

SEED MORPHOLOGICAL STUDIES ON SOME MONOCOT FAMILIES (EXCLUDING GRAMINEAE) AND THEIR PHYLOGENETIC IMPLICATIONS

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Abstract

Seed morphological studies of 46 taxa from Pakistan belonging to 7 monocotyledonous families viz., Alismataceae, Araceae, Arecaceae, Commelinaceae, Cyperaceae, Eriocaulaceae and Iridaceae included in 5 monokotyledonous orders viz., Alismatales, Arecales, Asparagales, Commelinales and Poales have been carried out by using light and scanning electron microscopy (SEM). Great variation in various seed morphological characters have been observed at order, family, subfamily, generic and specific levels. These seed micromorphological characters are used to assess the evolutionary relationship among the families of the studied taxa.

Introduction

Seed is a vital genetic source and dispersal unit between successive generation of plants (Armstrong, 1999) and it possesses very reliable and constant characters in various groups of seed plants (Berggren, 1969; Corner, 1976; Qaiser, 1987; Ahmad & Qaiser, 1989; Otto, 2002). Seed morphological studies have great value and these characters can be individually used as a beneficial tool for the identification of plant species at various levels (Berggren, 1962, 1981; Corner, 1976; Ahmed & Qaiser, 1989; Omer and Qaiser, 1995; Abid & Qaiser, 2009; Ather *et al.*, 2009, 2010; Kanwal *et al.*, 2009, 2010). Similarly, Matias & Soares (2009) examined the genus *Echinodendrus* of the family Alismataceae for its seed morphology and they concluded that seed morphology could play an important role in specific delimitation. Likewise, seed morphological characters in the family Araceae were studied by few workers (Corner, 1976; Kirkbride *et al.*, 2006; Bojnansky & Fargasova, 2007). Attention was also paid on seed morphology of the family Arecaceae (Kirkbride *et al.*, 2006; Watson & Dallwitz, 1992; Salm, 2005). Furthermore, the family Cyperaceae shows great variation in surface pattern of seeds which was significantly used for the specific delimitation of various genera (Corner, 1976; Kirkbride *et al.*, 2006; Bojnansky & Fargasova, 2007; Pignott & Mariotti, 2004; Strong, 2006). In the family Eriocaulaceae the seed coat morphology was examined by various workers (Nair, 1987; Giulietti *et al.*, 1988; Phillip, 1995, 1996, 1997). Similarly, there are various reports available on seed characters of the family Iridaceae (Wagner & Goldblatt, 1984; Goldblatt *et al.*, 1989; Caiola *et al.*, 2010). Seed morphological characters also have the significant importance in tracing the evolutionary and phylogenetic relationships of different taxa (Murley, 1951; Hufford, 1995; Akbari & Azizian, 2006; Fawzi *et al.*, 2010; Ather *et al.*, 2013). Besides the academic fields seed morphological characters can also be utilized by agriculturists and foresters in the field to distinguish the weeds seeds from the seeds of economically important plant species (Khalid & Shad, 1990). Present study is carried out to trace out the phylogenetic relationship of 46 monocotyledonous taxa belonging to 7 families viz., Araceae, Arecaceae, Alismataceae, Commelinaceae, Cyperaceae, Eriocaulaceae and Iridaceae. Although various reports are available on seed morphological studies of various monocotyledonous families from different parts of the world, but there are no

detailed information regarding to the seed morphology of any monocot family from Pakistan. The purpose of the present report is to provide the detailed seed macro and micro morphological characters as an additional tool to strengthen the taxonomic delimitation of various monocotyledonous taxa from Pakistan.

Materials and Methods

Mature and healthy seeds of 46 taxa distributed in 25 genera of 7 monocot families were collected from herbarium specimens. Mostly 20 seeds per plant and 10 plants per species were studied. The list of voucher specimens is deposited in KUH. Seed morphological characters were examined under light microscope (Nikon Type 102) and scanning electron microscope (JSM-6380A). For scanning electron microscopy dry seeds were directly mounted on metallic stubs using double adhesive tape and coated with gold for a period of 6 minutes in a sputtering chamber and observed under SEM. The terminology used is in accordance of Lawrence (1970), Berggren (1981) and Stearn (1983) with slight modifications. The following characters were studied: Presence of aril, size, colour, shape, surface (testa), and position of hilum (Table 1).

Numerical analysis

Hierarchical clustering was performed by using Euclidean distance index and group strategy with the computer package (SPSS 18, 2012). Each of the species is treated as operational taxonomic unit (OTU). Characters are recorded in binary state and coded as presence or absence (1 or 0 respectively). The average values of the quantitative characters viz., seed length and breadth were directly used (Tables 2 & 3).

Observations

General seed characters of the order Alismatales

Seeds 1-6 x 0.5-6 mm, oblong, obovate, elliptic pyriform, grooved and ridged, orbicular or ovate, dull brown, golden brown, orange brown, rust brown or black, shiny or unshiny, hairy (pilose) or glabrous, reticulate, rugose, ribbed or unribbed, hilum basal, sub-basal or lateral. It is represented by two families viz., Alismataceae and Araceae (Table 1).

Table 1. Seed morphological characters of monocotyledonous taxa.

Name of taxa	Name of family	Aril	colour	Shape	Size (mm)	Surface	Hilum
<i>Alisma plantago-aquatica</i>	Alismataceae	Absent	golden brown, shiny	oblong, grooved and ridged	2-2.5x1.5	reticulate	Basal
<i>A. gramineum</i>	Alismataceae	Absent	golden brown, shiny	obovate, grooved and ridged	2x1.5	reticulate	Sub-basal
<i>Sagittaria trifolia</i>	Alismataceae	Absent	rust brown, shiny	elliptic pyriform, centrally grooved	3x3	reticulate	Lateral
<i>Linnophyton obtusifolium</i>	Alismataceae	Absent	black, shiny	obovate, shortly beaked	1x0.5	reticulately ribbed, pilose	Basal
<i>Arisaema flavum</i>	Araceae	Absent	brown, unshiny	orbicular	3-4x3-4	rugose	Sub-basal
<i>A. jacquemontii</i>	Araceae	Absent	rust brown, unshiny	orbicular-ovate	5-6x5-6	rugose	Sub-basal
<i>A. tortuosum</i> var. <i>curvatum</i>	Araceae	Absent	rust brown, unshiny	orbicular-ovate	3-4x3-4	rugose	Sub-basal
<i>Lemna aequinoctialis</i>	Araceae	Absent	light brown-dark brown, dull shiny	triangular	3x1.5	tuberculate and reticulate	Basal
<i>Areca catechu</i>	Areaceae	Present	dust brown, dull shiny	deltoid	10-15x5-8	psilate	Basal
<i>Livistonia chinensis</i>	Areaceae	Present	dust brown-maroon, dull shiny	sub-orbicular	10-15x10-12	psilate	Sub-basal
<i>Nannorrhops ritchiana</i>	Areaceae	Present	light brown, unshiny	orbicular	10-15x10-15	psilate	Basal
<i>Phoenix dactylifera</i>	Areaceae	Present	chest nut brown, dull shiny	elliptic, ventrally grooved	20-25x6-8	ruminate	Lateral
<i>Commelina benghalensis</i>	Commelinaceae	Absent	black, unshiny	reniform	3-4x2-4	ruminate	Lateral
<i>C. paludosa</i>	Commelinaceae	Absent	light brown, unshiny	narrow elliptic	5x2	ruminate	Lateral
<i>Setcreasea brevifolia</i>	Commelinaceae	Absent	grey, unshiny	sub-reniform	3-3.5x2	granulate	Lateral
<i>S. purpurea</i>	Commelinaceae	Absent	grey, unshiny	oblong, ventrally grooved	3x2	granulate	Lateral
<i>Bolboschoenus affinis</i>	Cyperaceae	Absent	cream, shiny	bigonous, elliptic with stipe	2.5-3x1.5-2	reticulate foveate	Basal
<i>Carex diluta</i>	Cyperaceae	Absent	light green, unshiny	trigonous, elliptic with stipe	3x2	lineolate	Basal
<i>C. divisa</i>	Cyperaceae	Absent	golden-brown, shiny	planoconvex, elliptic with stipe	3.5-4x1.5-2	lineate	Basal
<i>C. fedtia</i>	Cyperaceae	Absent	greenish brown, unshiny	trigonous, elliptic with stipe	4-5x1-1.5	pubescent	Basal
<i>C. flacca</i>	Cyperaceae	Absent	cream-maroon, dull shiny	trigonous, ovate with stipe	2-3x1-2	reticulate and appressedly colliculate	Basal

Table 1. (Cont'd).

<i>Cyperus laevigatus</i>	Cyperaceae	Absent	golden-chocolate brown, unshiny	elliptic-ovate, bi-trigonus with short stipe	1-2.5x0.5-1	reticulate	Basal
<i>Fimbristylis cymosa</i>	Cyperaceae	Absent	black, shiny	bigonous, ovate with stipe	1x0.5-1	reticulate	Basal
<i>F. ferruginea</i>	Cyperaceae	Absent	cream-grey brown, dull shiny	compressed, elliptic-orbicular with stipe	1-1.5x1	appressedly reticulate	Basal
<i>F. bisumbellata</i>	Cyperaceae	Absent	cream, shiny	obovate	1-1.5x0.5	ribbed, sclariiform between ribs	Basal
<i>F. quinqueangularis</i>	Cyperaceae	Absent	golden shiny	bigonous, elliptic-ovate	1-1.5x0.5-1	reticulate foveate	Basal
<i>F. squarrosa</i>	Cyperaceae	Absent	golden, shiny	bigonous, elliptic-ovate	0.5-1x0.5	reticulate	Basal
<i>F. turkestanica</i>	Cyperaceae	Absent	cream, dull shiny	compressed, obovate sub-orbicular	1.5-2x1-1.5	ruminate, foveate	Basal
<i>F. woodrowi</i>	Cyperaceae	Absent	white, shiny	sub-orbicular, bigonous	0.5x0.5	tuberculate	Basal
<i>Isolepis setacea</i>	Cyperaceae	Absent	golden brown, shiny	elliptic with short stipe	1x0.5	ribbed, sclariiform between ribs	Basal
<i>Juncellus pygmaeus</i>	Cyperaceae	Absent	chocolate brown, dull shiny	trigonus, elliptic	1-1.5x0.5	reticulate	Basal
<i>J. serotinus</i>	Cyperaceae	Absent	cream-grey, dull shiny	sub-orbicular	1-1.5x0.5-1	reticulate	Basal
<i>Kobresia laxa</i>	Cyperaceae	Absent	golden brown, shiny	linear, without stipe	2.5-3x0.5-1	lineolate and granulate	Basal
<i>K. royleana</i>	Cyperaceae	Absent	light brown, dull shiny	oblong with stipe	2-3x0.5-1	reticulate and granulate	Basal
<i>Kyllinga brevifolia</i>	Cyperaceae	Absent	golden, shiny	trigonus, oblong with short stipe	1-1.5x-0.5	muricate	Basal
<i>K. triceps</i>	Cyperaceae	Absent	rust brown, shiny	trigonus, oblong with short stipe	1-1.5x0.5	reticulate and foveate	Basal
<i>Pycurus flavidus</i>	Cyperaceae	Absent	golden, shiny	trigonus, ovate with short stipe	1x0.5	muricate	Basal
<i>P. pumilus</i>	Cyperaceae	Absent	cream, unshiny	trigonus, ovate with short stipe	0.5-1x0.5	colliculate, granulate	Basal
<i>Schoenoplectus litoralis</i> ssp. <i>thermalis</i>	Cyperaceae	Absent	chocolate brown, unshiny	bigonous, ovate with stipe	2x1-1.5	reticulate foveate	Basal
<i>S. lupulinus</i>	Cyperaceae	Absent	black, shiny	trigonus, elliptic with short stipe	1-1.5x0.5-1	undulate and lineate	Basal
<i>Scirpus setaceus</i>	Cyperaceae	Absent	golden-rust brown, shiny	bigonous, elliptic with stipe	0.5-1x0.5	ribbed, sclariiform between ribs	Basal
<i>Eriocaulon cinereum</i> var. <i>sieboldianum</i>	Eriocaulaceae	Absent	Maroon, shiny	ovate	1x0.5	lineate	Basal
<i>Moraea sisyriuchium</i>	Iridaceae	Absent	maroon and unshiny	elliptic	5x3	ruminately foveate	Basal
<i>Iris songarica</i>	Iridaceae	Absent	maroon and shiny	elliptic	5-8x4-5	ruminately foveate	Basal
<i>I. stocksii</i>	Iridaceae	Absent	maroon and unshiny	elliptic pyriform	4-5x3	ruminately foveate	Basal
<i>I. aitchisonii</i>	Iridaceae	Absent	dark brown, shiny	broadly elliptic	2-2.5x2	ruminately rugose	Indistinct

Key to the families

- 1 + Seeds oblong, obovate or elliptic pyriform Alismataceae
 - Seeds orbicular or ovate Araceae

General seed characters of the family Alismataceae

Seeds 1-3x0.5-3mm, oblong, obovate or elliptic pyriform, grooved and ridged, golden brown, orange brown or black, shiny, hairy (pilose) or glabrous, reticulate, ribbed or unribbed, hilum basal, sub-basal or lateral (Table 1). It comprises of 3 genera viz., *Alisma* L., *Linnophyton* Miq. and *Sagittaria* L. (Table 1).

Key to the genera

- 1 + Seeds oblong or obovate 2
 - Seeds elliptic pyriform *Sagittaria*
 2 + Seeds golden brown-maroon, surface grooved
 *Alisma*
 - Seeds black, surface not grooved *Linnophyton*

***Alisma* L.**

Seeds 2-2.5x1.5mm, oblong or obovate, grooved and ridged, reticulate, hilum basal or sub-basal. It is represented by 2 species viz., *Alisma plantago-aquatica* L. and *A. gramineum* Lej (Table 1).

Key to the species

- 1 + Seeds oblong *A. plantago-aquatica*
 - Seeds obovate *A. gramineum*

***Linnophyton* Miq.**

Seeds 1x0.5mm, black, shiny, obovate, shortly beaked, reticulately ribbed and pilose, hilum basal. It is represented by single species viz., *Linnophyton obtusifolium* L. (Miq.) (Table 1).

***Sagittaria* L.**

Seeds 3x3mm, orange brown, shiny, elliptic pyriform, centrally grooved, reticulate, hilum lateral. It is represented by single species viz., *Sagittaria trifolia* L. (Table 1).

General seed characters of the family Araceae

Seeds 3-6x1.5-6mm, dull brown, light brown-dark brown or rust brown, unshiny, orbicular, ovate or triangular, tuberculate-reticulate or rugose, hilum basal or sub-basal. It is represented by 2 subfamilies viz., Arecoideae and Lemnoideae (Table 1).

Key to the subfamilies

- 1 + Seeds orbicular or ovate, surface rugose, hilum sub-basal Arecoideae
 - Seeds triangular, surface tuberculate-reticulate, hilum basal Lemnoideae

Table 2. List of characters, scored for cluster analysis for monocot taxa in Table 3.

No.	Character description
1.	Length (mm)
2.	Breadth (mm)
	Colour
3.	Cream: Absent (0), Present (1)
4.	White: Absent (0), Present (1)
5.	Light brown: Absent (0), Present (1)
6.	Brown: Absent (0), Present (1)
7.	Dark brown: Absent (0), Present (1)
8.	Golden brown: Absent (0), Present (1)
9.	Grey brown: Absent (0), Present (1)
10.	Chocolate brown: Absent (0), Present (1)
11.	Greenish brown: Absent (0), Present (1)
12.	Chest nut brown: Absent (0), Present (1)
13.	Dust brown: Absent (0), Present (1)
14.	Rust brown: Absent (0), Present (1)
15.	Grey: Absent (0), Present (1)
16.	Light green: Absent (0), Present (1)
17.	Golden: Absent (0), Present (1)
18.	Maroon: Absent (0), Present (1)
19.	Black: Absent (0), Present (1)
	Shape
20.	Triangular: Absent (0), Present (1)
21.	Elliptic: Absent (0), Present (1)
22.	Elliptic pyriform: Absent (0), Present (1)
23.	Oblong: Absent (0), Present (1)
24.	Linear: Absent (0), Present (1)
25.	Orbicular: Absent (0), Present (1)
26.	Sub-orbicular: Absent (0), Present (1)
27.	Obovate: Absent (0), Present (1)
28.	Reniform: Absent (0), Present (1)
29.	Sub-reniform: Absent (0), Present (1)
30.	Ovate: Absent (0), Present (1)
31.	Pyriform: Absent (0), Present (1)
32.	Deltoid: Absent (0), Present (1)
	Surface
33.	Psilate: Absent (0), Present (1)
34.	Ruminate: Absent (0), Present (1)
35.	Reticulate: Absent (0), Present (1)
36.	Rugose: Absent (0), Present (1)
37.	Foveate: Absent (0), Present (1)
38.	Granulate: Absent (0), Present (1)
39.	Lineate: Absent (0), Present (1)
40.	Lineolate: Absent (0), Present (1)
41.	Pubescent: Absent (0), Present (1)
42.	Colliculate: Absent (0), Present (1)
43.	Ribbed: Absent (0), Present (1)
44.	Scalariform: Absent (0), Present (1)
45.	Tuberculate: Absent (0), Present (1)
46.	Muricate: Absent (0), Present (1)
	Hilum
47.	Inconspicuous hilum: Absent (0), Present (1)
48.	Basal hilum: Absent (0), Present (1)
49.	Sub-basal hilum: Absent (0), Present (1)
50.	Marginal hilum: Absent (0), Present (1)
51.	Lateral hilum: Absent (0), Present (1)
52.	Aril: Absent (0), Present (1)

Table 3. Data matrix of Monocots scored for 52 characters present in table 2.

Name of taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
<i>Alisma</i>	2.25	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Areca</i>	17.6	6.5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Arisaema</i>	4.5	5	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Bolboschoenus</i>	2.75	1.25	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Carex</i>	3	1.5	1	0	0	1	0	0	0	0	1	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0
<i>Commelina</i>	4	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
<i>Cyperus</i>	1.5	0.75	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
<i>Eriocaulon</i>	1	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Fimbristylis</i>	1.2	0.9	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1
<i>Iris</i>	5	3.5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
<i>Isolepis</i>	1	0.5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Juncellus</i>	1.25	0.35	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1
<i>Kobresia</i>	2.5	0.75	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
<i>Kyllingia</i>	1.25	0.4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
<i>Lemma</i>	2.25	1.5	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Limnophyton</i>	1	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Livistonia</i>	16	11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0
<i>Moraceae</i>	4.5	2.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
<i>Nannorrhops</i>	11.5	12.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Phoenix</i>	22.5	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Pycurus</i>	0.5	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Sagittaria</i>	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Schoenoplectus</i>	1	0.5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
<i>Scripus</i>	0.75	0.4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0
<i>Setcreasea</i>	3.25	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0

General seed characters of the subfamily Arecoideae

Seeds 3-6x3-6mm, brown, rust brown, unshiny, orbicular or ovate, rugose, hilum sub-basal. It is represented by a single genus *Arisaema* comprising 3 species viz., *Arisaema flavum* (Forsk.) Schott, *A. jacquemontii* Blume, *A. tortuosum* (Wall.) Schott (Table 1).

Key to the species

- 1 + Seeds orbicular *A. flavum*
 - Seeds orbicular-ovate 2
 2 + Seeds 5-6 x 5-6 mm *A. jacquemontii*
 - Seeds 3-4 x 3-4 mm *A. tortuosum*

General seed characters of the subfamily Lemnoideae

Seeds 3x1.5mm, light brown- dark brown, dull shiny, triangular, tuberculate and reticulate, hilum basal. It is represented by a single genus *Lemna* L., with a single species viz., *Lemna aequinoctialis* Welw. (Table 1; Fig. 4N-O).

General seed characters of the order Arecales

Seeds 10-25x5-15mm, light brown, dust brown or chest nut brown, dull shiny or unshiny, deltoid, orbicular, sub-orbicular or elliptic and grooved, psilate or runcate, hilum basal, sub-basal or lateral. It is represented by a single family Arecaceae comprising 4 genera viz., *Areca* L., *Livistonia* R. Br., *Nannorrhops* H. Wendl. and *Phoenix* L. (Table 1).

Key to the genera

- 1 + Seeds elliptic or deltoid 2
 - Seeds orbicular-sub-orbicular 3
 2 + Seeds elliptic 20-25 mm long *Phoenix*
 - Seeds deltoid, 10-15 mm long *Areca*
 3 + Seeds orbicular, hilum basal *Nannorrhops*
 - Seeds sub-orbicular, hilum sub-basal *Livistonia*

***Areca* L.**

Seeds 10-15x5-8mm, dust brown, dull shiny, deltoid, psilate, hilum basal. It is represented by a single species viz., *Areca catechu* L. (Table 1).

***Livistonia* R. Br**

Seeds 10-15x10-12mm, dust brown-maroon, dull shiny, sub-orbicular, psilate, hilum sub-basal. It is represented by a single species viz., *Livistonia chinensis* (N.J. Jacquin) R. Brown ex Martius (Table 1).

***Nannorrhops* H. Wendl.**

Seeds 10-15x10-15mm, light brown, unshiny, orbicular, psilate, hilum basal. It is represented by a single species viz., *Nannorrhops ritchiana* H. Wendl. (Table 1).

***Phoenix* L.**

Seeds 20-25x6-8mm, chest nut brown, dull shiny, elliptic ventrally grooved, runcate, hilum lateral. It is represented by a single species viz., *Phoenix dactylifera* L. (Table 1).

General seed characters of the order Asparagales

Seeds 2-8x2-5mm, maroon or dark brown, shiny or unshiny, elliptic or elliptic pyriform, runcately foveate or runcately rugose, hilum indistinct or basal. It is represented by a single family Iridaceae comprising 2 genera viz., *Moraea* P.Miller and *Iris* L. (Table 1)

General seed characters of the family Iridaceae

Seeds 2-8x2-5mm, maroon or dark brown, shiny or unshiny, elliptic or elliptic pyriform, runcately foveate or runcately rugose, hilum indistinct or basal. Comprising 2 genera viz., *Moraea* P.Miller and *Iris* L. (Table 1; Fig. L-M).

Key to the genera

- 1 + Seed elliptic pyriform, surface runcately foveate *Moraea*
 - Seeds elliptic-elliptic pyriform, surface runcately rugose *Iris*

***Moraea* P.Miller**

Seeds 5x3mm, maroon, unshiny, elliptic, runcately foveate, hilum basal. It is represented by a single species viz., *Moraea sisyrinchium* (L.) Ker. Gawl. (Table 1).

***Iris* L.**

Seeds 2-8x2-5mm, maroon or dark brown, shiny or unshiny, elliptic-elliptic pyriform, runcately rugose, hilum indistinct or basal. It is represented by 3 species viz., *Iris songarica* Shrenk, *I. stocksii* (Baker) Boiss. *I. aitchisonii* (Table 1; Fig. L-M).

Key to the species

- 1 + Seeds with basal hilum 2
 - Seeds with indistinct hilum *I. aitchisonii*
 2 + Seeds elliptic *I. songarica*
 - Seeds elliptic pyriform *I. stocksii*

General seed characters of the order Commelinales

Seeds 3-5x2-4mm, light brown, grey or black, unshiny, reniform, narrow elliptic, sub-reniform or oblong, ventrally grooved, runcate or granulate, hilum lateral. It is represented by a single family Commelinaceae (Table 1).

General seed characters of the family Commelinaceae

Seeds 3-5x2-4mm, light brown, grey or black, unshiny, reniform, narrow elliptic, sub-reniform or oblong, ventrally grooved, ruminant or granulate, hilum lateral. It is represented by 2 genera viz., *Commelina* L. and *Setcreasea* K. Schum. & Sydow (Table 1).

Key to the genera

- 1 + Seeds light brown or black, reniform or elliptic *Commelina*
 - Seeds grey, oblong or sub-reniform *Setcreasea*

***Commelina* L.**

Seeds 3-5x2-4mm, light brown or black, unshiny, reniform or narrow elliptic, ruminant, hilum lateral. It is represented by 2 species viz., *Commelina benghalensis* L., *C. paludosa* Blume (Table 1).

Key to the species

- 1 + Seeds black, reniform *C. benghalensis*
 - Seeds light brown, narrow elliptic *C. paludosa*

***Setcreasea* K. Schum. & Sydow**

Seeds 3-3.5x2mm, grey, unshiny, sub-reniform or oblong, ventrally grooved, granulate, hilum lateral. It is represented by 2 species viz., *Setcreasea brevifolia* (Torr.) Schum. & Sydow and *S. purpurea* (Schau.) Boom (Table 1; Fig. 1A-D).

Key to the species

- 1 + Seeds sub-reniform *S. brevifolia*
 - Seeds oblong *S. purpurea*

General seed characters of the order Poales

Seeds 0.5-5x0.5-2mm, cream, light green, golden-brown, greenish brown, cream-maroon, golden-chocolate brown, cream-grey brown, golden, white, rust brown, golden-rust brown, maroon or black, shiny or unshiny, bigonous or trigonous, planoconvex, compressed, with or without stipe, elliptic, ovate, orbicular, obovate, sub-orbicular or oblong, reticulate, foveate, lineolate, lineate, pubescent or glabrous, reticulate and appressedly colliculate, appressedly reticulate, ribbed or unribbed, scariform between ribs, ruminant, foveate, tuberculate, ribbed, lineolate-granulate, reticulate-granulate, muricate, colliculate, granulate or undulate - lineate, hilum basal.

Key to the families

- 1 + Seeds maroon, without stipe Eriocaulaceae
 Seeds other than maroon, but when maroon always with stipe Cyperaceae

General seed characters of the family Cyperaceae

Seeds 0.5-5x0.5-2mm, cream, light green, golden-brown, greenish brown, cream-maroon, golden-chocolate brown, cream-grey brown, golden, white, rust brown, golden-rust brown, or black, shiny or unshiny, bigonous, trigonous, planoconvex, compressed, with or without stipe, elliptic, ovate with stipe, orbicular, obovate, sub-orbicular or oblong, reticulate, foveate, lineolate, lineate, pubescent, reticulate and appressedly colliculate, appressedly reticulate, ribbed, scariform between ribs, ruminant, foveate, tuberculate, ribbed, lineolate and granulate, reticulate and granulate, muricate, colliculate, granulate or undulate and lineate, hilum basal (Table 1; Fig. 1F-O, 2 A-B, 3 A-B, 4 A-I).

Generic key could not be constructed due to overlapping characters.

***Bolboschoenus* (Aschers.) Palla**

Seeds 2.5-3x1.5-2mm, cream, shiny, bigonous, elliptic with stipe, reticulate or foveate, hilum basal. It is represented by a single species viz., *Bolboschoenus affinis* (Roth) Drobov. (Table 1; Fig. 1 E-F).

***Carex* L.**

Seeds 2-5x1-2mm, light green, golden-brown or greenish brown, unshiny bigonous or trigonous, planoconvex, with stipe, elliptic, ovate, lineolate, lineate, pubescent or glabrous or reticulate and appressedly colliculate, hilum basal. It is represented by 4 species viz., *Carex diluta* M.Bieb., *C. divisa* Hudson, *C. fedia* Nees, *C. flacca* Schreb (Table 1; Fig. 1G-N).

Key to the species

- 1 + Seeds planoconvex *C. divisa*
 - Seeds not planoconvex 2
 2 + Seeds ovate, cream-maroon *C. flacca*
 - Seeds elliptic, light green or greenish brown 3
 3 + Seeds hairy *C. fedia*
 - Seeds glabrous *C. diluta*

***Cyperus* L.**

Seeds 1-2.5x0.5-1mm golden-chocolate brown, unshiny, elliptic-ovate, bigonous or trigonous with short stipe, reticulate, hilum basal. It is represented by a single species viz., *Cyperus laevigatus* L. (Table 1; Figs. 1O, 2A).

***Fimbristylis* Vahl**

Seeds 0.5-1.5x0.5-1.5mm, black, cream, grey brown, golden, white, shiny, dull shiny, bigonous, ovate, elliptic, orbicular, obovate, elliptic or sub-orbicular, stiped, compressed, reticulate, ribbed, scariform between ribs, reticulate foveate, ruminant, foveate or tuberculate, hilum basal.

It is represented by 7 species viz., *Fimbristylis bisumbellata* (Forssk.) Bubani, *F. cymosa* R. Br. *F. ferruginea* (L.) Vahl, *F. quinquangularis* (Vahl) Kunth, *F. squarrosa* Vahl, *F. turkestanica* (Regel) B.Fedtsch., *F. woodrowi* C.B.Clarke (Table 1; Fig. 2 B-O).

Key to the species

- 1 + Seeds compressed 2
 - Seeds not compressed 3
 2 + Seeds elliptic-orbicular, surface reticulate
 *F. ferruginea*
 - Seeds obovate-sub-orbicular, surface ruminant and
 foveate *F. turkestanica*
 3 + Seed surface ribbed *F. bisumbellata*
 - Seed surface non-ribbed 4
 4 + Seeds white, surface tuberculate *F. woodrowi*
 - Seeds black or golden, surface not tuberculate 5
 5 + Seeds black *F. cymosa*
 - Seeds golden 6
 6 + Seed surface foveate *F. quinquangularis*
 - Seed surface reticulate *F. squarrosa*

***Isolepis* R. Brown**

Seeds 1x0.5mm, golden brown, shiny, elliptic with short stipe, ribbed, scleriform between ribs, hilum basal. It is represented by a single species viz., *Isolepis setacea* (L.) R.Br. (Table 1; Fig. 3 A-B).

***Juncellus* (Griseb.) C.B. Clarke**

Seeds 1-1.5x0.5-1mm, cream, grey or chocolate brown, dull shiny, trigonous, elliptic or sub-orbicular, reticulate, hilum basal. It is represented by 3 species viz., *Juncellus pygmaeus* (Rottb.) C.B. Clarke, *J. serotinus* (Rottb.) C.B. Clarke (Table 1; Fig. 3 C-F).

Key to the species

- 1 + Seeds elliptic, chocolate brown *J. pygmaeus*
 - Seeds sub-orbicular, cream-grey *J. serotinus*

***Kobresia* Willd.**

Seeds 2-3x0.5-1mm, light brown or golden brown, shiny or dull shiny, linear or oblong, with or without stipe, lineolate, reticulate or granulate, hilum basal. It is represented by 2 species viz., *Kobresia laxa* Nees, *K. royleana* (Nees) Boeck (Table 1; Fig. 3 G-J).

Key to the species

- 1 + Seeds oblong with stipe, surface reticulate
 *K. royleana*
 - Seeds linear without stipe, surface lineolate
 *K. laxa*

***Kyllinga* Rottb.**

Seeds 1-1.5x0.5mm, golden or rust brown, trigonous, oblong with short stipe, muricate, reticulate or foveate, hilum basal. It is represented by 2 species viz., *Kyllinga brevifolia* Rottb., *K. triceps* Rottb. (Table 1; Fig. 3 K-N).

Key to the species

- 1 + Seeds golden, surface muricate *K. brevifolia*
 - Seeds rust brown, surface reticulate and foveate
 *K. triceps*

***Pycreus* P. Beauv.**

Seeds 0.5-1x0.5 mm, cream or golden, shiny or unshiny, trigonous, ovate with short stipe, muricate, colliculate or granulate, hilum basal. It is represented by 2 species viz., *Pycreus flavidus* (Retz.) T. Koyama, *P. pumilus* (Table 1; Figs. 3O, 4A-C).

Key to the species

- 1 + Seed surface muricate *P. flavidus*
 - Seed surface colliculate and granulate ... *P. pumilus*

***Schoenoplectus* (H.G.L. Reichenb.) Palla**

Seeds 1-2x0.5-1.5mm, chocolate brown-black, shiny or unshiny, trigonous, elliptic with short stipe, bigonous, ovate with stipe, reticulate foveate, or undulate and lineate, hilum basal. It is represented by 2 species viz., *Schoenoplectus litoralis* (Schard.) Palla ssp. *thermalis* and *S. lupulinus* (Nees) V. Krecz (Table 1; Fig. 4 D-G).

Key to the species

- 1 + Seeds bigonous, ovate, surface reticulate and foveate
 *S. litoralis*
 - Seeds trigonous, elliptic, surface undulate and
 lineate *S. lupulinus*

***Scripus* L.**

Seeds 0.5-1x0.5mm, golden-rust brown, shiny, bigonous, elliptic with stipe, ribbed scleriform between ribs, hilum basal. It is represented by a single species viz., *Scripus setaceus* L. (Table 1; Fig. 4H-I).

General seed characters of the family Eriocaulaceae

Seeds 1x0.5mm, maroon, shiny, ovate, lineate, hilum basal. It is represented by a single species viz., *Eriocaulon cinereum* var. *sieboldianum* (Sieb. & Zucc.) T. Koyama ex Huang (Table 1; Fig. 4N-O).

Results and Discussions

Seed morphological data fully support the taxonomic delimitation of monocotyledonous taxa at various levels. The dendrogram based on seed morphology clearly shows two distinct groups (Fig. 5). The first group includes 4 genera of the family Arecaceae viz., *Areca*, *Livistonia*, *Nannorrhops* and *Phoenix*. This group is usually characterized by the presence of trees and rarely shrubs, stem covered with ring of dead scales and actinomorphic flowers (Malik, 1984), sulcate pollen grains (Sporne, 1972; Harley & Baker, 2001) and 15-30mm long and arillate seeds. Due to these primitive characters, this group occupies basal position in the dendrogram and is considered as more primitive than other group.

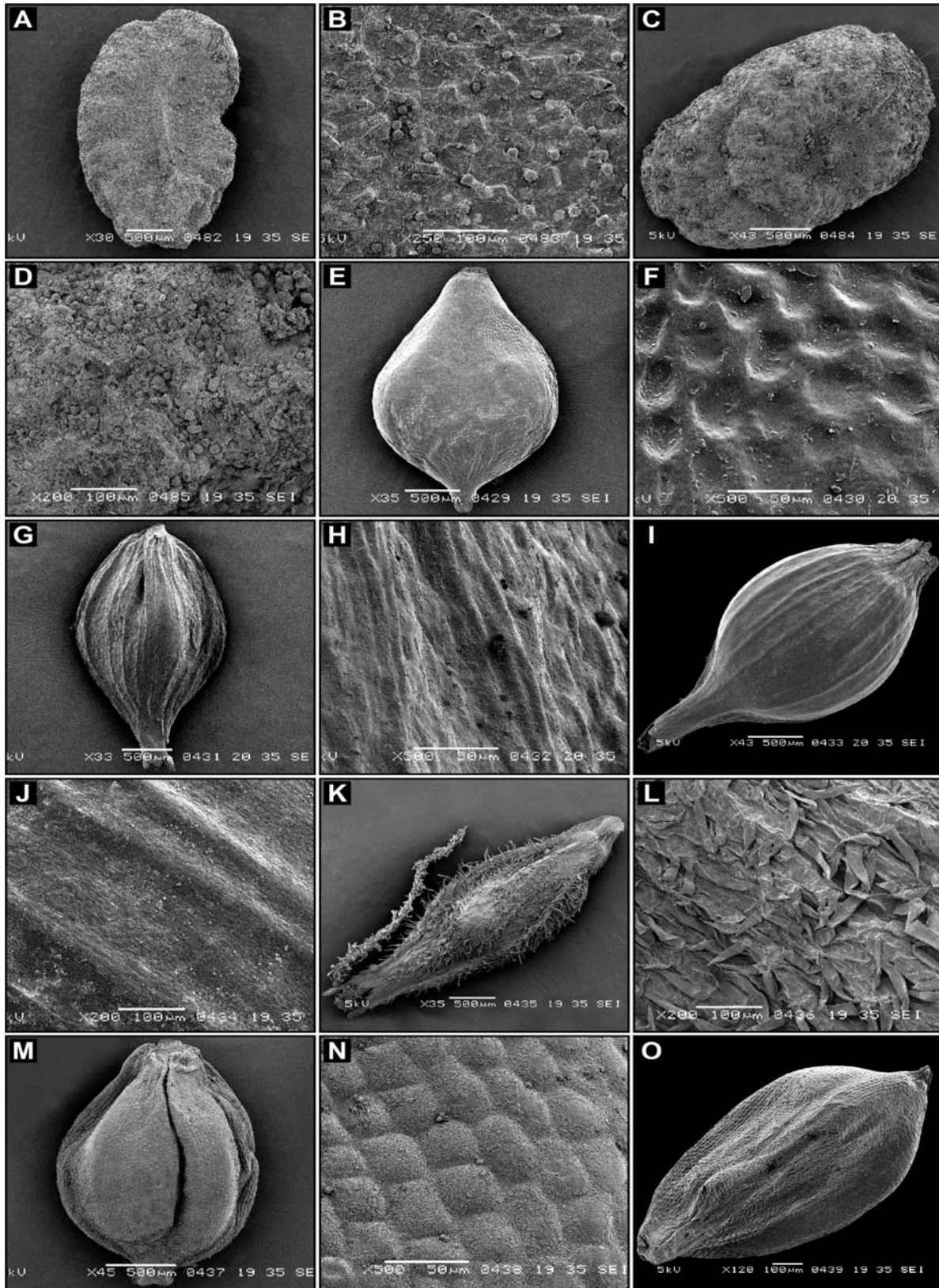


Fig. 1. Scanning electron micrographs. *Setcreasea brevifolia*: A, seed; B, surface. *S. purpurea*: C, seed; D, surface. *Bolboschoenus affinis*: E, seed; F, surface. *Carex diluta*: G, seed; H, surface. *C. divisa*: I, seed; J, surface. *C. fedia*: K, seed; L, surface. *C. flacca*: M, seed; N, surface. *Cyperus laevigatus*: O, seed. (Scale bars: A, C, E, G, I, K, M, = 500 μ m; B, D, J, L, O = 100 μ m; F, H, N=50 μ m).

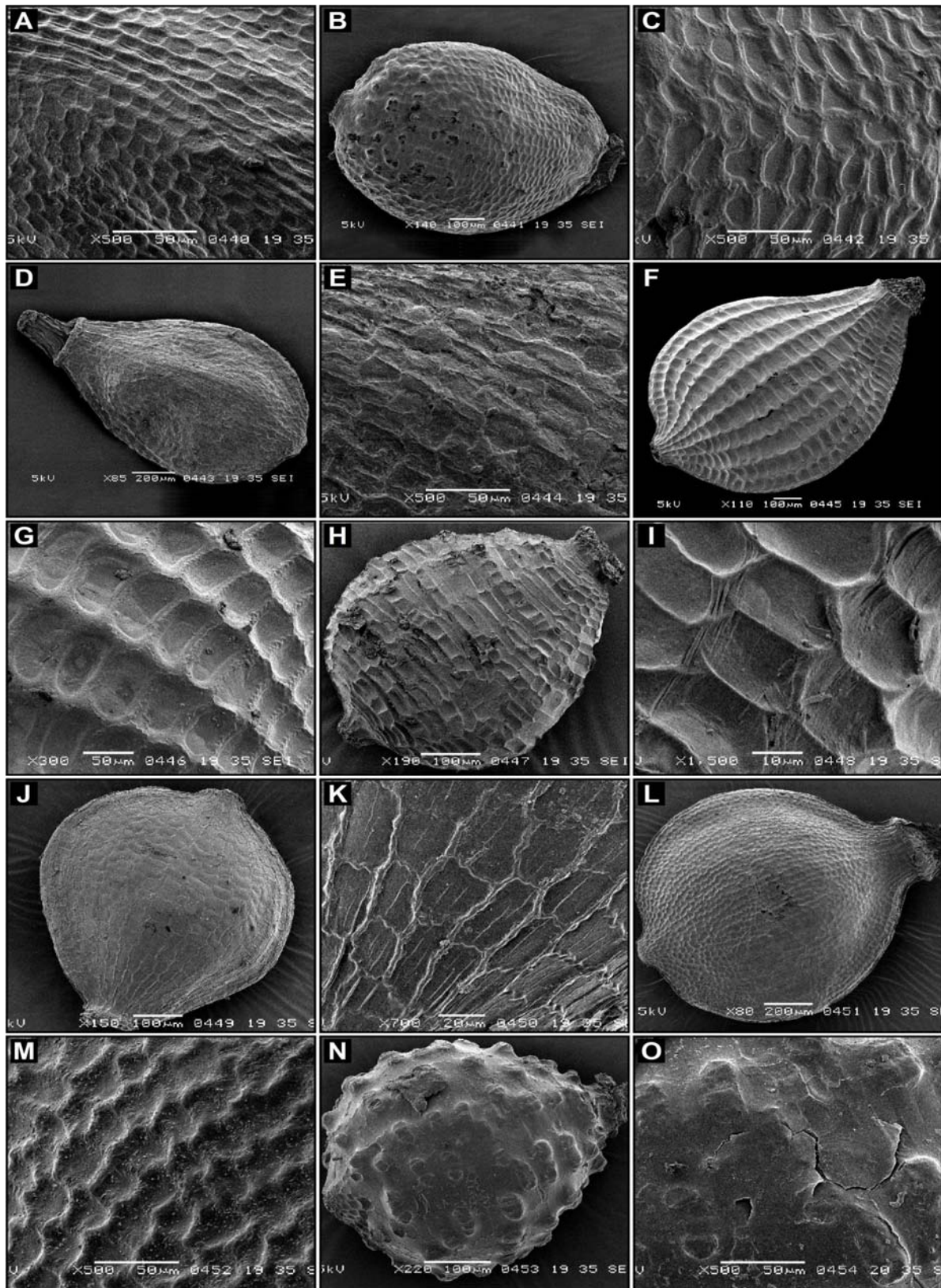


Fig. 2. Scanning electron micrographs. *Cyperus laevigatus*: A, surface. *Fimbristylis cymosa*: B, seed; C, surface. *F. ferruginea*: D, seed; E, surface. *F. bisumbellata*: F, seed; G, surface. *F. quinquangularis*: H, seed; I, surface. *F. squarrosa*: J, seed; K, surface. *F. turkestanica*: L, seed; M, surface. *F. woodrowi*: N, seed; O, surface. (Scale bars: D, L = 200 µm; B, F, H, J, N = 100 µm; A, C, E, G, M, O = 50 µm; K=20 µm; I=10 µm).

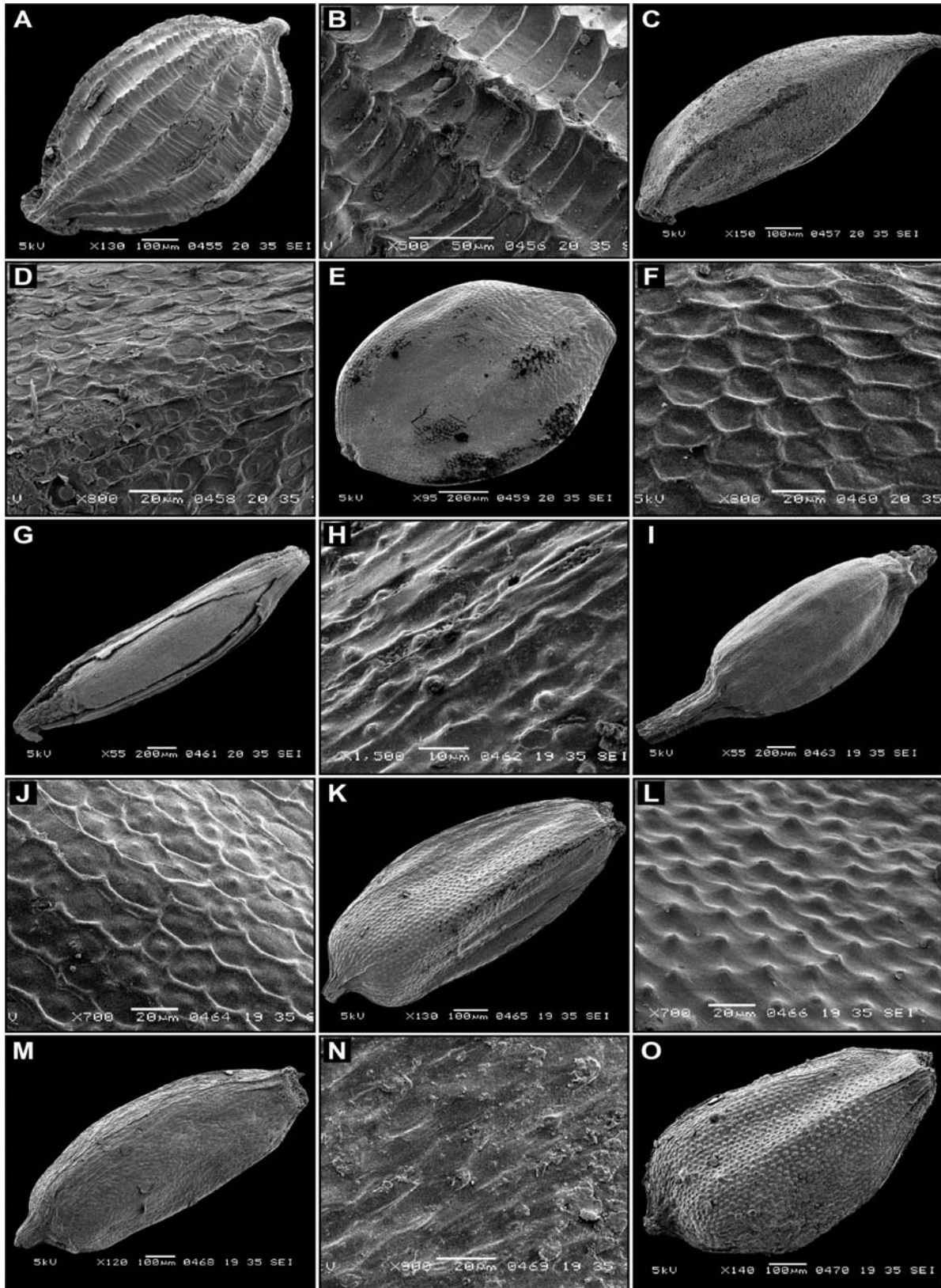


Fig. 3. Scanning electron micrographs. *Isolepis setacea*: A, seed; B, surface. *Juncellus pygmaeus*: C, seed; D, surface. *J. serotinus*: E, seed; F, surface. *Kobresia laxa*: G, seed; H, surface. *K. royleana*: I, seed; J, surface. *Kyllinga brevifolia*: K, seed; L, surface. *K. triceps*: M, seed; N surface. *Pycurus flavidus*: O, seed. (Scale bars: E, F, G, I = 200 μ m; A, C, K, M, O=100 μ m; B =50 μ m; D, J, L, N=20 μ m; H, 10= μ m).

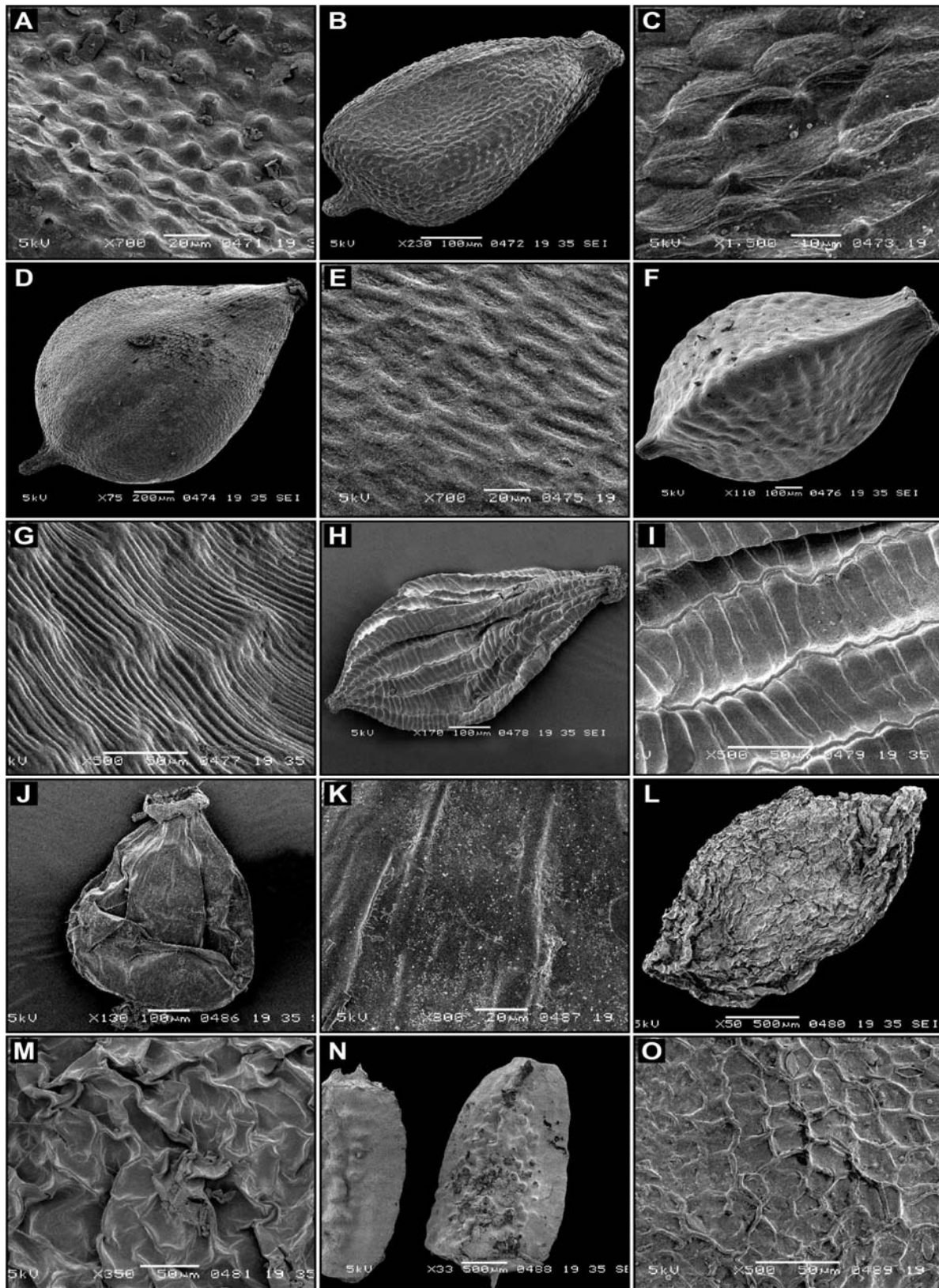


Fig. 4. Scanning electron micrographs. *Pycreus flavidus*: A, surface. *P. pumilus*: B, seed; C, surface. *Schoenoplectus littoralis* ssp. *thermalis*: D, seed; E, surface. *S. lupulinus*: F, seed; G, surface. *Scripus setaceus*: H, seed; I, surface. *Eriocaulon cinereum* var. *sieboldianum*: J, seed; K, surface. *Iris tenuifolia*: L, seed; M, surface. *Lemna aequinoctialis*: N, seed O, surface. (Scale bars: L, N= 500 µm; D = 200 µm; B, F, H, J=100 µm; G,I,M,O=50 µm; A,E,K=20 µm; C=10µm).

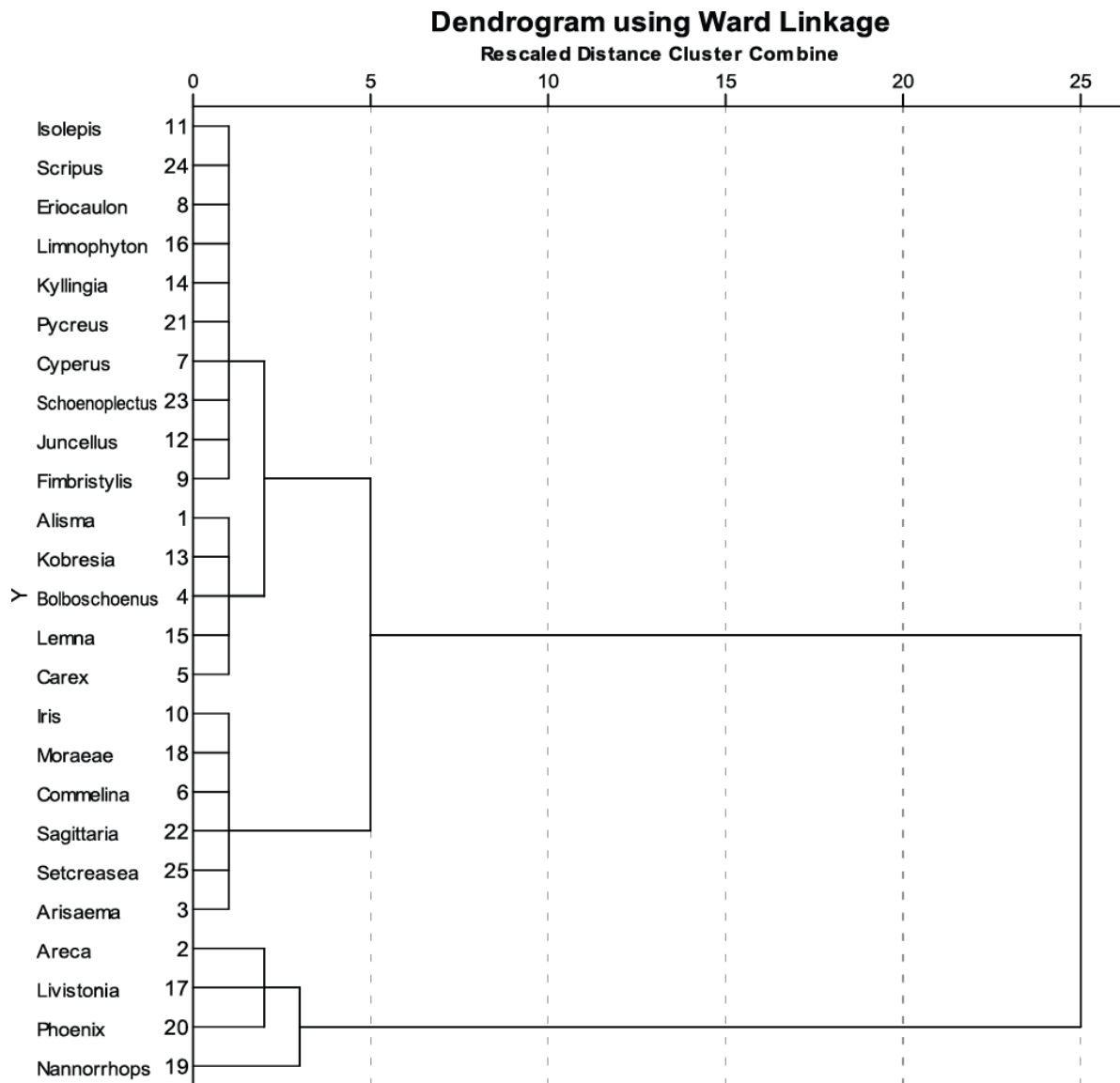


Fig. 5. Dendrogram showing the relationship within 25 genera of monocot families.

The second group comprises 21 genera of remaining 6 families viz., Alismataceae, Araceae, Commelinaceae, Cyperaceae, Eriocaulaceae and Iridaceae. This group is characterized by having herbs, rarely shrubs (Malik, 1984) colpate or porate pollen grains (Erdtman, 1952) and 0.5-8 mm long, non-arillate and non-psillate seeds. The second group of dendrogram occupies the terminal position which point out its advancement. The present findings are also supported by the previous findings of Sporne (1972) where non-arillate and smaller seeds were considered more advanced as compared to larger and arillate seeds. The second group is further separated into three subgroups. The first subgroup includes 6 genera viz., *Arisaema*, *Commelina*, *Iris*, *Moraeae*, *Sagittaria* and *Setcreasea* distributed in 4 families viz., Alismataceae, Araceae, Commelinaceae and Iridaceae. This subgroup is usually characterized by the presence of axile placentation, which also proves its primitiveness as

compared to the other subgroups (Ghafoor, 1974; Nasir, 1978; Qaiser & Jafri, 1975; Ali & Mathew, 2000) and 2-8 mm long, non-angular, oblong, obovate, elliptic, elliptic pyriform, orbicular, ovate, reniform or sub-reniform seeds. All the genera included in this subgroup arise from the common point which proves strong affinities between the above said families viz., Alismataceae, Araceae, Commelinaceae and Iridaceae. The second subgroup includes 5 genera viz., *Alisma*, *Bolboschoenus*, *Carex*, *Kobresia* and *Lemna* belonging to the families Alismataceae, Cyperaceae and Lemnaceae. This group is distinguished on the basis of basal placentation (Ghafoor, 1974; Hashmi & Omer, 1986; Kukkonen, 2001) and 0.5-5mm long, bigonous or trigonous nuts, oblong, obovate or elliptic pyriform seeds. This subgroup is comparatively advanced as compared to the first subgroup. Besides this, the advancement of this group is also strengthened by the presence of some genera of the family Cyperaceae, as this

family is assumed most advanced amongst all of the monocots (Kukkonen, 2001; APG III, 2009). Presently 0.5-5mm long, non-arillate seeds have been observed in the family Cyperaceae which also proves the advancement of this family (Sporne, 1972).

The last subgroup having 10 genera viz., *Isolepis*, *Scripus*, *Eriocaulon*, *Linnophyton*, *Kyllingia*, *Pycneus*, *Cyperus*, *Schoenoplectus*, *Juncellus* and *Fimbristylis* distributed in the families Alismataceae, Cyperaceae and Eriocaulaceae. This subgroup is characterized by having mostly basal, rarely axile placentation (only in *Linnophyton*), spike (Cyperaceae), capitate (Eriocaulaceae) and receme or panicle inflorescence in Alismataceae (Ghafoor, 1974; Ghazanfar, 1982; Kukkonen, 2001) and 0.5-3mm long, bigonous or trigonous, oblong, obovate, ovate or elliptic pyriform seeds. The second and third subgroups sharing more or less same gross morphological and seed morphological characters, but third subgroup is considered to be more advance than second subgroup due to more advance morphological features. Presently the advancement of this subgroup is also supported by the presence of minute seeds. It is also noteworthy that the family Alismataceae comprises all the three subgroups which point out its paraphyletic nature.

Acknowledgement

This research work is a part of the project "The Seed Atlas of Pakistan" sponsored by HEC, which is gratefully acknowledged. Thanks are due to Director, Center for Plant conservation for providing the facilities of scanning electron microscopy.

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(Received for publication 24 June 2013)