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Original Article

Aerobiological study of pollen and mold in Seoul, Korea

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Abstract

In a large number of allergic individuals, inhalant allergens are important causative and triggering agents in respiratory allergies. It is essential to survey the pollen and mold around the patient's environment for the diagnosis and treatment of airborne allergy. Rotorod samplers were installed at well-ventilated places in seven collecting stations in Seoul, the capital of Korea, which has a population of 12 million. Airborne particles carrying allergens were collected daily from each station for 2 years (1 October 1995 to 30 September 1997). After being stained with Calberla's fuchsin, they were identified, counted and recorded. The weather in Seoul was also recorded. Pollen was found from the middle of February through to the end of December. The peak date for pollen was 12 May (peak mean daily count: 701 grains/m^3/day) and for mold it was 23 June (peak mean daily count: 936 spores/m^3/day). Alder, birch, pine, oak, maple, elm, juniper, willow, and gingko trees were prevalent during the tree season, lasting from the middle of February to late July. Then sagebrush, ragweed, Japanese hop, and pigweed followed during the weed season, which lasts from the middle of July to the end of December. In skin prick test results, house dust mite was the most common positive allergen in Seoul, followed by cockroach. Among the pollens, mugwort was the most common positive, followed by ragweed mix, alder, birch, and grasses mix. Among the molds, there were high counts of *Cladosporium* and *Alternaria* during the year, excluding January. *Ascospore* of *Leptospheria* was highest during the monsoon season.

Key words: aero-allergen, Korea, mold, pollen, Seoul.

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Introduction

In a large number of allergic subjects, inhalant outdoor allergens such as pollen and mold, as well as indoor allergens such as house dust mites and cockroach, are causative triggering agents in respiratory allergy.[1–3]

The Korean peninsula is located in a temperate zone and has four distinct seasons. Early March marks the beginning of spring. During the relatively hot and rainy summer season, the average temperature is 20°C (68°F). The monsoon rains usually begin at the end of June and last until late July. The coming of autumn in late September brings continental winds and clear, dry weather. December to February is cold and dry with occasional rain or snow.

Seoul, the capital of South Korea, has a population of approximately 12 million people living in an area of 607.28 km^2. The geographic position is 127° east longitude and 37° north latitude.

Even though positive skin tests for pollen and mold have been reported in 20–30% of respiratory allergic patients, there have been only a few published reports on pollen counts, which were limited to just one station in Seoul.

In this study, we described the annual pollen and mold distributions in Seoul and its vicinity, with seven collecting stations as the aero-allergen network. This provides a firm reference for the area, which can be used to evaluate trends in aero-allergen prevalence.

MATERIALS AND METHODS

Pollen and mold collection

Seven stations were established for a collection of pollen and mold in Seoul and its vicinity: one for the north-eastern part of Seoul (a); one for the north-eastern area (b); one for the central area of Seoul (c); one for the western area (d); two for the southern areas (e,f); and one for the south-western part of Seoul (g) (Fig. 1). Samples were collected from 1 October 1995 to 30 September 1997 in five stations.

Each station was installed with the same model of Rotorod sampler (Model 40, Sampling Technologies Inc. MN, USA) which was fixed with a sampling interval of 60 s out of every 10 min on an unobstructed rooftop at 35–50 feet above the ground.[4,5] The collecting agent of each station exchanged the retraction head with greased I rods from the samplers every morning, excluding Sundays. The rods were stored in storage vials with the exposed faces inwards, recording on each vial the dates sampled for each rod at the numbered vial locations. The storage vials were sent to the sample analysis center at the Hanyang University Kuri Hospital every two weeks.

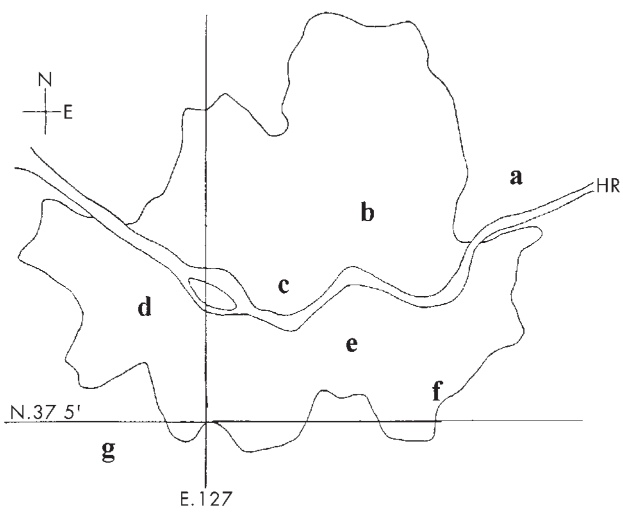

Fig. 1 Map of Seoul showing seven collection stations. a, Hanyang University Kuri Hospital; b, Hanyang University Seoul Hospital; c, Soonchunhyang University Hospital; d, Hallym University Hospital; e, Kangnam Civic Hospital; f, Youngdong Severance Yonsei University Hospital; g, Ajou University Hospital. HR, Han River.

Pollen and mold analysis

Rods were placed face-up in the shallower grooves of the microscope stage support. A small amount of Calberla's stain solution was supplied on rods with a 22×30 mm coverglass. Once mounted in the dye, the rods were counted within 30 min.

The entire exposed surface of the rotorod was 23 mm $\times$ 1.59 mm. For pollen, the entire rod surface was counted, using a 400$\times$ magnification. For mold spores, one longitudinal traverse of the rod was counted using 1000$\times$ magnification with oil immersion. We calculated the volume of air as particles/m^3. The equation for this is as follows:

$$\text{Volume sampled (m}^3) = \text{rod area} \times \text{minutes sampled} \times \pi \times \text{diameter of swing} \times \text{r.p.m.} \ (\pi = 3.142; \text{diameter of rod swing} = 0.085 \text{ m; r.p.m.} = 2400)$$

To determine the airborne concentration (C) of particles, we divided the number of particles counted by the volume of air sampled using the sample volume conversion factor ($K_l = 0.02267$).

$$\text{Concentration of particles (C)} = \text{Number of particles counted}/K_l \times 144 \text{ min}$$

We recorded the pollen and mold count data with the daily weather of Seoul, obtained from the National Meteorological Observatory. We then compared the pollen and mold data obtained from each station. The mean daily count and the mean total annual count were calculated from seven stations.

Allergic skin prick test

A total of 940 boys and girls between the ages of 7 and 13 years from 10 elementary and 10 middle schools around Seoul were selected to take the allergic skin prick test. Subjects were divided into allergic children and normal controls from the results of a questionnaire for International Study for Asthma and Allergies in Childhood (ISAAC).[6] Prick tests were performed with allergen extracts of house dust mites (*Dermatophagoides pteronyssinus, Dermatophagoides farinae*), cockroaches, dog hair, cat fur, buckwheat, mugwort, *Aspergillus, Alternaria,* oak, birch, alder, grass mix, tree mix, ragweed mix (giant ragweed and short ragweed) allergens (ALK, Copenhagen, Denmark and Center Lab, Port Washington, NY, USA). Histamine was used as a positive control (1 mg/mL) and diluent, which was an unbuffered saline containing 0.03% human serum albumin (ALK), was used as a negative control. The area of the wheal was marked on the skin with a ballpoint pen. Clear adhesive tape was then applied to the marked skin. The tape with the pen markings was removed from the skin and taped to paper. Wheals of more than half the area of histamine reaction, after subtracting the response to the diluent control, were considered positive. The skin test data for other pollens were obtained from previous studies in Seoul.[7,8]

RESULTS

Seasonal variation

In spring, many trees and grasses were the common pollen sources, depending on the amount of rain, temperature and other climatic conditions in Seoul. The peak pollen count was 701 grains/m^3/day on May 12. Spore counts of mold were moderately increased because of warmer temperatures in spring. However, in summer, counts of tree pollen decreased to low levels, whereas counts of weed pollen increased (Fig. 2). Korea has a monsoon season from the middle of June through to late July. Mold spore counts are dependent on rainfall and humidity. During this season, spore levels were abruptly increased with the *ascospores* of *leptospheria* and their counts were at their highest for the year, that is, 936 spores/m^3 on 23 June. In autumn, pollen levels (weed) increased once again. The second peak pollen count was 273 grains/m^3/day on 8 September. The mold spore count remained substantial, unless affected by severe drought or rainfall. In winter, pollen and spore counts both fell after the middle of December because of lower temperatures and dry air (Fig. 3).

Tree pollen

Figure 4 shows the results of the tree pollen count for 12 months in Seoul. Alder started to pollinate in the middle of February and shed by far the greatest mean daily amount of pollen with 49 grains/m^3/day and a mean total yearly count of 900 grains/m^3 in March. It was followed by birch (peak mean daily count of 39 grains/m^3; mean total annual count of 1036 grains/m^3), juniper (71 grains/m^3/day; 802 grains/m^3), poplar (14 grains/m^3/day; 569 grains/m^3) and hazelnut (27 grains/m^3/day; 390 grains/m^3) in March, and oak (114 grains/m^3/day; 1285 grains/m^3), maple (52 grains/m^3/day; 1014 grains/m^3), elm (18 grains/m^3/day; 466 grains/m^3), willow (15 grains/m^3/day; 304 grains/m^3), sycamore (12 grains/m^3/day; 228 grains/m^3), ginkgo (9 grains/m^3/day; 122 grains/m^3) in April and May. Pine pollination was at its peak in the middle of May and this was maintained until the middle of June, which is the beginning of monsoon rain. The greatest daily mean amount of pine was 597 grains/m^3/day. Pine is a tree which pollinates maximally with a mean total annual amount of 7762 grains/m^3 in Seoul (Table 1). In July and August, a few pollens of pine and elm were often counted.

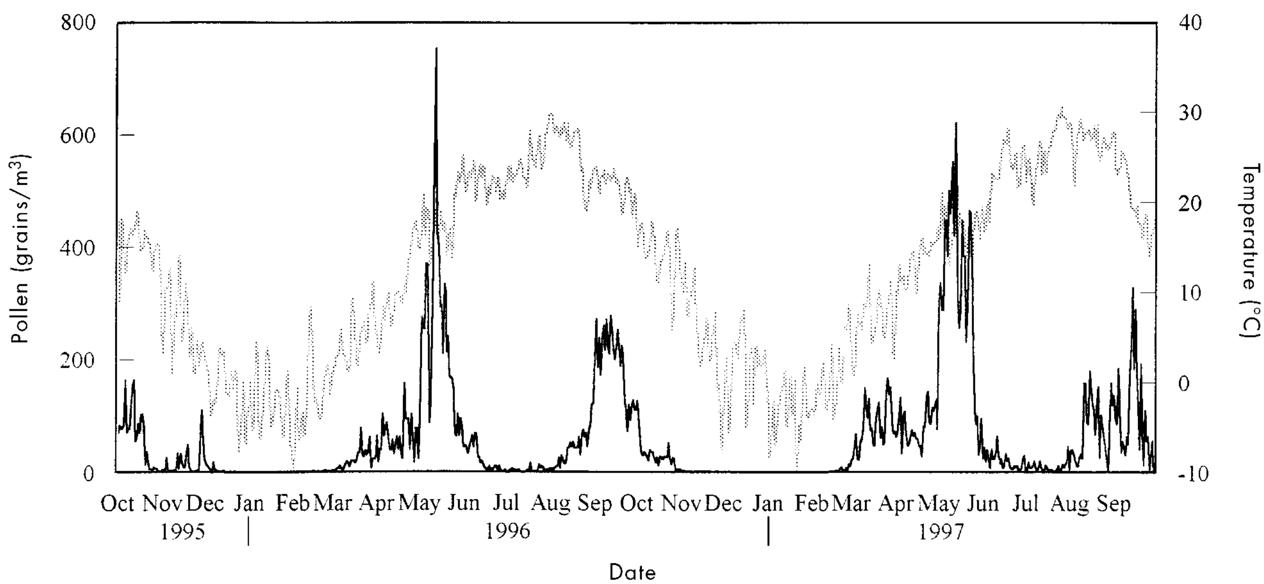

Fig. 2 The correlation between the distribution of pollen count and temperature in Seoul for 2 years (1 October 1995–30 September 1997). –, pollen; ·····, temperature.

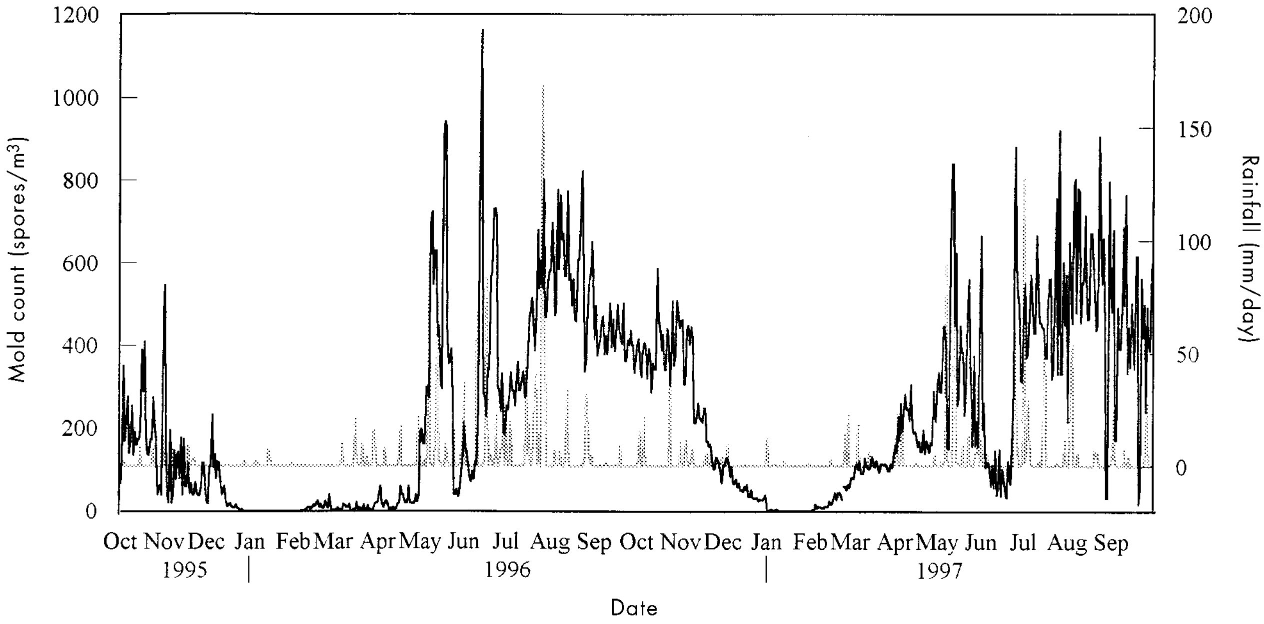

Fig. 3 The correlation between the distribution of airborne mold count and the amount of rainfall in Seoul for 2 years (1 October 1995–30 September 1997). –, mold; ·····, rainfall.

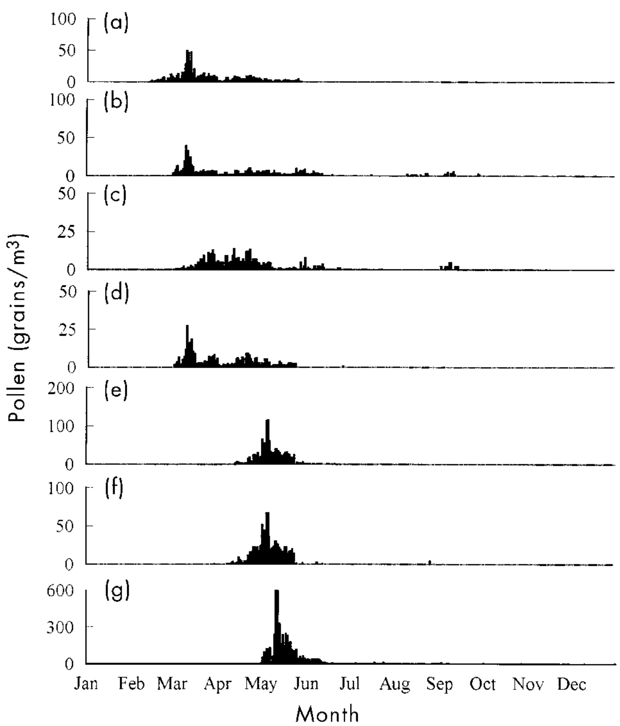

Fig. 4 The annual variations in the pollen count of individual common trees in Seoul. a, alder; b, birch; c, poplar; d, hazelnut; e, maple; f, oak; g, pine.

Grass and weed pollen

The pollination of grasses began at the end of February and continued to the middle of November. Grass pollen was detected year-round except in January, but it was most prevalent between March and September, shown in Fig. 5. The peak daily count of grass species was 106 grains/m^3/day on September 9. The mean total annual count of grass pollen was 4608 grains/m^3.

In autumn, the pollination of weed was high. The sagebush started to pollinate in late July, followed by ragweed, the *Amaranthus* and *Chenopodium* species, hops, English plantain, chrysanthemum, trifolium, dock, lambsquarters and rumex in August and September, and some weeds continued to pollinate to the end of November. Among weeds, sagebush was the most common in Seoul with a mean total annual count of 2803 grains/m^3/day. The peak daily count of sagebush was 102 grains/m^3 on 8 September. The second most common weed pollen was ragweed, with a mean total annual count of 1637 grains/m^3. The peak mean daily count of ragweed was 84 grains/m^3/day on 12 September, as shown in Fig. 5. Other frequently observed weed pollen were hops (41 grains/m^3/day; 729 grains/m^3), the *Amaranthus* and *Chenopodium* species (18 grains/m^3/day; 383 grains/m^3), English plantain (14 grains/m^3/day; 244 grains/m^3) (Table 1).

Table 1. The peak mean daily count and the mean annual total count of common pollens counted from seven stations in Seoul and its vicinities

Species of common pollen	Date of peak pollen count	Peak mean daily count* (grains/m^3/day)	Mean annual total count** (grains/m^3)
Trees			
Alder	9 Mar	49	900
Birch	10 Mar	39	1036
Hazelnut	15 Mar	27	390
Juniper	4 Apr	71	802
Poplar	11 Apr	14	569
Willow	23 Apr	15	304
Ginkgo	2 May	9	122
Maple	2 May	52	1014
Oak	6 May	114	1285
Pine	12 May	597	7762
Elm	21 May	18	466
Sycamore	23 May	12	228
Grasses	26 Mar	106	4608
Weeds			
Sagebrush	9 Sep	102	2803
Ragweed	12 Sep	84	1637
Pigweed	19 Sep	18	383
Hops	20 Sep	41	729

*Mean value of counts obtained from seven stations daily; **total count of mean daily counts obtained from seven stations for one year.

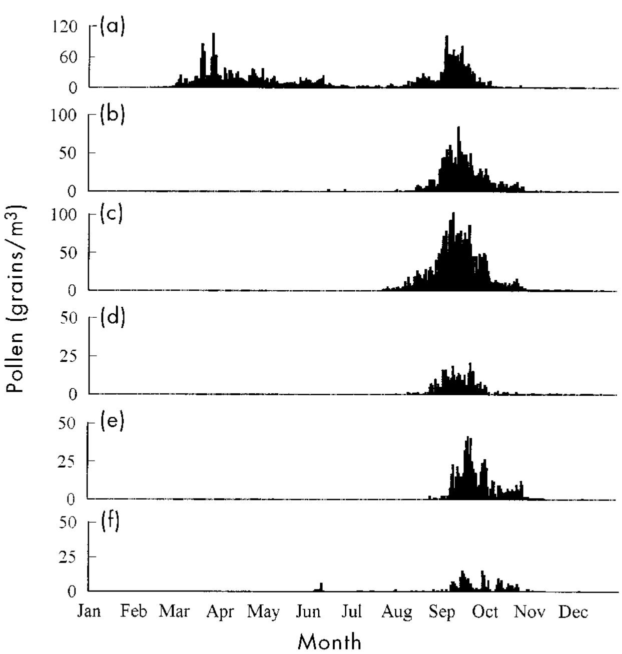

Fig. 5 The annual variations in the pollen count of grasses and individual common weeds in Seoul. a, grasses; b, ragweed; c, sagebush; d, pigweed; e, hops; f, plantain.

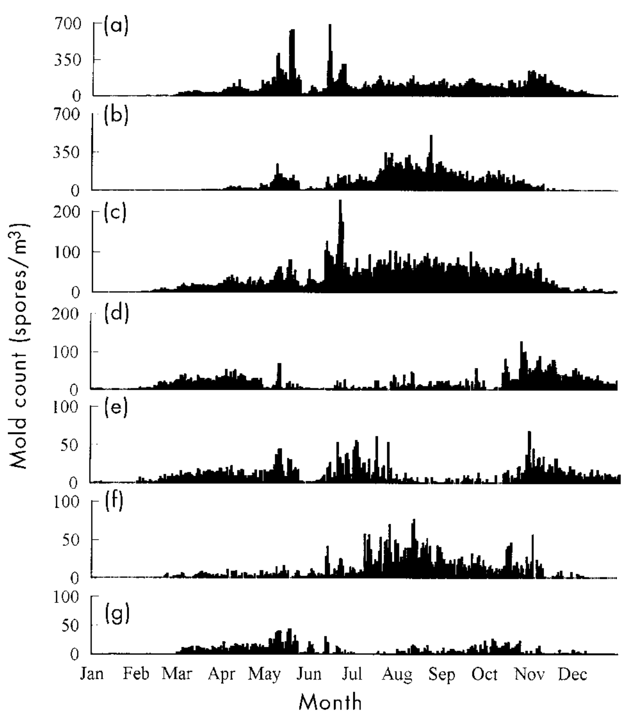

Fig. 6 The annual variations in the count of individual common molds in Seoul. a, Cladosporium, b Ascospore; c, Alternaria; d, Periconia; e, Myxomycetes; f, Basidiospore; g, Stemphyllium.

Table 2. The peak mean daily count and the mean annual total count of major molds counted from seven stations in Seoul and its vicinity

Species of common mold	Date of peak spore count	Peak mean daily count* (spores/m^3/day)	Mean annual total count** (spores/m^3)
Stemphyllium	18 May	43	2265
Alternaria	13 Jun	126	13 247
Cladosporium	24 Jun	305	31 872
Helminthosporium	15 Jul	24	443
Ascospores	23 Jul	341	23 736
Drechslera	25 Jul	33	575
Basidiospores	12 Aug	76	3903
Rust Urediniospores	17 Aug	143	5253
Torula	6 Sep	15	777
Myxomycetes	30 Oct	67	3905
Periconia	6 Nov	77	7088

*Mean value of counts obtained from seven stations daily; **total count of mean daily counts obtained from seven stations for one year.

Mold

The *ascospores* and *basidiospores* are released in very humid conditions, resulting in large bursts of these spore types during or after rainfall. After monsoon rains, the mold spore count increased between the middle of June and the end of August. The peak spore count was 1088 spores/m^3/day on 23 August, as shown in Fig. 3. In autumn, *Cladosporium* (peak mean daily count of 305 spores/m^3; mean total yearly count of 31 872 spores/m^3) and, to a lesser extent, *Alternaria*, increased 3 to 4 days after rain (126 spores/m^3/day; 13 247 spores/m^3). *Periconia* (77 spores/m^3/day, 7088 spores/m^3) and myxomycetes (67 spores/m^3/day, 3905 spores/m^3) was increased in dry autumn and early winter (Fig. 6). *Drechslera* (33 spores/m^3/day, 575 spores/m^3), *Helminthosporium* (24 spores/m^3/day, 443 spores/m^3), *Torula* (15 spores/m^3/day, 777 spores/m^3), *Stemphyllium* (43 spores/m^3/day, 2265 spores/m^3) were also frequently counted (Table 2). *Epicoccum, Amphispheria, Pithomyces, Fusarium, Pleospora, Oidium*, *Curvularia*, *Nigraspora*, *Corynespora*, *Cercospora, Peronospora*, *Cerebella*, *Agaricus*, *Pestalotia*, *Aspergillus* and some others were common year-round. The large amount of *Rust urediniospores* (peak mean daily count of 143 spores/m^3; mean total annual count of 5253 spores/m^3) was counted exclusively in one of the southern stations.

Table 3. The percentage of positive reactions to skin prick test

	Children with allergic history % (n = 353)	Normal controls % (n = 587)
*Dermatophagoides pteronyssinus**	29.4	17.4
*Dermatophagoides farinae**	28.9	16.9
Cockroach	9.4	8.6
Cat hair*	4.8	1.5
Dog fur	2.3	1.5
Mugwort	9.1	6.3
Ragweed mix**	5.6	3.2
Alder*	6.0	2.2
White birch*	5.7	2.4
Tree mix	3.4	1.9
Grass mix	3.1	4.1
Buckwheat	1.4	1.2
Alternaria	2.3	1.5
Aspergillus	2.0	0.9

*P < 0.01; **P < 0.05.

The comparison of pollens and mold spores among the collection stations

The mean total annual count of Japanese hops (*Humulus japonica*) was different between the stations in downtown Seoul and those in the vicinity of Seoul, which has mountainous terrain (mean total annual count of 243 grains/m^3 vs 1247 grains/m^3). Grasses pollen in the southern stations located next to the Olympic stadium complex and Olympic Park were more abundant than in the other stations (mean total annual count of 6520 grains/m^3 vs 2836 grains/m^3). Pine pollen in the vicinity surrounded by mountains was much higher than the count in the downtown area (mean total yearly count of 10 627 grains/m^3 vs 2796 grains/m^3). As for mold count, the large amount of *Rust urediniospores* (peak mean daily count of 144 spores/m^3; mean total yearly count of 5253 spores/m^3) was counted in one of the southern stations (total yearly count of 28 816 grains/m^3). The other pollen and mold species were not different among the collecting stations.

The association between pollen count and allergic skin prick test

House dust mite was the most common positive allergen in Seoul (*Dermatophagoides pteronyssinus*: allergic children vs controls = 29.5 vs 17.4%, $P < 0.01$; *Dermatophagoides farinae*: 28.9 vs 16.9%, $P < 0.01$). Cockroach followed with 9.4%. Among the pollens, the most positive was mugwort (9.1%), followed by ragweed mix (5.6 vs 3.2%, $P < 0.05$), alder (6.0 vs 2.2%, $P < 0.01$), birch (5.7 vs 2.4%, $P < 0.01$) and grasses mix (3.2%) (Table 3). Alder and birch were the most common pollens of early spring (Fig. 4) while ragweed was one of the most common pollens of autumn (Fig. 5).

Discussion

In a large number of allergic cases, inhalant allergens are important causative and triggering agents of respiratory allergy. It is essential to survey the airborne pollen and mold in human living areas for diagnosis and treatment of airborne allergy. Pollen and mold, which are among the common allergens, have been investigated in many countries.[9–12] There is a great number of allergic patients in Korea. However, only a few records of studies related to airborne pollens have been recorded since the first report in 1965. Most studies collected pollens from only one collecting station in the city. Furthermore, studies of mold prevalence in Korea have never been conducted.[7,8,13] In this study, seven collecting stations, evenly distributed throughout Seoul, were selected for pollen and mold count.

The curve of pollen count has two peaks a year: 11 May for pine pollen (mean daily count of 701 grains/m^3) and 9 September for sagebrush pollen (mean daily count of 273 grains/m^3). Pine pollen is a very weak allergen, whereas sagebrush is a very strong one. Therefore, the prevalence of allergic patients with pollinosis is high in the autumn in Korea. Some studies reported that rainfall and temperatures below 10°C inhibit pollen shedding.[14,15] In our studies, pollen count was shown to have decreased in the middle of November when temperatures dropped to below 10°C, while rainfall made pollen count decrease in the beginning of June.

In the case of trees, there were many different species of trees from other countries such as Japan and China. Alder first started to pollinate in the middle of February. *Alnus japonica* and *Alnus hirsuta* were vegetated among alder species in Seoul, and are followed by the other major allergenic trees growing in Seoul such as birch (*Betula davurica, Betula ermani*), juniper (*Juniperus chinensis, Juniperus rigida*) poplar (*Populus alba*) and hazelnut (*Corylus heterophylla, Corylus sieboldiana*) in March, and oak (*Quercus dentata, Q. aliena, Q. serrata, Q. acutissima, Q. mongolica*), maple (*Acer mono, A. pseudosieboldianum, A. palmatum, A. triflorum, A. ginnale*), elm (*Ulmus laciniata, U. parvifolia*), willow (*Salix babylonica*, *S. glandulosa*, *S. matsudana*, *S. koreensis*, *S. graciliglans*, *S. japonica*, *S. gracilistyla*), sycamore (*Platanus orientalis, P. occidentalis, P. acerifolia*), ginkgo (*Ginkgo biloba*) and pine (*Pinus koraiensis, P. pumila, P. rigida, P. densiflora, P. thumbergii*). Pollination of trees continued until the middle of June, which marks the beginning of monsoon rain.

With regard to grasses, the gramineae has over 100 species of primarily wind-pollinated plants such as rice grass, perennial rye, mugwort, red top, orchard, and timothy, but it was impossible to distinguish each species microscopically. Interestingly, the ragweed species was not found until 1965, and there were no cases of pollinosis with ragweed in Korea until 1970. However, ragweed has recently become one of the major aero-allergens in Seoul.[7,8,13] The ragweed species may have been imported from the United States, coinciding with increased ragweed pollinosis since the 1970s. *Ambrosia artemisiifolia, A. trifida, A. integrifolia* were found. In our studies, sagebrush was the most common weed in Korea. Sagebrushes have grown over 10 species of wind-pollinated plants in Korea, such as *Artemisia orientalis*.[16]

Because a single anemophilous plant may liberate millions of pollen grains, global production of wind-borne pollen is astounding, although no more than 5–10% achieve appreciable dispersion. As they leave a source, particles are continuously depleted by fallout or impact on projecting surfaces and are diluted by diffusion, vertical convection, and wind action. A minority of particles may be carried for hundreds of kilometers before deposition.[17–19] Clinical effects are closely correlated with proximity to sources. Therefore, we divided Seoul into seven places to compare the output of pollen and mold in each station. In the comparison of pollen and mold among the seven collection stations, the mean total annual count of hops that is grown near water and in valleys was different from the downtown area and the surroundings of Seoul, which are mountainous. Japanese hops (*Humulus japonica*) is a major aero-allergen of autumn in Korea.[8,20] The count of grasses in some stations located next to the Olympic stadium complex and Olympic Park was higher than those of the other stations. The count of pine pollens in the vicinity of mountainous areas was much higher than those of the downtown area. However, the counts of the other pollen species were not different among the collecting stations.

Vegetative hyphae of most molds grow best between 18 and 32°C.[21] In our studies, the mold grew year-round, although colder temperatures during January decreased the total spore count substantially. Rains not only have a cleansing effect on the air but also provide the necessary moisture for mold growth and an essential relative humidity of over 65%.[22]

The *ascospores* and *basidiospores* are released in very humid conditions, resulting in large bursts of these spore types during rainfall. High local levels of rust and smut spores are associated with heavily infected crops.[23] A large amount of *Rust urediniospores* was found in some stations where infected crops might be located.

Dry spore dispersal increases as airspeed rises and relative humidity falls in sunny weather. During these temperate dry times, *Cladosporium, Alternaria, Stemphyllium, Helminthosporium, Periconia,* myxomycetes and some smuts reached peak level.

In our study comparing the skin prick test and pollen count, ragweed was the common allergen in autumn in Seoul, and alder and birch were the most common allergens in early spring in Seoul. In the previous study, sagebush was the most common allergen (8.6%), followed by ragweed (4.7%) in autumn. Pine was the common allergen (6.1%), followed by alder (3.6%) and birch (3.0%) in spring. However, pine pollen is a very weak allegen.[7]

In the future, we plan to study the aerobiological survey of national pollen and mold, looking at 11 stations over 3 years. We will also study the survey of the distribution of trees, grasses and weeds which have allergenic pollens. Furthermore, we hope to evaluate the correlation between pollen and mold counts, and the prevalence of pollinosis of each province in Korea.

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