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Inflorescence architecture in species of *Fimbristylis* (Cyperaceae) from Gujarat, India

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Abstract

Phylogenetic analyses based on morphological data remain scarce for family Cyperaceae due to its diverse and complex inflorescence. *Fimbristylis s. s.* possess several taxonomic problems due to their intra specific divisions. The wide diversity of the synflorescence in 18 species from Gujarat were analyzed and described to demonstrate the trends of diversification in inflorescence architecture. The study also aims to understand phenetic evaluation between the species. Unispiculate (pseudolateral or terminal), anthelate and capitate synflorescences were recorded. In the paracladial zone normal branching was observed. Foliose structures with an intermediate form between a setaceous bract and a glume are frequently found at the spikelet base. A set of morphological features were recorded and a cluster analysis was carried out. The macro-morphological characters such as structure of inflorescence, branching order, length and position of paraclades and the number of bractiform structures proposed to be useful for proper delimitation of studied taxa. The paracladial ramification of the inflorescence seems to be the main character with potential for taxonomic and phenetic implications.

Keywords: Anthelodium, bractiform structures, Fimbristylis, Gujarat, paracladial ramification, synflorescence.

Introduction

Cyperaceae are the third largest monocotyledonous family; it comprises 109 genera and approximately 5,500 species, has a cosmopolitan distribution (Govaerts et al., 2007; Muasya et al., 1998) and has been resolved as monophyletic & sister to Juncaceae (Goetghebeur, 1998; Bruhl, 1995). Genus Fimbristylis (L.) Vahl is the 4th largest genus within the Cyperaceae, having 306 species including several homogenous subunits (World checklist of Monocots, 2006; Bruhl & Wilson, 2007) distributed worldwide in tropical & temperate zones. In India, genus Fimbristylis is represented by 91 species (Karthikeyan et al., 1989) of which 22 are reported from Gujarat state (Shah, 1978; Meena, 2004). While, several infrageneric classifications have been proposed for Fimbristylis, most of them based on specimens from restricted geographical regions (Ohwi, 1944; Koyama, 1961; Kern, 1974). In Indian Fimbristylis, Hooker (1894) recognized four sections on the basis of number of spikelet, bi-/ trifid style as well as the lower glume phyllotaxis. Ohwi (1944), Kern (1974) and Hooker (1894) included the genus Abildgaardia Lye within the genus Fimbristylis Vahl. Molecular phylogenetic analyses of the family Cyperaceae depict Abildgaardia and Fimbristylis to be more closely related to each other than any

other genera and suggested that few characters are available for proper construction of the phylogenetic tree (Muasya et al., 1998, 2002, 2009; Simpson et al., 2007; Ghamkhar et al., 2007). Tribe Fimbristylideae Vahl (=Abildgaardieae Lye) is resolved as sister to Fuireneae and Eleocharideae, but phylogenetic hypotheses at generic level have not yet been established (Vrijdaghs et al., 2009). Moreover, phylogenetic analyses based on morphological data remain scarce because identifying an adequate number of phylogenetically valuable characters is a problem in sedges due to reduced and similar characters (Raynal, 1971; Simpson, 1993; Bruhl, 1995; Goetghebeur, 1998; Mausya et al., 2009; Naczi, 2009). As inflorescence diversification play a pivotal role in understanding the relationship between different taxa, it appears appropriate to consider it from a new viewpoint (Tucker & Grimes, 1999). In this context, the typology-based system developed by Troll (1964) and Weberling (1989) has proved to be a useful tool to describe inflorescences in flowering plants (Rua, 1999).

In a typological interpretation, 'a system of flower bearing branches and their position on the plant is called a synflorescence' (Troll, 1964). The term 'inflorescence' is deliberately kept rather imprecise in order to have a convenient word, for each inductive attempt at the analysis of an unknown inflorescence system. On the other hand, use of the term 'synflorescence' requires the analysis of structure of a given inflorescence within the context of the whole branching system of a taxon and its allies (Weberling, 1992). Synflorescence, not only determine the external appearance to a great extent, but also at the same time provide important criteria for their relationships. It must therefore be established which part of the flower corresponds to one another within a plant and between different plants, before any assertions can be made about which modifications distinguished on the inflorescence of one plant, from that of another (Troll, 1964; Vegetti, 2003). The word 'spikelet' is used in the strict sense for a racemosely branched structure consisting of an axis (rachilla) of potentially indefinite growth bearing lateral, true flowers (Eiten, 1976). The terminal spikelet of the main axis of the inflorescence is the main florescence (HF). The lateral branches preceding the main florescence are known as paraclades (Pc); each paraclade consists of a short hypopodium, a prophyll, an epipodium of variable length and a terminal spikelet, named co-florescence (cof). The paraclades can be represented by only one spikelet (short paraclades, sPc) or by a more complex structure of ramifications (long paraclades, IPc), formed by numerous sPc. The paracladial zone is usually composed of subzones sPc and IPc (Vegetti, 2003; Reutemann et al., 2009). Basically, cyperoid flowers are actinomorphic and pentacyclic having 2 trimerous whorls of perianth (bristles & scales), a trimerous androecium and a trimerous gynoecium; although reduction tendencies and many modifications may occur (Vrijdaghs et al., 2009). Liu et al. (2005) and Rua & Aliscioni (2002) have also used reduction pattern to indicate traits of considerable phylogenetic value for family Poaceae and Guarise & Vegetti (2008b) and Reutemann et al. (2009) for family Cyperaceae.

The aim of this work is to re-evaluate the inflorescences of *Fimbristylis* Vahl from a typological point of view, as a way to contribute to the knowledge of the inflorescence of the genera and provide characters with potential use in further taxonomic and phylogenetic studies.

Materials and methods

Specimens belonging to 18 species of *Fimbristylis* Vahl were examined and their names are given in

Table 1. Inflorescences were either obtained from BARO Herbarium or collected from the fields of Gujarat state, India. Voucher specimens for all the collected species were submitted to BARO along with details. Mature inflorescences were dissected under an Olympus SZ61 stereoscopic microscope, and photographed using an Olympus FE-5010 digital camera. For the typological interpretation, terminologies described by Vegetti (2003), Guarise & Vegetti (2008 b) and Vrijdaghs *et al.* (2010) have been followed.

Morphological studies have been done for 20 inflorescences of each species. Measurements have been recorded for 40 characters of reproductive parts of specimens and averages of it were schematized in a comparative way (Table 1, 2). The numbers of branches of primary, secondary, tertiary, etc. order were counted for each ramification pattern. The positions of the different types of branching were observed. The length of distal and proximal paraclades, bracts and prophylls were measured from the insertion to the apex of their terminal spikelets (Table 3). The coding for the morphological characters have been done after following Bhrul (1995), Naczi (2009) and Reutemann et al. (2009) and provided in Table 4. The dendrogram was constructed on the basis of quantitative and qualitative characters which depict Ward's linkages for all the studied taxa. Cluster analysis with Square Euclidean distance was used as a measure of similarity. Phenotypic correlation coefficients were estimated with the help of SPSS ver.11 software (Ingrouille, 1986).

Results

In all the studied species of Fimbristylis, the following zones can be distinguished on the whole plant: innovation zone (IZ), inhibition zone (HZ) and the inflorescence or unit of inflorescence (UIF) (Fig. 1a). The IZ bears reduced leaves with axillary buds, which produce new shoots with a similar structure to that of the mother shoot. Above this region is the HZ, which shows well-developed leaves with axillary buds which do not develop. The internodes above the distal vegetative leaf often elongates, forming a scape, which still belongs to the inhibition zone. In the distal portion of the shoot is the UIF, formed by the terminal spikelet of the main axis (main florescence HF) and, in most cases, by the paracladial zone (PZ) below it (Fig. 1b). Qualitative and quantitative inflorescence characters of the studied species of Fimbristylis are listed in Table 2.

No.	Accepted name	Coll. No.										
1	<i>F. alboviridis</i> (C.B.Clarke ex Scott Elliot) C.B.Clarke	RJD/371, 435, 660, 783; Sabnis/ 128, 129, 130, 402										
2	F. argentea (Rottb.) Vahl	Bedi/2883, 2884; RJD/112, 209, 388; Sabnis/53, 55, 56, 57										
3	F. bisumbellata (Forssk.) Bubani	JVJ/354, 353; RJD/332, 466, 749, 782, 802, 803										
4	F. cymosa (Roth) T.Koyama subsp. cymosa	RJD/278, 365, 381, 788, 834; Sabnis/134, 221, 222, 223, 224, 225										
5	F. dichotoma (L.) Vahl subsp. dichotoma	JVJ/41, 223, 330, 730; PPB/23, 110; RJD/125, 243, 581; Sabnis/86, 220, 262										
6	F. falcata (Vahl) Kunth	Sabnis/ 22, 23,24, 152, 166, 167										
7	F. ferruginea var. typica Domin	DNT/1096; JVJ/185, 195; P&T/137; RJD/217, 263, 612; Sabnis/213, 320, 452, 468										
8	F. ferruginea (L.) Vahl var. ferruginea	DNT/1196; JVJ/385, 1115, 1915;RJD/385, 423, 634; Sabnis/451										
9	F. littoralis Gaudich.	JVJ/ 2177; RJD/244, 462, 364; PPB/840; Sabnis/ 54, 113, 257, 258, 268, 390, 416										
10	F. merrilli J.Kern	RJD/188, 246, 466, 784, 795, 800										
11	F. ovata (Burm.f.) J.Kern	Bedi/328, 2644, 2646; JVJ/1055, 1298; RJD/265, 640, 678; Sabnis/46, 165, 218, 256										
12	F. polytrichoides (Retz.) R.Br.	JVJ/869, 1182 ; RJD/337, 641, 700; Sabnis/157, 270, 305										
13	F. quinquangularis (Vahl) Kunth	Bedi/1627, 1629, 2028, 2903; JVJ/358, 1175, 1993;RJD/189, 376, 525; Sabnis/130, 356, 390, 465										
14	F. schoenoides (Retz.) Vahl	DNT/ 817, 1199; JVJ/183; PPB/838; RJD/190, 372, 415, 519; Sabnis/64, 71, 126, 127										
15	F. tenera Schult.	Bedi/1606; DNT 643; JVJ/ 184, 837, 957; PPB/ 753;RJD/165, 367, 643; Sabnis/121,123, 226, 349										
16	F. tetragona R.Br.	PPB/833 ; RJD/361, 645, 661; Sabnis/ 271, 387, 463										
17	F. umbellaris (Lam.) Vahl	RJD/267, 648, 781, 762, 799, 804										
18	F. woodrowii C.B.Clarke	DNT/180; JVJ/226, 332; Sabnis/22, 31, 166, 242, 375, 526										

Table 1. List of studied Taxa of *Fimbristylis* with Herbarium accession numbers.

The inflorescences are unispiculate or more commonly, paucispiculate or plurispiculate. The latter can have an anthela-like shape (anthelodium; indeterminate inflorescences) or can be reduced to a more or less contracted head, like a capitulum (Fig. 2; Table 2). The anthelodium can be lax or congested and can bear paraclades of first (simple anthelodium), second and even third order (compound anthelodium) with an evident epipodium (Fig. 2). The capituliform inflorescences do not have developed epipodia. Main florescences (HF) are also observed (Fig. 1b) in all the studied taxa, therefore the inflorescences are heterothetic (Vegetti, 2003). Variations in the structure of the unit of inflorescence of studied species follow:

1). Unispicate (only HF): Inflorescence reduced to main florescence e.g. *F. ovata* (Fig. 3a),

F. polytrichoides (Fig. 3b), *F. tetragona* (Fig. 3c), *F. schoenoides* (Fig. 3d).

2). Simple anthelodium: Inflorescence composed of the main florescence and only the subzones of short paraclades (HF+sPc) e. g. *F. alboviridis* (Fig. 3f), *F. merrilli* (Fig. 3t), *F. schoenoides* (Fig. 3e), *F. ferruginea* var. *ferruginea* (Fig. 3i); inflorescences comprising the main florescence and a paracladial zone composed of subzones of short paraclades and few first-order long paraclades (HF+lPc+sPc) e.g. *F. alboviridis* (Fig. 3g), *F. bisumbellata* (Fig. 3h), *F. ferruginea* var. *typica* (Fig. 3j), *F. falcata* (Fig. 3k), *F. dichotoma* (Fig. 3l), *F. tenera* (Fig. 3m).

3). Inflorescence comprising the main florescence and the paracladial zone composed of subzones of short and long paraclades with a more complex

No	Name of Taxa	Inflorescence	Structure of Inflorescence	Max. order of ramification	No. of spikelet / inflorescence	Bractiform structure	No. of Fertile glumes/ spikelet	Achene shape & Texture
	F. alboviridis	Simple anthelodium	HF+sPc	1°	3-8	ю	6-14	Lenticular, striped
7	F. argentea	Capitate	HF+sPc	1°	15-30	0	50-80	Lenticular, smooth
З	F. bisumbellata	Simple anthelodium	HF+sPc+lPc	2°	11-20	7	6-12	Lenticular, striped
4	F. cymosa subsp. cymosa	Simple anthelodium/ Fasciculate	HF+sPc+lPc	2°	20-50	0	12-34	Lenticular/ trigonous, smooth
IJ	F. dichotoma subsp. dichotoma	Simple anthelodium	HF+sPc+lPc	2°	15-30	7	12-20	Lenticular, striped
9	F. falcata	Simple anthelodium	HF+sPc+lPc	ů	11-25	7	4-12	Trigonous, warty
	F. ferruginea var. typica	Simple anthelodium	HF+sPc+lPc	2°	4-10	ю	20-40	Lenticular, smooth
∞	F. ferruginea var. ferruginea	Simple anthelodium	HF+sPc	1°	4-10	ю	12-22	Lenticular, smooth
6	F. littoralis	Compound anthelodium	HF+sPc+lPc	ů	60-100	1	50-80	Trigonous, warty
10	F. merrilli	Simple anthelodium	HF+sPc	1°	1-6	2	20-50	Lenticular, striped
11	F. ovata	Unispicate	HF	0°	1	4	8-18	Trigonous, warty
12	F. polytrichoides	Unispicate	HF	0°	1	3	35-50	Lenticular, warty
13	F. quinquangularis	Compound anthelodium	HF+sPc+lPc	ů	70-120	1	40-60	Trigonous, warty
14	F. schoenoides	Unispicate	HF/HF+sPc	0°/1°	1-2	2	45-70	Trigonous, smooth
15	F. tenera	Simple anthelodium	HF+sPc+lPc	ъ	8-20	7	15-30	Lenticular, warty
16	F. tetragona	Unispicate	HF	0°	1	3	60-110	Oblong, striped
17	F. umbellaris	Compound anthelodium	HF+sPc+lPc	ů	60-100	1	06-09	Lenticular, warty
18	F. woodrowii	Simple anthelodium	HF+sPc	1°	2-5	1	6-14	Trigonous, warty

Table 2. Type of inflorescence, spikelet and flower data for studied species.

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Character No.	Character and character state
1	Habit : Perrenial (0), Annual (1)
2	Culm: Axillary (0), Central (1)
3	Culm : Penta-Quadrangular (0), Triquetrous (1), Terete (2)
4	Basal leaves: Phyllopodic (0), Aphyllopodic (1)
5	Leaf sheath: Glabrous (0), Hairy (1)
6	Leaves: Laminate (0), Elaminate (1)
7	Phyllotaxy: Spiral (0), Tristichous (1), Distichous(2)
8	Ligule : Absent (0), Present (1)
9	Inflorescence position: Terminal (0), Pseudo-lateral (1)
10	Inflorescence type: Unispiculate(0), Simple anthelate (1), Compound anthelate (2), Capitate (3)
11	Inflorescence structure: Only HF (0), HF+lPc+sPc (1), HF+lPc (2), HF+sPc (3)
12	No. of spikelet per inflorescence : 1-10 (0), 11-30 (1), 31-50 (2), ≥51
13	Involucral bract: Shorter than inf. (0), Overtopping the inf. (1)
14	Length of lower most bract (cm): 0.1-2.49 (0), 2.5-4.99 (1), ≥5.0 (2)
15	Length of upper most bract (cm): 0.03-0.13 (0), 0.14-0.27 (1), ≥0.28 (2)
16	Length of lower most prophyll (cm): 0.03-0.24 (0), 0.25-0.49 (1), ≥0.50(2)
17	Length of upper most prophyll (cm): 0.03-0.09 (0), 0.1-0.19 (1), ≥0.20 (2)
18	Maximum order of ramification: $1^{\circ}(0)$, $2^{\circ}(1)$, $3^{\circ}(2)$, $\ge 4^{\circ}(3)$
19	Lower most paracladial length (cm) : 0(0), 0.1-5 (1), 5.1-10 (2), ≥ 10.1 (3)
20	No. of spikelet on lower most paracladia: 1-10(0), 11-20(1), 21-30(2), ≥31(3)
21	No. of paracladia with evident epipodium: $0(0)$, 1- $6(1)$, 7- $13(2)$, $\geq 14(3)$
22	Length of epipodium of 1° Pc (cm): 0 (0), 0.1-1.6(1), 1.7-3.3(2), ≥3.4(3)
23	Spikelet: Pedicellate (0), Sessile (1)
24	Solitory spike shape: Linear (0), Pyriform-Ovoid (1), Globose (2)
25	Spikelet length (cm): 0.1-0.4(0), 0.5-0.9(1), 1-1.4 (2), ≥1.5(3)
26	No. of Bractiform structure : 0 (0), 1 (1), 2-3 (2), ≥4 (3)
27	No. of fertile glume per spikelet: 1-18 (0), 19-37(1), 38-57(2), ≥58 (3)
28	Lower glumes: Spiral (0), Distichous (1)
29	Perigynia nature: Hyaline (0), Membranous (1), Chartaceous (2)
30	Perigynia apex: Obtuse (0). Acute (1), Acuminate- mucronate (2), Aristate (3)
31	Perigynia texture: Glabrous (0), Hairy (1)
32	Perigynia Keel: Absent (0), Present (1)
33	Perigynia nerves no.: 15-11 (0), 10-6 (1), 5-1 (2)
34	Perigynia colour: White-Green (0), Yellow-Brown (1), Red-purple (2)
35	Rachilla: Winged (0), Non-winged (1)
36	Stamen no.: 1 (0), 2 (1), 3 (2)
37	Style branch: 2 (0), 3 (1)
38	Style texture: Glabrous (0), Hairy (1)
39	Achene texture: Glabrous (0), Striped - Warty (1)
40	Achene colour: White-Yellow(0), Brown (1), Purple-red (2), Black (3)

Table 3. Character and character state used in the present study with potential phylogenetic value (adopted from Bhrul, 1995; Naczi, 2009; Reutemann *et al.*, 2009).

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Taxon No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Char- acter No.																		
1	1	1	1	0	0	0	0	0	1	1	0	0	1	1	1	1	0	0
2	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	0	1
3	1	2	1	1	1	1	1	1	0	2	1	2	0	2	1	0	1	0
4	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0
5	1	0	1	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0
6	0	0	0	1	1	0	1	1	1	0	0	0	1	1	0	1	1	1
7	0	0	1	2	1	0	1	1	2	1	1	1	0	0	1	2	1	0
8	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
10	1	3	2	2	2	2	1	1	2	1	0	0	2	0	1	0	2	2
11	1	3	1	1	1	1	1	1	1	3	0	0	1	0	1	0	1	1
12	0	1	1	2	1	1	0	0	3	0	0	0	3	0	1	0	3	2
13	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0
14	0	1	1	1	2	0	2	2	1	0	0	0	2	0	1	0	1	1
15	0	1	2	1	2	0	2	2	1	0	0	0	2	0	1	0	1	1
16	0	0	1	1	2	0	2	2	1	0	0	0	2	0	1	0	1	1
17	0	0	1	1	2	0	2	2	1	0	0	0	2	0	1	0	1	1
18	1	0	1	2	1	1	1	1	2	0	0	0	3	0	1	0	2	2
19	1	0	1	2	2	1	2	2	1	1	0	0	2	0	0	0	1	1
20	0	0	0	1	1	0	0	0	1	0	0	0	3	0	0	0	2	0
21	1	0	1	2	2	1	1	1	2	1	0	0	3	0	1	0	2	2
22	2	0	3	3	3	1	3	3	3	1	0	0	3	1	3	0	3	3
23	0	1	0	0	1	0	0	0	0	0	1	1	0	1	1	1	1	0
24	1	0	1	1	0	1	1	1	2	0	1	1	1	1	0	2	2	1
25	0	2	0	0	0	0	2	1	1	1	2	1	1	2	1	2	1	0
26	2	0	1	1	1	0	2	2	0	1	3	2	0	1	1	2	0	0
27	0	3	1	1	0	0	2	2	3	2	0	2	2	3	1	3	3	0
28	0	1	0	0	0	2	0	0	0	0	1	0	0	0	1	0	0	0
29	2	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1
30	2	1	2	0	2	1	1	1	1	1	2	0	2	2	1	0	1	1
31	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0
32	1	1	0	0	0	1	0	1	1	1	1	0	1	0	1	1	1	1
33	2	2	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	1
34	2	1	2	1	2	2	2	1	1	1	1	0	1	1	1	0	1	1
35	0	0	1	0	1	1	0	0	0	0	1	0	0	0	1	0	0	1
36	0	0	1	1	0	2	1	1	1	1	2	0	0	2	0	1	1	1
37	0	1	0	0	0	1	0	0	1	0	1	0	1	0	1	0	1	1
38	0	1	1	1	1	0	1	1	0	0	0	1	0	1	0	1	0	0
39	1	0	1	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1
40	0	0	0	3	0	0	0	0	0	2	0	3	0	0	0	1	0	0

 Table 4. Character states of studied taxa (Character no. as per Table 3)



Fig. 1. Typological interpretation of vegetative and reproductive shoot system of *Fimbristylis*. **a.** Structure of shoot system; **b.** Unit of the inflorescence comprising the main florescence and paraclades; **c.** & **d.** Closer view of paraclades showing setiform bracts and tubular prophylls; **e.** Distichously arranged 4 foliose structures and lower glumes in *F. ovata;* **f.** Spirally arranged 3 foliose structures and lower glumes in *F. ferruginea* var. *ferruginea;* **g.** Closer view of spikelet showing indeterminate apex and laterally originated flower and its subtending perigynia (UIF - Unit of the inflorescence, HZ - Inhibition zone, IZ - Innovation zone, HF - Main florescence, Cof - Co-florescence, sPc - short paracladia, IPc - long paracladia, Br - Bract, Pr - Prophyll, Fl- Flower, P - Perigynia).

structure of ramification– compound anthelodium (only HF+sPc+lPc) e.g. *F. cymosa* subsp. *cymosa* (Fig. 3n), *F. umbellaris* (Fig. 3q), *F. littoralis* (Fig. 3r), *F. quinquangularis* (Fig. 3s).

4). In case of simple anthelodium with short paracladia, when the length of epipodium is reduced or not evident then the inflorescence turned into the capitate type (only HF+sPc) e.g. *F. argentea* (Fig. 3u). At the same time, *F. cymosa* subsp. *cymosa* depicted different types of inflorescences i.e. lax anthelodium (Fig. 3n) or congested anthelodium (Fig. 3o) and capituliform (Fig. 3p).

The shape and length of the bracts and prophylls are variable (Table 3 & 4). Within the same inflorescence, the bracts vary from setiform and well-developed to glumaceous and reduced toward the apex of the inflorescence. In turn, the prophylls vary from tubular to glumaceous

and more reduced at the distal portion of each paraclade (Fig. 1 c & d). In all the studied species, branching order and the number and length of the paraclades also reduce toward the apex of the inflorescence. The paraclades are originated from axillary buds of the bracts disposed over the main axis or over the long paraclades, which generate paraclades of normal/axillar branch. The paraclades are generally disposed in a spiral arrangement which follows a right-handed or lefthanded spiral and generally exhibits a homodromic arrangement, where both the primary paraclades and the secondary paraclades are spiral in the same manner. In most studied species the spikelets have winged rachillas (as recorded in 12 species), whereas wingless rachillas occur in only 4 species. Most of the species show foliose structures at the base of the spikelets, the proximal ones resembling bracts and the distal ones resembling glumes, (Fig. 1e & f). Such structures are absent in *F. argentea*. In



Fig. 2. Structure of synflorescence. **a.** Unispicate (HF only); **b.** Bispicate (HF+1 sPc only); **c.** Simple anthelodium (HF+sPc); **d.** Capitate (HF+sPc); **e.** Lax compound anthelodium (HF+sPc+lPc); **f.** Simple anthelodium (HF+sPc+lPc); **g.** Congested compound anthelodium (HF+sPc+lPc). (HF- Main florescence, Cof- Co-florescence, sPc- short paracladia, IPc- long paracladia, Pc 1°- Primary paracladia, Pc 2°- Secondary paracladia, Pc 3°- Tertiary paracladia, Pc 4°- Quaternary paracladia).

most studied species both basal foliose structures and glumes are spirally arranged (Fig. 1f), but in *F. ovata* the basal foliose structures as well as the lower glumes are distichous (Fig. 1e). From the observed morphological characters, presently studied taxa were segregated in to two major groups on the basis of inflorescence type *i.e.* group **A** with anthelodia (HF+ sPc+lPc)



Fig. 3. Variations of synflorescence in *Fimbristylis* species. a. *F. ovata;* b. *F. polytrichoides;* c. *F. tetragona;* d & e. *F. schoenoides;* f. & g. *F. alboviridis;* h. *F. bisumbellata;* i. *F. ferruginea* var. *ferruginea;* j. *F. ferruginea* var. *typica;* k. *F. falcata;* l. *F. dichotoma;* m. *F. tenera;* n - p. *F. cymosa* subsp. *cymosa;* q. *F. umbellaris;* r. *F. littoralis;* s. *F. quinquangularis;* t. *F. merrilli;* u. *F. argentea*



Fig. 4. Dendrogram showing relationships between studied 18 taxa of *Fimbristylis*.

and group B with unispicate (HF) and capitate/ simple anthelodia (HF+sPc). Species with simple anthelodia, lower order $(1^{\circ}/2^{\circ})$ of ramification and presence of 1-2 bractiform structures separates group \mathbf{A}_1 from group \mathbf{A}_2 , with compound anthelodia, higher order (3°/4°) paracladial ramification and presence of 2-3 bractiform structures. In A, F. cymosa subsp. cymosa is separated out due to having 20-50 spikelets per inflorescence, 8-15 spikelets per paracladia and bifid style, although in natural conditions trifid style florets can be also recorded. Members of group **B** have reduced inflorescences. \mathbf{B}_{1} is separate from \mathbf{B}_{1} on the basis of inflorescence structure i.e. **B**₁ with HF+sPc and **B**₂ with HF only. In \mathbf{B}_{1} , *F. argentea* can be segregated from *F. merrilli* because of having capitate inflorescences. F. ovata is unique due to its pseudo-lateral inflorescences and distichous lower glumes in the spikelet (Fig. 4, Table 3 & 4).

Discussion

Synflorescences with foliate stem along with terminal as well as lateral inflorescence are primitive in nature, and reduction trends from plesiomorphic inflorescence are observed in Cyperaceae (Guarise

& Vegetti, 2008b). In Fimbristylis, inflorescence architectures follow the general pattern earlier described by Vegetti (2003), Guarise & Vegetti (2008b) and Reutemann et al. (2009). The rachilla is indeterminate with new glumes always originating laterally, immediately below the rachilla apex (Fig. 1g), thus the inflorescences are polytelic as in most cyperaceae and monocotyledons (Alves et al., 2000; Guarise & Vegetti, 2008b; Vrijdaghs et al., 2010; Weberling, 1989). The differential increase of the internodal growth of paraclade axes has influenced the shape of inflorescence, especially in the manner in which branches are grouped in the distal portion of a paraclades which are responsible for the structural variations in the UIF (Guarise & Vegetti, 2008a). In the present work 3 types of inflorescences lax and congested anthelodia and capituliform/capitate (Fig. 3n, o & p) are noticed in F. cymosa subsp. cymosa R. Br., due to which it is sometimes misidentified as F. cymosa subsp. umbellato-capitata (Hbd.) T. Koyama; number of stigmas and achene shape can be however used to separate them (Wagner, 1999). At the same time, in *F. schoenoides*, unispicate and bispicate inflorescence were noticed (Fig. 3d & e) and in F. alboviridis simple anthelodium of both types i.e. HF+sPc and HF+sPc+lPc were noticed (Fig. 3f & g). In these cases most frequently recorded types were used as character states to construct the dendrogram. In anthelodium of all the studied species paraclades are arranged in a homodromic arrangement, an obsevation shared with Reutemann *et al.* (2009). Perusal of literature suggest that, from all the presently studied species only *F. ovata* (=*A. ovata*) and *F. dichotoma* were worked out earlier by Reutemann *et al.* (2009) and present observations for both are in accordance with them. During present investigation unispiculate pseudo lateral inflorescence is recorded for *F. ovata* only, while Reutemann *et al.* (2009) reported terminal and bispiculate inflorescence for the same.

Although, the synflorescences show different appearances, a careful observation of branching systems reveals a common structural pattern with different degree of development of their components (Table 2). Intermediate forms of foliose structures has been recorded in all the species, at the base of the spikelets which are empty and does not consist flower. According to Reutemann *et al.* (2009) such structures has more resemblance with bracts than glumes, hence it called as bractiform structure.

As far as inflorescence characteristics are concerned, overall structure, branching order, length and position of paraclades, size of bracts and prophylls, number of bractiform structures and number of styles seem to be the main characteristics with taxonomic potential for phenetic implications at generic/species level. Unlike any other species of *Fimbristylis*, *F. ovata* is found to be exceptional during present study due to its pseudo-lateral inflorescences and distichous lower glumes in the spikelet. The inclusion of Abildgaardia ovata (Burm.f.) Kral within the genus Fimbristylis (as F. ovata) is supported with the help of present statistical analysis as it is showing close resemblance with unispicate species of Fimbristylis (Fig. 4, Table 3 & 4); as supported and mentioned in earlier works (Ohwi, 1944; Kern, 1974; Hooker, 1894; Muasya et al., 1998, 2002, 2009; Simpson et al., 2007; Ghamkhar et al., 2007).

Rua (1999) and Guarise and Vegetti (2008b) have given the typology based diversification of synflorescence for the family Poaceae and Cyperaceae; where in the homogenization, truncation and racemization are the main processes of diversity in synflorescence. Unispicate inflorescences and anthelodia appear to be the basic structures from which the most evolved capitate inflorescences has been originated due to arrest of intercalary growth of the internodes (Guarise & Vegetti, 2008a; Reutemann *et al.*, 2009). The major trend of synflorescence evolution among and within the genera is reductive, but the possibility of the occurrence of amplification within or between the groups must not be neglected. Beyond parallelism and reversion within the inflorescence architecture, it is possible to identify groups of taxa in which particular types of inflorescences have evolved within the family / genus (Tucker & Grimes 1999, Guarise & Vegetti, 2008a & b). Further, more intensive phylogenetic studies involving character homology at molecular level are warranted.

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