

Prevalence of allergenic pollen grains in the aerosol of the city of Calcutta, India: a two year study

Jyotshna Mandal · Pampa Chakraborty ·
Indrani Roy · Soma Chatterjee ·
Swati Gupta-Bhattacharya

Received: 5 February 2008 / Accepted: 24 June 2008
© Springer Science+Business Media B.V. 2008

Abstract The role of pollen grains as a causative agent of respiratory allergic disorders such as asthma and allergic rhinitis is common and very well established. The aim of this study was to assess the frequencies of airborne pollen in the Calcutta metropolis and to identify the taxa which cause significant amounts of sensitization. An aeropalynological survey of the atmosphere of Calcutta was carried out from 2004 to 2006. Skin tests were performed with a panel of the most common pollen types on local patients with clinical features of pollinosis. The meteorological factors responsible for the frequency of the pollen types were analysed. The results of monthly visits to the clinic by these patients were correlated with the monthly pollen counts of three dominant and perennial pollen taxa. The dominant pollen types were *Trema* (19%), Poaceae (12.98%), *Casuarina* (5.76%), *Cocos* (5.7%), *Azadirachta* (4.65%), *Peltophorum* (3.71%), Cyperaceae (3.68%), *Delonix* (3.18%) and *Areca* (2.56%). Total pollen concentration seems to have a significant positive correlation with temperature and wind speed whereas there was a negative correlation with humidity. Skin tests were most frequently found to be positive with the pollen of Poaceae (49%), *Azadirachta* (46%), *Cocos* (47%), Cyperaceae

(35%), *Peltophorum* (33%), *Areca* (29%), *Phoenix* (26%), and *Borassus* (23%). A positive correlation occurred between visits to the clinic and monthly pollen count of *Areca*, *Cocos*, and Poaceae. This is the first study to design a pollen calendar for Calcutta city; it will provide useful data for enabling allergologists to achieve accurate diagnosis for patients with pollen hypersensitivity.

Keywords Aerobiology · Calcutta, India · Pollen calendar · Spearman's rank correlation coefficient · Skin-prick test · Tropical humid climate

1 Introduction

Atmospheric pollen grains are a major cause of the allergies historically known as “hay fever” (Garcia Mozo et al. 2006; Leuschner et al. 2000). In India, an increase in allergic disease from 10% to 30% has been reported in the last 40 years (Sharma et al. 2006). The increase in atmospheric contamination in recent decades and the resulting environmental and health issues have raised awareness of institutions and populations towards such problems. This has led to a marked increase in the number of atmospheric monitoring stations. The correlation of atmospheric concentrations of specific aeroallergens with clinical symptoms of pollinosis helps to establish threshold levels for particular pollen grains above which symptoms might predictably occur (Kosisky and

J. Mandal · P. Chakraborty · I. Roy · S. Chatterjee ·
S. Gupta-Bhattacharya (✉)
Bose Institute, Kolkata, India
e-mail: swatigb_29@rediffmail.com

Carpenter 1997). In each geographical region there is a succession of different flowering species throughout the year following a rhythm mainly established by climatic conditions. Specific meteorological conditions affect both the ontogeny of pollen grains and their dispersion (Rodríguez-Rajo et al. 2003).

An aeropalynological survey was initiated in Calcutta (Chanda and Sarkar 1972), in part-using gravitational samplers. In the mid eighties, a survey of airborne pollen grains was conducted by Banik and Chanda (1990). Calcutta is the largest and the fastest growing metropolis in the eastern part of India; as a result there has been an enormous change in vegetation and climatic conditions over the years (Mandal and Gupta-Bhattacharya 2006). The city has undergone rapid urbanization as a result of which the existing heterogeneous plant community has undergone large-scale destruction. New taxa have been introduced which could have allergenic potential. The profile of pollen types must be checked and screened (Mandal et al. 2008). The objectives of this study are:

1. to restart aerobiological studies to describe the seasonal periodicity of current anemophilous taxa in the city after a gap of almost two decades;
2. to check the allergenic potential of the recorded pollen types to cause respiratory allergy in the city population; and
3. to correlate the seasonal periodicity of airborne allergenic pollen with that of respiratory allergic complaints for those visiting the city allergy clinic.

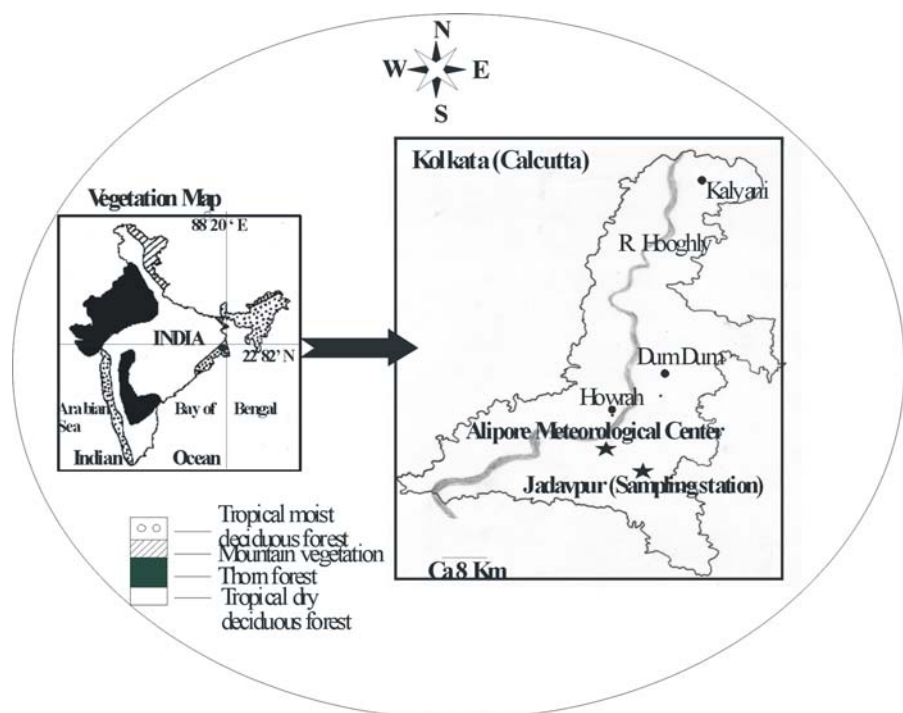
The effect of meteorological conditions on the airborne pollen concentration in Calcutta has remained unclear. This is the first study to assess the role of meteorological conditions on total airborne pollen load in Calcutta.

2 Materials and methods

2.1 Study area

Calcutta city, with a population of more than 13 million (e-CENSUS India 2001) is located in the plains of eastern India at 22°82' N, 88°20' E in the Gangetic delta and is the capital city of the state of West Bengal (Fig. 1). It is spread linearly along the banks of the River Ganges in a north–south direction. The city is at an elevation of 1.5–9 m above sea level.

Fig. 1 Vegetation map of India, geographical location of Calcutta city, and the sampling site



2.2 Vegetation

The flora around the site is typical of that of tropical moist vegetation and of the vegetation associated with the Indo-Gangetic plains. The urban flora is mainly composed of exotic trees and shrub species that are cultivated for ornamental purposes in streets, avenues, and parks over the entire city. Several avenue trees such as *Alstonia scholaris*, *Peltophorum pterocarpum*, *Delonix regia*, *Casuarina equisetifolia*, and *Lagerstroemia speciosa* dominate the city. Various palm trees such as *Areca*, *Cocos*, *Borassus*, and *Phoenix* are seen, and several fruit-yielding trees such as *Carica papaya*, *Mangifera indica*, *Mimusops elengi*, *Psidium guajava*, *Tamarindus indicus*, and *Zizyphus jujuba*. The dominant shrubs in this locality are *Caesalpinia pulcherrima*, *Cassia sophora*, *Cassia occidentalis*, *Hibiscus rosasinensis*, *Lantana camara*, *Rosa indica*, and *Ricinus communis*. Herbaceous vegetation occurs spontaneously in open areas or is

cultivated in parks and private gardens. The most important herbaceous pollen sources belong to the families Poaceae, Cyperaceae, Asteraceae, and Amaranthaceae-Chenopodiaceae.

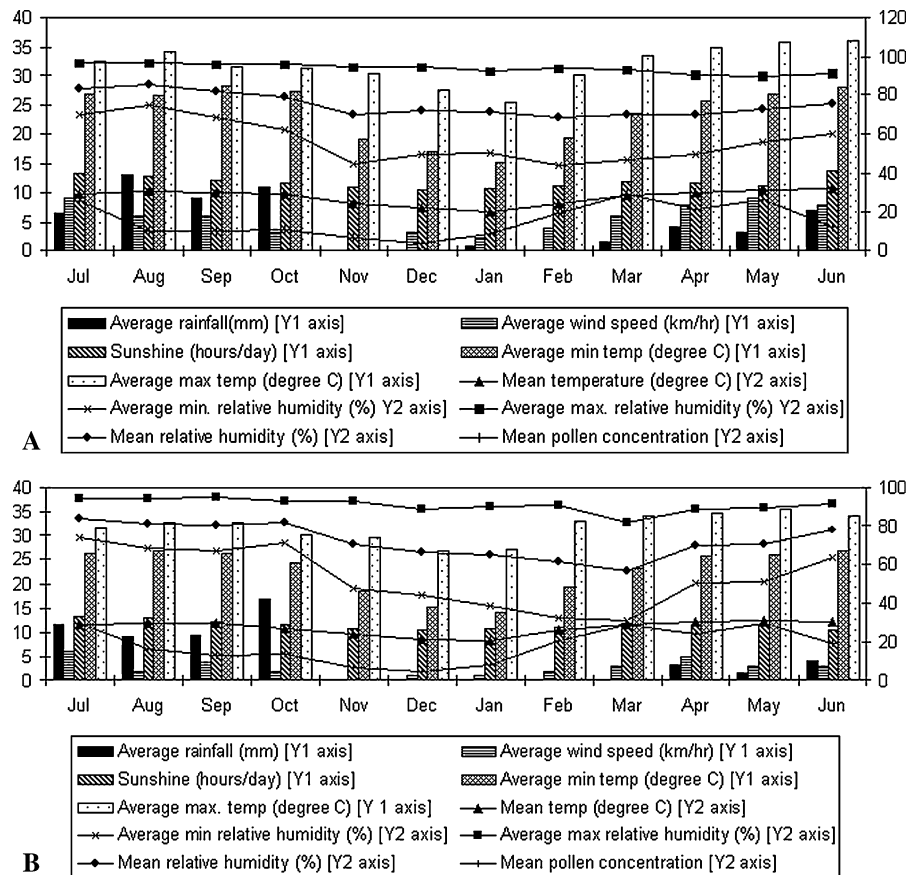
2.3 Climate

Calcutta has a sub-tropical monsoon climate, with five distinct seasons:

1. monsoon (July to September);
2. autumn (October);
3. winter (November to January);
4. spring (February to March); and
5. summer (April to June).

The Alipore Meteorological Station of Calcutta, situated about 4 km away from the sampling site, provided detailed meteorological data (Fig. 2a, b). Mean temperature and mean pollen are plotted on the Y2 axis of Fig. 2.

Fig. 2 Monthly meteorological conditions for Calcutta city during 2004–2005 (a) and 2005–2006 (b)



2.4 Aerobiological sampling

Twenty-four-hour counts (12 noon–12 noon) were carried out using a seven day volumetric Burkard Sampler (Burkard Manufacturing, Rickmansworth, Hertfordshire, UK). It was installed on the rooftop (approx. 40 feet above ground level) of the Solar Energy Building of The Indian Association for the Cultivation of Science, in Jadavpur, southern Calcutta. The building is located in an open area, free from obstacles, allowing free airflow. The research institute is surrounded by other academic institutions and residential areas. Melinex tapes (Burkard Manufacturing) coated with petroleum wax were fixed on the rotating drum of a seven-day Burkard automatic volumetric sampler for trapping airborne particles. The sampler draws 10 l air per minute. At the end of the sampling week the tape was cut into seven segments, 48 mm each (corresponding to one day). They were mounted and fixed with gelvatol to make permanent slides. Pollen grains trapped from the air were studied microscopically by light microscopy (Leitz, Diaplan, Germany) at 400X. Grains were counted from the exposed tapes according to the guidelines of The British Aerobiology Federation (1995). The resulting slides were counted along 24 traverses spaced at 2 mm (1 h) intervals in order to obtain the mean hourly concentration. The 24 hourly counts were then averaged to obtain the daily mean concentration that, in turn, gave the weekly and monthly mean concentrations. The daily pollen concentration was expressed as number of pollen grains per cubic meter of air. Airborne pollen grain was identified by comparing the pollen types with the reference palynological collection (of the Palynology section, Department of Botany, Bose Institute, Calcutta) prepared from the local flora and by consultation of specific bibliographies (Erdtman 1952; Erdtman 1969; Faegri and Iverson 1964).

2.5 Patient population and skin tests

Skin tests were performed with pollen allergen extract (1:50 w/v) on adult respiratory allergic patients attending the Allergy Unit of The Institute of Child Health, Calcutta, selected because they all had clinical manifestations of seasonal rhinoconjunctivitis and/or bronchial asthma. The pollen extracts of the test panel were selected because of their

prevalence in the area and because of their allergic significance. The exclusion criteria were perennial or severe asthma, pregnancy or lactation, malignancy or other severe systemic diseases during skin testing or sera collection. To avoid masking of possible symptoms, corticosteroids and antihistamines were prohibited. The study was approved by the Ethics Committee of the hospital. The allergen extracts were prepared by extracting the pollen at 95% purity with phosphate-buffered saline (Shivpuri 1962; Sheldon et al. 1967). Histamine diphosphate (1 mg/ml) and phosphate-buffered saline (1 mg/ml) were used as positive and negative controls respectively. The reaction measurement was performed after 20 min. Tests were performed with 20 µl allergen solution placed on the ventral side of the forearm with a 26 G. disposable hypodermic needle. According to International guidelines, positivity was defined as mean wheal diameter ≥ 3 mm compared with negative control (Dreborg and Frew 1993). The reaction was graded from +1 to +3 level (+1 = erythema, 20 mm in diameter, +2 = erythema >20 mm in diameter, +3 = wheal and erythema) according to Stytiš et al. (1982). The consent of each patient was obtained prior to skin testing.

2.6 Statistical analysis

The relationship between the meteorological conditions (temperature, relative humidity, average wind speed, average rainfall, and sunshine hours) and monthly total pollen concentration were calculated using Spearman nonparametric correlation coefficients. The total monthly visit to the allergy clinic by the respiratory allergic patients of Calcutta was also correlated with three perennial and dominant pollen types, chosen because they were present in the atmosphere year-round and also led to a high percentage of sensitization. SPSS version 10.0 was used for statistical analysis. $P < 0.05$ and $P < 0.01$ were considered to be significant.

3 Results and discussion

Aerobiological monitoring of the atmosphere of Calcutta city was initiated in July 2004 and was continued non-stop until June 2006. During the study a total of 35 pollen types were identified at the

family, genus, or species level (Table 1). The most abundant pollen types originated from *Trema orientalis* followed by Poaceae and then *Casuarina equisetifolia*. Other dominant pollen types were

Cocos nucifera, *Azadirachta indica*, *Carica papaya*, Cyperaceae, Brassicaceae, Chenopodiaceae-Amaranthaceae, *Peltophorum pterocarpum*, and *Areca catechu*. Apart from all these, there were some whose

Table 1 Annual mean concentration and relative percentage contribution of each of the pollen types to the total air spora of Calcutta city from July 2004–June 2006

Pollen type	Yearly mean count			% Contribution to total air spora		
	2004–2005	2005–2006	Average	2004–2005	2005–2006	Average
1. <i>Ageratum conizyoides</i>	2.11	0.93	1.52	1.12	0.43	0.76
2. <i>Alstonia scholaris</i>	0.54	0.64	0.59	0.31	0.27	0.29
3. <i>Areca catechu</i>	4.5	6.11	5.31	2.37	2.76	2.56
4. Asteraceae	4.16	5.04	4.6	2.18	2.27	2.23
5. Apiaceae	1.14	1.06	1.1	5.93	4.75	5.34
6. <i>Azadirachta indica</i>	10.1	9.09	9.6	5.24	4.05	4.65
7. <i>Barringtonia</i> sp.	0.58	0.84	0.71	0.31	0.38	0.35
8. <i>Borassus flabellifer</i>	2	2.6	2.3	1.06	1.19	1.13
9. <i>Bougainvillea spectabilis</i>	1.22	1.11	1.7	0.62	0.48	0.55
10. Brassicaceae	4.52	1.33	2.9	2.37	0.6	1.485
11. <i>Cassia</i> sp.	3.01	4.53	3.77	1.56	2.05	1.805
12. <i>Carica papaya</i>	3.62	3.57	3.6	1.87	1.56	1.72
13. <i>Casuarina equisetifolia</i>	12.28	11.35	11.81	6.43	5.1	5.76
14. Cheno-Amaranthaceae	3.31	4.49	3.1	1.75	2	1.87
15. <i>Cocos nucifera</i>	11.08	12.89	11.98	5.74	5.78	5.76
16. Cucurbitaceae	1.93	1.55	1.74	0.99	0.7	0.85
17. Cyperaceae	5.61	9.86	7.73	2.93	4.43	3.68
18. <i>Delonix regia</i>	5.22	8.05	6.63	2.74	3.62	3.18
19. <i>Eucalyptus citriodora</i>	0.47	0.62	0.54	0.25	0.27	0.26
20. Euphorbiaceae	3.36	3.78	3.57	1.75	1.73	1.74
21. Fabaceae-Monad	4.28	4.96	4.62	2.25	2.22	2.24
22. Fabaceae-Polyad	1.98	1.96	1.97	1.06	0.86	0.96
23. <i>Lagerstroemia speciosa</i>	0.69	2.16	1.42	0.37	0.97	0.67
24. <i>Lantana camara</i>	4.35	5.58	4.96	2.25	2.48	2.36
25. <i>Litsaeae</i> sp.	0.96	1	0.98	0.5	0.43	0.47
26. <i>Moringa oleifera</i>	1.46	1.46	1.46	0.75	0.64	0.7
27. <i>Mimusops elengi</i>	2.51	4.1	7.71	1.31	1.83	1.57
28. <i>Mangifera indica</i>	3.11	2.22	2.5	1.62	1.02	1.32
29. Myrtaceae	1.26	1.65	1.46	0.69	0.76	0.73
30. <i>Peltophorum pterocarpum</i>	7.22	8.21	7.71	3.74	3.67	3.71
31. <i>Phoenix sylvestris</i>	1.77	3.16	2.5	0.94	1.41	1.18
32. Poaceae	24.48	29.4	26.94	12.73	13.24	12.98
33. <i>Psidium guajava</i>	3.3	6.38	4.84	1.75	2.86	2.31
34. <i>Terminalia</i> sp.	4.25	3.19	3.72	2.18	1.41	1.8
35. <i>Trema orientalis</i>	35.24	43.76	39.5	18.34	19.68	19.01
36. Unidentified types	3.89	4.58	4.23	1.99	2.05	2.02
Total	181.51	213.21	197.36			

identity could not be established even at the family level, because of their ill-defined structure. They were classified as “Unidentified”. A previous aerobiological survey, conducted by Chanda and his group (Chanda and Sarkar 1972), also reported a high concentration of Poaceae pollen grains in the atmosphere of Calcutta and its suburbs, probably because of their wide distribution and strictly anemophilous nature. This high representation in the pollen spectrum can be explained partially due to local factors because it is dominant in the local vegetation and the consecutive flowering patterns of different grass species is responsible for the long pollination period. Similarly, Poaceae pollen grains have been reported to be the most dominant types in aeropalynological surveys by other authors (Recio et al. 2006; Celenk and Bicakei 2005; Weryszko-Chmielewska and Piotrowska 2004; Riberio et al. 2003). The yearly pollen concentration pattern of each taxon shows marked seasonality, although *Trema orientalis*, Poaceae, *Casuarina equisetifolia*, *Cocos nucifera*, Chenopodiaceae-Amaranthaceae, *Areca catechu*, and Asteraceae occur year-round. *Trema orientalis* and Poaceae pollen grains are the major contributors to the annual pollen load, similar to previous results from aerobiological sampling of a farm in West Bengal by Chakraborty et al. (1998).

The general trend shows an increase in pollen counts from winter to spring reaching a maximum in summer. Of the total pollen load, 14.43% and 14.27%, respectively, were recorded in May and July, 2004. In the following year May again had the highest amount of pollen grains (13.9%) followed by July (13.81%). During the rainy season, pollen concentration starts to decrease because of the scarcity of flowering species. Few pollen grains were observed in the winter months from November to January. The lowest concentration was observed in December 2004 (2% in 2004 and 1.8% in 2005; Fig. 3).

Trees are considered to be the main pollen producers because of their common incidence and the rate of pollen production per anther, inflorescence, or individual tree (Molina et al. 1996). Tree pollen grains were dominant in this study also, and comprised pollen from *Trema orientalis*, *Casuarina equisetifolia*, *Cocos nucifera*, *Azadirachta indica*, *Carica papaya*, *Areca catechu*, *Peltophorum pterocarpum*, and *Delonix regia* among others. The diversity and abundance of plant families and genera

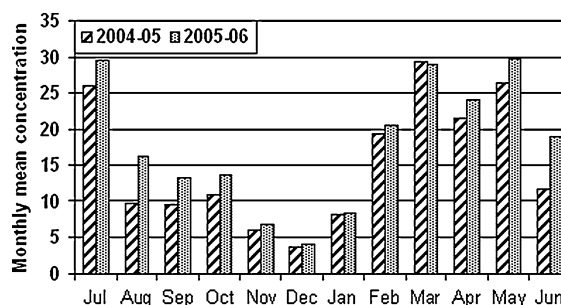


Fig. 3 Monthly mean total pollen concentrations for the years 2004–2006 in Calcutta city

represented in the air samples correspond to the rich flora in the study area. There is a noticeable change in the pollen composition compared with the previous pollen survey (Banik and Chanda 1992). In this study the presence of pollen grains of *Alstonia scholaris*, *Lagerstroemia speciosa*, and *Peltophorum pterocarpum* has been recorded for the first time in Calcutta. The change is probably because of their extensive introduction in recent years as ornamental trees. Similar reports have also been reported regarding ornamentals by many authors (Stefanic et al. 2007; Leticia and Angeles 2005; Tripathi et al. 2004; Riberio et al. 2003). Therefore it is necessary to monitor from time to time to acquire a better understanding about the dynamic processes of the atmospheric pollen load in a particular area.

The following are the ten taxa that produced the greatest amount of pollen. Of the 35 pollen types, these exceeded 2% of the total relative concentration (Fig. 4):

1. *Trema orientalis* (Family—Ulmaceae): Pollen grains of this taxon constituted 18.34% (in 2004–2005) and 19.68% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. They were recorded all year round. The peak concentration was noted in July and lowest in the month of December (Fig. 4a).
2. Poaceae: Pollen grains of this family constituted 12.73% (in 2004–2005) and 13.24% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. They were recorded throughout the year. The highest value was noted in May in the first year of the survey and in July in the next year. The lowest concentration was seen during the winter in December (Fig. 4b).
3. *Casuarina equisetifolia* (Family—Casurina-ceae): Pollen grains of this taxon constituted

Fig. 4 Seasonal variation of dominant pollen grains recorded in the atmosphere of Calcutta during the sampling period (2004–2006)

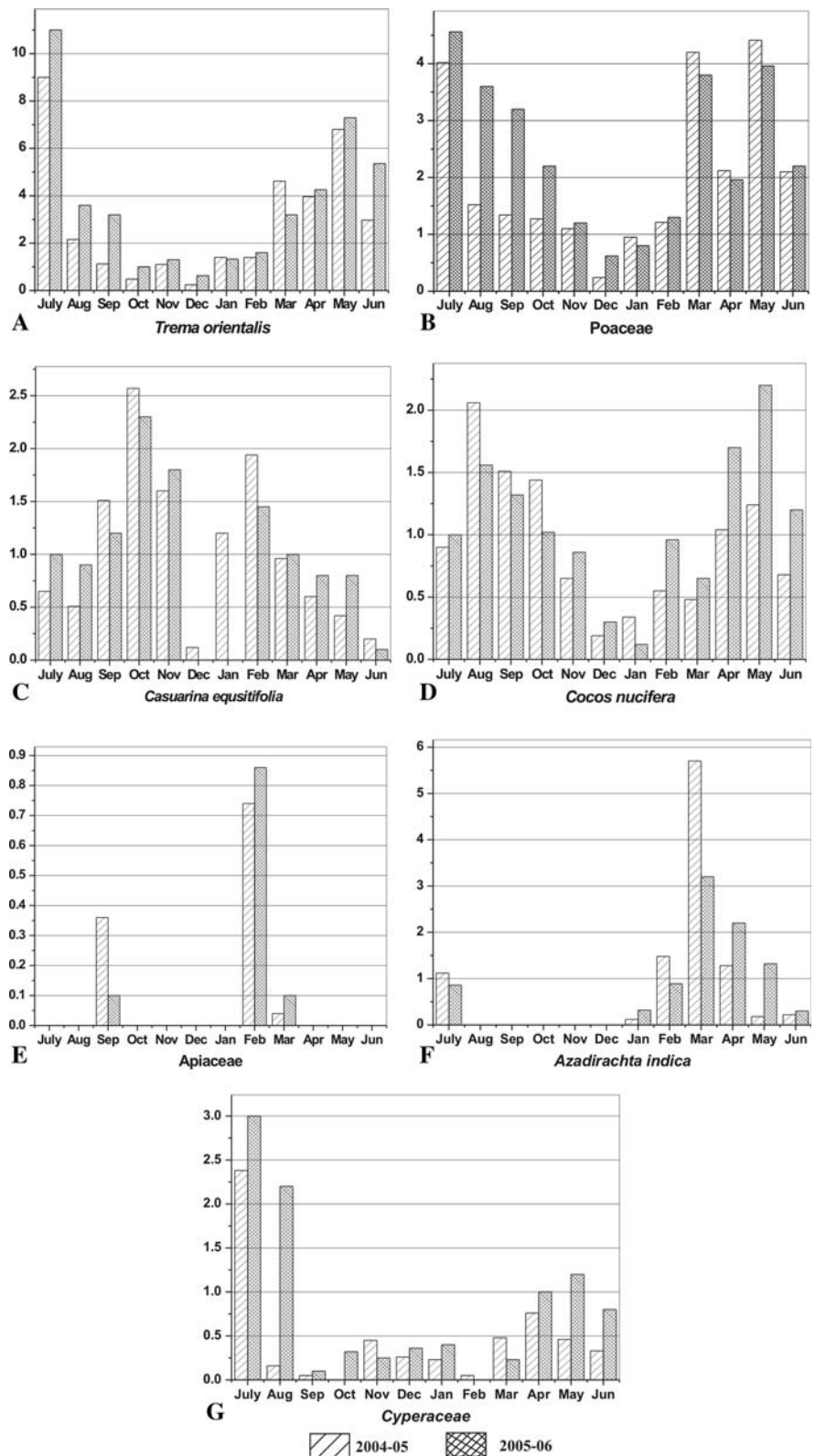
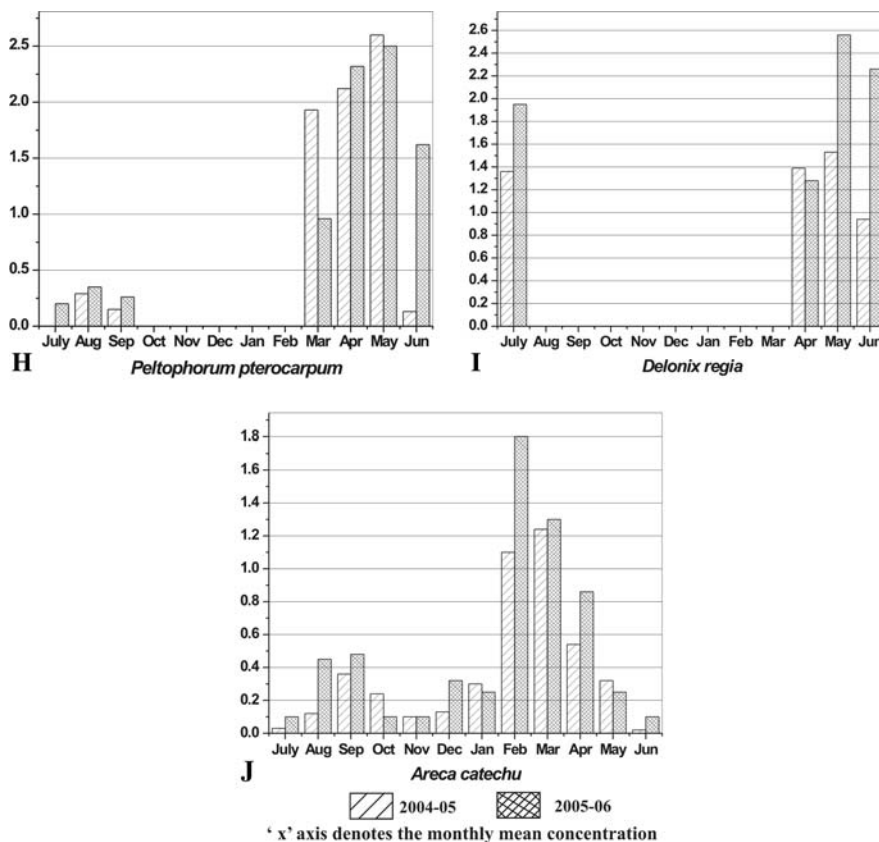


Fig. 4 continued



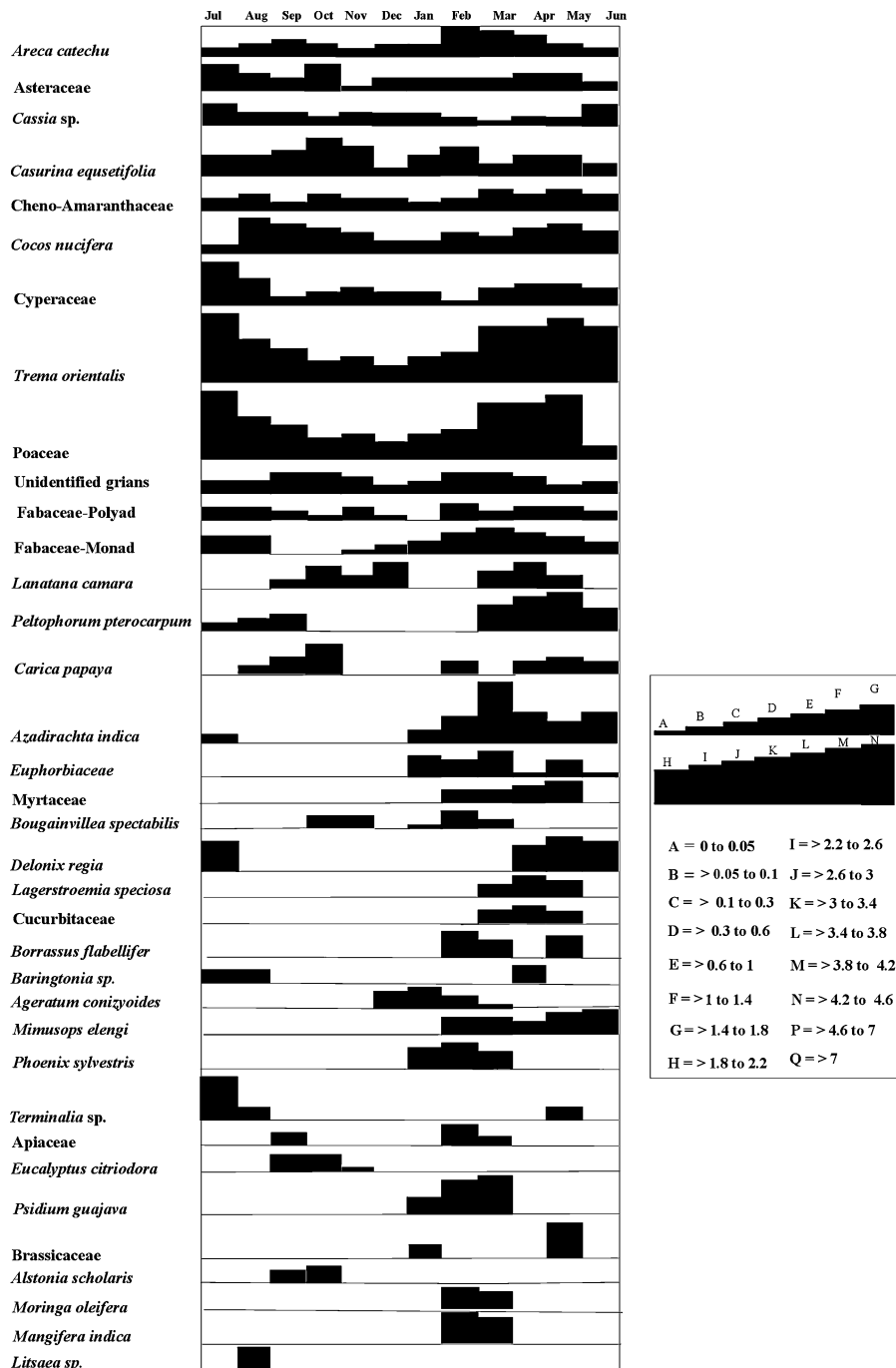
6.43% (in 2004–2005) and 5.1% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. They were recorded throughout the year. The highest value was recorded in October. Lowest concentrations were observed in winter (Fig. 4c).

4. *Cocos nucifera* (Family—Arecaceae): Pollen grains of this taxon constituted 5.74% (in 2004–2005) and 5.78% (in 2005–2006) of the total pollen load of Calcutta. They were recorded throughout the year. The highest value was noted in August in the first year and May in the next year. Lowest concentrations were observed during the winter (Fig. 4d).
5. *Apiaceae*: Pollen grains of this family constituted 5.93% (in 2004–2005) and 4.75% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. The highest value was noted in February (Fig. 4e).
6. *Azadirachta indica* (Family—Meliaceae): Pollen grains of this taxon constituted 5.24% (in 2004–2005) and 4.05% (in 2005–2006) of

the total pollen load in the atmosphere of Calcutta. Pollen season started in January and ended in July. The highest value was noted in March (Fig. 4f).

7. *Cyperaceae*: Pollen grains of this family constituted 2.93% (in 2004–2005) and 4.43% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. They were recorded throughout the year. The highest value was noted in July (Fig. 4g).
8. *Peltophorum pterocarpum* (Family—Fabaceae): Pollen grains of this taxon constituted 3.74% (in 2004–2005) and 3.67% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. It has two flowering seasons, one from March to June and the other August to September. The highest value was noted in May. This pollen grain was not recorded in the earlier survey in Central Calcutta (Banik and Chanda 1992). It has, however, been recorded from the suburbs in North Calcutta (Chakraborty et al. 1998) (Fig. 4h).

Fig. 5 Pollen calendar for Calcutta city, using data obtained from July 2004 to June 2006



9. *Delonix regia* (Family—Fabaceae): Pollen grains of this taxon constituted 2.74% (in 2004–2005) and 3.62% (in 2005–2006) of the total pollen load in the atmosphere of Calcutta. It had a short flowering season from April to July.

The peak concentration was recorded in May (Fig. 4i).

10. *Areca catechu* (Family—Arecaceae): Pollen grains of this taxon constituted 2.37% (in 2004–2005) and 2.76% (in 2005–2006) of the

total pollen load in the atmosphere of Calcutta. They were recorded throughout the year. The highest value was noted in February in the first year and March in the next year (Fig. 4j).

Because of social and medical implications, our objective was also to provide an updated pollen calendar for the city (Fig. 5), based on two years of continuous sampling, to document the trends and fluctuations of atmospheric pollen grains. The calendar shows each taxon's average monthly value during the study period calculated from the weekly average. It provides a guide to the timing and duration of seasons of all the encountered pollen types in the atmosphere of Calcutta.

3.1 Clinical study and skin-prick test (SPT)

Of the 2,909 patients who visited the Allergy Unit of The Institute of Child Health, 2568 (88.3%) had a history of allergy to one or more pollen types (Table 2). Most of these patients had symptoms of cough (84.3%), breathlessness (81.3%), wheezing (78.2%), sneezing (76.7%), nasal blockage (73.3%), and skin rash (21.7%). A large number of the patients (76.1%) were suffering from asthma and rhinitis, and 23% and 11.1%, respectively, were suffering from asthma and rhinitis alone. Rhinitis and asthma were diagnosed on the basis of combined study of case history, symptom score, skin reaction, and pulmonary function test in the clinic.

Twenty-one pollen types induced a positive response in the SPT. The tests were performed over a varying number of patients, primarily because of the availability of patients with a relevant case history. In skin testing, Amaranthaceae and

Chenopodiaceae, i.e., Chenopodiaceae type, was represented by *Amaranthus viridis* and *Chenopodium album*. Similarly, Asteraceae was represented by *Parthenium hysterophorus*, Cyperaceae by *Cyperus rotundus*, and Poaceae by *Saccharum officinarum*. All of these induced a 1+ reaction in allergic patients. Table 3 summarizes the positive results in the skin tests performed.

Highly allergenic pollen types showing 2+ to 3+ positive reaction were *Saccharum officinarum* (Poaceae), *Cyperaceae*, *Azadirachta indica*, *Cocos nucifera*, *Phoenix sylvestris*, *Borassus flabellifer*, *Carica papaya*, and *Peltophorum pterocarpum*. Earlier studies by Banik and Chanda (1992) differed in respect to percentage of positive response to antigenic extracts of *Areca catechu*, *Cocos nucifera*, *Borassus flabellifer*, *Carica papaya*, *Azadirachta indica*, *Moringa oleifera*, *Peltophorum pterocarpum*, and *Phoenix sylvestris* pollen, which were reported to cause a much lower allergenic response. Common pollen types such as *Lantana camara* induced less allergenicity in the asthmatic population in Calcutta, but others, for example *Delonix regia*, even though it is seasonal in its presence, causes significant allergenicity. The present result is consistent with the results of Chakraborty et al. (1998), that the allergenicity of pollen is not related to its abundance in air. Allergic response caused by Poaceae grains was commensurate with its high airborne concentration.

The symptoms of pollen allergy confirm a good correlation with the airborne pollen count (Boral et al. 2004). However the most important factors conducive to pollen allergy are genetic and environmental (air pollution, exposure to allergens, infection of respiratory tract, diet, and microflora of pollen grains) (Puc 2003). The analysis of airborne pollen

Table 2 Distribution of patients as per symptom and history of pollen allergy

Disease	Total patients (<i>n</i> = 2,909) (Male/female = 1,462/1,447)		Patients with history of pollen allergy (<i>n</i> = 2,568) (Male/female = 1,298/1,270)	
	<i>n</i>	%	<i>n</i>	%
Bronchial asthma	761	26.16	589	22.9
Allergic rhinitis	310	10.65	286	11.13
Asthma with rhinitis	2,178	74.8	1,954	76.09
Asthma with skin allergies	96	3.3	81	3.15

Table 3 Results of skin-prick tests with antigenic extracts of dominant pollen types

Pollen allergen extract (family)	Current investigation (2004–2006)			Previous investigation (1985–1987) (Banik and Chanda)		
	Total no. of patients	% Response (total)	% Response (+2/more)	Total no. of patients	% Response (total)	% Response (+2/more)
<i>Saccharum officinarum</i> (Poaceae)	832	49.27	14.4	156	67	0.64
<i>Cocos nucifera</i> (Arecaceae)	2,079	47.6	10.1	1,626	31	4.7
<i>Azadirachta indica</i> (Meliaceae)	2,212	45.93	14.1	1,502	49	3.26
<i>Cyperus rotundus</i> (Cyperaceae)	1,178	34.97	8.4	–	–	–
<i>Peltophorum pterocarpum</i> (Fabaceae)	2,100	33.38	5	202	19	0.50
<i>Delonix regia</i> (Fabaceae)	2,234	31.1	5.8	675	15	0.74
<i>Areca catechu</i> (Arecaceae)	1,532	28.98	6.5	638	13	4.6
<i>Phoenix sylvestris</i> (Arecaceae)	897	25.8	11.14	22	13	–
<i>Borassus flabellifer</i> (Arecaceae)	760	23.15	7.8	94	15	–
<i>Carica papaya</i> (Caricaceae)	1,100	22.72	4.09	503	18	–
<i>Parthenium hysterophorus</i> (Asteraceae)	753	22.3	7.4	148	33.78	2.7
<i>Eucalyptus citriodora</i> (Myrtaceae)	600	21.6	1	289	31	5.61
<i>Lantana camara</i> (Verbenaceae)	467	19.7	1.08	–	–	–
<i>Moringa oleifera</i> (Moringaceae)	532	16.9	0.56	86	12	–
<i>Chenopodium album</i> (Chenopodiaceae)	661	16.3	3.4	–	–	–
<i>Alstonia scholaris</i> (Apocynaceae)	412	15.7	2.4	18	22.20	–
<i>Amaranthus viridis</i> (Amaranthaceae)	337	15.1	1.5	–	–	–
<i>Lagerstroemia speciosa</i> (Lythraceae)	160	15.6	0.63	10	20	–
<i>Mangifera indica</i> (Anacardiaceae)	110	15.4	–	–	–	–
<i>Mimusops elengi</i> (Sapotaceae)	286	14.7	–	152	15.79	–
<i>Trema orientalis</i> (Ulmaceae)	625	13.76	–	43	13.95	–

concentration, skin-prick test, allergy symptoms, and serum immunoglobulins in allergic people in Cracow, Poland suggested a high correlation between these factors (Obtulowicz et al. 1991). Our study confirms that the pollen grains of the grasses, Cyperaceae, *Azadirachta indica*, *Cocos nucifera*, *Peltophorum pterocarpum*, and *Areca catechu* are the common aeroallergens of Calcutta city causing significant allergic symptoms in susceptible individuals. A positive seasonal correlation was observed between the *Areca catechu*, *Cocos nucifera*, and Poaceae pollen load in the atmosphere and the number of patients visiting the allergy clinic, however was only significant for *Areca catechu* (Table 4, Fig. 6a–c). In Australia, Erbas et al. (2007) reported that grass pollen levels affect asthma hospital admissions whereas more than 50% of asthmatic symptoms are attributed to allergic reactions.

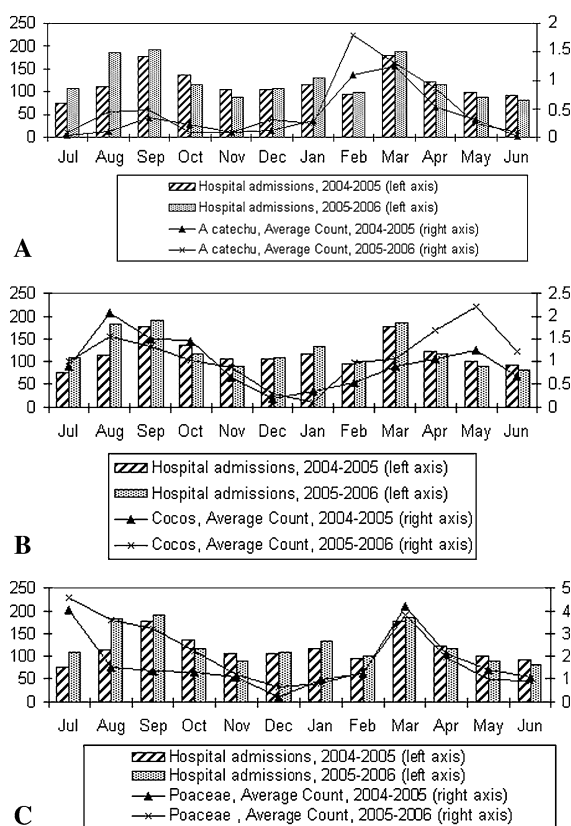
3.2 Statistical analysis

Apart from the individual rhythm of plant pollination, meteorological conditions are considered the most important factors determining the dispersion and content of pollen in the air (Puc and Wolski 2002; Bianchi and Olabuenaga 2006).

The results of the Spearman's correlation analysis between the meteorological conditions, on the one hand, and the average monthly pollen concentrations on the other hand, for the whole study period, reveal significant correlations (Table 5). When investigations are considered separately for each year, the variation of the total pollen load showed a statistically significant positive correlation with temperature (maximum and mean) in both years and with average wind speed (only in 2005–2006). There was a negative correlation with relative humidity (maximum) in both the years.

Table 4 Spearman's rank correlation coefficient (r) between monthly visit to the clinic by respiratory allergic patients and monthly pollen counts of three dominant allergenic pollen grains

Year	Visit to clinic with respiratory allergy complaints
July 2004–June 2005	0.573 ^a
	0.343 ^b
	0.238 ^c
July 2005–June 2006	0.502 ^a
	0.088 ^b
	0.515 ^c
July 2004–June 2006	0.602 ^a
	0.326 ^b
	0.238 ^c

* Significance level— $P < 0.05$ ^a *A. catechu* pollen^b *C. nucifera* pollen^c Poaceae pollen**Fig. 6** Graphical representation of correlation between monthly visit to the clinic by respiratory allergic patients and monthly pollen counts of three dominant allergenic pollen grains

The results of correlation analysis for the whole period (2004–2006) between meteorological conditions and total pollen load showed statistically significant positive correlation with mean maximum temperature ($P < 0.01$) and average wind speed ($P < 0.01$). A negative correlation existed between the total pollen load and mean relative humidity. Spearman's coefficient explains that temperature and wind speed are the meteorological conditions that best explain atmospheric pollen concentration variations, showing the fundamental importance of their effects on the dispersion and transport of pollen grains (Stefanic et al. 2005). Several other surveys in different countries (Rutherford et al. 1997; Riberio et al. 2003; Stennett and Beggs 2004) of total pollen studies have, like ours, shown significant positive correlations between total pollen load and temperature. Therefore, the aerobiological survey in relation to meteorological conditions has consistently shown that these factors have a substantial effect on the variation of pollen grains in the atmosphere.

4 Conclusions

It can be concluded that atmospheric pollen concentrations in the city of Calcutta showed seasonal variability throughout the year with a well-defined summer maximum. Pollen grains of *Trema orientalis* and Poaceae were the highest contributors to the airborne pollen load of Calcutta. Meteorological conditions such as temperature and wind speed have, in general, a significant positive effect on pollen concentration, whereas relative humidity has a negative correlation. This study, based on data from two consecutive years, is open to confirmation and refinement with more data, which will be obtained from more years of sampling. It would be necessary to extend these studies to other strategically placed areas in the city to achieve a regional pollen calendar for the city. This could help in the establishment of flowering forecasts and aid clinicians in the diagnosis and therapy of respiratory allergic patients in the population. Thus long-term sampling and more extended network at local and regional scales could possibly lead to the development of predictive models of airborne pollen concentrations in Calcutta city. Nevertheless, there is a potential for these results to be used by public health authorities in prediction of

Table 5 Spearman's rank correlation coefficient (r) between the total pollen count and meteorological conditions

Year	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Mean temperature (°C)	Average rainfall (mm)	Mean maximum relative humidity (%)	Mean minimum relative humidity (%)	Mean relative humidity (%)	Average wind speed (km/h)	Sunshine hours (h/day)
July 2004–June 2005	0.629*	0.343	0.448	0.221	−0.343	0.35	−0.035	0.751**	0.476
July 2005–June 2006	0.818**	0.497	0.664*	0.153	−0.161	0.133	0.084	0.732**	0.462
July 2004–June 2006	0.748**	0.357	0.587*	0.238	−0.364	0.035	−0.035	0.755**	0.497

* Significance level— $P < 0.05$ ** Significance level— $P < 0.01$

pollen levels. The pollen calendar will also help respiratory allergic patients and clinicians by identifying the potential allergy risk seasons.

Acknowledgments Sincere thanks to the University Grants Commission, New Delhi, India for providing financial assistance to the first and second authors. The authors are grateful to Professor Sunirmal Chanda for his valuable suggestions and Professor A.K. Barua of Indian Association for Cultivation of Science, Calcutta, for providing facilities to install the aerobiological sampler. The authors also thank the Alipore Meteorological Station of Calcutta for providing the meteorological data. Thanks are also due to Mr C. Chakraborty and Mr A. Bera of the Botany Department of Bose Institute for their technical assistance.

References

- Banik, S., & Chanda, S. (1990). A comparative airborne pollen survey of urban (Central Calcutta) and Suburban (Madhyamgram) areas of Greater Calcutta. *Transactions of the Bose Research Institute*, 53, 71–86.
- Banik, S., & Chanda, S. (1992). Airborne pollen survey of central Calcutta, India, in relation to allergy. *Grana*, 31, 72–75.
- Bianchi, M. M., & Olabuenaga, S. E. (2006). A 3-year airborne pollen and fungal spore record in San Carlos de Bariloche, Patagonia, Argentina. *Aerobiologia*, 22, 247–257.
- Boral, D., Chatterjee, S., & Bhattacharya, K. (2004). The occurrence and allergising potential of airborne pollen in West Bengal, India. *Annals of Agricultural and Environmental Medicine*, 11, 45–72.
- Celenk, S., & Bicaekci, A. (2005). Aerobiological investigation in Bitlis, Turkey. *Annals of Agricultural and Environmental Medicine*, 12, 87–93.
- Chakraborty, P., Gupta Bhattacharya, S., Chakraborty, C., Lacey, J., & Chanda, S. (1998). Airborne allergenic pollen grains on a farm in West Bengal, India. *Grana*, 37, 53–57.
- Chanda, S., & Sarkar, P. K. (1972). Pollen grains as a causative agent for respiratory allergy with reference to aeropalynology of greater Calcutta. *Transactions of Bose Research Institute*, 35, 61–67.
- Dreborg, S., & Frew, A. J. (1993). Allergen standardization and skin tests. *Allergy*, 48(14), 49–82.
- e-CENSUS India. (2001). September, from <http://www.censusindia.gov.in/>.
- Erbas, B., Chang, J. H., Dharmage, S., Ong, E. K., Hyndman, R., Newbigin, E., et al. (2007). Do levels of airborne grass pollen influence asthma hospital admissions? *Clinical and Experimental Allergy*, 37(11), 1641–1647.
- Erdtman, G. (1952). *Pollen morphology and plant taxonomy*. Stockholm: Almqvist and Wiksells.
- Erdtman, G. (1969). *Handbook of palynology*. Copenhagen: Munksgaard.
- Faegri, K., & Iverson, J. (1964). *Textbook of pollen analysis*. Copenhagen: Munksgaard.
- Garcia Mozo, H., Perez-Badia, R., Fernandez-Gonzalez, F., & Galan, C. (2006). Airborne pollen sampling in Toledo, Central Spain. *Aerobiologia*, 22, 55–66.
- Kosisky, S. E., & Carpenter, G. B. (1997). Predominant tree aeroallergens of Washington, DC area: A six year survey (1989–1994). *Annals of Allergy Asthma & Immunology*, 78, 381–392.
- Leticia, T., & Angeles, B. (2005). First volumetric airborne pollen sampling in Montevideo City, Uruguay. *Aerobiologia*, 21, 33–41.
- Leuschner, R. H., Christen, H., Jordan, P., & Vonthein, R. (2000). 30 years of studies of grass pollen in Basel, Switzerland. *Aerobiologia*, 16, 381–391.
- Mandal, J., & Gupta-Bhattacharya, S. (2006). *Peltophorum pterocarpum* (Yellow Gulmohar tree) pollen: A new aeroallergen from Calcutta, India. *8th International Congress on Aerobiology*, Neuchâtel, Switzerland, 2006.
- Mandal, J., Roy, I., Chatterjee, S., & Gupta-Bhattacharya, S. (2008). Aerobiological and in vitro studies on pollen grains of two dominant avenue trees from Kolkata (Calcutta), India. *Journal of Investigational Allergology & Clinical Immunology*, 18(1), 22–30.
- Molina, R. T., Rodriguez, A. M., Palacios, L. S., & Lopez, F. G. (1996). Pollen production in anemophilous trees. *Grana*, 35, 38–46.
- Obtulowicz, K., Szczepanek, K., Radwan, J., Grzywacz, M., Adamus, K., & Szczeklik, A. (1991). Correlation between airborne pollen incidence, skin-prick tests and serum immunoglobulins in allergic people in Cracow, Poland. *Grana*, 30, 136–141.

- Puc, M. (2003). Characterization of pollen allergens. *Annals of Agricultural and Environmental Medicine*, 10, 143–149.
- Puc, M., & Wolski, T. (2002). *Betula* and *Populus* pollen counts and meteorological conditions in Szczecin, Poland. *Annals of Agricultural and Environmental Medicine*, 9, 65–69.
- Recio, M., Trigo, M. M., Toro, F. J., Docampo, S., Gracia Gonzalez, J. J., & Cabezudo, B. (2006). A three-year aeropalynological study in Estepona (Southern Spain). *Annals of Agricultural and Environmental Medicine*, 13, 201–207.
- Riberio, H., Cunha, M., & Abreu, I. (2003). Airborne pollen concentration in the region of Braga, Portugal, and its relationship with meteorological parameters. *Aerobiologia*, 19, 21–27.
- Rodriguez-Rajo, F. J., Jato, V., & Aira, M. J. (2003). Pollen content in the atmosphere of Lugo (NW Spain) with reference to meteorological factors (1999–2001). *Aerobiologia*, 19, 213–225.
- Rutherford, S., Owen, J. A. K., & Simpson, R. W. (1997). Survey of airspora in Brisbane, Queensland, Australia. *Grana*, 36, 114–121.
- Sharma, S., Kathuria, P. C., Gupta, K. C., Nordling, C., Ghosh, B., & Singh, A. B. (2006). Total serum immunoglobulin E levels in a case-control study in asthmatic/allergic patients, their family members and healthy subjects from India. *Clinical and Experimental Allergy*, 36, 1019–1027.
- Sheldon, J. M., Lovell, R. G., & Mathews, K. D. (1967). *A manual of clinical allergy*. Philadelphia: W.B. Saunders Co.
- Shivpuri, D. N. (1962). Comparative evaluation of sensitivity of common methods of diagnostic antigen tests in patients of respiratory allergy. *Indian Journal of Chest Disease*, 4, 102–108.
- Stefanic, E., Kovacevic, V., & Lazanin, Z. (2005). Airborne ragweed pollen concentration in north eastern Croatia and its relationship with meteorological parameters. *Annals of Agricultural and Environmental Medicine*, 12, 75–79.
- Stefanic, E., Rasic, S., Merdic, S., & Colakovic, K. (2007). Annual variation of airborne pollen in the city of Vinkovci, northeastern Croatia. *Annals of Agricultural and Environmental Medicine*, 14, 97–101.
- Stennett, P. J., & Beggs, P. J. (2004). Pollen in the atmosphere of Sydney, Australia and relationships with meteorological parameters. *Grana*, 43, 209–216.
- Stytis, D. P., Stobo, J. D., Fudenberg, H., & Wells, J. V. (1982). *Basic and clinical immunology* (4th ed.). Singapore: Lange Medical Publishers, Maruzen Asia Pvt Ltd.
- The British Aerobiology Federation. (1995). *A guide to trapping and counting*. Larkfield, Aylesford, Kent, UK: Kimberley Clark Ltd.
- Tripathi, D. M., Kale, M., & Rajan, K. E. (2004). Atmospheric pollen and fungal spores at Pune city. *Indian Journal of Allergy, Asthma, and Immunology*, 18(1), 45–50.
- Weryszko-Chmielewska, E., & Piotrowska, K. (2004). Airborne pollen calendar of Lublin, Poland. *Annals of Agricultural and Environmental Medicine*, 11, 91–97.