Foliar anatomical studies of some selected species of *Dendrobium* Sw. (Orchidaceae) in Manipur, India

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Abstract

With an aim to understand adaptive significance and also to provide supplementary anatomical characters in addition to usual morphological features for identification of taxa at species level, foliar anatomical studies was carried out in 12 species of *Dendrobium* Sw. (Orchidaceae) from Manipur, India.

Structure and distribution of epidermal and hypodermal layers, stomatal type and density, mesophyll cells, wax secreting cells, trichomes etc. were studied in the present investigation. A key based on foliar anatomical characters is provided to ease the identification of species at vegetative stage.

Key words: *Dendrobium*, Epidendroideae, Leaf anatomy, North-east India, Orchid

INTRODUCTION

Dendrobium Sw. (Orchidaceae, Epidendroideae), an orchid genus of mostly epiphytic species, comprises nearly 3038 species (Govaerts *et al.* 2018) in the world. Most of the species of this genus are distributed in Sino-Himalayan region, Australia, New Zealand and Pacific Islands (Wood 2006). Some species are lithophytic too. The genus is represented by ca. 115 species in India (Misra 2007), of which, about 80 species are found in north-eastern part (Rao 2007; Chowdhery 2009). The north-eastern state Manipur harbours about 58 species as reported by some recent workers viz. Kumar & Kumar (2005), Nanda *et al.* (2012, 2013, 2014), Kishor *et al.* (2013), Meitei *et al.* (2014) and Khuraijam & Roy (2016). They generally grow in varied eco-climatic conditions ranging from tropical to sub-alpine habitats and are characterized in having globose or fleshy cane like stems with one or many, scattered or apically clustered leaves. The leaves vary in size, colour and texture; some are thick, fleshy and almost succulent with curious shapes. In many species, the leaves are short-lived and deciduous and shed off as soon as the dry season approaches. In others, leaves last for many years, even throughout the life of the plant.

As, the leaves are responsive to the environmental changes, they act as key characters in evaluating the effect of the environment on the plant and as well as to point out its adaptations to the environment (Dunbar *et al.* 2009). Anatomical formations of leaf are the basis of its physiological functions. The changes in leaf anatomical structures greatly affect plant growth and metabolisms (Vendramini *et al.* 2002; Pandey *et al.* 2009). Several anatomical features like stomatal furrows, sunken stomata, epidermal cuticles, etc. are commonly considered as adaptations to water scarcity; all these structures enhance boundary layer resistance, thereby limiting transpiration (Haworth & McElwain 2008; Mill & Stark 2009). Many foliar anatomical

attributes have also contributed character information for phylogenetic classifications of orchids (Dressler & Dodson 1960; Garay 1960, 1972a; Vermeulen 1966; Brieger *et al.* 1970-1995; Dressler 1981, 1993; Rasmussen 1985; Burns-Balogh & Funk 1986; Szlachetko 1995; Freudenstein *et al.* 1999).

This paper deals with foliar anatomy of twelve species of *Dendrobium* from different eco-climatic conditions of Manipur, India. The aims of the study were to find out the important anatomical characters for identification of taxa at species level as well as to understand their adaptive significance.

MATERIALS AND METHODS

12 species of *Dendrobium* Sw. (Table 1) were taken into consideration for the present study. These were collected from various eco-climatic regions of Manipur, India. For leaf anatomical studies, thin cross sections through the middle portion of matured leaves of each species were done by a sharp razor blade and stained with safranin (Guan *et al.* 2010). Stained sections were examined under compound microscope (Olympus CX31) at different magnifications.

Table 1. List of species under study with their distribution (in Manipur), habitat and macro-morphological vegetative characteristics

Species	Distribution in the State (Districts)	Altitude (m)	Habitat	Stem size [length(L), diameter(D)] (cm)	Number of leaves on stem	Leaf size [length(L), width(W)] (cm)
<i>Dendrobium chrysotoxum</i> Lindl.	Chandel & Senapati	500 – 1800	Tropical-Sub-tropical	L: 15-19 D: 01- 02	04 – 06	L: 12-15 W: 3.0-4.5
<i>Dendrobium densiflorum</i> Lindl.	Senapati, Tamenglong & Kamjong	1300 – 2000	Sub-tropical	L: 25-30 D: 01-02	04 – 06	L: 13-17 W: 3.0-4.5
<i>Dendrobium falconeri</i> Hook.	Senapati & Tengnoupal	600 – 2000	Tropical - Sub-tropical	L: 35-40 D: 0.2-0.4	20 – 25	L: 5-6.4 W: 0.2-0.4
<i>Dendrobium fimbriatum</i> Hook.	Senapati & Tamenglong	1000 – 1660	Sub-Tropical	L: 60-90 D: 0.9-1.2	20 – 30	L: 12-14 W: 1.5-2.5
<i>Dendrobium infundibulum</i> Lindl.	Tengnoupal	400 – 1434	Tropical - Sub-tropical	L: 30-40 D: 0.6-0.8	12 – 17	L: 10-12 W: 2.0-2.5
<i>Dendrobium jenkinsii</i> Wall. ex Lindl.	Senapati, Tengnoupal & Jiribam	60 – 1400	Tropical – Sub Tropical	L: 2.0-2.5 D: 0.5-0.7	01	L: 3.5-4.2 W: 1.5-2.0
<i>Dendrobium longicornu</i> Lindl.	Senapati	1330 – 3000	Sub-tropical - Temperate	L: 6-10 D: 0.2-0.3	07 – 10	L: 4.0-5.5 W: 0.8-1.1
<i>Dendrobium ochreatum</i> Lindl.	Jiribam, Churchandpur & Senapati	50 – 1800	Tropical - Sub-tropical	L: 20-38 D: 1.0-1.3	08 – 16	L: 9-11 W: 3.0-3.9
<i>Dendrobium parcum</i> Rchb.f.	Kangpokpi (the then Senapati) & Tamenglong	1200 – 1660	Sub-tropical	L: 20-24 D: 0.3-0.5	05 – 08	L: 4-5 W: 1.0-1.3

Figure 1. Habit of different species of *Dendrobium*. *a.* *D. chrysotoxum*, *b.* *D. densiflorum*, *c.* *D. falconeri*, *d.* *D. fimbriatum*, *e.* *D. infundibulum*, *f.* *D. jenkinsii*, *g.* *D. longicornu*, *h.* *D. ochreatum*, *i.* *D. parcum*, *j.* *D. spatella*, *k.* *D. tamenglongense* and *l.* *D. williamsonii*

Species	Distribution in the State (Districts)	Altitude (m)	Habitat	Stem size [length(L), diameter(D)] (cm)	Number of leaves on stem	Leaf size [length(L), width(W)] (cm)
<i>Dendrobium spatella</i> Rehb.f.	Tamenglong	1000 – 1800	Sub-Tropical	L: 18-25 D: 0.3-0.5	10 – 17	L: 3.0-3.5 W: 0.8-1.3
<i>Dendrobium tamenglongense</i> R. Kishor, Y. N. Devi, H. B. Sharma, J. Tongbram & S. P. Vij	Tengnoupal (the then Chandel)	400 – 1000	Tropical - Sub-tropical	L: 60-75 D: 0.3-0.5	15 – 20	L: 7-9 W: 1.5-2.0
<i>Dendrobium williamsonii</i> Day & Rehb.f.	Senapati, Kangpokpi (the then Senapati) & Kamjong (the then Ukhrul)	1300 – 1800	Sub-tropical	L: 13-16 D: 0.5-0.7	07 – 10	L: 10-13 W: 2.0-2.5

To study trichomes, stomata, wax secreting cells etc., the adaxial and abaxial epidermis of fresh, matured leaves were peeled off. The area of stomatal apparatus was calculated following Guan *et al.* (2010) and the stomatal density was calculated following routine formula: Number of stomata/ Number of grids $\times$ area of 1 grid square. Character analyses for all the species were made following the method of Freudenstein and Rasmussen (1999) and results were presented as Mean $\pm$ Standard Error (M $\pm$ SE).

Character analysis (based upon coded characters):

- A. First adaxial hypodermal layer: 0 = absent, 1 = present
- B. Second adaxial hypodermal layer: 0 = absent, 1 = present
- C. Abaxial hypodermal layer: 0 = absent, 1 = present
- D. Mesophyll: 0 = palisade and spongy not differentiated, 1 = palisade and spongy slightly differentiated, 2 = palisade and spongy distinctly differentiated
- E. Shape of middle vascular bundle: 0 = globular, 1 = ovate, 2 = obovate, 3 = elongated oval
- F. Shape of adaxial leaf epidermal cells: 0 = polygonal, 1 = irregular or nearly polygon
- G. Shape of abaxial leaf epidermal cells: 0 = polygonal, 1 = irregular or nearly polygon
- H. Stomata: 0 = anomocytic, 1 = paracytic
- I. Slightly sunken stomata: 0 = absent, 1 = present
- J. Shape of guard cells: 0 = elliptic, 1 = sub-orbicular
- K. Subsidiary cells: 0 = present, 1 = not distinguishable
- L. Wax secreting cells: 0 = absent, 1 = present
- M. Nature of adaxial wax secreting cells: 0 = single, 1 = double, 2 = mixed, 3 = not present
- N. Nature of abaxial wax secreting cells: 0 = single, 1 = double, 2 = mixed, 3 = not present
- O. Trichome: 0 = absent, 1 = present

Figure 2. T.S. of Leaves. **a.** *D. chrysotoxum*, **b.** *D. densiflorum*, **c.** *D. falconeri*, **d.** *D. fimbriatum*, **e.** *D. infundibulum*, **f.** *D. jenkinsii*, **g.** *D. longicornu*, **h.** *D. ochreatum*, **i.** *D. parcum*, **j.** *D. spatella*, **k.** *D. tamenglongense* and **l.** *D. williamsonii*. **Ab** abaxial epidermis, **Ad** adaxial epidermis, **Cu** cuticle, **ET** epidermal tissue, **HD** hypodermis, **LVB** lateral vascular bundle, **MVB** middle vascular bundle, **PT** palisade tissue, **ST** spongy tissue. Scale bars, 500µm – j, 100µm – (a – i and k – l).

RESULTS

Observations made in the study are discussed below in detail under various headings along with data in tabular forms (Tables 2 – 4). Photographic plates are also given as Figures 1 – 4. A key based on foliar anatomy was also given to facilitate easy identification of species.

Cuticle: In all the species observed, cuticle was recorded on both the adaxial and abaxial surfaces. Cuticle of adaxial surface was found thicker than the abaxial surface in all the species except in *D. parcum*. *D. infundibulum* was recorded with the thickest adaxial cuticle layer (16.50 μm) followed by *D. williamsonii* (16.10 μm) and *D. jenkinsii* (14.80 μm).

Epidermal layers: Epidermal cells were polygonal in all the species except in *D. densiflorum* where they are irregular to nearly polygonal (Figure 4b). Thickest adaxial epidermal layer was observed in *D. ochreatum* (51.00 μm) and the thinnest in *D. densiflorum* (20.40 μm), while thickest abaxial epidermal layer (34.30 μm) was found in *D. williamsonii* and the thinnest (06.50 μm) in *D. falconeri*.

Hypodermal layers: Out of the 12 species, only 2 species viz. *D. chrysotoxum* and *D. jenkinsii* showed the presence of hypodermis. Further, it was also observed that *D. jenkinsii* had two adaxial and one abaxial hypodermal layers (Figure 2f) while in *D. chrysotoxum* only one layer of hypodermis was found in both surfaces (Figure 2a).

Mesophyll layers: It has been observed that mesophyll layer is thickest in *D. spatella* (8555.25 μm) and the minimum is in *D. parcum* (145.00 μm). Mesophyll cells were clearly differentiated into palisade and spongy cells in *D. jenkinsii* (Figure 2f) and slightly differentiated in *D. infundibulum* (Figure 2e). Palisade cells have comparatively few numbers of chloroplasts than spongy cells.

Various shapes of vascular bundles were observed. In *D. falconeri*, *D. infundibulum*, *D. parcum* and *D. spatella*, the vascular bundles were globular in shape, whereas in *D. chrysotoxum*, *D. densiflorum*, *D. fimbriatum* and *D. williamsonii*, they were ovate. In *D. jenkinsii* and *D. ochreatum*, vascular bundles were elongated oval and in *D. tamenglongense* and *D. longicornu* they were obovate.

Stomata: In all the species, the stomata were observed only on lower surface (hypostomatic). In two species viz. *D. spatella* and *D. williamsonii*, the stomata were of paracytic type (Figure 3j & l) and in rest of the species they were anomocytic. It is also interesting to note that only one species viz. *D. ochreatum* (Figure 3h) showed slightly sunken stomata. Stomatal density was maximum in *D. chrysotoxum* (16.45/ mm^2) and minimum in *D. spatella* (02.82/ mm^2). Further, the size of stomatal apparatus area (A_s) was maximum in *D. williamsonii* (1838.80 μm) and the minimum in *D. jenkinsii* (639.90 μm).

The shape of the guard cell was elliptic in *D. jenkinsii* and *D. parcum* (Figure 3f & i), whereas the remaining species showed guard cells are sub-orbicular. Presence of chloroplasts were also observed in all the species.

Wax secreting cells: Wax secreting cells on both adaxial and abaxial surfaces were observed in all the species except in *D. infundibulum*, *D. longicornu* and *D. williamsonii* which were observed with trichomes. The adaxial wax secreting cells were observed maximum in *D. spatella* (53.00/ mm^2) whereas minimum in *D. parcum* (01.40/ mm^2).

Trichomes: Unicellular dark brown trichomes were observed on both the surfaces of *D. infundibulum*, *D. longicornu* and *D. williamsonii*. The density of trichomes were found more on abaxial surface than the adaxial. The size of the trichome was longer in *D. infundibulum* (Figure 4-e).

Table 2. Character analysis of 12 species of *Dendrobium*

Species	Characters														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
<i>D. chrysotoxum</i>	1	0	1	0	1	0	0	0	0	1	1	1	2	0	0
<i>D. densiflorum</i>	0	0	0	1	1	1	1	0	0	1	1	1	2	2	0
<i>D. falconeri</i>	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
<i>D. fimbriatum</i>	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0
<i>D. infundibulum</i>	0	0	0	0	0	0	0	0	0	1	1	0	3	3	1
<i>D. jenkinsii</i>	1	1	1	2	3	0	0	0	0	0	1	1	0	0	0
<i>D. longicornu</i>	0	0	0	0	2	0	0	0	0	1	1	0	3	3	1
<i>D. ochreatum</i>	0	0	0	0	3	0	0	0	1	1	1	1	0	0	0
<i>D. parcum</i>	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
<i>D. spatella</i>	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0
<i>D. tamenglongense</i>	0	0	0	0	2	0	0	0	0	1	1	1	2	2	0
<i>D. williamsonii</i>	0	0	0	0	1	0	0	1	0	1	0	0	3	3	1

Key to the identification of species

- 1a. Mesophyll differentiated into palisade and spongy layers.2
 1b. Mesophyll not differentiated3
 2a. Hypodermis multilayered*D. jenkinsii*
 2b. Hypodermis absent*D. densiflorum*
 3a. Trichomes present4
 3b. Trichomes absent6
 4a. Stomatal density less than 5 per mm².....*D. williamsonii*
 4b. Stomatal density more than 5 per mm²5
 5a. Central vascular bundle globular in shape*D. infundibulum*
 5b. Central vascular bundle obovoid in shape*D. longicornu*
 6a. Stomata paracytic*D. spatella*
 6b. Stomata anomocytic7
 7a. Cuticle is thicker on abaxial surface*D. parcum*
 7b. Cuticle is thicker on adaxial surface8
 8a. Hypodermis single layered on both the surfaces*D. chrysotoxum*
 8b. Hypodermis absent9
 9a. Density of wax secreting cells more than 25 per mm² on adaxial surface..*D. falconeri*
 9b. Density of wax secreting cells less than 20 per mm² on adaxial surface..10
 10a. Stomata slightly sunken.*D. ochreatum*
 10b. Stomata not sunken11
 11a. Central vascular bundle ovoid in shape*D. fimbriatum*
 11b. Central vascular bundle obovoid in shape*D. tamenglongense*

DISCUSSION

Adaxial cuticle was found thicker than the abaxial cuticle in all the species except in *D. parcum*. Characters like small size of the leaves, their position on the repeatedly branched stem which subject to frequent exposure of lower surface (abaxial) to the sunlight might have probably warranted the species *D. parcum* to develop thicker cuticle in abaxial surface

Figure 3. Stomata at abaxial leaf epidermis. **a.** *D. chrysotoxum*, **b.** *D. densiflorum*, **c.** *D. falconeri*, **d.** *D. fimbriatum*, **e.** *D. infundibulum*, **f.** *D. jenkinsii*, **g.** *D. longicornu*, **h.** *D. ochreatum*, **i.** *D. parcum*, **j.** *D. spatella*, **k.** *D. tamenglongense* and **l.** *D. williamsonii*. CL chloroplast, GC guard cell, SC subsidiary, SA stomatal aperture. Scale bars, 30 μm (a - j), 100 μm (k - l).

Table 3. Leaf traits of *Dendrobium* species under study

[**Abbreviations used:** LT – leaf thickness; CT_{ad} – cuticle thickness (adaxial surface); CT_{ab} – cuticle thickness (abaxial surface); ET_{ad} – epidermis thickness (adaxial surface); ET_{ab} – epidermis thickness (abaxial surface); HD_{ad}^{1st} – first adaxial hypodermal layer, HD_{ad}^{2nd} – second adaxial hypodermal layer, HD_{ab}^{1st} – first abaxial hypodermal layer, MT- mesophyll thickness, VBML- length of middle vascular bundle, VBMW- width of middle vascular bundle. Results were presented as mean±SE]

Species	LT (µm)	CT _{ad} (µm)	CT _{ab} (µm)	ET _{ad} (µm)	HD _{ad} ^{1st} (µm)	HD _{ad} ^{2nd} (µm)	ET _{ab} (µm)	HD _{ab} ^{1st} (µm)	MT (µm)	VBML (µm)	VBMW (µm)
<i>D. chrysotoxum</i>	646.3±4.6	14.1±0.6	7.1±0.4	24.9±0.9	77.5±3.6	–	12.3±1.3	33.8±2.7	462.5±6.7	361.9±22.6	294.0±13.8
<i>D. densiflorum</i>	547.5±4.5	11.5±0.5	6.8±0.6	20.4±1.2	–	–	14.3±0.7	–	486.3±6.0	297.1±5.3	213.3±4.3
<i>D. falconeri</i>	216.3±22.1	13.9±0.9	7.0±0.3	29.4±2.1	–	–	6.5±0.5	–	170.0±3.8	105.0±2.3	102.6±3.3
<i>D. fimbriatum</i>	256.23±6.8	12.1±0.6	7.1±0.5	30.9±2.6	–	–	21.1±1.6	–	200.0±3.7	166.8±6.0	125.7±4.0
<i>D. infundibulum</i>	395.0±5.7b	16.5±0.4	6.0±0.5	40.6±1.7	–	–	23.6±0.9	–	308.8±6.7	214.2±5.2	233.2±5.0
<i>D. jenkinsii</i>	1205.0±18.6	14.8±0.7	9.4±0.4	25.0±0.8	30.5±1.7	43.1±1.7	24.0±1.4	22.8±0.7	1060.0±14.9	257.9±3.7	195.4±6.1
<i>D. longicornu</i>	347.5±14.8	12.9±0.5	9.3±0.9	26.1±1.2	–	–	21.1±1.1c	–	276.3±11.6	133.9±2.5	110.8±2.9
<i>D. ochreatum</i>	567.50±43.46	12.75±4.1	10.62±0.53	51.0±0.8	–	–	33.25±1.27	–	428.75±46.54	143.75±24.7	82.50±8.9
<i>D. parcum</i>	195.0±4.3	5.5±0.2	10.3±0.3	31.3±1.9	–	–	23.0±0.8	–	145.0±4.3	137.1±3.7	117.0±2.2
<i>D. spatella</i>	8575.0±87.79	12.50±0.62	12.02±0.60	21.50±2.12	–	–	22.75±0.85	–	8555.25±79.87	95.50±5.37	82.40±5.83
<i>D. tamenglongense</i>	368.8±8.6	10.4±0.3	10.4±0.3	31.3±3.8	–	–	18.6±1.5	–	298.8±6.8	175.9±2.9	151.2±2.0
<i>D. williamsonii</i>	376.3±8.2	16.1±1.3	13.3±0.3	42.7±1.8	–	–	34.3±1.6	–	247.5±6.1	165.4±2.8	138.9±3.4d

Figure 4. Wax secreting cells and trichomes at adaxial leaf epidermis. **a.** *D. chrysotoxum*, **b.** *D. densiflorum*, **c.** *D. falconeri*, **d.** *D. fimbriatum*, **e.** *D. infundibulum*, **f.** *D. jenkinsii*, **g.** *D. longicornu*, **h.** *D. ochreatum*, **i.** *D. parcum*, **j.** *D. spatella*, **k.** *D. tamenglongense* and **l.** *D. williamsonii*. WSC wax secreting cell, TR trichome. Scale bars, 50 μ m.

Table 4. Leaf traits *Dendrobium* species (contd.)

[**Abbreviations used:** *d* – stomatal density, *A_s* – stomatal apparatus area, *WN_{ad}* – adaxial wax secreting cells number, *WN_{ab}* – abaxial wax secreting cells number, *TL_{ad}* – adaxial trichome length, *TL_{ab}* – abaxial trichome length. Results were presented as mean±SE]

Species	<i>d</i> (mm ⁻²)	<i>A_s</i> (μm ²)	<i>WN_{ad}</i> (mm ⁻²)	<i>WN_{ab}</i> (mm ⁻²)	<i>TL_{ad}</i> (μm)	<i>TL_{ab}</i> (μm)
<i>D. chrysotoxum</i>	16.45±0.39	834.2± 44.6	16.0±0.52	58.60±0.84	–	–
<i>D. densiflorum</i>	12.20±0.33	805.9± 38.4	14.7±0.7	37.2±1.62	–	–
<i>D. falconeri</i>	14.7±0.44	740.3± 23.5	42.3±1.85	33.9±1.18	–	–
<i>D. fimbriatum</i>	7.02±0.17	912.8± 56.8	16.80±0.48	40.5±1.20	–	–
<i>D. infundibulum</i>	9.32±0.13	1511.3± 44.9	–	–	471.3± 61.0	768.8± 72.3
<i>D. jenkinsii</i>	11.55±0.18	639.9± 23.2	31.20±1.01	31.8±1.62	–	–
<i>D. longicornu</i>	11.28±0.18	1316.5± 53.1	–	–	355.0± 22.1	281.3± 12.7
<i>D. ochreatum</i>	12.20±0.12	1378.04±36.13	3.90±0.23	4.40±0.27	-	-
<i>D. parcum</i>	15.2±0.14	730.8± 31.0	1.40±0.24	14.10±0.78	–	–
<i>D. spatella</i>	2.82±0.15	757.41±25.55	53.00±0.60	29.30±0.45	-	-
<i>D. tamenglongense</i>	8.5±0.19	1105.4± 48.0	15.6±0.74	26.1±0.90	–	–
<i>D. williamsonii</i>	4.19±0.79	1838.8± 62.6	–	–	405.0± 31.4	433.8± 6.9

in order to prevent water loss. Thickness of cuticle plays an important role for preventing water loss from the lamina (Bargel *et al.* 2004; Mill & Stark 2009). The presence of thick cuticle on the leaf surface is an indicator of arid habitats for the plants (Haworth & McElwain 2008). The thick cuticle layers on *D. chrysotoxum*, *D. infundibulum*, *D. jenkinsii* and *D. williamsonii* leaves can reduce rate of transpiration and increase water use efficiency during scarcity of water.

Large epidermal cells in many species of orchids serve as water-storage cells. Olantunji and Nengim (1980) have called these water storage cells as tracheoidal elements. Such club-shaped and columnar water storage cells mainly present in the leaf and run parallel to the length of the organ, which suggest the formation of a dispersed water conducting system unlike continuous vascular system. These may be helpful for imbibition of water during favourable conditions to ensure a luxuriant growth and survival of species.

Stomatal distribution, size, density and morphology are closely associated with plant transpiration (Willmer & Fricker 1996). Larger stomata have a greater potential for hydraulic dysfunction under drought conditions (Aasamaa *et al.* 2001). Plants with lower stomatal density are usually able to tolerate a more arid environment than plants with higher stomatal density (Kebede *et al.* 1994). Generally, the stomatal density of orchid leaves is low in the entire plant kingdom (Karasawa & Saito 1982; Willmer & Fricker 1996). In the present study, *D. spatella* with its least stomatal density and *D. jenkinsii* with its small stomatal apparatus area appear to be more tolerant to the arid environment. Though, *D. williamsonii* has large stomatal apparatus area, it has minimum stomatal density next to *D. spatella* to minimize the higher rate of transpiration.

Wax secreting cells act as a protective against sunlight. They also aid in shedding rain so that the leaf cells do not become over saturated with water (Ferry 2008). In this study, *D. spatella* had maximum numbers of adaxial wax secreting cells which may protect the species from high intensity of sunlight and regulate the inner water content during heavy rain fall.

Trichomes can be protective against sun or herbivores and may help in air circulation by increasing turbulence (Yukawa *et al.* 1990). They also help in absorbing water in

Bromeliaceae and in orchids (Pleurothallidinae) (Pridgeon & Stearn 1982). In the present study, the trichomes observed in *D. infundibulum*, *D. longicornu* and *D. williamsonii* may probably help in absorbing water during the rainy season which is stored and consumed during subsequent dry winter period.

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