. Bundle sheath inconspicuous... *Alternanthera philoxeroides*
5. Bundle sheath conspicuous
6. Primary vein stout; veins associated with dilated tracheids ... *Tidestromia lanuginosa*
6. Primary vein weak; veins not associated with dilated tracheids ... *Brayulinea densa*
3. Venation pattern weak brochidodromous
7. Areoles imperfect; multiseriate dilated tracheids present ... *Amaranthus blitum*
7. Areoles well developed; multiseriate dilated tracheids absent
8. Primary vein stout; Dilated tracheids associated with veins present ... *Pupalia lappacea* var. *velutina*
8. Primary vein weak; Dilated tracheids associated with veins absent
9. Bundle sheath and terminal tracheids present ... *Aerva sanguinolenta*
9. Bundle sheath and Terminal tracheids absent ... *Achyranthes aspera*
2. Venation pattern mixed brochidodromous
10. Isolated vein endings present
11. Areoles imperfect; Inter secondaries present ...... *Alternanthera paronychioides*
11. Areoles incomplete; Inter secondaries absent ... *Alternanthera bettzickiana*
10. Isolated vein endings absent
12. Marginal ultimate venation incomplete ... *Celosia polygonoides*
12. Marginal ultimate venation fimbriate
13. Highest vein order 5°
14. Primary vein massive or stout
15. Primary vein massive; veins associated with spherocrystals ... *Celosia argentea* var. *argentea*
15. Primary vein stout; veins not associated with sphaerocrystals ... *Alternanthera dentata*
14. Primary vein moderate
16. Tertiary vein shows per current pattern... *Iresene herbstii*
16. Tertiary vein shows random reticulate pattern... *Iresene lendeni*
13. Highest vein order 6°
17. Bundle sheath absent ... *Achyranthes bidentata*
17. Bundle sheath present ... *Celosia argentea* var. *cristata*

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