Foliar Micromorphologic Features for Climatic Stress Impact Assessment

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***Abstract*: Foliar epidermal features of seven species of Acanthaceae grown in natural habitat (control) and in areas of environmental stress were analysed using micromorphological and histochemical characters. The parameters include size of stomata, size of epidermal cells, and size of cystolith, palisade ratio, stomatal frequency and stomatal index. Histochemical localisation of starch indicated abnormalities in stomatal complex under environmental stress. How ever, mesogenous stomatal complex though a vegetative entity is least deviated by the environmental stress; can be considered as reliable as any other conservative taxonomic character for delimiting Acanthaceae. Length and breadth of stomata, epidermal cell and cystolith were analysed on the basis of student's t test. In majority of cases, significant variations were obtained. In the plants grown under environmental stress when tested with chi square, no significant change was observed for palisade ratio and stomatal index. Stomatal frequency showed significant variation under enviromnteal stress, except in Strobilanthes ciliatus. Justicia gendarussa appears to be the most tolerant species while Justicia betonica and Ruellia tuberosa are highly susceptible to environmental stress.**

***Keywords*: Micromorphology, Histochemistry, climatic stress**

1. Introduction

The effect of climaticstress on plants has been known for long and several incidents of environmental ill effects have started gaining the attention of botanists. Jacobson and Hill (1970) have provided a pictorial atlas based on external symptoms to recognise different damage patterns due to air pollution. Heck, Tailor& Heggestard (1973) and Heath (1980) reviewed the plant damage due to air pollution. Cutter (1978) mphasised the importance of epidermis as it is the tissue that is in direct contact with the environment which is subjected to structural modifications by various atmospheric factors. Investigations of Walker & Dunn (1967); Sharma & Dunn (1968, 1969); Sharma (1972, 1977); Sharma & Tyree (1973); Sahu & Santra (1989) Panday (1990) and Prasad and Inamdar (1990)Cárcer et al.,(2017), Drack & Vázquez (2018), Oliveira (2013) Shahid et al., (2017), and Wuyts et al., (2015), have increased the awareness regarding this problem.

Patel & Devi (1985) are of opinion that a comparison of the histochemical localization of metabolites such as starch, insolublepolysaccharides and lipids in the normal and polluted leaves give a clear vision of the physiological status of the plant. The present study aims at a better understanding of the structural as well as histochemical variations due to environmental stress. An effort is also made to find out the parameters which are least deviated by the environmental stress.

2. Methodology

The effect of environmental stress is studied in the following seven species of plants under study.

(1) EcboliumlinneanumKurz var. laetevirens
(2) EranthemurncapenseL.
(3) JusticiabetonicaL.
(4) J.gendarussa Burm.f.
(5) Rhinacanthus communis Nees
(6) RueiliatuberosaL.
(7) StrobilanthesciliatusNees

The parameters viz, stomatal size, epidermal cell size, size of the cystolith, Stomatal Index, stomatal frequency and palisade ratio are recorded for both control plants from natural habitat and samples from areas of environmental stress. Histochemical characterisation of stomatal complex was done through localisaiton of startch with I_2 KI solution (Jensen, 1962). P_1represents plants of natural habitat (control) and P_2 represents plants grown with environmental stress. The significance of variation is statistically analysed with the help of chai squre test, students t test and percentage of variation.

3. Results

3.1. Structural variations

In normal plants from natural habitat, the anticlinal walls of the epidermis show undulations in all the seven species. In plants grown with environmental stress either the degree of undulation is reduced as in the case of EranthemumcapenseL. (Pl. 1, Fig. K) or the sinuous walls become straight as in StrobilanthesciliatusNees., II B (Pl. 1, Fig. B).The typical diallelomesogenous stomata of Acanthaceae is observed in all the species from natural habitat and polluted environment. In samples from plants grown with environmental stressno major change occurs m the morphology of mature stomatal complex. However a reduction in the size of the stomata and subsidiary cells is usually met with in the leaves from stress induced habitat

(Pl. 1, Figs. B,H). In addition to this, stomatal abnormalities like arrested development (Pl. 1, Figs. C.F.K), stomata with single guard cell (Pl. 1, Figs.E) and stomata with aborted or degenerated guard cells (Pl. 1, Fig. H) are frequently recorded in leaves from stress induced habitat. Such abnormal stomatal types are of rare occurrence in the samples from non-polluted environment and their frequency is also insignificant.The difference in the size of epidermal cells, stomata and cystolith of the controll and stress inducedsamples is charted in Table 1. The comparative observations regarding the Stomatal Index, stomatal frequency and palisade ratio are given in Table 2.Among the plants of the natural habitat, the length of the stomata ranges from 14.52 µm(S.ciliatus Nees) to 45.65µm(E.Iinneanum Kurz var.laetevirens), whereas 'the Stomatal length of the taxa from polluted area varies from 12.50 µm (S. ciliatus Nees) to 38.97 µm. (J.gendarussa Burm.f.).

Table 1. Effect Of Environmental Stress On Foliar Epidermis

Data On The Size Of Stomata Epidermis And Cystolith

SPECIES		Stomata *		Epidermis *		Cystolith *	
		L	B	L	B	L	B
Ecbolium linneanum Kurz. var. laetevirens	P_1	45.65 ± 1.5740	22.72 ± 2.0990	66.8 ± 5.9012	36.520 ± 1.3640	126.92 ± 1.3640	45.64 ± 2.8381
	P_2	36.250 ± 0.7880	17.26 ± 0.7886	50.25 ± 2.2000	25.0 ± 1.6801	74.60 ± 3.4315	31.73 ± 0.3274
Eranthemum capense L.	P_1	42.31 ± 0.7898	25.60 ± 1.5750	104.37 ± 4.2982	50.10 ± 8.3520	313.38 ± 2.759	24.39 ± 1.4400
	P_2	31.17 ± 2.0820	21.15 ± 2.0840	68.75 ± 6.2560	36.25 ± 3.7517	107.99 ± 0.8037	23.38 ± 0.8900
Justicia betonica L.	P_1	42.31 ± 1.4808	33.96 ± 0.7846	43.83 ± 3.8921	30.89 ± 2.5600	287.80 ± 3.4340	41.76 ± 0.6588
	P_2	25.05 ± 1.3645	1 5.58 ± 0.7898	28.48 ± 2.4607	22.24 ± 2.16	156.42 ± 2.0092	24.49 ± 2.0829
J. gendarussa Burm.f.	P_1	41.19 ± 0.7876	24.49 ± 0.7894	140.46 ± 3.2901	70.97 ± 4.2612	60.53 ± 1.0880	17.69 ± 1.3600
	P_2	38.97 ± 0.7879	21.71 ± 1.3650	132.15 ± 1.3901	58.86 ± 3.1618	59.28 ± 0.9275	15.03 ± 1.3638
Rhinacanthus communis Nees	P_1	35.63 ± 1.5740	26.16 ± 1.5745	139.76 ± 5.7124	60.1 ± 2.6742	192.04 ± 0.6678	25.88 ± 1.6760
	P_2	24.49 ± 2.0837	20.60 ± 0.7890	90.84 ± 2.3450	43.27 ± 3.4210	116.90 ± 0.6818	23.38 ± 1.3651
Ruellia tuberosa L.	P_1	42.86 ± 2.3710	21.15 ± 0.8736	120.63 ± 6.0864	69.71 ± 4.1771	168.67 ± 2.7258	27.83 ± 2.1290
	P_2	26.16 ± 0.8887	15.58 ± 2.0840	70.64 ± 7.6902	40.16 ± 1.6770	119.68 ± 2.9510	20.04 ± 2.6047
Strobilanthes ciliatus Nees	P_1	14.52 ± 0.7758	8.71 ± 0.5507	104.0 ± 4.8208	51.35 ± 4.3440	854.87 ± 1.8391	82.26 ± 3.3352
	P_2	12.50 ± 0.3106	7.37 ± 0.5542	67.6 ± 4.3406	33.15 ± 2.7612	426.88 ± 2.5446	57.36 ± 2.0174

* All measurements are in microns; L – Length;B – Breadth; P_1- From plants of natural habitat (Control)P_2- From plants grown with environmental stress

The breadth of the stomata from non-polluted samples varies from 8.71 µmJ. betonicaL.).In the polluted environment, the stomatalbreadth ranges from 7.37 µm(S.ciliatus) to 21.71µm. (J. gendarussa Burm.f.).Themaximum stomatal frequency among the taxa under study is reported in Rhinacanthus communis Nees both from control and (160.00/mm^2) and stress induced (196.00/mm^2) environment. The minimum value of stomatal frequency from stress induced and natural habitat is recorded in EranthemumcapenseL.(84.00/mm^2). From the stress induced samples under study, the lowest stomatal frequency is observed in StrobilanthesciliatusNees., (93.61 /mm^2).Fromthe control taxa under study, the maximum valueof Stomatal Index is reported for RuelliatuberosaL., (23.95) and the lowest being 17.13 in J. betonicaL. Among theplants fromstress induced environment, the Stomatal Index ranges from 17.74 (EranthemumcapenseL.) to 26.31 (RuelliatuberosaL.).

Table 2. EFFECT OF ENVIRONMENTAL STRESS ON FOLIAR EPIDERMIS					
Data on Palisade Ratio, Stomatal Frequency and Stomatal Index					
Species		Palisade Mean	Ratio Range	Stomatal Frequency/mm^2	Stomatal Index
Ecbolium linneanum Kurz. var. laetevirens	P_1	4.10	(3.0 - 5.0)	96.00	15.81
	P_2	4.00	(3.25-4.75)	105.88	18.76
Eranthemum capense L.	P_1	11.90	(9.0 -13.75)	84.00	15.96
	P_2	1 1.66	(10.0 -14.0)	102.90	17.74
Justicia betonica L.	P_1	6.33	(5.50 - 7.50)	148.00	17.13
	P_2	6.00	(5.00 - 7.00)	172.00	19.95
J. gendarussa Burm.f.	P_1	7.05	(6.25 - 8.25)	129.66	19.50
	P_2	7.01	(6.0 - 7.75)	135.30	20.10
Rhinacanthus communis Nees	P_1	5.70	(4.50 - 7.50)	160.00	20.95
	P_2	5.66	(4.50 - 6.50)	196.80	24.56
Ruellia tuberosa L.	P_1	16.50	(13.00-17.25)	136.00 .	23.95
	P_2	14.43	(12.75-17.00)	192.00	26.31
Strobilanthes ciliatus Nees	P_1	10.20	(8.00 - 12.00)	88.00	15.74
	P_2	9.25	(8.00 - 9.75)	93.61	18.95

P_1- From plants of natural habitat (Control); P_2- From plants grown with environmental stress

The size of the epidermal cells showsconsiderablevariationswith respect to different taxa. Among the control species understudy, the maximum length of epidermal cells noted is 140.46µm(J. gendarussa Brum.f.) while the minimum value is 43.83 µm (J. betonicaL.). In the stress induced area, the length of the epidermal cells varies from 28.48 µm. J.betonicaL.) to 132.15 µm (J. gendarussaBurm.f.). In normal plants, the breadth of the epidermal cells ranges from 30.89 µm(J. betonicaL.) to 70.97 µm (J.gendarussa Burm.f.),while the stress induced taxa give a variationfrom 22.24µm (J. betonicaL.) to 58.86 µm (J. gendarussa Burm.f.).

Both in control and stress induced materialsunder study, the sizeof the cystolith varies with species. In taxa from natural area thelength of thecystolith gives a minimumvalueof 60.53 µm inJ. gendarussaBurm.f. and a maximum value of854.87 µm inS.ciliatus Nees. The length of cystolith in stress induced samples varies from59.28 µm.J gendarussaBurm.f.) to 426.88 µm. (S.ciliatus Nees). From the plants of control area the lowest value for the breadth of cystolith is recorded inJ. gendarussa Burm.f.(17.69 µm)andthehighest being 82.26 µm., as in S. ciliatus Nees, The leaves from stress induced environment show a difference in the breadth of the cystolith ranging from 15.03 µm. J. gendarussa Burm.f.) to 57.36 µm (S.ciliatus Nees).Among the taxa investigated, the highest value of palisade ratiois recorded forRuelliatuberosa L., bothfor natural and (16.50 µm) and stress induced (14.43) materials. The lowest value of palisaderatio is represented by Ecboliumlinneanum Kurz var. laetevirensand the mean palisade ratio values of the species from the control and stress induced area being 4.10 µm and 4.00 µm respectively.

3.2. Distribution of starch

When tested with I_2 -KI, starch grainsappear blue-black in colour, and in all the samples they are confined to the guard cells. The stomata from normal healthy show the presence of large globular starch grains (Pl. 1, Figs- A,D,G,J,L). Stress induced samples are characterised by stomata having ill-formed starch grais which are found to be reduced (PI. 2, Figs.E,H) when compared with that of the control samples. In abnormal stomata the cytoplasm of the stomatocyte appears to be filled with amorphous blue-black fluid (Pl. 1, Figs. F,I,K) indicating the presence of starch. However the grain formation is found to be arrested m such cases.

3.3. Statistical analysis

Data on the different parameters under study were subjected to statistical analysis to find out the significance of variation (Table 3).

Table 3. SIGNIFICANCE OF VARIATION OF THE EPIDERMAL FEATURES OF PLANTS FROM NATURAL HABITAT AND PLANTS GROWN WITH ENVIRONMENTAL STRESS

Computed t test and chi square (χ^2) values

SPECIES	Size of stomata*		Size of epidermal cells*		Size of cystolith*		Palisade ratio**	Stomatal frequency**	Stomatal Index**
	L	B	L	B	L	B			
Ecbolium linneanum Kurz. var. laetevirens	8.36	4.22	4.55	10.06	24.54	8.43	0.0122	5.0841	2.7522
Eranthemum capense L.	8.67	2.95	8.13	2.62	123.79	1.03	0.0242	21.2625	0.9926
Justicia betonica L.	14.85	28.59	5.77	4.77	57.20	13.70	0.0860	19.4595	2.3292
J. gendarussa Burm.f.	3.45	3.05	4.03	3.95	1.51	2.39	0.0011	1.2267	0.0923
Rhinacanthus communis Nees	7.39	5.47	13.72	6.72	146.05	2.00	0.0014	42.3200	3.1103
Ruellia tuberosa L.	11.42	4.27	8.83	11.37	22.56	4.01	1.2085	115.2941	1.1628
Strobilanthes ciliatus Nees	4.19	2.97	9.72	6.12	236.11	11.06	0.4424	1.7882	3.2732

* Computed t test values; ** Computed chi square test values; L – Length; B - Breadth

3.3.1. Students 't' test

The length and breadth of stomata, expidermal cells and cystolith under normal and polluted conditions were analysed on the basis of students 't' test. In the majority of cases, significant variations were obtained for each parameter. Under polluted conditions, the changes appeared to be insignificant in the following cases.

(a) Breadth of the epidermal cell in **E.** capense L.
(b) Length of the cystolith in J. gendarussa J Burm.f.
(c) Breadth of the cystolith in J.gendarussa Burm.f. andR.communisNees.

3.3.2. Chi-square test(χ^2 test)

The parameters such as palisaderatio, stomatal frequency and Stomatal Index under natural and stress induced conditions were tabulated by this method. No significant change occurred in the palisade ratio and Stomatal Index.

Onthe contrary, stomatal frequency showed significant variation under pollution stress, except for S.ciliatus Nees (Table 3).

The study exemplifies well the fact that Stomatal Index and palisade ratio are more reliable than other criteria such as stomatal frequency, size of epidermal cells, size of stomata and size of cystolith.

3.3.3. Percentage of variation

The percentages of variation in the epidermal features were tabulated (Table 4). The variations in the length and breadth of stomata are maximum in J. betonica L., and minimum in J. gendarussaBurm.f.

Table 4. PERCENTAGE OF VARIATION OF THE EPIDERMAL FEATURES OF PLANTS FROM NATURAL HABITAT AND PLANTS GROWN WITH ENVIRONMENTAL STRESS

Species	%of variation in the size of the stomata		%of variation in the size of the expidermis (L& B)		%of variation in the size of the cystolith (L& B)		%variation in palisade ratio	%of variation stomatal frequency	%of variation - stomatal index
	L	B	L	B	L	B			
Ecbolium linneanum Kurz. var. laetevirens	-20.29	-24.03	-24.77	-33.45	-41.22	-30.47	-2.43	10.29	24.98
Eranthemum capense L.	-26.32	-17.38	-34.12	-27.64	-65.54	-4.14	-2.01	22.50	11.15
Justicia betonica L.	-40.79	-54.12	-35.02	-28.00	-45.64	-41.35	-5.21	16.21	16.46
J. gendarussa Burm.f.	-5.38	-11.35	-5.91	-17.06	-2.07	-15.36	-0.56	4.34	1.50
Rhinacanthus communis Nees	-31.26	-21.25	-35.00	-28.00	-39.12	-9.65	-0.70	23.00	17.23
Ruellia tuberosa L.	-38.96	-26.33	-41.39	-42.38	-29.04	-27.99	-12.54	41.17	9.85
Strobilanthes ciliatus Nees	-13.91	-15.38	-35.23	-35.44	-50.06	-30.26	-9.31	6.37	20.39

L – Length; B – Breadth

The increase in the Stomatal Index is maximum in S. ciliatus Nees and is minimum in J. gendarussa Burm.f. Regarding the stomatal frequency, minimum deviation is observed in J. gendarussa Burm.f., while the maximum deviation is encountered in R. tuberosa L.The mean palisade ratio value of J. gendarussa is least deviated bythe stress from pollution while the percentage of variation is maximum in R. tuberosa L. The later species is also characterised by the maximum deviation in the size of the epidermal cells. The epidermal cells of J. gendarussa Burm.f. show minimum deviation due to environmental stress. In S. ciliatus Nees., the cystolith shows maximum deviation in length. The percentage of variation in the length of cystolith is minimum in J. gendarussa. With regard to the reduction in the breadth of the cystolith, maximum variation is shown by J.betonicaL., while R. communis Nees, shows minimum variation.The study indicates that, of the seven species under study, J. gendarussaBurm.f., appears to be the most tolerant species while J. betonica L., and R. tuberosa L., are highly susceptible to environmental stress.

4. Discussion

Mansfield (1973) reports that stomata provide the main route of entry for pollutants into the plant and they play a leading role in determining the overall response of plants to aerial pollutants. In the present study, the main pollutants that cause structural variations in the foliar epidermis may be H_2S and acidic fumes from the chemical laboratory and automobile exhausts from the roads. The present comparison of the epidermal features of stress induced and samples from natural habitat generally indicates a reduction in the size of stomata, epidermal cells and cystoliths. While stomatal frequency and Stomatal Index increase, palisade ratio values show insignificant changes.Jafariet. al., (1979); Chakrabarthy & Gupta (1981) and Inamdar & Chaudhary (1984) have shown that stomatal frequency increases due to environmental pollution. The present work is in agreement with this view. The increase in the Stomatal Index due to pollution is already established in the species of Acanthaceae viz. Peristrophebicalycuiata Nees (Inamdar & Chaudhary l.c). This holds truefor all the taxa under study.With regard to the size of the cystolith, the length decreases in all the taxa investigated.Inamdar **&** Chaudhary (l.c.) havegiven a controversial report that the length of the cystolith increases due to pollution. However, the pollutants differ in these twocases. Patel & Devi (1985) are of opinion that the effect of pollution on foliar epidermis varies with species.In order to obtain a comparative measure of the variation of epidermal features of different taxa under stress from pollution, the significance of variation was statistically analysed, percentage of variation was also calculated.

Reports of Ahmed (1964) and Ahmad & Yunus (1981) have revealed thatabnormal stomata are present in Acanthaceae and other gamopetalous families. Besides, publications of Chaphekar & Karbhari (1974), Bull & Mansfield (1974), Srivastava et al, (1975) and Capron &Mansfield (1976) have shown that when plants are exposed to Sulphur dioxide and Nitrogen dioxide, there is a reduction in the photosynthetic activity. The increased number of stomatal abnormalities, reduction in the size of mature stomata, reduction in the number and size of starch grains in the polluted plants and the arrested starch grain formation in abnormal stomata, indicate the decrease in the efficiency of the metabolic system of foliar epidermis. This is also in keeping with the views of Patel & Devi (1985) and Ahmad & Yunus (1981). The high stomatal frequency may be a compensatory mechanism adopted by the plant to fill this gap.Gostin (2009) studied air pollution effects on the leaf structure of some species of Fabaceae. This includes cuticular and foliar anatomical response of the selected taxa to induced pollution.

5. Conclusions

The presentwork is a comparative study of epidermal features of seven species of Acanthaceaegrown under natural habitat and locality under environmental stress. The stomatal Index and palisade ratio values are least affected by environmental stress. However, Stomatal abnormalities of taxa are well exemplified by plants under pollution stress. When compared to plants grown under natural habitat, the parameters such as size of stomata, epidermal cells and cystolith are affected by environmental stress.Histochemcial localisation of starch is done in both types of plants. Though the results exhibit variation in the epidermal features, the ontogeny and structure of mature stomatal complex remain constant in both control plants and taxa under environmental stress. It can be concluded that the mesogenous stomatal complex though a vegetative entity, is least deviated by the environmental stress and can be considered as reliable as any other conservative taxonomic character for delimiting Acanthaceae.Justicia gendarussa appears to be the most tolerant species.

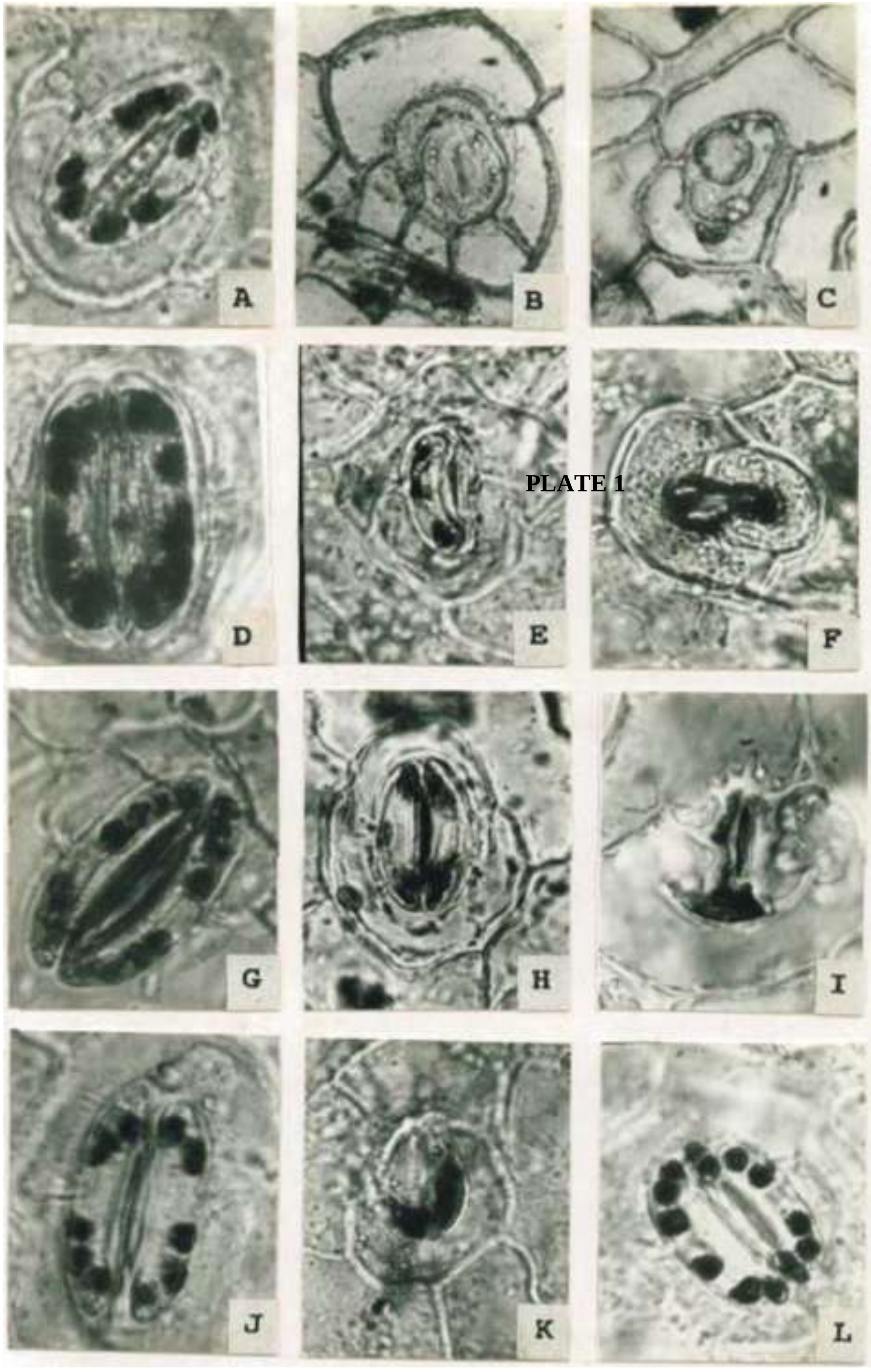

PLATE 1

PL 1. Figs. A – L. Light micrographs with starch localization (Figs. A - L x 1000).

A. StrobilanthesciliatusNees, (P_1). Maturestomatal complex with well developed starch grains.

B. S. ciliatusNees, (P). stomatal complex with reduced size and ill formed starch grains.

C. StrobilanthesciliatusNees,(P_2).Arrested stomatal development

D. JusticiagendarussaBurm.f., (P_1).Maturestomatal complexwith well developed starch grains.

E. G. gendarussaBurm.f., (P).Stoma withsingle guard cellhaving lesser number of starch grains.

F. G gendarussaBurm.F (P). Stomatal initial showing arresteddevelopment.I_2 KI detects the presence of starch, but grainformation is arrested.

G. RhmacanthuscommunisNees, (P_1). Well developed starch grains in the mature stomata.

H. R. communisNees (P_2). reduction in the size of the stomatal complex. The starch grains are of smaller size.

I. R. communisNees (P). distorted guard cells with stomatal pore in the centre. The starch is detected in the guard cells but the grain formation is arrested.

J. Eranthemumcapense(P_1)Maturestomatal complex with well developed starch grains.

K. K.E. capenseL., (P). stomatocyte showing arrested development.

L. L. EcboliumlinneanumKurz var. laetevirens, (P_1) Guard cells with well-developed starch grains

References

Ahmad, K J., 1979.Stomatal features of Acanthaceae. In 'Structure and function of stomata' 43-60.Bishen Singh Mahendra Pal Singh. Dehra Dun.Ahmad , K. J. (1964). Cuticular studies with special reference to abnormal stomatal cells in Cestrum spp. J. Indian Bot. Soc. 43: 165-177.

Ahmad K J and Yunus M., 1981. Studies on epidermal characteristics of leaf in response to air pollution. In the symposium on Methods in plant response to pollution. ITRC, Lucknow.

Bull J L and T A Mansfield., 1974. Photosynthesis in leaves exposed to So1 and No2 Nature 250 433.444.

Capron T M and T A Mansfield., 1976. Inhibition of net photosynthesis in tomato in air polluted with No and No2. J. Expt. Bot.27: 1181-1186

Carcer, P.S., C Signarbieux, R Schlaepfer, A Buttler, P. Vollenweider., 2017. Responses of antinomic foliar traits to experimental climate forcing in beech and spruce saplings, Environmental and Experimental Botany , Volume 140, , Pages 128-140

Chakrabarthy T and D Gupta., 1981. Morphohistologic studies on the herbaceous sps. of railwayt rack. -Proc. -Indian -Acad. -Sci. (Plant Sci.) 90 : 305-312.

Chaphekar S B and M R Karbhari., 1974. Sulphur dioxide injury to plants. Some experiments. Geo Bios (Jodhpur) I: 141-142.

Cutter E G., 1978. Plant anatomy Part 1 Cells and tissue second edn Edward Arnold London

Drack JME. and D P. Vázquez., 2018. Morphological response of a cactus to cement dust pollution, Ecotoxicology and Environmental Safety,Volume 148,Pages 571-577

Gostin I N., 2009. Air pollution effects on the leaf surface of some Fabaceae species Not. Bot. Hort. Agrobot. Cluj 37 (2) 57-63

Heath R., 1980. Initial events in injury to plants by air pollutions. Ann Rev. Pl Physiol .31 : 395-431.

Heck W W, Tailor O C & H E Heggestad., 1973. Air pollution research needs: herbaceous and ornamental plants and agriculturally generated pollutants. Apca J. 23: 257 - 266.

Inamdar J A & G S Chaudhary., 1984. Effects of environmental pollution on leaf epidermis and leaf architecture. J Plant Anat. Morph. (JODHPUR) 1 : 1-8..

Jacobson J S and A C Hill., 1970. Recognition of air pollution injury to vegetation. A pictorial Atlas. APCA, U.S.A.

Jafri S, Srivasthava K and K J Ahmed., 1979., Environmental pollution and epiermal structure in Syzygium kumini (L) Skeel, Indian J Air Pollution Control 2 : 74-77

Jensen W A., 1962. Botanical Histochemistry, Mc Graw Hill NewYork

Mansfield T A., 1973. The role of stomata in determining the response of plants to air pollutants. Commentaries in PI. Sci. 2 : 11-20.

Oliveira, A B., Maria S. de Mendonca, Ranata MSA Meira., 2013. Anatomy of vegetative organs of Scutellaria agrestis, a medicinal plant cultivated by riverine populations of the Brazilian Amazon ,Revista Brasileira de Farmacognosia,Volume 23, Issue 3,Pages 386-397

Panday G P., 1990. Foliar response of Gladiolus t o gasious Hydrogen fluoride pollution. Proc. Indian Sci. Cong. 77. Sect. Botany p. 203.

Patel J D and G S Devi., 1985. Studies in the leaf epidermis of some angiosperm species growing under pollution stress of a fertiliser complex. J. PI. Anat. Morph. 2 : 1-10.

Prasad M S V and J A Inamdar., 1990. Effect of Cement Dust Pollution on growth Parameters and Chlorophyll content of Cyamopsis teregnoloba (L). Proc. Indian. Sci Cong. Sect.Bot. P 203.

Shahid M, C Dumat, S Khalid, E Schreck, N K Niazi., 2017. Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake, Journal of Hazardous Materials, Volume 325. Pages 36-58

Sahu A K and S C Santra., 1989. Industrial air pollution and its e f f e c t on plant's foliar traits- A case study from West India. (Hemigraphis hirta). Feddes report. 100 : 177- 186.

Sharma G K., 1972. Environmental modifications of leaf epidermis and morphological f e a t u r e s in Verbena canadensisSwest. Nat. 17 : 221-228.

Sharma G K., 1977. Cuticular features as indicators of environmental pollution. Water, air and soil pollution 8 :15-19

Sharma G K and D B Dunn., 1968. Environmental modifications of leaf surface traits in Datura stramonium. Can. J. Bot. 47 : 1211-1216.

Sharma G K and J Tyree., 1973. Geographic leaf cuticular and gross morphological variations in Liquid amber Styraciflua L and their possible relationship to environmental pollution Bot. Gaz 134 : 179-184.

Srivastava H S, Jollifee P A and Runeckles V C., 1975. Inhibition of gas exchange in bean leaves by NO_2Can J Bot 53 : 466-474.

Walker N E & Dunn D B., 1967. Environmental modifications of cuticular characteristics of "Alaskan" pea plants Trans MO Acad Sci. 1 : 17 -24.

Wuyts, K., S Adriaenssens, J Staelens, T Wuytack, S V Wittenbergh, P Boeckx, R Samson, K Verheyen., 2015. Contributing factors in foliar uptake of dissolved inorganic nitrogen at leaf level Author links open overlay panel, Science of The Total Environment, Volume 505, Pages 992-1002.