

POLLINATION TYPES AND POLLEN CHARACTERS WITHIN FLORA OF KARACHI

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Abstract

The correlation between pollen characters and pollination types in 218 genera and 351 species belonging to 67 angiosperm families from Karachi was studied. Entomophily is the dominant (65.24%) pollination type, while 33.04% taxa are anemophilous and about 1.71% taxa altogether exhibit ornithophily, hydrophily and zoophily. A definite relationship occurs between pollen characters and pollination types especially in entomophily and anemophily. Pollen grains of entomophilous taxa are characterized by compound apertures i.e., 3-colporate, prolate-spheroidal shape, generally large, thick walled, sticky and with reticulate tectum, while pollen grains of anemophilous taxa are with simple apertures i.e., monoporate, spheroidal, small, thin walled, dry and with scabrate-areolate tectum.

Introduction

Karachi, situated on the coast of Arabian sea (Lat. 24°, 50'-25°-15' N and Long. 65° 51'-67° 40' E) is the largest city of Pakistan. Climatically the area is characterised as a subtropical maritime desert (Chaudhri, 1961). Physiographically Karachi exhibits considerable variation on the vegetation. Three broad physiographic categories viz., 1) Hilly region, 2) Alluvial plains, 3) Coastal areas are recognized and each has a different type of dominant vegetation (Hussain, 1984). About 413 species distributed in 75 families have been reported from the area (Jafri, 1966; Nasir & Ali, 1970-1989; Ali & Nasir, 1990-1993). The dicots are represented by 60 families with c.146 genera and c.251 species, and monocots by 15 families with 64 genera and c.162 species. Although, the area of Karachi is well explored botanically, however, there are no previous reports on palynological survey in relation to pollination mechanisms of plants growing in the area. The present report gives an account of the relationship between pollen characters and pollination types within the flora of Karachi.

Materials and Methods

A detailed literature survey of 351 taxa for the pollinating agents was carried out. Field observations on most of the taxa were also made and compared with the available literature. For the examination of qualitative and quantitative pollen characters the survey is based on light and scanning microscope. All measurements were made on acetolyzed pollen prepared according to the method of Erdtman (1952). For light microscopy pollen grains were mounted in glycerine jelly and examined under Nikon Type-102 microscope. Scanning (S.E.M) examination was carried out with a Jeol T-200 microscope. Different pollination types viz., entomophily, ornithophily, hydrophily and anemophily have been recognized. An attempt has also been made to correlate palynological characters with the pollination types.

Results

Insects (entomophily) and wind (anemophily) are found to be the most common pollinating agents, while few taxa are pollinated by water (hydrophily) and birds (ornithophily).

Entomophilous taxa and their pollen characters: Entomophily is the most dominant pollination type in the present study. About 65.24% of the taxa are pollinated by insects (Table 1).

Table 1. Different Pollination types in flora of Karachi.

Type of pollination	Taxa	%
Entomophily	229	65.24
Anemophily	116	33.04
Ornithophily	2	0.57
Hydrophily	2	0.57
Zoophily	2	0.57

Shape and size of the pollen grains: Oblate-spheroidal to prolate - spheroidal pollen grains of $9.11 (36.1 \pm 1.12) 111.32 \mu\text{m}$ size are found in entomophilous taxa.

Exine surface or sculpturing: Pollen grains exhibit a considerable range of variation in their exine surface. In the present study reticulate sculpturing (fine-coarse reticulum) has been the major exine pattern of most of the entomophilous taxa (Fig.1 A, Table 2), whereas the families like Malvaceae, Sterculiaceae, Compositae and the genus *Ipomoea* (Convolvulaceae) are characterized by echinate tectum (Fig.1 B). However, in several taxa like *Heliotropium* and *Trichodesma* (Boraginaceae), *Spergularia* (Caryophyllaceae), Polygalaceae, Aizoaceae and many species of *Solanum* (Solanaceae), subpsilate and scabrate tectum have also been observed (Fig.1 C & D). The exine in entomophilous taxa is $0.2 (3.38 \pm 1.6) 10.11 \mu\text{m}$ thick.

Apertures: The type and size of apertures among the entomophilous taxa are quite distinctive and variable. The majority of the taxa have tricolporate pollen (42.69%, Fig.1 E), followed by pantoporate (39.47%, Fig.1 F), and colpate (14.03%, Fig.2A). In addition more specialized heterocolpate grains (3.22%, Fig.2 B) also occur, which includes the taxa like *Ammannia baccifera* L. (Lythraceae), *Peristrophe paniculata* (Frossk.) Brummit, *Hygrophila polysperma* (Roxb.) T. Anders (Acanthaceae) and the members of the genus *Heliotropium* (Boraginaceae). The length of colpus is $7.18 (23.74 \pm 2.2) 78.97 \mu\text{m}$, and in porate grains the diameter of pore is $3.21 (4.28 \pm 1.1) 5.53 \mu\text{m}$.

Pollen-kitt: Pollen-kitt also known "tryphine" or "pollen coat" is a complex mixture of lipid substances found on the surface of pollen. Pollen-kitt is useful for adherence to the pollinating insects, so it is usually present on the pollen grains of entomophilous taxa. In the present study pollen-kitt was present in very abundant quantity (+ + +, Table 2) on the grains of majority of taxa, while absent (-) from the pollen grains of few taxa.

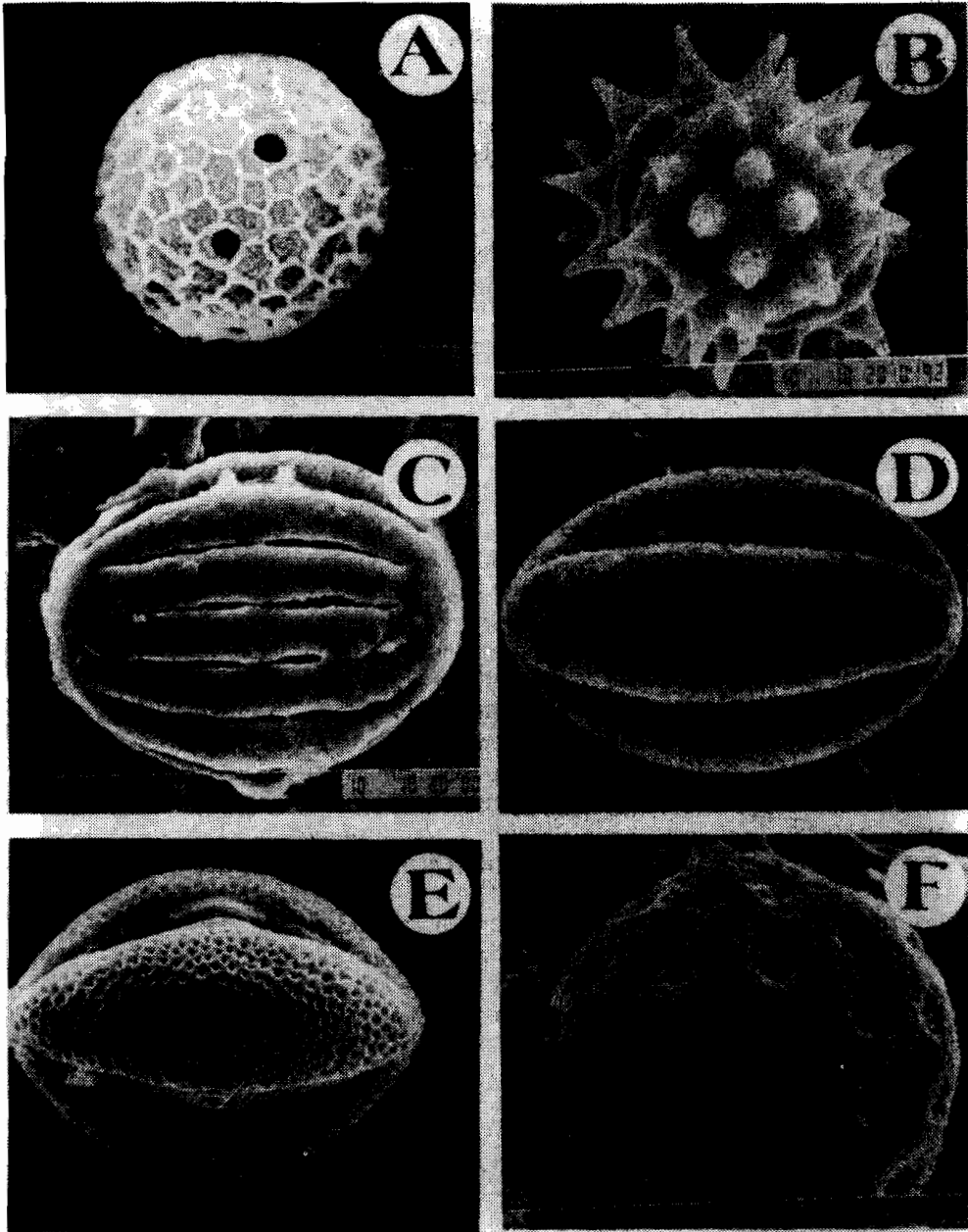


Fig.1. Scanning Electron micrographs of the pollen grains. *Ruellia patula*: A, pollen grain showing reticulate tectum. *Blumea obliqua*: B, pollen grain showing echinate tectum. *Polygala irregularis*: C, pollen grain showing psilate tectum. *Zaleya pantandra*: D, pollen grain showing scabrata tectum. *Argemone mexicana*: E, colpate pollen grain. *Amaranthus graecizans*: F, Pantoporate pollen grain. Scale bar = 10 μ m

Meliitophily: About 91.3% entomophilous taxa are pollinated by bees (Hymenoptera). Pollen grains of Meliitophilous taxa show considerable variation particularly in apertures and sculpturing (Table 2).

Myophily: About 5.24% of entomophilous taxa are pollinated by flies (Diptera). Pollen grains of myophilous taxa are usually colpate or colporate, tectal surface is scabrate-punctate or psilate and lacking pollen-kitt. However, in *Aristolochia bracteolata* (Sapromyophilous), the pollen grains are non-aperturate, exine rugulate-fossulate with very abundant amount (+ + +) of pollen-kitt or oil (Table 2).

Psychophily: About 1.74% of entomophilous taxa are pollinated by butterflies (Lepidoptera). Pollen grains of these taxa are usually colpate, tectum reticulate with abundant amount (+ +) of oil (Table 2).

Phalaenophily: Only 1.74% of entomophilous taxa are pollinated by moth (Lepidoptera). Pollen grains of these taxa are tricolporate with striate or rugulate-fossulate tectum and less (+) amount of oil (Table 2).

Cantharophily: Only 0.87% of entomophilous taxa are pollinated by beetles (Coleoptera). The pollen grains of these taxa are colpate (mono-tricolpate), tectum reticulate or rugulate-fossulate with abundant amount of oil (Table 2).

Anemophilous taxa and their pollen characters: Anemophily is the 2nd most dominant (33.04%) pollination type in the present study (Table 1).

Shape and size of pollen grains: Mostly pollen grains are spheroidal or oblate-spheroidal, Cyperaceae is the only exception where triangular grains are observed (Fig.2C, *Ascolepis brasiliensis*). However, in the family Juncaceae and in the single species of Typhaceae (*Typha elephantina* Roxb.) pollen grains are united in tetrads (Fig.2D). Pollen is 16.81 (28.0 ± 1.23) 72.11 μm in diameter.

Exine surface: The surface pattern of the anemophilous pollen is mostly scabrate or areolate-scabrate (Fig.2E), *Cenchrus ciliaris* (Gramineae). However, in few taxa, such as members of Typhaceae and Juncaceae reticulate or foveolate type of tectum is observed, whereas in *Chenopodium album* L., and *Atriplex stocksii* (Wt.) Boiss., (Chenopodiaceae) spinulose tectum is found. The thickness of exine in anemophilous taxa is 0.14 (1.43 ± 2.32) 1.52 μm.

Apertures: In anemophilous taxa, mostly simple porate grains are found, the number of pore varies from 1-3 (more commonly monoporate). However, in the genus *Rumex* (Polygonaceae), and the family Haloragaceae colporate or colpate apertures are observed, but these apertures are reduced in size (Fig.2F). In many members of family Gramineae annulus or operculum or sometimes both are observed in the apertural area. The diameter of aperture is 0.7 (2.5 ± 1.1) 3.59 μm.

Pollen-kitt: Pollen grains of most of the anemophilous taxa are dry and devoid (-) of pollen-kitt.

Ornithophilous taxa and their pollen characters: About 0.57% taxa are pollinated by birds (Table 1). Pollen grains of ornithophilous taxa are very sticky, tricolporate or colpate, 16.81-39.51 μm in diameter, prolate-spheroidal to sub-prolate, exine 1.41 (1.74 ± 0.07) 2.12 μm thick, tectum reticulate. *Capparis decidua* (Forssk.) Edgew., and *Tecomella undulata* (Roxb.) Seem., are pollinated by birds.

Hydrophilous taxa and their pollen characters: About 0.57% taxa utilize water as pollinating agent. Pollen grains of hydrophilous taxa are spheroidal 24-35 μm in diameter, non-aperturate, apolar with coarsely reticulate tectum, exine c. 0.5 μm thick, oil absent. Potamogetonaceae is the only family whose members are hydrophilous.

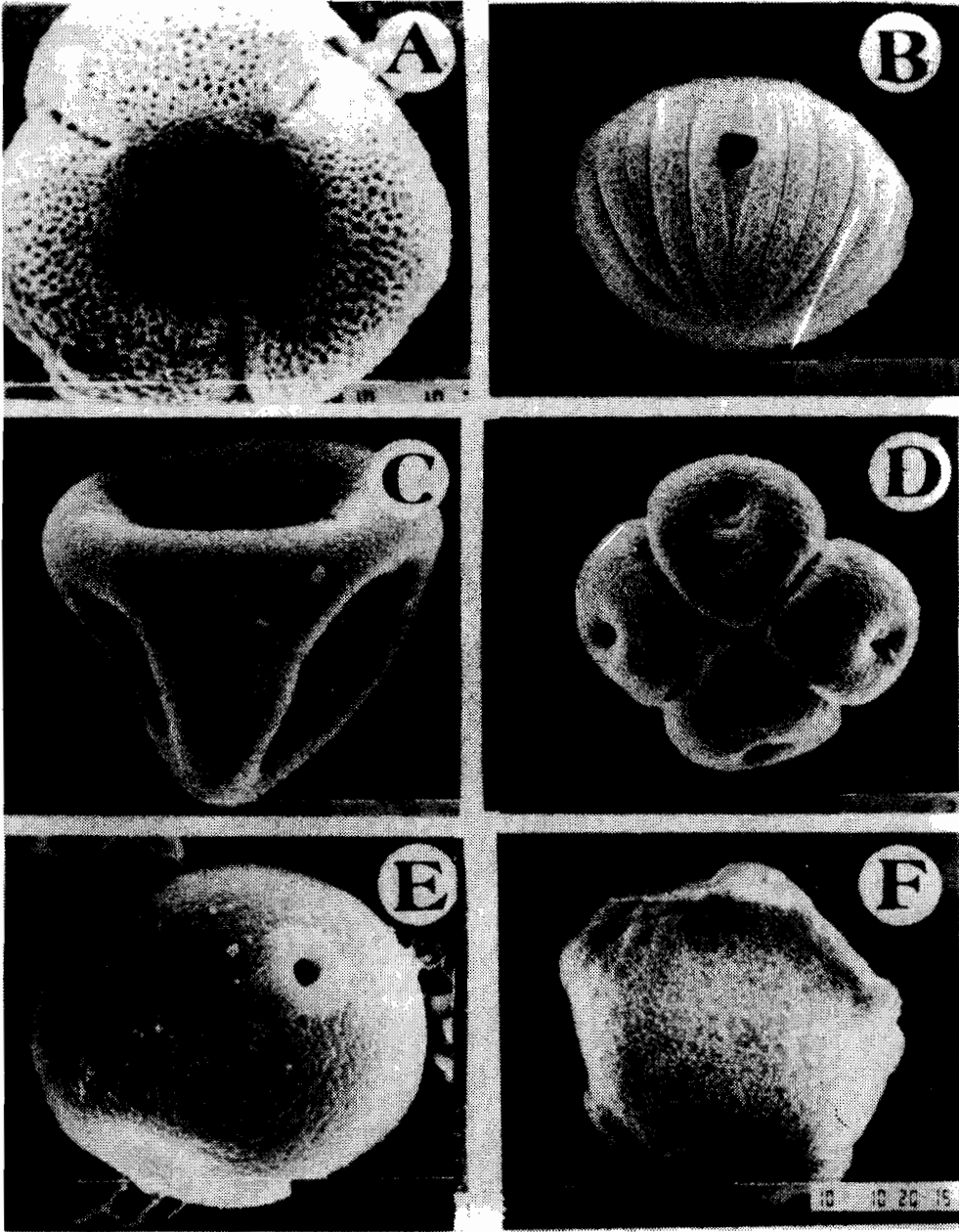


Fig.2. Scanning Electron micrographs of the pollen grains. *Euphorbia indica*: A, Tricolporate pollen grain, *Hygrophila polysperma*: B, Heterocolpate pollen grain, *Asclepis brasiliensis*: C, Triangular pollen grain. *Typha elephantina* D, pollen grains in tetrads. *Cenchrus ciliaris*: E, pollen grains showing scabrate/areolate tectum. *Myriophyllum verticillatum*: F, pollen grains showing reduce colpi. Scale bar = 10 μ m

Table 2. Pollen characters and Pollination types.

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
Acanthaceae		Melittophily (Faegri & Pijl, 1971)		
<i>Barleria hochstetteri</i> Nees	IV	Melittophily	+++	Lopho-reticulate
<i>B. prionitis</i> L.	IV	-do-	+++	Lopho-reticulate
<i>Blepharis sindica</i> Stocks ex T. Anders.	II	Melittophily (Faegri & Pijl, 1971)	++	Foveolate
<i>Hygrophila polysperma</i> (Roxb.) T. Anders.	V	Melittophily	++	Reticulate
<i>Peristrophe paniculata</i> (Forssk.) Brummitt	V	-do-	+++	Reticulate
<i>Ruellia patula</i> Jacq.	III	-do-	+++	Reticulate
Aizoaceae		Myophily		
<i>Corbichonia decumbens</i> (Forssk.) Exell	II	-do-	-	Scabrate-punctate
<i>Limeum indicum</i> Stocks ex T. Anders.	II	-do-	-	-do-
<i>Zaleya pentandra</i> (L.) Jeffrey	II	-do-	-	Scabrate-punctate
Anacardiaceae		Melittophily		
<i>Rhus mysurensis</i> Heyne ex Wight	IV	Melittophily	+++	Striate
Apocynaceae		Melittophily, Psychophily, Ornithophily (Reid & Chandler, 1933; Muller, 1968)		
<i>Rhazya stricta</i> Decne.	IV	Melittophily	++	Sub-psilate, sparsely punctate
Aristolochiaceae		Myophily (Faegri + Pijl, 1971)		
<i>Aristolochia bracteolata</i> Lamk.	I	Sapromyophily	+++	Rugulate-fossulate
Brassicaceae		Melittophily		
<i>Farsetia jacquemontii</i> Hook. f. & Thomson	II	Melittophily (Percival, 1969)	+++	Reticulate
Boraginaceae		Melittophily		
<i>Arnebia hispidissima</i> (Lehm.) A.D.C.	IV	Melittophily (Chandler, 1961)	+++	Densely spinulate
<i>Heliotropium crispum</i> Desf.	V	-do-	+	Sub-psilate, densely scabrate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Heliotropium curassavicum</i> L.	V	Melittophily	++	Sub-psilate
<i>H. bacciferum</i> Frossk.	V	-do-	++	-do-
<i>H. europaeum</i> L.	V	-do-	++	Sub-psilate
<i>H. ligosum</i> Vatke	V	-do-	++	Densely fossulate to sub-psilate
<i>H. ophioglossum</i> Stocks ex Boiss.	V	-do-	++	Striate-rugulose
<i>H. strigosum</i> Willd.	V	-do-	++	Sub-psilate
<i>H. subulatum</i> (DC.) Vatke	V	-do-	++	Sub-psilate scabrate
<i>Sericostoma pauciflorum</i> Stocks & Wight	II	-do-	++	Sparsely scabrate-punctate
<i>Trichodesma amplexicaule</i> Roth	IV	Melittophily, Psychophily & Myophily	++	Scabrate-punctate
Burseraceae		Melittophily		
<i>Commiphora stocksiana</i> (Engl.) Engl.	IV	-do-	++	Reticulate with spinulose muri
<i>C. whigtii</i> (Arn.) Bhandari	IV	-do-	++	-do-
Caesalpinaceae		Melittophily, Psychophily, Ornithophily (Elsik, 1968) Chiropterophily (Legoux, 1978)		
<i>Senna alexandriana</i> Miller	IV	Melittophily	+++	Rugulate
<i>S. holosericea</i> (Fresen.) Greuter	IV	-do-	+++	Finely-rugulate
<i>S. italica</i> Miller	IV	-do-	+++	Fossulate-rugulose
<i>S. surattensis</i> (Burm.f.) Irwin & Barneby	IV	-do-	+++	Finely-reticulate
Capparaceae		Melittophily & Myophily Ornithophily		
<i>Cadaba fruticosa</i> (L.) Druce	IV	Melittophily	++	Densely-spinulated
<i>C. heterotricha</i> Stocks ex Hook.	IV	-do-	++	Densely spinulose
<i>Capparis spinosa</i> L.	IV	-do-	++	Sub-psilate
<i>Cleome brachycarpa</i> Vahl ex DC.	II	-do-	++	Densely-spinulose- verrucate
<i>C. viscosa</i> L.	IV	-do-	++	Reticulate-rugulate
<i>C. scaposa</i> DC.	IV	-do-	++	Densely spinulated
<i>Gynandropsis gynandra</i> (L.) Briq.	IV	Melittophily	++	Striate-rugulate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Maerua arenaria</i> (DC.) Hook.f. & Thoms.	IV	Melittophily	++	densely-spinulose
Caryophyllaceae		Myophily & Melittophily (Proctor, 1978)		
<i>Polycarpaea spicata</i> Wight & Arn.	II	Myophily	-	Spinulated punctate
<i>Spergularia diandra</i> (Guss.) Heldr. & Sart.	II	Myophily	-	Densely scabrate
<i>S. marina</i> (L.) Criseb.	II	Myophily	-	Scabrate, sparsely punctate
Commelinaceae		Melittophily & Psychophily		
<i>Commelina albescens</i> Hasskari	II	Melittophily	+++	Spinulose
<i>C. paludosa</i> Blume	II	-do-	+++	-do-
Compositae		Melittophily, Psychophily, Myophily, Phalaenophily (Percival, 1969; Faegri & Pijl, 1971)		
<i>Amberboa ramosa</i> (Roxb.) Jafri	IV	Melittophily	+++	Densely spinulose
<i>Blainvillea latifolia</i> (L.f.) DC.	IV	Melittophily	+++	Echinate
<i>Blumea obliqua</i> (L.) Druce	IV	Melittophily	+++	-do-
<i>B. lacera</i> (Burm.f.) DC.	IV	-do-	+++	-do-
<i>Conyza canadensis</i> (L.) Cronquist	IV	-do-	+++	-do-
<i>Dicoma tomentosa</i> Cass.	IV	-do-	+++	Densely verrucate
<i>Echinops echinatus</i> DC.	IV	-do-	+++	Spinulose
<i>Eclipta prostrata</i> (L.) L.	IV	-do-	+++	Echinate
<i>Enhydra fluctuans</i> Lour.	IV	-do-	+++	-do-
<i>Gnaphalium americanum</i> L.	IV	-do-	+++	Spinulose
<i>Hochstetteri schimperii</i> DC.	IV	-do-	+++	Spinulose
<i>Iphiona grantioides</i> (Boiss.) A. Andenberg	IV	-do-	+++	Echinate
<i>Lactuca remotiflora</i> DC.	IV	-do-	+++	Echinolophate
<i>Lactuca</i> sp.	IV	-do-	+++	-do-
<i>Launaea residifolia</i> (L.) O. Kuntze	IV	-do-	+++	-do-

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Launaea nudicaulis</i> (L.) Hk.f.	IV	Melittophily	+++	Echinolophate
<i>Pluchea lanceolata</i> (DC.) Oliv.	IV	-do-	+++	Echinate
<i>P. arguta</i> Boiss.	IV	-do-	+++	-do-
<i>Pulicaria angustifolia</i> DC.	IV	-do-	+++	-do-
<i>P. boissieri</i> Hook.f.	IV	-do-	+++	-do-
<i>Sonchus asper</i> (L.) Hill	IV	-do-	+++	-do-
<i>S. oleraceus</i> L.	IV	-do-	+++	-do-
<i>Tridax procumbens</i> L.	IV	-do-	+++	-do-
<i>Vernonia cinerea</i> (L.) Lees.	III	-do-	+++	Echinolophate
<i>V. cinerascens</i> Schultz.-Bip.	IV	-do-	+++	-do-
Convolvulaceae		Myophily, Melittophily, (Pares Regali et al., 1974; 1974b; Legoux (1978) Ornithophily (Percival, 1969)		
<i>Convolvulus arvensis</i> L.	II	Melittophily	++	Finely reticulate-scabrate
<i>C. glomeratus</i> Choisy	II	-do-	++	Densely-punctate scabrate
<i>Convolvulus prostratus</i> Forssk.	II	Melittophily	++	Densely punctate
<i>C. rhyniospermus</i> Hochst. ex Choisy	II	-do-	+++	Finely punctate scabrate
<i>Cressa cretica</i> L.	II	-do-	+++	Spinulose
<i>Ipomoea aquatica</i> Forsk.	III	-do-	+++	Echinate
<i>I. carnea</i> Jacq. subsp. <i>fistulosa</i> (Mart. ex Choisy) D. Austin	III	-do-	+++	-do-
<i>I. eriocarpa</i> R.Br.	III	-do-	+++	-do-
<i>I. pes-caprae</i> (L.) R. Br.	III	-do-	+++	-do-
<i>Merremia aegyptica</i> (L.) Urban	II	-do-	++	Scabrate-punctate
Cucurbitaceae		Ornithophily (Grant, 1950) Melittophily		
<i>Citrullus colocynthis</i> (L.) Schard.	IV	Melittophily	++	Coarsely-reticulate
<i>Coccinia grandis</i> (L.) Voigt	IV	-do-	++	Coarsely reticulate
<i>Cucumis prophetarum</i> L.	III	-do-	++	Reticulate-rugulate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Momordica balsamina</i> L.	IV	Melittophily	++	Medium-reticulate
Cuscutaceae		Myophily		
<i>Cuscuta hyalina</i> Roth	II	-do-	-	Densely punctate
<i>C. reflexa</i> Roxb.	II	-do-	+	Reticulate-rugulose
Elatinaceae		Melittophily		
<i>Bergia ammannioides</i> Roth	IV	-do-	++	Foveolate-fossulate
<i>B. suffruticosa</i> (Del.) Fenzl.	IV	-do-	++	Foveolate-fossulate
Euphorbiaceae		Melittophily & Myophily (Percival, 1969) Ornithophily, (Faegri & Pijl, 1971) Phalaenophily, Chiropterophily (Reid & Chandler, 1933)		
<i>Andrachne aspera</i> Spreng.	IV	Melittophily	++	Striate
<i>Chrozophora tinctoria</i> (L.) Raf.	IV	-do-	++	Reticulate
<i>Euphorbia caducifolia</i> Haines	IV	-do-	++	Reticulate
<i>E. clarkeana</i> Hook.f.	IV	-do-	++	-do-
<i>E. dracunculoides</i> Lamk.	IV	-do-	++	-do-
<i>Euphorbia hirta</i> L.	IV	Melittophily	++	Reticulate
<i>E. hypericifolia</i> L.	IV	-do-	++	-do-
<i>E. indica</i> Lamk.	IV	-do-	++	-do-
<i>E. prostrata</i> Ait.	IV	-do-	++	-do-
<i>Phyllanthus rotundifolius</i> Klein ex Willd.	IV	-do-	++	Rugulate
Gentianaceae		Melittophily, Psychophily Ornithophily. (Elsik, 1968; Crepet and Daghlian, 1981)		
<i>Enicostemma verticillatum</i> (L.) Engler	IV	Melittophily	++	Reticulate
Geraniaceae		Psychophily (Percival, 1969)		
<i>Monsonia senegalensis</i> Guill. & Perr.	II	Psychophily	++	Coarsely reticulate
Illecebraceae		Melittophily		
<i>Cometes surattensis</i> L.	II	-do-	++	Scabrate-punctate
Labiatae		Melittophily (Faegri & Pijl, 1979)		

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Leucas urticifolia</i> (Vahl) R.Br.	II	Melittophily	++	Rugulate-reticulate
<i>Salvia santolinifolia</i> Boiss.	II	-do-	++	Reticulate
Liliaceae		Melittophily & Ornithophily (Percival, 1969)		
<i>Asparagus dumosus</i> Baker	II	Melittophily	++	Fossulate-rugulate
<i>Asphodelus teunifolius</i> Cavan	II	-do-	++	Reticulate
<i>Dipcadia erythraeum</i> Webb & Benth.	II	-do-	++	Striate
Lythraceae		Melittophily, Myophily, Phalaenophily, Chiropterophily (Reid & Chandler, 1933; Germeraad et al., 1968)		
<i>Ammannia baccifera</i> L.	V	Myophily	-	Foveolate
Malvaceae		Melittophily & Psychophily (Percival, 1969)		
<i>Abutilon alii</i> S. Abedin	III	Melittophily	+++	Echinate
<i>A. figarianum</i> Webb	III	-do-	+++	-do-
<i>A. fruticosum</i> Guill. & Perr.	III	-do-	+++	-do-
<i>A. hirtum</i> (Lamk.) Sweet	III	-do-	+++	-do-
<i>A. indicum</i> (L.) Swt.	III	-do-	+++	-do-
<i>A. muticum</i> (Del.ex DC.) Sweet	III	-do-	+++	-do-
<i>A. pannosum</i> (Forst. f.) Schlecht	III	-do-	+++	-do-
<i>Gossypium stocksii</i> Mast.	III	-do-	+++	-do-
<i>Hibiscus aristivalvis</i> Garcke	III	-do-	+++	-do-
<i>H. obtusilobus</i> Garcke	III	-do-	+++	-do-
<i>H. micranthus</i> L.f.	III	-do-	+++	-do-
<i>Malvastrum coromendelianum</i> (L.)Garcke	III	-do-	+++	-do-
<i>Pavonia procumbens</i> (Wall. ex Wight & Arn.) Wallp.	III	-do-	+++	Echinate
<i>Senra incana</i> Cav.	III	Melittophily	+++	Echinate
<i>Sida cordifolia</i> L.	III	-do-	+++	-do-
<i>S. ovata</i> Forssk.	III	-do-	+++	-do-
<i>S. tiagii</i> Bhandari	III	-do-	+++	-do-
Menispermaceae		Melittophily		

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Cocculus hirsutus</i> (L.) Diels	IV	-do-	+	Reticulate-rugulate
<i>C. pendulus</i> (J.R. & G. Forst.) Diels	IV	-do	+	Reticulate
Menyanthaceae		Melittophily & Psychophily (Barrett, 1988)		
<i>Nymphoides cristata</i> (Roxb.) O. Ktze.	II	Melittophily	-	Densely spinulose
Mimosaceae		Chiropterophily, Melittophily, Ornithophily (Salard-Cheboldaeff, 1978, 1979; Crepet & Dilcher, 1977; Daghlian et al., 1980)		
<i>Acacia jacquemontii</i> Benth.	I	Melittophily	+	Sub-psilate
<i>A. nilotica</i> (L.) Delile subsp. <i>hemispherica</i> Ali & Faruqi	I	-do-	+	Foveolate
<i>A. nilotica</i> (L.) Delile subsp. <i>indica</i> (Benth.) Brenan	I	Melittophily	++	Foveolate-rugulose
<i>A. nilotica</i> (L.) Delile subsp. <i>subalata</i> (Vatke) Brenan	I	-do-	++	Foveolate
<i>A. senegal</i> (L.) Willd.	I	-do-	+	Foveolate densely granulate
<i>Mimosa hamata</i> Willd.	I	-do-	+	Foveolate
<i>Prosopis cineraria</i> (L.) Druce	IV	-do-	+	Foveolate-fossulate
<i>P. glandulosa</i> Torr.	IV	-do-	+	Sparsely foveolate
<i>P. juliflora</i> (Swartz) DC.	IV	-do-	+	Foveolate
Molluginaceae		Myophily		
<i>Glinus lotoides</i> L.	II	-do-	-	Scabrate
Nelumbonaceae		Cantharophily (Schneider & Buchanon, 1980) Melittophily & Myophily (Sohmer- Sefton, 1978)		
<i>Nelumbo nucifera</i> Gaertn.	II	Cantharophily	++	Rugulate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
Neuradaceae		Melittophily		
<i>Neurada procumbens</i> L.	VI	Melittophily	-	Reticulate
Nyctaginaceae		Melittophily		
<i>Boerhavia procumbens</i> Banks & Roxb.	III	-do-	+++	Tubuliferous-spinulose
<i>B. repens</i> L.	III	-do-	+++	-do-
<i>Commicarpus boissieri</i> (Heimerl) Cufod.	III	-do-	+++	-do-
Nymphaeaceae		Cantharophily (Wiersema, 1988)		
Orobanchaceae		Melittophily, Myophily, Ornithophily Phalenophily (Reid & Chandler, 1933; Pares Regali et al., 1974a, 1974b)		
<i>Cistanche tubulosa</i> (Schrenk) Hook.f.	II	-do-	+	Densely Rugulose-fossulate
Oxalidaceae				Melittophily
<i>Oxalis corniculata</i> L.	II	-do-	++	Reticulate
Papaveraceae		Melittophily & Psychophily (Faegri & Pijl, 1971)		
<i>Argemone mexicana</i> L.	II	Melittophily	++	Reticulate
Papilionaceae		Melittophily, Psychophily (Knuth 1908; Leppik, 1966) Ornithophily (Faegri & Pijl, 1971)		
<i>Alhaji maurorum</i> Medic.	IV	Melittophily	++	Medium-reticulate
<i>Alysicarpus heterophyllus</i> (Baker) Jafri & Ali	IV	-do-	++	Rugulose-fossulate
<i>A. monilifer</i> (L.) DC.	IV	-do-	++	Rugulose-fossulate
<i>Argyrolobium roseum</i> (Camb.) Jaub. & Spach s.sp. <i>ornithopodioides</i> (Jaub. & Spach) Jafri & Ali	IV	-do-	++	Medium-reticulate
<i>Astragalus fatmensis</i> Hochst. ex Blatter	IV	-do-	++	Finely-reticulate
<i>Clitoria ternatea</i> L.	II	-do-	++	Densely granulated

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Crotalaria burhia</i> Buch.-Ham. ex Benth.	IV	-do-	++	Medium reticulate
<i>C. medicaginea</i> Lamk.	IV	-do-	++	Coarsely-reticulate
<i>Goniogyna hirta</i> (Willd.) Ali	IV	Melittophily	++	Coarsely reticulate
<i>Indigofera argentea</i> Burm. f.	IV	-do-	++	Sub-psilate
<i>I. articulata</i> Gouan	IV	-do-	++	Finely-reticulate
<i>I. cordifolia</i> Heyne ex Roth	IV	-do-	++	Rugulose-fossulate
<i>I. hochstetteri</i> Baker	IV	-do-	++	+ Rugulose
<i>I. linifolia</i> (L.f.) Retz.	IV	-do-	++	Densely-rugulate
<i>I. oblongifolia</i> Frosk.	IV	-do-	++	Areolate-finely punctate
<i>I. sessiliflora</i> DC.	IV	-do-	++	Rugulose-fossulate
<i>Lotus garcinii</i> DC.	IV	-do-	++	Foveolate-fossulate
<i>Medicago lupulina</i> L.	IV	-do-	++	Rugulate-fossulate
<i>M. polymorpha</i> L.	IV	-do-	++	Fossulate
<i>Melilotus alba</i> Desr.	IV	-do-	++	Finely reticulate
<i>M. indica</i> (L.) All.	IV	-do-	++	Finely reticulate
<i>Psoralea plicata</i> Delile	IV	-do-	++	Coarsely-reticulate
<i>Rhynchosia capitata</i> (Heyne ex Roth) DC.	IV	-do-	++	Reticulate-rugulate
<i>Rhynchosia minima</i> (L.) DC.	IV	Melittophily	++	Reticulate
<i>R. pulverulenta</i> Stocks	IV	-do-	++	Coarsely reticulate
<i>Taverniera cunefolia</i> (Roth) Arn.	II	-do-	++	Reticulate
<i>T. lappacea</i> (Forrsk.) DC.	II	-do-	++	-do-
<i>Tephrosia subtriflora</i> Baker	IV	-do-	++	Foveolate-reticulate
<i>T. uniflora</i> Pers.	IV	-do-	++	Medium foveolate- reticulate
<i>Trigonella monantha</i> C.A. Meyer subsp. <i>incisa</i> (Benth.) Ali	IV	-do-	++	Rough reticulate
Polygalaceae		Melittophily (Doubinger & Chotin, 1975)		
<i>Polygala erioptera</i> DC.	IV	Melittophily	-	Psilate
<i>P. irregularis</i> Boiss.	IV	Melittophily	-	Psilate, sparsely punctate
Polygonaceae		Melittophily & Myophily (Percival, 1969; Faegri & Pijl, 1971)		

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Persicaria glabra</i> (Willd.) Gomes	III	Melittophily	+	Coarsely reticulate
<i>Polygonum plebejum</i> R.Br.	IV	-do-	+	Finely scabrate
<i>Pteropryum oliveri</i> J. & S.	IV	Melittophily	+	Reticulate
Portulacaceae		Melittophily (Percival, 1969)		
<i>Portulaca oleracea</i> L.	II	-do-	++	Tubuliferous- spinulose
<i>P. quadrifida</i> L.	II	-do-	++	Tubuliferous- spinulose
Primulaceae		Melittophily & Myophily (Percival, 1969)		
<i>Anagallis arvensis</i> L. var. <i>caerulea</i> (L.) Gouan	IV	-do-	++	Reticulate
Pontederiaceae		Melittophily & Psychophily (Barrett, 1988)		
<i>Eichhornia crassipes</i> (Mart.) Sloma	II	Melittophily	-	+ areolate
Plumbaginaceae		Psychophily (Percival, 1969)		
<i>Limonium stocksii</i> (Boiss.) O.Ktze.	II	-do-	++	Reticulate
Resedaceae		Melittophily		
<i>Ochradenus baccatus</i> Delile	II	-do-	++	Reticulate
Rhamnaceae		Psychophily (Percival 1969)		
<i>Ziziphus nummularia</i> (Burm.f.) Wr. & Arn.	IV	Melittophily	++	Strio-rugulate
<i>Z. spina-christi</i> (L.) Willd.	IV	-do-	++	Striate
Rubiaceae		Melittophily, Psychophily, Ornithophily, (Krutzsch, 1970)		
<i>Kohautia retrosa</i> (Boiss.) Bremek.	IV	Psychophily	++	Reticulate
Salvadoraceae		Myophily		
<i>Salvadora oleoides</i> Decne.	IV	-do-	+	Foveolate-reticulate
<i>Salvadora persica</i> L.	IV	Melittophily	+	Reticulate-rugulate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
Sapindaceae		Melittophily (Kemp, 1976; Belsky et al. 1965; Boltenhagen, 1976; Venkatachala and Sharma, 1974)		
<i>Cardiospermum halicacabum</i> L.	VI	Melittophily	+	Reticulate
Scrophulariaceae		Melittophily (Faegri & Pijl, 1971)		
<i>Bramia monnieri</i> (L.) Penn.	IV	-do-	+	Reticulate
<i>Lindenbergia indica</i> (L.) Ktze.	IV	Melittophily	+	Reticulate
<i>Schweinfurthia papilionacea</i> (Burm.f.) Boiss.	IV	-do-	+	Medium reticulate
<i>S. pedicellata</i> (T. Anders.) Bth. & Hk.f.	IV	Melittophily	+	Medium reticulate
Solanaceae		Melittophily, Myophily, Phalaenophily, Chiropterophily (Reid & Chandler, 1933)		
<i>Datura fastuosa</i> L.	IV	Phalaenophily	+	Striate
<i>D. innoxia</i> Miller	IV	-do-	+	-do-
<i>D. stramonium</i> L.	IV	-do-	+	Striate
<i>Lycium edgeworthii</i> Dunal	IV	Melittophily	++	Striate-rugulate
<i>Nicotiana plumbaginifolia</i> Viv.	IV	Phalaenophily	+	Rugulose-fossulate
<i>Physalis divaricata</i> D. Don.	IV	Melittophily	+	Densely verrucate
<i>S. cordatum</i> Forssk.	IV	-do-	+	-do-
<i>S. forskalii</i> Dunal	IV	-do-	+	-do-
<i>S. incanum</i> L.	IV	-do-	+	Scabrate-verrucate
<i>Solanum nigrum</i> L.	IV	Melittophily	+	Densely scabrate
<i>S. surattense</i> Burm.f.	IV	-do-	+	-do-
<i>Withania coagulans</i> (Stocks) Dunal	IV	-do-	+	Densely-scabrate
<i>W. somnifera</i> (L.) Dunal	IV	-do-	+	Striate-rugulate
Sphenocleaceae		Melittophily (Faegri & Pijl 1971)		

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Sphenoclea zeylanica</i> Gaertn.	IV	Melittophily	++	Sub-psilate to punctate
Sterculiaceae		Melittophily & Myophily (Faegri & Pijl, 1971)		
<i>Melhania denhamii</i> R.Br.	III	Melittophily	+++	Echinate
Tamaricaceae		Melittophily & Myophily (Percival, 1969)		
<i>Tamarix aphylla</i> (L.) Karst.	II	Melittophily	+	Reticulate
<i>T. dioica</i> Roxb. ex Roth	II	-do-	+	Reticulate
<i>T. indica</i> Willd.	II	-do-	+	-do-
<i>T. pakistanica</i> Qaiser	II	-do-	+	-do-
<i>Tamarix passerinoides</i> Del. ex. Desv. var. <i>macrocarpa</i> Ehrenb.	II	Melittophily	+	Reticulate
Tiliaceae		Melittophily		
<i>Corchorus depressus</i> (L.) Stocks	IV	-do-	+	Reticulate
<i>C. olitorius</i> L.	IV	-do-	+	-do-
<i>C. tridens</i> L.	IV	-do-	+	-do-
<i>C. trilocularis</i> L.	IV	-do-	+	-do-
<i>Grewia tenax</i> (Forsk.) Fiori	IV	-do-	+	-do-
<i>G. villosa</i> Willd.	IV	-do-	+	-do-
Verbenaceae		Melittophily, Psychophily (Percival, 1969)		
<i>Clerodendrum phlomidis</i> L.f.	II	Melittophily	++	Finely reticulate with spinulose
<i>Priva cordifolia</i> (L.f.) Druce	IV	-do-	++	Sub-psilate-punctate
<i>Phyla nodiflora</i> (L.) Greene	IV	-do-	++	Sub-psilate-punctate
Violaceae		Melittophily (Percival, 1969)		
<i>Viola stocksii</i> Boiss.	IV	-do-	-	Sub-psilate
Zygophyllaceae		Melittophily, Myophily and Psychophily		
<i>Fagonia indica</i> Burm.f. var. <i>indica</i>	IV	Melittophily	+	Medium reticulate
<i>F. indica</i> var. <i>schweinfurhii</i> Hadidi	IV	-do-	+	-do-
<i>Tribulus longipetalus</i> Viv.	III	-do-	++	Coarsely-reticulate
<i>T. pentandrus</i> Forssk.	III	-do-	++	Coarsely-reticulate
<i>Tribulus terrestris</i> L.	III	-do-	++	Coarsely-reticulate
<i>Zygophyllum propinquum</i> Decne.	IV	-do-	++	Reticulate

Table 2 (Cont'd)

TAXA	POLLEN TYPES	POLLINATION TYPES	OIL	EXINE PATTERN
<i>Z. simplex</i> L.	IV	-do-	++	-do-
Amaranthaceae	III	Anemophily (Nowicke & Skvarla, 1979)	-	Scabrate rarely punctate
Chenopodiaceae	III	Anemophily (Nowicke & Skvarla, 1979)	-	Scabrate rarely spinulose
Cyperaceae	VI	Anemophily (Faegri & van der Pijl, 1979)	-	Scabrate/ areolate
Gramineae	III	Anemophily (White head, 1969; Cook, 1988; Faegri & van der Pijl, 1971; 1979)	-	Scabrate to areolate/scabrate
Polygonaceae				
<i>Rumex</i>	IV	Anemophily (Wodehouse, 1935)	-	Scabrate-punctate
Haloragaceae	II	Anemophily (Cook, 1988)	-	Scabrate - punctate
Juncaceae	I	Anemophily (Rendle, 1959)	-	Lophate - reticulate
Typhaceae	III	Anemophily (Krattinger, 1975, Cook, 1988)	-	Fevolate- reticulate
Capparaceae				
<i>Capparis decidua</i> (Forssk.) Edgew.	IV	Ornithophily	+	Finely-reticulate
Bignoniaceae		Ornithophily (Grant, 1950) Chiropterophily (Faegri & Pijl, 1971)		
<i>Tecomella undulata</i> (Roxb.) Seem.	II	Ornithophily	+++	Reticulate
Potamogetonaceae	I	Hydrophily (Cook, 1988)	-	Reticulate
Lemnaceae	III	Zoophily (Lándolt, 1986)	+	Spinulose-punctate

Pollen types I = Non-aperturate, II = Colpate, III = Porate, IV = Colporate, V = Heterocolpate, VI = Miscellaneous, Oil = (-) Absent, (+) less, (++) Abundant, (+++) very abundant.

Zoophilous taxa and their pollen characters: Only members of family Lemnaceae (0.57% of entomophilous taxa) are pollinated by other animals, such as small mites, spider and flies. Pollen grains of these taxa are very small, 20-24 μm in diameter, spheroidal, monoporate, exine 0.5 (1.73 \pm 0.12) 3.33 μm thick, less amount of oil and spinulose tectum.

Discussion

In the present study entomophily was the most dominant pollination type. In entomophilous taxa pollen grains are mostly oblate-spheroidal to prolate-spheroidal, usually tricolporate, 36.7 μm in diameter, exine 3.38 μm thick, sticky, tectum usually reticulate. However, pollen grains of these taxa are highly variable in their apertures and exine sculpturing. Generally apertures are relatively large (Colpi 23.74 μm long, pore 4.28 μm in diameter). In members of the families Malvaceae, Convolvulaceae and Nyctaginaceae pollen grains are pantoporate with spines and spinulose tectum. heterocolpate pollen grains were also observed in *Ammannia baccifera* L., *Peristrophe paniculata* (Frossk.) Brummitt and the genus *Heliotropium*. Similarly, exine sculpturing ranges from reticulate to rugulate, spinulose, echinate, fossulate and striate. Even sub-psilate to scabrate exine was also observed but usually with large and open apertures i.e., colpi or colpi with ora. Generally, sub-psilate to psilate exine is considered to be the characteristic features of the anemophilous taxa (Whitehead, 1969; Hesse, 1986; Cook, 1988). However, Grayum (1986) after reporting psilate exine in many cantharophilous taxa pointed out to reconsider the correlation of psilate pollen with anemophily. Our data also supports Grayum's suggestion as sub-psilate pollen have not been observed in anemophilous taxa.

Pollen-kitt in great quantity was observed on pollen grains of entomophilous taxa particularly with echinate and spinulose exine. Pollen-kitt may function to protect pollen from harmful environment particularly radiation hazards, desiccation and also useful for adherence to pollinating insects.

No definite relationship between pollen characters particularly exine sculpturing, aperture and melittophily, myophily, phalaenophily, and cantharophily was observed. However, pollen grains of myophilous taxa are mostly devoid of pollen-kitt, and size of cantharophilous pollen was much larger than the rest of the insects pollinating taxa.

About 33.04% taxa are pollinated by wind. Anemophily has evolved secondarily in the angiosperms, thus seems to be derived condition in the angiosperms (Arber & Parkin, 1907; Whitehead, 1969; Faegri & van der Pijl, 1979; Walker & Wølker, 1984; Crane, 1986; Cook, 1988). However, wind pollination has originated several times from diverse stocks.

In contrast to entomophilous taxa the pollen of anemophilous species do not depict much variation in their pollen characters. The pollen grains of anemophilous taxa are usually spheroidal, 28.0 μm in diameter tectum scabrate to areolate with fine scabrae, with 1.43 μm thick exine, mostly porate, apolar and dry (devoid of pollen-kitt).

In anemophilous taxa, apart from general similarity few exceptions were also observed. In Juncaceae (*Juncus maritimus* Lamk.) and Typhaceae (*Typha elephantina* Roxb.) pollen grains are united in tetrads with reticulate-rugulate or foveolate tectum. This reticulate or foveolate condition of anemophilous plants of aquatic or semi-

aquatic plant families seems to be an adaptation against the aquatic and semiaquatic habitat, because it is generally accepted that the aquatic angiosperms have been evolved from the terrestrial ancestors.

Similarly, in the genus *Rumex* (Polygonaceae) pantocolporate grains are found but colpi are reduced to fine slits, with very small circular ora. Similar reduction in the colpus length was also observed in several anemophilous taxa. As the size of aperture is of considerable importance, and small apertures offer best protection against desiccating climatic conditions, therefore the reduction of aperture (colpi) and presence of operculum and annulus or both may indicate their adaptive significance.

Pollen grains of ornithophilous (bird-pollinated) taxa are similar to that of entomophilous taxa, although their exine seems to be less thick (i.e., 1.9 μm and much sticky. Similar results have also been reported by Arroyo (1976) and Ferguson & Skvarla (1982).

Pollen grains of hydrophilous taxa are spheroidal, non-aperturate, coarsely reticulate tectum with (0.5 μm thick) thin exine. The thin elastic exine and reduced or omniperatures (non-aperturate) are considered as characteristic features of hydrophilous taxa by Punt (1986) and Thanikaimoni (1986). The reticulate exine may be helpful in keeping the pollen afloat as described by Schwanitz (1967) in *Ruppia*. The pollen grains of *Lemna gibba* L., and *L. aequinoctialis* Welw. (Lemnaceae) are spinulose, monoporate, small (20 μm in diameter) and with 1.57 μm thick exine, pollen of these taxa are probably transferred on the legs of different kinds of Arthropods i.e., flies, aphids, mites and small spiders.

Cook (1988) considered wind and water as the pollen vector in Lemnaceae. However, pollen characters such, as spiny and sticky exine, small size of grains in the present study suggest it to be zoogamous (Landolt, 1986).

The present study indicates that entomophily is the major pollination type in the study area. Different pollination types particularly entomophily and anemophily may easily be recognized on the basis of their pollen characters. However, certain variation have also been observed in pollen characters with respect to pollination types which is obvious that other selective forces apart from pollinating agents must also be operative, so the variation cannot be fully explained on this basis alone.

Acknowledgement

We are thankful to the National Scientific Research Development Board (NSRDB), University Grants Commission Pakistan for providing financial support. We are also grateful to the Director of Biological Research Centre for providing facilities of scanning microscope.

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(Received for Publication 2 January 1994)