

Flowering Phenology, Pollination Modes, and Morphological Diversity of Airborne Pollen in Meerut: An Aeropalynological Study

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Abstract: *Aeropalynological investigations provide important information on the diversity, seasonal occurrence, and morphological characteristics of airborne pollen. This study examines the relationships among flowering periods, pollen-capture periods, reported pollination modes, and pollen morphological characters of plant taxa recorded during an aeropalynological investigation in Meerut, Uttar Pradesh, India, in 2000–2001. The compiled dataset includes angiosperms and gymnosperms from several botanical families, with pollen types varying in aperture number and arrangement, shape, and exine ornamentation. Anemophilous, entomophilous, and amphiphilous taxa are represented. Several taxa show extended flowering and pollen-capture periods, whereas others exhibit more restricted seasonal occurrence. These observations provide a basis for examining the temporal relationship between flowering phenology and airborne pollen detection and for evaluating the usefulness of pollen morphology in identifying airborne pollen types. However, pollen capture may not exactly correspond to the flowering period because of atmospheric transport, pollen release, environmental conditions, and the persistence of airborne pollen. The study establishes a historical reference dataset for aeropalynological research in Meerut and provides a foundation for further quantitative analysis of pollen seasonality and its relationship with meteorological variables.*

Keywords: Aeropalynology; airborne pollen; flowering phenology; pollination mode; pollen morphology; pollen calendar; Meerut; seasonal distribution.

I. INTRODUCTION

Aeropalynology studies airborne pollen, including its occurrence, concentration, seasonal distribution, and relationship with environmental conditions. Airborne pollen monitoring provides information relevant to plant ecology, environmental assessment, and pollen calendar preparation. Standardized sampling and identification procedures are important for obtaining reliable and comparable aerobiological observations (Hirst, 1952; Thibaudon et al., 2013; Galán et al., 2014).

The seasonal occurrence of airborne pollen is influenced by flowering phenology, pollen production and release, atmospheric transport, and weather conditions. Flowering periods indicate when plants may produce pollen, whereas pollen monitoring records the occurrence of pollen in the sampled atmosphere. These periods may overlap but do not necessarily coincide. Differences in the definition of pollen seasons can also affect the interpretation and comparison of aerobiological observations (Jato et al., 2006; Berger et al., 2018).

Pollen morphology provides important characters for the identification and classification of pollen grains. Aperture number and arrangement, pollen shape, and exine ornamentation are widely used in palynological studies. Erdtman (1969) provided a foundational account of pollen morphology, taxonomy, and ecology, while Moore et al. (1991) described pollen identification and analysis methods. Nevertheless, morphological similarities between taxa may limit identification to the species level, particularly when pollen is examined using routine light microscopy (Rittenour et al., 2012).

Pollination mode is another relevant ecological characteristic. Anemophilous plants release pollen for wind-mediated pollination, whereas entomophilous plants primarily depend on insects. Pollen from insect-pollinated plants may also be detected in air samples, so airborne occurrence should not be interpreted as direct evidence of wind pollination. The relationship between pollination biology and atmospheric pollen occurrence therefore requires careful interpretation.

Historical aeropalynological datasets are valuable because they preserve observations from a defined location and period. Such records can provide a baseline for future comparisons, provided that differences in sampling methods, taxonomic identification, and pollen-season definitions are considered (Thibaudon et al., 2013; Galán et al., 2014; Berger et al., 2018).

The present study documents the flowering periods, pollen-capture periods, reported pollination modes, and morphological characteristics of pollen types recorded during an aeropalynological investigation in Meerut, Uttar Pradesh, India, during 2000–2001. The study aims to characterize the seasonal occurrence and morphological diversity of the recorded pollen types and establish a historical reference for subsequent quantitative investigations.

II. MATERIALS AND METHODS

Airborne pollen sampling

The study was conducted in Meerut, Uttar Pradesh, India, during 2000–2001. For the aeroscope investigation, microscopic slides measuring 75 mm × 25 mm were coated with a thin film of molten glycerin jelly stained with safranin. The coated surface measured approximately 24 mm × 60 mm, matching the dimensions of the coverslip. These slides were exposed to ambient air for pollen collection and replaced at 24-hour intervals. The sampling procedure was continued for two consecutive years, 2000 and 2001. An aeroscope was installed on the terrace of a residential building in Meerut district, approximately 6 m above ground level. The instrument was employed to collect airborne biological particles, including pollen grains, fungal spores, and other associated biological materials. For pollen identification, reference preparations were made using pollen collected from plants growing in the surrounding locality. The reference slides were prepared without acetolysis and were therefore unacetolysed. The morphological features of pollen recovered from the atmospheric samples were compared with those of the reference preparations to facilitate identification.

Classification of pollination modes

The pollination modes listed in the original dataset were classified as:

Anemophilous: pollination primarily mediated by wind.

Entomophilous: pollination primarily mediated by insects.

Amphiphilous: pollination involving both wind and insect-mediated mechanisms, as reported in the dataset.

These categories were retained as reported and should be verified against reliable botanical references before publication. Pollination mode alone was not considered sufficient evidence of the mechanism responsible for the airborne occurrence of a particular pollen type. We compiled the flowering and pollen-capture periods from the original dataset and expressed them as calendar months. Flowering periods were treated as indicators of the documented reproductive season, whereas pollen-capture periods represented the intervals during which the corresponding pollen types were recorded in atmospheric samples.

The two periods were analyzed separately because the beginning, end, and duration of a pollen season depend on the criteria used to define and record atmospheric pollen occurrence (Jato et al., 2006; Berger et al., 2018). Where monthly pollen counts are available, standardized definitions of the main pollen season can be considered for further quantitative analysis.

Pollen Morphological Characters

Pollen morphological characters were compiled from the original dataset and identification records to facilitate the identification and preliminary classification of airborne pollen types. The recorded characteristics included aperture number, type and arrangement, pollen shape and size, where available, and exine ornamentation. These morphological features are important taxonomic criteria for distinguishing pollen types and supporting their identification.

The pollen wall consists of two principal layers: the inner intine and the outer exine. The exine possesses characteristic structural and sculptural features that are particularly valuable for taxonomic identification. Important morphological

parameters include the polar and equatorial diameters, general shape of pollen grains, and the number, position and type of apertures. Apertures are specialized regions of the pollen wall associated with pollen germination and may vary in number, position and form. Depending on their morphology, the recorded aperture types included colpate, porate and colpate forms, along with zonoporate and pantoporate types where documented.

Exine ornamentation provides additional diagnostic information and may include reticulate, psilate, smooth, granulate, spinulate or spinose patterns. Other ornamentation types, such as striate, foveolate, scrobiculate, baculate and clavate, may also occur in pollen grains, but should be reported for the present study only when supported by the original observations or identification records. Structurally, the exine comprises the inner nexine and the outer sexine, which may contain sculptural elements contributing to the characteristic surface pattern of pollen grains.

The morphological descriptions were retained from the original dataset for preliminary analysis. Standard palynological terminology and established identification references were considered necessary for verifying and standardizing the recorded descriptions (Erdtman, 1969; Moore et al., 1991).

III. DATA ANALYSIS

The compiled dataset was analyzed descriptively to characterize the recorded taxonomic groups, including the number of pollen taxa and families, flowering periods, pollen-capture intervals, reported pollination modes, and pollen morphological characteristics. The seasonal correspondence between flowering periods and pollen-capture intervals was examined descriptively to identify similarities and differences between the documented flowering season and the period of atmospheric pollen detection.

Table 1: Showing Flowering Period of Maximum Catch ,Mode of Pollination and Pollen Morphology of Airborne Pollens of Meerut During 2000 and 2001

SNo.	Family and Genera	Period of Flowering	Pollen-Capture Period	Mode of Pollination	Morphological Characters
1	AMARANTHACEAE				
	Achyranthus sp.	8–10	2–4	Anemophilous	Pantoporate, Psilate
	Amaranthus sp.	10–6	Throughout the year	Anemophilous	Pantoporate, Psilate
2	ANACARDIACEAE				
	Mangifera indica L.	2–3	3–6	Anemophilous	3-Zonocolpate, Reticulate
3	APIACEAE				
	Coriandrum sp.	12–3	1–3	Entomophilous	3-Zonocolpate, Foveolate
4	APOCYNACEAE				
	Plumeria sp.	3–10	4–11	Anemophilous	Tricolpate, Smooth
	Thevetia sp.	4–10	5–11	Anemophilous	Tricolpate, Smooth
	Vinca rosea	Throughout the year	Throughout the year	Anemophilous	Tricolpate, Smooth
5	ARECACEAE				

SNo.	Family and Genera	Period of Flowering	Pollen-Capture Period	Mode of Pollination	Morphological Characters
	Phoenix sylvestris (L.) Roxb.	2–3	3–5	Anemophilous	Monocolpate, Psilate
6	ASTERACEAE				
	Ageratum conyzoides Linn.	Throughout the year	Throughout the year	Anemophilous	3-Zonocolporate, Spinulate
	Artemisia sp.	9–12	11–12	Anemophilous	Tricolporate, Spinose
	Chrysanthemum sp.	12–4	1–4	Anemophilous	Tricolporate, Reticulate
	Parthenium hysterophorus L.	Throughout the year	Throughout the year	Anemophilous	Tricolporate, Spinulate
	Xanthium sp.	7–10	8–11	Anemophilous	Tricolporate, Reticulate
7	BETULACEAE				
	Alnus sp.	9–10	9–11	Anemophilous	4(5)-Zonoporate
8	BRASSICACEAE				
	Brassica campestris Linn.	10–4	10–5	Anemophilous	Tricolpate, Reticulate
9	CAESALPINIACEAE				
	Cassia fistula L.	5–7	6–8	Anemophilous	Tricolporate, Reticulate
10	CANNABINACEAE				
	Cannabis sativa L.	2–7	3–11	Anemophilous	Tricolporate, Granulate
11	CARICACEAE				
	Carica papaya	8–11	9–11	Anemophilous	Tricolporate, Reticulate
12	CASUARINACEAE				
	Casuarina sp.	12–7, 7–10	3–4, 7–10	Anemophilous	Trizoniporate, Psilate
13	CUSCUTACEAE				
	Cuscuta sp.	9–2	1–4	Entomophilous	Pantoporate, Spinulate
14	CHENOPODIACEAE				
	Chenopodium sp.	11–12, 1–4	12, 1–3	Anemophilous	Pantoporate, Psilate
15	CONVOLVULACEAE				
	Ipomoea sp.	6–3	7–2	Entomophilous	Pantoporate,

SNo.	Family and Genera	Period of Flowering	Pollen-Capture Period	Mode of Pollination	Morphological Characters Spinulate
16	CYPERACEAE				
	Cyperus sp.	1–4, 6–7	2–11	Anemophilous	Monocolpate, Granulate
17	EUPHORBIACEAE				
	Croton sp.	Throughout the year	Throughout the year	Anemophilous	Tricolporate, Reticulate
	Euphorbia hirta L.	9–1	9–12	Anemophilous	Tricolporate, Reticulate
	Ricinus sp.	Throughout the year	Throughout the year	Anemophilous	Tricolporate, Reticulate
18	FABACEAE			Anemophilous	Trizonocolporate, Psilate
19	LAMIACEAE				
	Ocimum basilicum Linn.	7–11	8–11	Anemophilous	6-Colpate, Smooth
	Ocimum sanctum	6–10	7–10	Anemophilous	6-Colpate, Reticulate
20	LILIACEAE				
	Allium cepa	2–4	1–3	Entomophilous	Mono-Colpate, Reticulate
21	MALVACEAE				
	Abutilon sp.	1–4	1–3	Entomophilous	Trizonocolporate, Spheroidal
	Sida sp.	8–10	9–10	Entomophilous	Pantaporate, Spheroidal
22	MELIACEAE				
	Azadirachta indica	2–4	3–4	Anemophilous	4-Zonocolporate, Psilate
23	MIMOSACEAE				
	Acacia sp.	Throughout the year	Throughout the year	Anemophilous	Pantaporate, Spinulate
24	MORACEAE				
	Morus alba	2–4	3–4	Anemophilous	2-Porate, Smooth
25	MYRTACEAE				
	Eucalyptus sp.	11–4	11–4	Entomophilous	Trizonocolporate, Smooth

SNo.	Family and Genera	Period of Flowering	Pollen-Capture Period	Mode of Pollination	Morphological Characters
	Psidium guajava	4-7	4-5	Entomophilous	Trizonocolporate, Smooth
26	NYCTAGINACEAE				
	Bougainvillea sp.	2-5	1-6	Entomophilous	Trizonocolporate, Reticulate
	Boerhavia sp.	Throughout the year	Throughout the year	Anemophilous	Pantoporate, Spinulate
27	PAPAVERACEAE				
	Argemone mexicana	12-6	2-6	Amphiphilous	Trizonocolporate, Faveolate
	Papaver sp.	2-5	4-5	Amphiphilous	Trizonocolporate, Smooth
28	POACEAE				
	Cynodon dactylon	Throughout the year	Throughout the year	Anemophilous	Monoporate, Psilate
	Saccharum sp.	8-12	3-4	Anemophilous	Monoporate, Psilate
29	POLYGONACEAE	2-6	2-6, 9-11	Amphiphilous	Tricolporate, Reticulate
30	PROTEACEAE				
	Grevillea sp.	4-5	4-5	Anemophilous	Trizonocolporate, Reticulate
31	RUTACEAE				
	Citrus sp.	6-4	6-4	Entomophilous	3(4)-Zonocolporate
32	ROSACEAE	2-4	2-4	Anemophilous	Tricolporate, Smooth
33	SOLANACEAE				
	Solanum sp.	8-2	9-1	Entomophilous	Trizonocolporate, Smooth
	Petunia sp.	8-10	8-10	Entomophilous	Trizonocolporate, Granulate
34	TYPHACEAE				
	Typha sp.	4-5	4-5	Anemophilous	Monoporate, Reticulate
35	URTICACEAE				
	Holoptelea sp.	3-4	2-4	Anemophilous	Porate, Obscure
36	VERBENACEAE				
	Lantana camara	Throughout	Throughout	Anemophilous	Tricolporate,

SNo.	Family and Genera	Period of Flowering	Pollen-Capture Period	Mode of Pollination	Morphological Characters
		the year	the year		Spinulose
37	ZYGOPHYLLACEAE	Round the year	Round the year	Anemophilous	Pantoporate, Reticulate
GYMNOSPERMS					
38	CUPRESSACEAE				
	Cupressus sp.	2–5	2–6	Anemophilous	Spheroidal, Psilate
	Thuja sp.	12–3	12–3	Anemophilous	Spheroidal, Psilate
39	PINACEAE				
	Pinus sp.	2–4	2–5	Anemophilous	Monocolpate, Reticulate

IV. RESULTS

1. Taxonomic diversity of recorded pollen types

The compiled table includes angiosperm and gymnosperm taxa representing a broad range of botanical families. The recorded angiosperm groups include Amaranthaceae, Anacardiaceae, Apiaceae, Apocynaceae, Asteraceae, Brassicaceae, Euphorbiaceae, Fabaceae, Malvaceae, Myrtaceae, Poaceae, Solanaceae, and other families. Gymnosperm records include Cupressaceae and Pinaceae. The dominant pollen type, observed round the year was that of the family Asteraceae; contributed 36.02% in 2000 and 35.84% in 2001, followed by Poaceae, Euphorbiaceae, Malvaceae, Amaranthaceae, were also observed round the year. Minimum number of pollens observed from the family Caricaceae, Lamiaceae, Cuscutaceae etc.

The table contains taxa with both restricted seasonal flowering and extended flowering periods. Examples of taxa reported to occur throughout the year include *Amaranthus* sp., *Ageratum conyzoides*, *Parthenium hysterophorus*, *Croton* sp., *Ricinus* sp., *Cynodon dactylon*, and *Lantana camara*. Their pollen-capture records are also listed as year-round.

Other taxa exhibit more restricted seasonal records. For example, *Mangifera indica* is listed as flowering during February–March, with pollen capture during March–June. *Phoenix sylvestris* is reported to flower during February–March, with pollen capture during March–May. *Artemisia* sp. is listed for September–December flowering and November–December pollen capture.

These records demonstrate that the compiled dataset includes both prolonged and relatively short seasonal intervals. However, the duration and intensity of pollen occurrence should be quantified using the underlying monthly observations rather than inferred solely from the listed date ranges.

2. Representation of pollination modes

Anemophily is the most frequently reported pollination category in the table. Several taxa belonging to Poaceae, Amaranthaceae, Asteraceae, Euphorbiaceae, and other families are classified as anemophilous. This is consistent with the importance of wind-mediated pollen dispersal in many herbaceous plants and trees. Based on the mode of pollination, the anemophilous type contributed. In both years (2000 & 2001) maximum pollens identified were found to be anemophilous, followed by entomophilous then amphiphilous.

Anemophilous pollens found dominant in January 2000 to December 2001 constituted 86.99% and 84.91%, respectively. The entomophilous pollens constituted 6.55% and 7.53% part in the year 2000 and 2001 respectively and amphiphilous constitute 5.58% in 2000 and 6.79% in 2001.

Dominancy of anemophilous pollen in both entomophilous and amphiphilous forms, is the result of many factors such as anemophilous pollen being produced in large quantity by the plants and they have some specific characteristics by

which they can be easily carried away by wind current, such as wings found in *Pinus* pollens. Many of the anemophilous pollens are dry, light, fall apart and are lightly ornamented.

The presence of entomophilous Pollens in air is dependent upon several factors. One of the main possibility may be, they dropped out from the pollen basket of honey bees as they travel in the air and strong breeze can serve to keep entomophilous pollen buoyant in the air. In some *Eucalyptus* sp., which have an entomophilous mode of pollination, slightest breeze can shake lighter branches bearing flowers and release number of pollens in the air.

Entomophilous taxa are also represented, including *Coriandrum* sp., *Allium cepa*, *Abutilon* sp., *Sida* sp., *Eucalyptus* sp., *Psidium guajava*, *Bougainvillea* sp., *Solanum* sp., and *Petunia* sp. Their inclusion illustrates that airborne pollen records may contain pollen from plants that are not predominantly wind-pollinated.

The dataset also lists *Argemone mexicana*, *Papaver* sp., and Polygonaceae and Rosaceae records under amphiphilous pollination. These classifications should be checked against taxon-specific botanical references before the final manuscript is prepared.

A numerical comparison of pollination categories should be performed after resolving entries where a family is listed without a genus or species and confirming that all records represent distinct, identifiable pollen taxa.

3. Morphological diversity of pollen

The recorded pollen types display substantial variation in aperture morphology and exine ornamentation. The table includes monoporate, pantoporate, colpate, tricolpate, tricolporate, and other zonal aperture configurations.

Examples of porate pollen include *Cynodon dactylon*, *Saccharum* sp., and *Typha* sp., which are listed as monoporate. *Morus alba* is reported as 2-porate, while *Alnus* sp. is listed as 4(5)-zonoporate. *Amaranthus* sp. and *Achyranthes* sp. are described as pantoporate.

Colpate and colporate pollen types are also common in the table. *Brassica campestris* is recorded as tricolpate, while *Mangifera indica*, *Coriandrum* sp., and several other taxa are listed as tricolporate or zonocolporate. The recorded pollen types also exhibit variation in exine ornamentation, including reticulate, psilate, smooth, granulate, spinulate, spinose, and foveolate patterns.

Gymnosperm pollen records include *Cupressus* sp. and *Thuja* sp., both described as spheroidal and psilate, and *Pinus* sp., listed as monocolpate and reticulate. These descriptions should be rechecked against the original pollen slides or identification references, especially where diagnostic features are important for distinguishing taxa.

The morphological information provides a preliminary basis for comparing pollen types. Nevertheless, individual characters should not be assumed to be unique to a taxon, and taxonomic identification should use combinations of morphological features where possible.

The compiled dataset indicates three principal patterns:

The recorded pollen types include plants with both prolonged and seasonally restricted flowering and pollen-capture periods.

Anemophilous taxa are widely represented, but pollen from entomophilous and amphiphilous taxa is also included.

Pollen morphology varies in aperture configuration and exine ornamentation, providing useful descriptive characters for aeropalynological identification.

V. DISCUSSION

1. Flowering phenology and atmospheric pollen detection

The recorded flowering and pollen-capture periods indicate that the seasonal occurrence of airborne pollen should not be treated as identical to the flowering period of its source plant. Differences may arise from the timing of pollen release, atmospheric transport, weather conditions, and the temporal resolution of sampling. Pollen-season definitions also influence the estimated beginning, end, and duration of pollen occurrence (Jato et al., 2006; Berger et al., 2018).

2. Pollination mode and airborne pollen

The dataset includes taxa classified as anemophilous, entomophilous, and amphiphilous. These categories provide an ecological context for interpreting the recorded pollen types. However, the presence of pollen in an atmospheric sample does not by itself establish the pollination mechanism of the source plant. Airborne detection of pollen from entomophilous plants may occur through incidental release, disturbance, or transport from nearby vegetation.

Consequently, pollination mode should be interpreted as a characteristic of the plant's reproductive biology rather than as a direct measure of its contribution to atmospheric pollen. Quantitative pollen counts would be required to compare the atmospheric representation of the different categories.

3. Morphological diversity and identification

The variation in aperture configuration and exine ornamentation documented in the table illustrates the descriptive value of pollen morphology. Aperture number, arrangement, and surface features are established characters in pollen identification and classification (Erdtman, 1969; Moore et al., 1991). Nevertheless, identification accuracy depends on the quality of the pollen preparation, the available reference material, and the diagnostic value of the observed characters.

Where species-level identification cannot be confirmed, reporting a genus or pollen type is preferable to assigning an uncertain species name. This is consistent with the recognized limitations of microscopic pollen identification (Rittenour et al., 2012).

4. Value and limitations of historical observations

The 2000–2001 dataset preserves information on the pollen types recorded in Meerut during a defined period. Such observations can support future comparisons of pollen diversity and seasonality. However, historical and contemporary datasets should only be compared after considering differences in sampling instruments, collection schedules, identification procedures, and definitions of pollen seasons (Thibaudon et al., 2013; Galán et al., 2014; Berger et al., 2018).

The compiled table alone cannot establish long-term trends or attribute observed patterns to climate change or urbanization. Such conclusions would require comparable datasets from multiple years and an appropriate analysis of environmental and meteorological variables.

VI. CONCLUSION

The compiled aeropalynological dataset from Meerut for 2000–2001 documents a diverse range of airborne pollen types, with variation in flowering periods, pollen-capture intervals, reported pollination modes, and pollen morphology. Both year-round and seasonally restricted records are represented. Anemophilous taxa are prominent in the table, although entomophilous and amphiphilous taxa are also recorded. Differences between flowering and pollen-capture periods emphasize the need to distinguish plant phenology from atmospheric pollen detection.

The morphological descriptions provide a useful preliminary resource for pollen identification and comparison, subject to verification and standardization. The dataset offers a historical baseline for future aeropalynological investigations in the region. Integration with monthly pollen counts and corresponding meteorological observations would permit a more rigorous assessment of pollen seasonality, taxon-specific abundance, and environmental relationships.

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