

Evaluation of indoor plantings as allergen exposure sources

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The role of indoor plantings as allergen sources was assessed by direct sampling of interior air. Homes with 10 or more plants in one room and three University of Michigan greenhouses were studied by means of a dc-powered rotorod and separate Andersen viable sampler collections incubated at 23° and 50° C. Sequential 30 and 60 sec Andersen samples were obtained during 15 min rotorod collections before and during watering of plants as well as during disturbance of foliage by a small fan. Relative humidity averaged 51% in homes and 78% in greenhouses. Aspergillus fumigatus recoveries were rare. Thermophiles, primarily bacteria, were present at low-to-moderate levels in homes, did not increase with watering or fan in homes, and rose only slightly with disturbance at greenhouse sites. Cladosporium and Penicillium dominated Andersen collections. Watering and fan increased levels of these taxa as well as rotorod recoveries of Alternaria, Epicoccum, and Pithomyces slightly in homes and markedly at greenhouse sites. We conclude that modest numbers of undisturbed house plants contribute minimally to aeroallergen prevalence in homes. However, especially under greenhouse conditions, plantings can harbor abundant fungus growth that may become airborne, especially when agitated directly. (J ALLERGY CLIN IMMUNOL 70:101, 1982.)

Natural plant communities and crops provide a dominant source of airborne allergens in all inhabited regions. Incremental exposure risks arise from the physical disturbance of vegetation, leading especially to the release of fungus particles.¹ Similarly, agricultural practices readily promote the dispersion of soil biomass.² These considerations have been translated into outdoor avoidance measures for those sensitive to fungi, algae, etc. A rational extension of these concerns has led clinicians to counsel against the keeping of house plants by groups of allergic patients.³ However, the wide appeal of plants and a growing public interest in horticulture often stimulate strong resistance to these well-meant injunctions. Furthermore, since plants have been indicted largely on theoretic grounds, the benefits of a vegetation-free home are, at best, controversial. To provide a more factual basis

for clinical strategy, we have directly monitored potential allergens associated with the presence and care of indoor plant growth—both in domestic and in conservatory settings.

MATERIALS AND METHODS

Seventeen homes, each with more than 10 house plants, were studied: 11 once, four twice, and two on three occasions. All samples were collected during cool months (from October 1979 to April 1980). Almost all homes were heated during this period, the majority by forced air, while a few had radiant heat; open windows were not uncommon, however, and no attempt was made to control or standardize these variables. Collections were made with samplers positioned on the floor within 2 to 3 ft of the plant groupings. A 6 V battery-powered rotorod sampler* (Ted Brown Associates, Los Altos Hills, Calif.; current supplier), carrying plastic l rods coated with silicone grease, was run continu-

*Motor and housing previously obtained from Metronics Assoc., Palo Alto, Calif.

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Abbreviations used

TSA: Trypticase soy agar
CFU: Colony-forming units

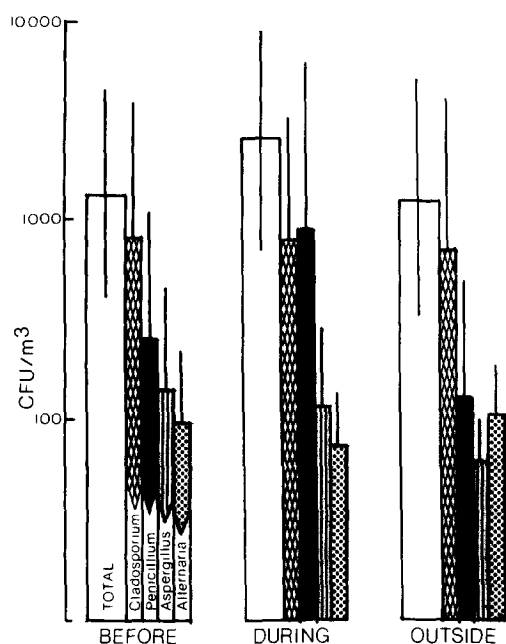


FIG. 1. Levels of four most abundant and frequent fungi recovered on Andersen/malt samples on 25 sampling occasions in house plant homes before and during watering, with concurrent outdoor samples (geometric means $\pm$ 1 SD).

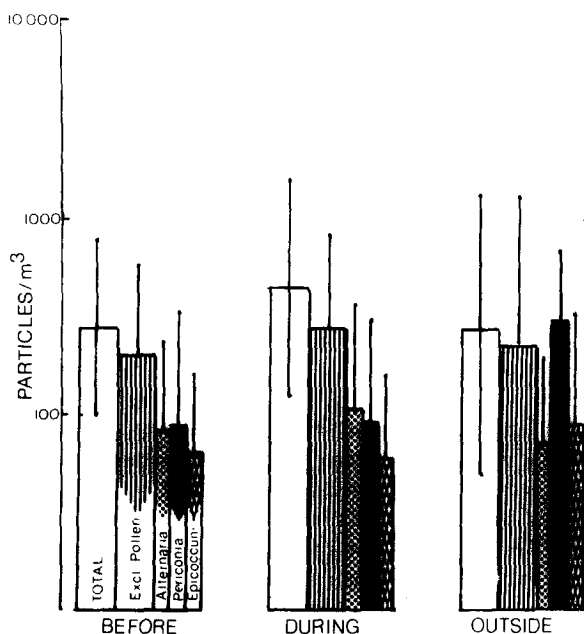


FIG. 2. Total particles, total excluding pollen, and levels of three most abundant fungi recovered on rotorods in 23 house plant homes (geometric means $\pm$ 1 SD).

ously for either 10 or 15 min periods. Three sequential rotorod samples were taken in each location: one, as a baseline, before the plants or rooms were disturbed in any way (except for activity related to sampler operation), a second during plant care activities (primarily watering), and

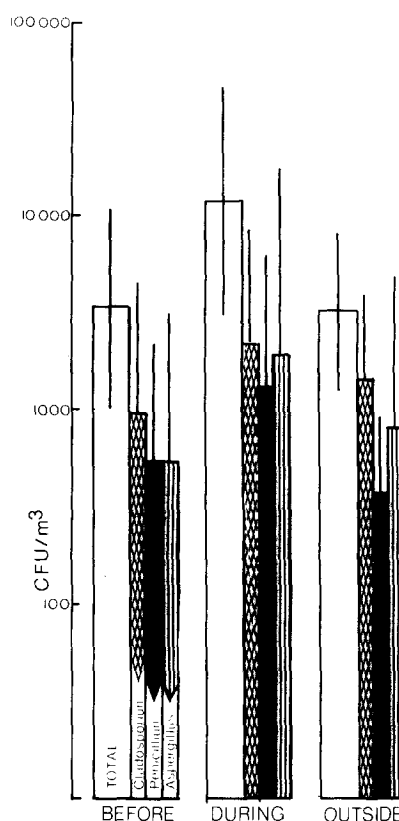


FIG. 3. Total recoveries and levels of three most abundant taxa recovered from Andersen/malt samples in greenhouses (geometric means $\pm$ 1 SD).

a final one during the operation of a small battery-powered fan aimed directly at the plant grouping. This unit produced substantial leaf movement and an air speed averaging 2.03 m/sec (ca. 4.5 mph). Care was taken to avoid blowing air directly across the Andersen sampler orifice. During each of these three periods of rotorod operation, three sequential 1 min samples were made with a six-stage Andersen sampler (Andersen Samplers, Inc., Atlanta, Ga.) calibrated to process 1 ft³ of air per minute.⁴ The first two of these samples utilized a single plate of malt extract agar (32 gm of malt extract, 16 gm of agar, and 1 gm of yeast extract in 1 L of distilled water; Difco, Detroit, Mich.) beneath the sixth stage; the third utilized TSA (Difco). A fourth rotorod sample with three concurrent Andersen samples was taken near ground level immediately outside each home. Residents, which included Allergy Clinic patients in 70% of cases, were asked not to water or otherwise disturb the plants for 24 hr before sampling. Plants were watered close to the soil surface using the owners' implements, with little or no wetting of foliage. Temperature and relative humidity (measured with a sling psychrometer) were recorded at each sample site.

Sampling at the University of Michigan Botanical Gardens, situated in a rural area near Ann Arbor, followed a similar protocol except that a 1 min Andersen sample with a single plate of V-8 agar (200 ml of V-8 juice, 3 gm of

TABLE I. Geometric means of 16 sampling occasions before activity, during watering, and during fan operation, with confidence interval comprising one SD above and below the geometric mean

	Before	During	Fan
Andersen	1650(433-6272)	3011(810-11188)	2221(844-5843)
Rotorod	106(42-267)	99(24-403)	90(28-285)

TABLE II. Percent recovery of taxa recovered on Andersen samples more than once in house plant homes

	Before watering (n = 50)	During watering (n = 79)	During fan operation (n = 37)	Outside (n = 37)
<i>Cladosporium</i>	90	98	97	95
<i>Penicillium</i>	82	86	89	57
<i>Aspergillus</i>	30	37	41	16
<i>A. fumigatus</i>	2	6	0	0
<i>Alternaria</i>	22(87)*	16(87)	19(88)	22(90)
<i>Aureobasidium</i>	12	12	16	27
<i>Rhodotorula</i>	18	8	11	19
Arthrospores†	12	14	14	24
<i>Wallemia</i>	12	4	11	8
<i>Epicoccum</i>	12(65)	8(82)	5(70)	35(52)
<i>Botryosporium</i>	2	12	11	5
<i>Botrytis</i>	12	10	3	5
Sphaeropsids‡	4	10	8	19
<i>Fusarium</i>	4	4	0	8
<i>Rhizopus</i>	0	8	3	3
<i>Cephalosporium</i>	2	2	3	3
<i>Rhinochadiella</i>	4	0	5	0
<i>Sporotrichum</i>	2	2	3	0
<i>Tritarachium</i>	2	3	0	0
<i>Beauvaria</i>	2	0	3	0
<i>Arthrimum</i>	0	2	0	3
<i>Candida</i>	2	0	0	3
<i>Doratomyces</i>	0	2	3	0
<i>Scopulariopsis</i>	0	4	0	0
<i>Myrothecium</i>	0	2	3	0

*Numbers in parentheses indicated percent recovery on simultaneous rotorod samples.

†Includes *Geotrichum* and arthrosporic imperfect stages of basidiomycetes.‡Primarily *Phoma*-type and *Ascochyta*-type organisms.

CaCO₃, and 20 gm of agar in 1 L of distilled water) was also included in each set of culture collections, with studies at two locations in each greenhouse before and during watering by gardens personnel. Samplers were operated on plant benches in three separate greenhouses, which held a variety of tropical and temperate species. Plants in greenhouses 2 and 3 were watered daily; those in the cactus house received water each week. Pots were, in general, watered close to the soil surface so that the foliage was only minimally wetted. By contrast, in the cactus house, the extensive in-ground plantings were sprayed from a distance of 5 to 10 ft with a garden hose.

After exposure, rotorods were stored dry in dust-proof containers pending microscopic examination. One rod of each pair was examined microscopically in Calberla's solution (5 ml of glycerine, 10 ml of 95% ethanol, 15 ml of

distilled water, and 2 drops of saturated aqueous basic fuchsin) on a lucite stage support.⁵ All apparent biologic particles were counted and either identified or labeled "unknown" (except *Aspergillus-Penicillium*-type [i.e., small spherical] spores and *Cladosporium* spores, which were not enumerated). V-8 and malt extract Andersen plates were incubated at room temperature under near ultraviolet illumination (General Electric "grow" lights) for 7 days. TSA plates were incubated at 56° C in a dark, humidified oven for 24 to 48 hr. All colonies were examined microscopically and identified to genus or categorized as nonsporulating, arthrospore-forming, sphaeropsidales, yeast, bacteria, or actinomycete.

All rotorod counts were converted to "spores retained/m³ of air sampled" by multiplying them by a factor that reflected rod surface area, distance traveled in one rota-

TABLE III. Percent recovery of taxa counted on rotorod samples in house plant homes*

	Before watering (n = 23)	During watering (n = 23)	After (n = 20)
Pollen	87	74	55
<i>Alternaria</i>	87	87	90
<i>Periconia</i>	57	74	35
<i>Epicoccum</i>	65	82	52
<i>Stemphylium</i>	4	13	5
<i>Pithomyces</i>	22	48	30
<i>Torula</i>	17	13	0
<i>Drechslera</i>	17	17	10
<i>Polythrincium</i>	9	9	0
<i>Erysiphe</i>	0	4	5
Algae	17	17	15
<i>Pestalotia</i>	0	0	5
<i>Curvularia</i>	9	4	0
Fern spores	0	0	5

*Data expressed as number of positive rods/total rods $\times 100$.
Cladosporium was abundant but was not counted.

tion, rotations per minute, and total minutes of sampling. Colonies on each Andersen plate (representing 1 ft³ of sampled air) were counted; counts were corrected for the probability of multiple impactions at one site.⁴ Counts so corrected were multiplied by 35.3 to obtain data expressed as CFU per cubic meter of air sampled.

RESULTS

Geometric means of overall particle levels before and during plant care (watering), measured as CFU by the Andersen sampler, are presented in Fig. 1 and as particle recoveries by the rotorod in Fig. 2. In addition, corresponding data from associated outdoor samples are shown. Particle concentrations indicated by both methods increased marginally ($p < 0.05$) during watering. During fan operation, both viable and nonviable particles exceeded preactivity values ($p < 0.05$) but were lower than levels measured during watering (sign test, $p < 0.005$) as shown in Table I. Indoor values before watering and outdoor levels were not significantly different.

The predominant fungus taxa recovered with the Andersen sampler were species of *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria*. As is evident in Fig. 1, the modest rise in particle recoveries due to watering was largely attributable to heightened *Penicillium* CFU, recoveries of which were significantly higher indoors (both before and during watering) than outdoors ($p < 0.01$). *Aspergillus fumigatus* was recovered once before watering and three times during watering, with a maximum concentration of 94 CFU/m³. Predominant particle types recovered with the rotorod were pollens (primarily from outdoor

sources), as well as spores characteristic of *Alternaria*, *Periconia*, and *Epicoccum* (Fig. 2). Increases in rotorod recoveries during plant watering comprised mainly pollens with slight increases also recorded in *Alternaria* spores. Outdoor patterns of biogenic particles were similar to those indoors except for *Periconia*-like spores, which were considerably more prevalent in free air.

Both culture and spore deposit data indicate that species of *Cladosporium*, *Alternaria*, *Penicillium*, *Epicoccum*, and *Aspergillus* were the fungi most frequently recovered indoors, comprising $>30\%$ of samples before activity as well as during watering and fan operation. This descending order of prevalence was also obtained outdoors, although levels of aspergilli were distinctly lower (Tables II and III).

Thermophilic actinomycetes were collected on 11 of 22 sampling occasions, with indicated levels ranging from 35 to 315 CFU/m³. Thermophilic bacteria were recovered more regularly (on 18 of 22 sampling occasions); concentrations ranged from 35 to 385 CFU/m³. These high temperature-dependent organisms showed no increase in prevalence with watering or with fan operations.

Rank correlation comparisons between relative humidity and total particle levels (Andersen and rotorod) in the 17 homes sampled were highly significant ($p < 0.0005$). By contrast, temperature and particle level correlations were not related significantly ($p > 0.1$).

Andersen sampler data from 19 "many-plant" homes (10 or more plants) and from 19 "few-plant homes" (fewer than three plants) matched for relative humidity and sampled during previous studies with identical methods were compared. No differences were found in baseline spore levels in these paired homes (sign test, 9+, 10-). The median particle level in many-plant homes was 99.9 CFU/m³, and in the few-plant homes this level was 110.3 CFU/m³.

At the University of Michigan Botanical Gardens, greenhouse 2 was studied at two sites on three occasions, greenhouse 3 at two sites on six occasions, and the cactus house four times at each of two sites. Greenhouse 2 contained potted plants on tables recently filled in with clean pebbles. Greenhouse 3 was similar except that half the tables contained old cinders. The cactus house contained potted plants on pebble-filled tables as well as an extensive area with plants growing directly in large sandy beds. Greenhouses 2 and 3 contained many common house plants as well as other more exotic taxa. Geometric means of overall CFU levels before and during watering, as measured on malt agar with the Andersen sampler, are presented in Fig. 3 and are summarized in Table

TABLE IV. Total Andersen/malt recoveries in three separate greenhouses sampled before and during watering

	Before watering	During watering
Greenhouse 2		
Mean	7864 $\pm$ 11939	6881 $\pm$ 3384
Geometric mean	4786 (1950-11749)	6166 (3631-10471)
Greenhouse 3		
Mean	9139 $\pm$ 15089	54541 $\pm$ 62590
Geometric mean	3536 (933-13489)	22387 (4266-117489)
Cactus		
Mean	11051 $\pm$ 7550	18305 $\pm$ 9220
Geometric mean	7413 (2291-23988)	13804 (4786-39811)

TABLE V. Geometric means (and conference limits based on 1 SD above and below the mean) of total recoveries on rotorod samples before and during watering in three separate greenhouses

	Before watering	During watering
Greenhouse 2	65(19-224)	212(24-1844)
Greenhouse 3	107(18-642)	3831(747-19649)
Cactus	126(14-1148)	1778(617-5129)

IV. CFU levels were significantly elevated during watering in greenhouse 3 ($p < 0.001$) and in the cactus house ($p < 0.025$, paired t test on log-transformed data); *Cladosporium*, *Penicillium*, and *Aspergillus* species contributed the bulk of these increases. *A. fumigatus* was not recovered at the botanical gardens in the course of this study. Overall rotorod recoveries from the three greenhouses are summarized in Table V. Particle types counted on rotorod samples are listed in Table VI, with their frequency of recovery expressed as a percentage of total rotorods examined. Within the fairly narrow ranges of relative humidity (70% to 100%) and temperature (70° to 90° F) prevailing at the Botanical Gardens, these variables were not correlated with particle levels. Table VII emphasizes the variability of absolute CFU levels and before/during ratios from one sampling occasion to another in data from greenhouse 3.

In greenhouse collections, recoveries on V-8 agar closely paralleled those on malt extract media. Thermophilic actinomycetes were present in eight of 12 TSA collections before watering, nine of 12 made during watering, and four of six outdoor samples; levels were moderate and doubled after watering (Table VIII). Thermophilic bacteria were recovered in eight of 12 samples before watering, nine of 12 after, and on all six outdoor samples. Levels of these bacteria were low and did not increase appreciably with watering. Thermophiles were neither consis-

TABLE VI. Frequency of recovery of the most common fungus taxa recovered on rotorod samples from the Botanical Gardens*

	Before watering (n = 18)	During watering (n = 18)	Outside (n = 8)
<i>Alternaria</i>	89	94	100
<i>Botrytis</i>	56	78†	50
Algae	56	50	38
<i>Epicoccum</i>	56	72	100
Ascospores	67	78	88
<i>Torula</i>	6	56†	25
<i>Beltrania</i>	6	39†	0
<i>Drechslera</i>	11	50	75
<i>Polythrincium</i>	17	28	75
<i>Erysiphe</i>	22	50†	50
<i>Pithomyces</i>	28	39	88
<i>Curvularia</i>	6	6	38
<i>Cercospora</i>	11	11	38
<i>Stemphylium</i>	6	33†	13
Downey mildew	6	11	25
<i>Arthrinum</i>	0	17†	0
<i>Fusarium</i>	0	6	0

*Data expressed as number of positive rods/total rods $\times$ 100.

Cladosporium was abundant but was not counted.

†Taxa with potential interior sources.

TABLE VII. Total Andersen/malt recoveries and before/during ratios for six separate sampling occasions in greenhouse 3

Sample occasion	Total recoveries (CFU/m ³)		
	Before watering	During watering	Before/during
1	876	3161	0.28
2	402	2556	0.16
3	1066	312	3.42
4	7693	149940	0.05
5	2674	29795	0.09
6	22776	60541	0.38

TABLE VIII. Geometric means (confidence interval based on 1 SD) of thermophile recovered on TSA in greenhouses

	Before watering	During watering	Outside
Actinomycetes	346(120-997)	676(166-2755)	268(83-889)
Bacteria	118(53-264)	153(86-272)	123(62-246)

tently recovered nor uniquely abundant at any greenhouse site.

DISCUSSION

The acknowledged abundance of microorganisms in soil and leaf-surface associations has focused increasing attention on possible health effects of indoor plant growth. This concern is heightened by the isolation of potentially pathogenic bacteria⁶ and fungi⁷ from the soil of house plants and the suggestion that, at times, these sources have determined serious human infection.⁷⁻⁹ In addition, living and processed plant materials have been implicated as substrates for saprophytic fungi that serve as inhalant allergens.^{10, 11}

Both the nature of the associated microflora and its potential for liberation into enclosed spaces will determine the extent of exposure risks associated with indoor botanical sources. Environmental temperature, air humidity, soil moisture, nutrient levels, and the prevalence of nonliving debris undoubtedly modulate microbial populations. Dispersion from these sources may be fostered by additional processes, notably soil and plant disturbance, as well as ambient air motion (including accelerations due to convection). Where these dispersive forces are weak, substantial microbial populations may be expected to exist on plant and soil surfaces with only minimal resulting air contamination. Such possible disparities emphasize the limitations of touch preparations¹¹ or soil culture data as the sole indicators of indoor air pollution caused by house plants. To avoid these pitfalls, the present study has focused on actual prevailing levels of biogenic materials under conditions of normal plant disposition and care.

As shown in Table II, most fungi recovered in culture close to house plants were of types widely prevalent in air, and pollen and spore types originating outdoors dominated the particle deposits (Table III). Contribution of outdoor aerosols to indoor particle levels, especially during the growing season, is well documented.^{12, 13} The strong representation of outdoor particle types (e.g., *Cladosporium* and *Alternaria*) in the present data almost certainly reflects this inward flux occurring within the October-to-April span of the present study and contrasts with periods having continual, major snow cover.¹²

The similarities of air spora in undisturbed indoor air to those prevailing outdoors (Fig. 1) suggest that sources in nature, rather than house plants (or other intramural factors), contributed the bulk of our particle recoveries. The very modest rise noted in suspended particles with plant disturbance (i.e., watering), supports this view and suggests that foliage and soil normally have only limited strength as passive sources. Prevalence levels during fan operation (which simulated air velocities close to the room vents of a forced-air heating system) were only slightly elevated above prewatering figures and below values measured during watering. The fan samples were begun exactly 10 min after starting the watering activity. During fan operation, the slight elevations of air spora above prewatering levels may have represented, in part, the end of a die-off curve after a brief burst of dispersion at the start of the preceding activity period; alternatively, recoveries may have resulted largely from primary or secondary particle liberation by the fan. In either case, it is clear that allergen-exposure risks associated with watering were variable in time and place, generally small in scale, and notably short lived.

Fungi occur regularly in most soils, although the types and species densities in house plant substrates have not been systematically examined. However, Staib et al.¹⁴ have recovered *Aspergillus fumigatus* and *A. niger* from potting soil and from the air in the vicinity of plants when soil was allowed to dry and then was actively disturbed.

Although we have isolated *A. fumigatus* and *A. niger* easily from outdoor soil and compost samples, we did not recover either fungus from four house plant soil samples with both direct "seeding" and dilution plate technique. Furthermore, *A. fumigatus* never exceeded average levels expected in outdoor air or room air without plants¹⁵ and, remarkably, was not recovered at all from the greenhouses sampled. Taken together, these findings suggest that in our area, the mere presence of house plants does not impose a risk of *A. fumigatus* exposure substantially beyond that often prevailing in outdoor air. Agricultural activities do introduce soil particles along with adherent spores and hyphae into the atmosphere, and we assume that removing devitalized tissues or repotting a plant in

nonsterile soil indoors will disperse soil organisms. Furthermore, like other indoor surfaces, leaves and soil can release previously deposited dusts when disturbed. The less vigorous agitation associated with watering potted plants apparently does not produce extensive airborne fungus contamination. However, even the smallest incremental exposure risk involving potential offenders such as *A. fumigatus* and *A. niger* may be unacceptable for particularly susceptible patients. This concern has prompted Staib⁷ to suggest that plants potted in soil should not be present in the hospital environment; similarly "sensitive" areas might include the homes of aspergillosis patients. Horticultural alternatives such as the currently popular liquid-grown plants, with their demonstrably lower microbial burdens,¹⁶ offer possible advantages in these sites.

The possibility that house plants might harbor and disperse a uniquely selected microbial flora was a basic concern of this study. However, infestations were not observed grossly on any house plant during this study, and recognizable spores of common phytopathogens were not recovered from home air. In the cactus house at the Botanical Gardens, high levels of *Erysiphe* spores were encountered on two occasions after splash-type watering, suggesting a direct plant source in this specialized, intensely planted, location. In general, however, house plants have undergone an intensive process of selection for disease resistance, whereas in outdoor environments, the plant pathogenic fungi are much better established and their spores readily dispersed. In addition, natural cover contains an abundance of composting debris, providing favorable substrates for the common saprophytes. Dead plant materials were present only sparsely in the homes and greenhouses examined in the course of these studies.

Measurements made during midwinter periods in our area have shown a strong correlation between relative humidity and levels of airborne fungi in domestic interiors.¹² This concordance is evident also in the present data, but here may reflect the higher outdoor fungus levels and relative humidities coexisting at the extremes of the growing season as much as the productivity of indoor microbial sources. Despite this uncertainty, it is clear that the maintenance of house plants may at times elevate indoor relative humidity, thereby secondarily promoting increased fungus levels. Possible effects of plants and associated humidity on mite populations also may deserve attention. Even if spills incidental to watering are excluded, evaporation from drainage sumps, porous pots, and soil, as well as leaf transpiration provide local moisture sources. Furthermore, many house-

holders regularly use supplementary humidifiers to prevent desiccation of tropical plant foliage, attaining moisture levels well above those required for human comfort. These factors were most clearly operative at the Botanical Gardens, although spore levels were rarely excessive in undisturbed air at greenhouse sites. Relative humidity in the greenhouses was always >70%. The lack of an evident spore level/relative humidity correlation in these enclosures can be ascribed to humidity being always in an optimal range for fungal growth.

In the greenhouse situations studied, except as mentioned above, substrates other than the plants themselves appeared to be major sources of dispersible airborne particles. When examined directly, old cinders in one greenhouse supported a luxurious surface growth of *Botrytis* sp, and this, as well as other fungi such as *Arthrinium* spp, were airborne abundantly after watering. Horticulturists at the Botanical Gardens had already recognized this problem and gradually replaced the cinders with clean pebbles during the course of our study. Samples made after conversion to pebble mulch showed a considerable decrease in postwatering spore levels. Spore levels after watering were consistently and sharply elevated only in the cactus house, where use of a garden hose seems to have promoted the splash dispersal of soil or leaf surface fungi.

One of the homes studied contained a number of potted plants that were flowering actively. In this residence, each plant was shaken systematically over a wastebasket before watering to remove dead floral parts. Sampling showed that pollens from a *Cyclamen*, several *Begonias*, and *Impatiens* became airborne in levels exceeding 2000/m³ of air when measured during this procedure. Despite this vigorous debridement, fungus spore levels did not increase to an unusual degree, again suggesting the low potential of house plants as sources of inhalant exposure to these agents. Although plants in flower were present in some additional homes, there was little evidence of pollen mobilization from these entomophilous types during disturbance by watering or by the fan employed.

We therefore conclude that healthy undisturbed house plants do not constitute a major exposure source for airborne fungus spores. Water damage associated with house plant maintenance (such as continuously damp organic plant containers, carpeting, blotting papers, etc.) were not encountered in the homes sampled, probably at least in part because of the very low relative humidity common during our cold months. Studies presented here may not apply to continuously warm and/or humid environments.

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