Original Research Article

Adaptive Features of Pollen Morphology of Hydrophytes in relation to Ecological Class

Abstract

Pollen morphology is used for comparative importance in taxonomy and evolutionary at all taxa levels. The pollen features are constant for each genera and while the exine is sculpturing pattern is highly recognizable for each genera. In this study we have narrated how pollen exine thickness acts as an adaptive feature of hydrophytes. There is a clear increase in exine thickness with respect to the ecological classes of hydrophytes which can be treated as an evolutionary schemes of the plant kingdom. An attempt is also made to find if there is any relation to pollen morphology and exine pattern. The value of such studies could be augmented appreciably where it is possible to supplement the other data with pollen records for the more distant past and experimental treatment of postulated vegetational process of hydrophytes.

Keyword: Aquatic and Hydrophyte Plant; Pollen Morphology; Adaptive Feature; Evolution.

Introduction

Palynology is the study of pollen and spores [1]. Palynology is unique in that one can obtain tremendous amount of information from a little material in a short time. The constant features and the sculpturing of the exine make pollen grains a highly recognizable object by which parent genera or even species may be recognized [2, 3]. Application of pollen morphology in plant taxonomy is best evidenced in the flowering plants, especially in the angiosperms. The largest variety of pollen morph types occurs among the angiosperm plants [4]. The importance of pollen character are of diagnostic value and of comparative importance in taxonomy and evolutionary at all taxa levels [5]. Lindley [6] was probably the first person to make use of pollen character in the classification of Orchidaceae, and later the significance of pollen morphology in planttaxonomy has been stressed by several workers, notably by Cranwell [7], Erdtman [8, 9], Fritzsche [10], Selling [11] and Woodhouse [12]. Angiospermous pollens are divided into two fundamental type's viz., monosulctae or its derivatives and tricolpate pollenor its derivatives. Colpate pollen is essentially restricted to dicotyledons, while sulctae pollen is found in gymnosperms, monocotyledons and some Ranalean dicot's [1]. The field of palynology has a tremendous contribution to the systematic and phylogeny of angiosperms because of the evolutionary trends in pollen wall architecture which provides an important source of phylogenetic information of major importance. A number of papers dealing with pollen morphology of various taxa have been appeared with enlightened its importance in plant systematic. Kuprianova [13] has studied the pollen characteristics of the whole of the monocotyledons. It is now unanimously accepted that pollen and spore morphology plays an important role in identification and the tracing relationship of plants at various taxonomic levels [4]. The importance of pollen in evolutionary schemes of the plant kingdom was first formulated by Wodehouse [14] and later by several authors [1, 4, 15, 16]. The pollen – spore morphology has come to be an inevitable tool in comparative morphology, taxonomy and evolution of plants Eames [17]. Data on pollen morphology of hydrophytes is rather scarce. Although few reports are available on hydrophytic plants, such as the families Typhaceae [4, 5, 18] Pontederiaceae [19,20]; Menyanthaceae [21]; Haloragaceae [22]; Alismataceae [12, 23, 24]; Butomaceae [25]; Hydrocharitaceae [26, 27]; Podostemaceae [28]; Najadaece [29]; Rubiaceae [30]; Callitrichaceae [31] and the hydrophilous angiosperms [32]. Some species of Potamogetonaceae have been studied by Sarosa [33]. Kuprianova and Tarasevich [34]. Landolt [35] and Tarasevich [36] examined the pollen morphology of Lemnaceae. Alwadie [37] examined pollen morphology of six aquatic angiosperm from Saudi Arab. Erdtman [8] and Shiga and Kadono [38] had described the pollen grains of Nymphaeceae. Pollens of the cultivated variety of *Nymphaea* were also studied by Singh et al. [39]. Further information on pollen grains of the members of Nymphaeaceae was added by Jones and Clarke [40]. Moreover, Murthy [41] had described the palynological features of six species of *Nymphaea* of India. Perveen [42] studied the palynology of aquatic flora of Karachi of Pakistan. Saadi–Al. and Al–Mayah [43] studied the pollen morphological features of forty nine dicotyledonous aquatic and marsh species of Southern Iraq. The present report is on a pollen morphological investigation of a vulnerable group namely the aquatic angiosperms.

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Materials and method

Pollen slides were prepared following acetolysis method [8]. Dry or fresh polliniferous materials were crushed on a finely washed brass sieve (0.11 sq.mm) resting ona funnel, set on a hard glass centrifuge tube. After each treatment the brass sieve was burnt on a flame to avoid sample-to-sample contamination. Acetolysis mixture was prepared in a measuring cylinder by slowly adding one part of concentrated sulphuric acid to nine parts of acetic anhydride. Acetolysis mixture was added in each tube containing the sample and stirred with clean and dry glass rod. The tubes are placed in water bath and placed in steaming condition or in an oven at 60º temperature. The mixture turned brown and it was allowed to cool down.It was then centrifuged and supernatant was decanted. Distilled water added to sediment and shaken vigorously. The mixture was centrifuged at 4000 rpm for 5 minutes and decanted. The washing was repeated twice or thrice. Distilled water was added once again and shaken, if foaming then few drops of acetone were added and sieved twice through finely meshed steel net, centrifuged and decanted. Distilled water was added in each tube and half of the mixture was transferred to another set of centrifuge tube. One set was centrifuged and 2 ml of 50% glycerine was added in each tube of the otherset and then a few drops of freshly prepared sodium chlorate solution and a few drops of concentrated hydrochloric acid were added and then centrifuged and decanted (Chlorination was avoided for thin walled pollen). The sediment was washed with distilled water, centrifuged at 4000 rpm for 5 minutes and decanted, 50% glycerine added. Both the sets were mixed centrifuged and decanted. The tubes were kept inverted on a piece of blotting paper for overnight. A minute piece of Kaiser's Glycerol Gelatin ™ Merck 1.09242100 at the tip of the clean platinum needle was taken and it was touched with the sediment at bottom of the tubes. The piece of jelly with acetolysed sediment was placed at the centre of the slide and a round cover glass was placed over it. A piece of sealing wax (melting point 60 - 62º C) was placed touching the margin of the cover glass. The slide was heated over a microflame just below the jelly (with specimen) occupied the central position and was gradually surrounded by the melted wax. The slide was kept on a flat and horizontal surface and allowed to cool down. The excess wax was scrapped off from the surface and then cleaned with a piece of soft cloth (no solvent was used). The prepared slide was labeled properly. The pollen measurements were obtained from the grains per sample: exine thickness, number of apertures, shape of pollen, exine ornamentation. The terminology used is in accordance with Walker and Doyle [1], Nair [4], Erdtman [8], Faegrie and Iversen [44]

Results and Discussion

On the basis of pollen morphological nature the hydrophytes and marsh plants of Tripura, can be categorized into six different groups' viz., (i) sulcate (ii) inaperturate (iii) porate (iv) pantoporate (v) trizonoporate (vi) tricolpate (vii) polycolpate (viii) heterocolpate (ix) colporate (x) trizonocolporate (xi) tricolporodiate and (xii) spiaperturate (Table 1). There is a definite relationship between pollen exine thickness and the habitat. A progressive increase in exine thickness with the increase in the zonation of the hydrophytes (Table 2; Fig.1). Pollens of the plants are classified into three group (i) Planktonic angiosperms which comprises the submerged-suspended hydrophytes (ii) Aquatic angiosperms comprising the Free floating - root shoot anchored hydrophytes and (iii) Wetland Helophytes consist **E**mergent - wetland hydrophytes. The exines of the submerged-suspended hydrophytes are 0.695 ± 0.657 which is followed by the free floating-root shoot anchored hydrophytes where the exine is 2.39 ± 0.548 thick. The highest degree of exine thickness was found from the emergent-wetland hydrophytes i.e. 2.62 ± 0.014 (Table 3). A progressive increase in exine thickness with the increase in the zonation of the hydrophytes (Table 2; Fig.1) which may be treated as an adaptive feature of hydrophytes. The exine protects the male spore and gametophyte from desiccation and other hazards of sub-aerial dispersal [45]. It is thought that airborne pollen grains must necessarily have a stable exine structure. Therefore, we believe that the reduced exines are correlated with underwater pollination. Wodehouse [14] suggested that the exine on the pollen of most terrestrial angiosperms is simply unnecessary on the pollen of aquatic plants. Aquatic plants also exhibit a strong relationship between pollen morphology, exine sculpturing and mode of pollination. The entomophilous pollens showed a wide array of diversity in terms of pollen aperture viz., tricolporate (19.64%), tricolpate (12.5%), pantoporate (8.92%), Heterocolpate (7.14%), monosulcate (16.07%), trizonoporate (5.36%), trizonocolporate (3.57%), inaperturate, polycolpate, porate, spiaperturate, tetracolporate and tricolporodiate each by 1.78%. The entomophilous pollens show much more diversity in relation to pollen aperture than the anemophilous pollens [46]. While the anemophilous pollens show less diversity in terms of pollen aperture viz., monosulcate (5.35%), pantoporate (3.57%), inaperturate and tricolporate by 1.78% respectively. The hydrophilous pollens are chiefly inaperturate in nature. The exine of the entomophilous pollens are predominantly reticulate (16.07%) followed by spinulate - spinulose (12.5%), regulate-regulate striate (10.71%), echinate (8.92%), psilate (8.92%), granulate, striate and verrucate to verrucate - striate each by 5.35%, gemmate and fossulate (3.57%), foveolate and scabrate each by 1.78 %. while the exine of entomophilous pollens are aerolate – aerolate - scabrate (5.35 %), spinulate (3.57%) echinate and striate-reticulate each by 1.78%. Proctor et al [47] stated that highly ornamented grains are often observed in entomophilous species, play a role in aggregating pollen into large clumps and allow more efficient pollen transfer inentomophily. Walker [48] also suggested that the sculpturing present in entomophilous taxa aids in attaching pollen to the pollinator and that combining with the oil droplets that produce functional pollen polyads assures a number of potential fertilizations from a single act of pollination. Wodehouse [12] reported that most pollen of anemophilous species is smooth in nature. The flower of the most aquatic plants angiosperms must be elevated above the water surface in order for pollination to occur. Hydrophytes are taxonomically diverse and they are pollinated by a large number of aerial and aquatic mechanisms [18, 49]. Pollination in most aquatic plants including submerged ones, occur in the air either through the biotic pollination or anemophily [18]. In the present work the studied 47 species are predominantly entomophilous in nature (82.45 %). The hydrophilous mode is more limited, and is categorized by the location of pollen transport. Hydrophily, or under water pollination, is relatively uncommon in angiosperms. The hydrophilous mode of pollination and is largely restricted to the monocotyledons. The different species of hydrophytes and marsh plant communities have a distinctive pollen morphology which allows a specific determination of the vegetation. The value of such studies could be augmented appreciably where it is possible to supplement the other data with pollen records for the more distant past and experimental treatment of postulated vegetational process [3, 50]. However, the present investigation is expected to invoke an integrated view on the plant community of hydrophytes and marsh plants. West [51] pointed out that the pollen assemblage of a particular locality does not normally an even mixture of pollen types rather than a mixture of different types, which indicates the mosaicness of plant communities. This is also expressed in the aquatic and marsh land pollen flora.

References

1. Hilly M, Adams ML, Nelson SC. A study of digit fusion in the mouse embryo. Clin Exp Allergy. 2002;32(4):489-98.
2. Walker JW, Doyle JA. The bases of Angiosperm Phylogeny: palynology. Annals of the Missouri Botanical Garden. 1975; 62(3): 664-723. https://doi.org/10.2307/2395271
3. Moore PD, Webb JA. An Illustrated Guide to Pollen Analysis. Hodder and Stoughton, London.1978

4. Harris DR. Plants, animals and man in the outer Leeward Island, West Indies. In: Keliman, MC. Plant Geography. Methuen & Co. Ltd., Lomdon. 1965; pp 131
5. Nair PKK. Advances in Palynology. National Botanical Garden, Lucknow, India. 1964
6. Nair PKK. Pollen Morphology. In: Nair PKK (ed.), Advances in Palynology. National Botanical Garden. Lucknow. 1970; pp 203 – 224
7. Lindley J. The genera and species of orchidaceous plants. London.1830
8. Cranwell LM. New Zealand pollen studies: The monocotyledons. Bulletin of Auckland Institute Musuem. 1952; 3:1-91
9. Erdtman G. Pollen Morphology and Plant Taxonomy- Angiosperms. Almqvist and Wiksell, Stockholm. 1952.
10. Erdtman G. Pollen Morphology and Plant Taxonomy. Gymnospermae, Pteridophyta, Bryophyta. Stockholm and New York. 1957.
11. Fritzsche CJ. Beitrage zur Kenntniss des pollen. Berlin. 1832; pp 48
12. Selling OH. Studies in Hawaiian Pollen Statistics, Part I & II. Bishop Museum Publ. Honolulu, Hawaii. 1947
13. Wodehouse RP. Pollen grains. McGraw Hill and Co. New York. 1935
14. Kuprianova LA. Morphologie des Pollens et Phylogenie des Monocotyledons enrusse. Comm. Komarov Institute Academic Science. 1948; 1(7): 163 – 262
15. Wodehouse RP. Pollen grains in the identification and classification of plants. 1936
16. Chaloner WG. Spores and land plant evolution. Review of Palaeobotanyand Palynology. 1967; 1: 83 – 93
17. Muller J. Palynological evidence on early differentiation of angiospenns. Biological Revision 1970; 45: 417 – 450
18. Eames AB. Morphology of the Angiosperms. New York. 1961
19. Cook CDK. Wind pollination in aquatic Angiosperms. Annals of Missouri Botanical Garden. 1988; 75: 768-777. https://doi.org/10.2307/2399365
20. Raj B, Saxena MR. Pollen morphology of aquatic angiosperms. Pollen et Spore. 1966; 8: 49- 55

21. Simpson M. Pollen ultrastructure of the Pontederiaceae. Grana.1987; 26(2): 113-126. http://dx.doi.org/10.1080/00173138709429941

22. Nilison S, Orndiff R. Menyanthaceae Dum. World Pollen and Spore Flora. 1973; 2: 1-20

23. Praglowski J.The pollen morphology of the Haloragaceae with referenceto taxonomy. Grana 1970; 10(3): 159 -239.

24. Argue CL. Pollen studies in the Alismataceae with special reference to taxonomy. Pollen et Spores. 1976; 18: 161 – 201

25. Chanda S, Nilson S, Blackemore S. Phylogenetic trends in the Alismatales with reference to pollen grains. *Grana*. 1988; 27: 257-272. https://doi.org/10.1080/00173138809429948

26. Argue CL. Pollen of the Butomaceae and Alismataceae. I. Developmentof pollen wall in *Butomus umbellatus* L.Grana. 1971; 11(3): 131-144 https://doi.org/10.1080/00173137109430488

27. Takahashil M. Pollen development in a submerged plant. *Ottelia alismoides* (L.) Pers. (Hydrocharitaceae). Journal of Plant Research. 1994; 107:161-164. https://doi.org/10.1007/BF02346012

28. Tanaka N, Uehra K, Murata J. Correlation between pollen morphology and pollination mechanism in Hydrocharitaceae. Journal of Plant Research. 2004; 117: 265-276. https://doi.org/10.1007/s10265-004-0155-5

29. Obson JM, O’Neil SP, El-Ghazaly G. Pollen morphology and ultastructure of *Marathrum schiedeanum* (Podestemaceae). Grana. 2000; 39 (5): 221-225. https://doi.org/10.1080/00173130052017253

30. Shuang-Quan H, You-Hao G, Robert GW, Yao-Hua, S, Kun S. Mechanism of underwater pollination in *Najas marina* (Najadaceae). Aquatic Botany. 2001; 70(1): 67 – 78

31. Lacroix CR, Kemp JR. Developmental morphology of the androceium and gynoceium in *Rubbia maritiam* L. Consideration for Pollination. *Aquatic Botany*.1997; 59 (3-4):253-262. https://doi.org/10.1016/S0304-3770(97)00074-0

32. Cooper RL, Osborn JM, Philbrick CT. Comparative pollen morphology and ultrastructure of Callitricaceae. American Journal of Botany. 2000; 87(2): 161-175. PMID: 10675302

33. Pettitt JM, Jermy AC. Pollen in hydrophilous angiosperms. *Micron.* https://doi.org/10.1016/0047-7206(74)90023-5Praglowski J (1970) The pollen morphology of the Haloragaceae with referenceto taxonomy. Grana 1975; 10(3): 159 -239.

34. Sorsa P. Pollen morphology of *Potamogeton* and *Groenalndia* (Potamogetonaceae) and its taxonomic significance. Annals Botanical Fennici. 1988; 25: 179-199. https://doi.org/10.11110/kjpt.2002.32.2.233

35. Kuprianova LA, Tarasevich VF. The ultra structure of the surface of pollen grain wall in some genera of the family Lemnaceae and the related genera of the family Areaceae. Botanicheskii Zhurnal. 1984; 69: 1656 – 1661

36. Landolt E. The Family of Lemnaceae - A Monographic Study. Vol. I. Veroffentlichungen des Geobotanischen Institutes. ETH Stiftung Rubel Zurich. 1986; 71: 1 – 566

37. Tarasevich VF. Palynological evidence on the position of the Lemnaceae family in the system of flowering plants. Botanicheskii Zhurnal. 1990; 75(7): 959 – 965

38. Alwadie HM. Pollen Morphology of six Aquatic Angiosperm fromSaudi Arab. Asian Journal of Biological Science. 2008; 1: 45-50. https://scialert.net/abstract/?doi=ajbs.2008.45.50

39. Shiga T, Kadono Y. Natural hybridization of two *Nuphar* species in Northern Japan: Homoploid hybrid speciation in Progress. *Aquatic Botany*. 2007; 86(2): 123-131. DOI:10.1016/j.aquabot.2006.09.008

40. Singh C B, Motial VS, Nair PKK. Pollen morphology of *Nymphaea.* Plant Science. 1969; 1: 53 – 56

41. Jones MR, Clarke GCS. Nymphaeaceae - The NEP Flora. Review of Palaeobotany and Palynology. 1981; 33: 57 -67

42. Murthy GVS. Pollen morphology of Nymphaeceae (*s.l.*). Bulletin of Botanical Survey of India. 2000; 42 (1 - 4): 73 - 80.

43. Perveen A. Pollen characters and their evolutionary significance with special reference to the flora of Karachi. Turkish Journal of Botany. 2000; 24(2): 365-377. Corpus ID: 59068090

44. Saadi Al, SAA, Al – Mayah ARA. Pollen morphological study of dicots wetland plants of Southern marshes of Iraq. Marsh Bulletin. 2012; 7(2): 169 – 188.

45. Faegri K, Iversen J. Text Book of Pollen Analysis. 1964; (2nd eds) Munksgaaard. Copenhagen.

46. Heslop-Harrison J. Pollen germination and pollen-tube growth. International Review of Cytology. 1987; 107: 1 – 78

47. Manso MML, Andres IM. Pollinic characters in Mediterranean salt marsh plants in relation to their pollination mechanism. Acta Botanica Gallica. 1993; 140(3): 263 - 274.

48. Proctor M, Yeo P, Lack A. The natural history of pollination. 1996; Timber press, USA.

49. Walker JW. Comparative pollen morphology and phylogeny of Ranalean complex. In Beck CB (ed): Origin and Early Evolution of Angiosperm. New York, Colombia University Press. 1976; pp. 241 – 299

50. Ackerman JD. Abiotic pollen and pollination: Ecological, functional, and evolutionary perspectives. Plant Systematics and Evolution. 2000; 222(1-4): 167 - 185.

51. Saucer JD. Plants and man on the Seychettes Coast, a study in historicalbiography. In: Kellman MC. Plant Geography. 1967; Methueu and Co. Ltd., London. pp. 131

52. West RG. Interrelation between ecology and quaternary paleobotany. Journal of Ecology. 1964; 52(Suppl.): 47 – 57

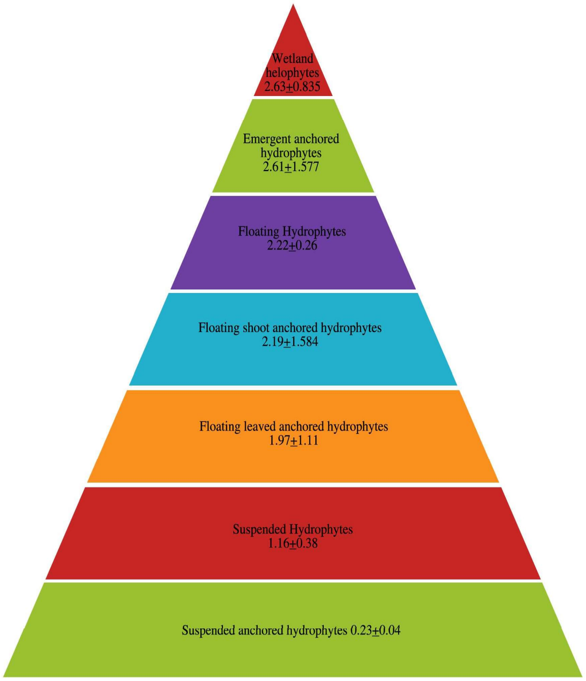

Fig. 1: Evolution of Pollen Morphology with respect to Exine thickness

Table 1: Pollen types of Hydrophytes and Marsh Plants

Type I: **Sulcate**	*Eichornia crassipes* (Mart.) Solm; *Commelina benghalensis* L.; *Commelina diffusa* Burm.*f*.; *Cyanotis axillaris* (L.) D.Don ex Sweet; *Monochoria hastata* (L.) Solm; *Monochoriavaginalis* (Burm.*f*.) C.Presl.; *Murdannia nudiflora* (L.) Brenan; *Nymphaea micrantha* Guill. & Perr.; *Nymphaea pubescens* Willd.; *Nymphaea rubra* Roxb.; *Nymphaea stellata* var. *major* Voigt.; *Nymphaea stellata* Willd.;

Type II: **Inaperturate**	*Limnocharis flava* (L.) Buchenau; *Ottelia alismoides* (L.) Pers.; *Vallisneria spiralis* L.; *Potamogeton octandrus* Poir.;
Type III: **Poarte**	*Drosera burmnni* Vahl
Type IV: **Pantoporate**	*Alternanthera philoxeroides* (Mart.) Griseb; *Alternanthera sessilis* (L.) R.Br. ex DC.; *Ipomoe aquatica* Forssk.; *Ipomoeacarnea* Jacq.; *Persicaria hydropiper* (L.) Delarbre; *Persicariaorientalis* (L.) Spach; *Sagittria sagitifolia* L.;
Type V: **Trizonoporate**	*Ludwigia octovalvis* subsp. *sessiliflora* (Micheli) P. H. Raven; *Ludwigia perennis* L.; *Utricularia ceruleaea* L.;
Type VI: **Tricolpate**	*Bacopa monnieri* (L.) Wettst.; *Limnophila repens* (Benth.) Benth.; *Limnophila rugosa* (Roth) Merr.; *Lindernia anagallis*(Burm.*f.*) Pennell; *Lindernia ciliata* (Colsm.) Pennell; *Nelumbo nucifera* Gaertn.; *Trapa natuns* var *bispinosa* (Roxb.) Makino.
Type VII: **Polycolpate**	*Myriophyllum tuberculatum* Roxb.;
Type VIII: **Heterocolpate**	*Ammania baccifera* L.; *Hygrophila auriculata* (Schumach.) Heine; *Hygrophila phomoides* Nees; *Hygrophila salicifolia* (Vahl) Nees
Type IX: Colporate	*Acmella ciliata* (Kunth) Cass.; *Aeschynomene indica* L.; *Eclipta prostrata* (L.) L.; *Enhydra fluctuans* Lour.; *Grangea maderaspatana* (L.) Poir.; *Lobelia zeylanica* L.; *Neptunia oleracea* Lour.; *Nymphoides cristata* (Roxb.) Kuntze; *Nymphoides indica* (L.) Kuntze; *Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne; *Rumex maritimus* L.; *Sphenoclea zeylanica* Gaertn.
i. Tricolporate	
ii. Tetracolporate	*Uticularia bifida* L.;
Type X: **Trizonocolporate**	*Centella asiatica* (L.) Urb.; *Hypericum japonicum* Thunb.;
Type XI: **Tricolporodiate**	*Hydrolea zeylanica* (L.) Vahl;
Type XII: **Spiaperturate**	*Utricularia gibba* L.

Table 2: Pollen Morphology of Hydrophytes and Marsh plants under different Ecological Classes

Sl no	Name of the plant	Family	Shape	Exine (µm)	Exine ornamentation	Aperture
Floating Hydrophytes						
1.	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Oblate	2.56 ± 0.14	Aerolate-scabrate	Monosulcate
2.	*Trapa natans* var. *bispinosa* (Roxb.) Makino	Trapaceae	Oblate-spheroidal	2.45 ±0.57	Verrucate	Tricolpate
			Mean exine thickness	2.50 ± 0.07		
Suspended Hydrophytes						
3.	*Utricularia bifida* L.	Lentibulariaceae	Prolate-spheroidal	1.24 ± 0.36	Psilate	Tetracolporate
4.	*Utricularia ceruleaea* L.	Lentibulariaceae	Oblate-spheroidal	1.43 ± 0.11	Psilate	Trizonoporate
5.	*Utricularia gibba* L.	Lentibulariaceae	Sub-oblate	1.24 ± 0.16	Gemmate	Spiaperturate
6.	*Vallisneria spiralis* L.	Hydrocharitaceae	Spheroidal	0.55 ± 0.22	Gemmate	Inaperturate
			Mean exine thickness	1.16 ± 0.38		

Submerged anchored hydrophytes						
7.	*Ottelia alismoides* (L.) Pers.	Alismataceae	Spheroidal	0.20 ± 0.4	Spinulose	Inaperturate
8.	*Potamogeton octandrus* Poir.	Potamogetonaceae	Spheroidal	0.26 ± 0.04	Reticulate	Inaperturate
			Mean exine thickness	0.23 ± 0.04		
Floating leaved anchored hydrophytes						
9.	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Sub- prolate	3.86 ± 0.93	Rugulate	Tricolpate
10.	*Nymphaea micrantha* Guill. & Perr.	Nymphaeceae	Oblate	1.56 ± 0.18	Gemmate	Monosulcate
11.	*Nymphaea pubescens* Willd.	Nymphaeceae	Oblate	1.63 ± 0.33	Striate	Monosulcate
12.	*Nymphaea rubra* Roxb.	Nymphaeceae	Oblate	1.23 ± 0.22	Fossulate	Monosulcate
13.	*Nymphaea stellata* var. *major* Voigt.	Nymphaeceae	Oblate	2.96 ±0.35	Foveolate	Monosulcate
14.	*Nymphaea stellata* Willd.	Nymphaeceae	Oblate	2.85 ± 0.56	Psilate	Monosulcate
15.	*Nymphoides cristata* (Roxb.) Kuntze	Menynthaceae	Oblate	0.79 ± 0.21	Spinulate	Tricolporate
16.	*Nymphoides indica* (L.) Kuntze	Menynthaceae	Sub-Oblate	0.87 ± 0.19	Spinulate	Tricolporate
			Mean exine thickness	1.97 ± 1.11		
Floating shoot anchored hydrophytes						
17.	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Spheroidal	1.47± 0.22	Granulate	Pantoporate

18.	*Ipomoea aquatic* Forssk.	Convolvulaceae	Spheroidal	4.56 ± 0.47	Echinate	Pantoporate
19.	*Myriophyllum tuberculatum* Roxb.	Haloragaceae	Sub-oblate	1.38 ±0.17	Scabrate	Polycolpate
20.	*Neptunia oleracea* Lour.	Mimosaceae	Prolate-spheroidal	1.33 ± 0.05	Striate-reticulate	Tricolporate
			Mean exine thickness	2.19 ± 1.58		
		Emergent anchored hydrophytes				
21.	*Aeschynomene indica* L.	Papilionaceae	Prolate	2.17 ± 0.76	Reticulate	Tricolporate
22.	*Enydra fluctuans* Lour.	Asteraceae	Prolate-spheroidal	3.02 ± 0.84	Echinate	Tricolporate
23.	*Limnocharis flava* (L.) Buchenau	Alismataceae	Spheroidal	1.33 ± 0.11	Spinulate	Inaperturate
24.	*Limnophila repens* (Benth.) Benth.	Scrophulariaceae	Sub-prolate	2.21 ± 0.79	Fossulate	Tricolpate
25.	*Limnophila rugosa* (Roth) Merr.	Scrophulariaceae	Sub-prolate	1.79 ± 0.53	Psilate	Tricolpate
26.	*Monochoria vaginalis* (Burm.*f.*) C.Presl.	Pontederiaceae	Oblate	1.62 ± 0.93	Aerolate	Monosulcate
27.	*Persicaria hydropiper* (L.) Delarbre	Polygonaceae	Spheroidal	5.42 ± 0.26	Reticulate	Pantoporate
28.	*Persicaria orientale* (L.) Spach	Polygonaceae	Spheroidal	5.50 ± 0.36	Reticulate	Pantoporate
29.	*Sagittaria sagittifolia* L.	Alismataceae	Spheroidal	1.71 ± 0.14	Spinulate	Pantoporate
30.	*Sphenoclea zeylanica* Gaertn.	Sphenocleaceae	Oblate-spheroidal	1.37 ± 0.23	Psilate	Tricolporate
			Mean exine thickness	2.61 ±1.57		

Wetland helophytes						
31.	*Acmella ciliata* (Kunth) Cass.	Asteraceae	Oblate-spheroidal	3.23 ±0.52	Echinate	Tricolporate
32.	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	Spheroidal	1.50 ± 0.12	Granulate	Pantoporate
33.	*Ammania baccifera* L.	Lythraceae	Prolate	1.96± 0.12	Rugulate-striate	Heterocolpate
34.	*Bacopa monnieri* (L.) Wettst.	Scrophulariaceae	Sub-prolate	2.01 ± 0.43	Reticulate	Tricolpate
35.	*Centella asiatica* (L.) Urb.	Apiaceae	Sub-prolate	2.05 ± 0.15	Rugulate-striate	Trizonocolporate
36.	*Commelina benghalensis* L.	Commelinaceae	Oblate	2.61 ± 0.24	Spinulose	Monosulcate
37.	*Commelina diffusa* Burm.*f.*	Commelinaceae	Prolate	2.84 ± 0.21	Spinulose	Monosulcate
38.	*Cyanotis axillaris* (L.) D.Don ex Sweet	Commelinaceae	Oblate	2.22 ± 0.24	Striate	Monosulcate
39.	*Drosera burmannii* Vahl	Droseraceae	Spheroidal	2.33 ± 0.05	Spinulose	Porate
40.	*Eclipta prostrata* (L.) L.	Asteraceae	Oblate-spheroidal	3.57 ± 0.52	Echinate	Tricolporate
41.	*Grangea maderaspatana* (L.) Poir.	Asteraceae	Oblate-spheroidal	2.56 ± 0.11	Echinate	Tricolporate
42.	*Hydrolea zeylanica* (L.) Vahl	Hydroleaceae	Sub-prolate	2.17 ± 0.76	Reticulate	Tricolporodiate
43.	*Hygrophila auriculata* (Schumach.) Heine	Acanthaceae	Sub-oblate	2.36 ± 0.12	Reticulate	Heterocolpate
44.	*Hygrophila phomoides* Nees	Acanthaceae	Sub-oblate	2.58 ± 0.25	Reticulate	Heterocolpate
45.	*Hygrophila salicifolia* (Vahl) Nees	Acanthaceae	Oblate-spheroidal	2.53 ± 0.21	Reticulate	Heterocolpate

46.	*Hypericum japonicum* Thunb.	Hypericaceae	Prolate-spheroidal	2.93 ± 0.42	Reticulate	Trizonocolporate
47.	*Ipomoea carnea* Jacq.	Convolvulaceae	Spheroidal	4.02 ± 0.08	Echinate	Pantoporate
48.	*Lindernia anagalis* (Burm.*f*) Pennell	Scrophulariaceae	Sub-prolate	2.89 ±0.42	Rugulate-striate	Tricolpate
49.	*Lindernia ciliata* (Colsm.) Pennell	Scrophulariaceae	Oblate-spheroidal	2.58 ± 0.36	Rugulate-striate	Tricolpate
50.	*Lobelia zeylanica* L.	Campanulaceae	Sub-prolate	2.79 ±0.27	Striate	Tricolporate
51.	*Ludwigia octovalvis* subsp. *sessiliflora* (Micheli) P. H. Raven	Onagraceae	Oblate	4.73±1.19	Verrucate	Trizonoporate
52.	*Ludwigia perennis* L.	Onagraceae	Sub-oblate	2.87± 1.19	Verrucate-striate	Trizonoporate
53.	*Monochoria hastata* (L.) Solm	Pontederiaceae	Oblate	2.26 ± 0.52	Aerolate	Monosulcate
54.	*Murdannia nudiflora* (L.) Brenan	Commelinaceae	Per-prolate	2.51± 0.12	Spinulate	Monosulcate
55.	*Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne	Lythraceae	Sub-prolate	2.19 ±0.11	Granulate	Tricolporate
56.	*Rumex maritimus* L.	Polygonaceae	Oblate-spheroidal	2.12 ± 0.22	Rugulate	Tricolporate
			Mean exine thickness	2.63 ± 0.67		

Table 3: Exine thickness of Hydrophytes and marsh plants under differentEcological Classes

Ecological Group	**Exine Thickness**	**Mean Exine Thickness**
Submerged-suspended hydrophytes		
Submerged Hydrophytes	0.23 ± 0.04	0.695 ± 0.657
Suspended Hydrophytes	1.16 ± 0.38	
Free floating - root shoot anchored hydrophytes		
Floating leaved anchored hydrophytes	1.97 ± 1.11	2.39 ± 0.548
Floating shoot anchored hydrophytes	2.19 ± 1.58	
Floating Hydrophytes	2.50 ± 0.07	
Emergent - wetland hydrophytes		
Emergent anchored hydrophytes	2.61 ±1.57	2.62 ± 0.014
Wetland helophytes	2.63 ± 0.67	