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HUMAN EXPOSURE TO AIRBORNE FUNGI FROM GENERA USED AS BIOCONTROL AGENTS IN PLANT PRODUCTION

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Abstract: The fungi *Trichoderma harzianum*, *T. polysporum*, *T. viride*, *Paeciliomyces fumosoroseus*, *P. lilacinus*, *Verticillium*/*lecanicillium lecanii*, *Ulocladium oudemansii*, *U. atrum* and *Beauveria bassiana* are used or considered to be used for biocontrol of pests and plant diseases. Human exposure to these fungi in environments where they may naturally occur or are used as biocontrol agents has not been directly investigated to date. This review aims to provide an overview of the current knowledge of human exposure to fungi from the relevant genera. The subject of fungal taxonomy due to the rapid development of this issue is also discussed. *B. bassiana*, *V. lecanii*, *T. harzianum*, *T. polysporum*, *P. lilacinus* and *U. oudemansii* were infrequently present in the air and thus people in general seem to be seldom exposed to these fungi. However, when *V. lecanii* was present, high concentrations were measured. Fungi from the genera *Trichoderma*, *Paecilomyces* and *Ulocladium* were rarely identified to the species level and sometimes high concentrations were reported. *T. viride* and *U. atrum* were detected frequently in different environments and sometimes with a high frequency of presence in samples. Thus, people seem to be frequently exposed to these fungi. Sequence data have led to recent revisions of fungal taxonomy, and in future studies it is important to specify the taxonomy used for identification, thus making comparisons possible.

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INTRODUCTION

Fungi used or considered to be used for biological control of pest insects and plant diseases belong to different genera, including *Beauveria*, *Paecilomyces*, *Trichoderma*, *Ulocladium* and *Verticillium*. Human exposure to these fungi in occupational settings, homes and outdoor environments where they may be naturally occurring or used as biocontrol agents has not been directly investigated to date. Furthermore, during recent years, attention has been drawn towards the possible health risks of handling, producing and using biocontrol products [30, 73]. Identifying environments where people are exposed to these microorganisms and generating knowledge about exposure levels are important factors for assessing the risk of using biocontrol agents (BCAs) for inoculation or inundation.

It is now recognized that exposure of the airways to microorganisms in occupational environments is associated with a wide range of adverse health effects with major public health impact [33]. Respiratory symptoms and lung function impairment are probably the most widely studied among organic dust-associated health effects. Fungi are well-known sources of allergens and are also sources of β-glucan, which causes non-allergic respiratory symptoms

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[33]. Thus the fungus *Aspergillus fumigatus* has been identified as the causing agent of hypersensitive pneumonitis of a female working in a poorly constructed greenhouse [138]. Another example is extracts of *Paecillomyces bacillosporus*, which produced immediate weal reactions in skin tests, precipitin reactions with sera, and rapid decrease in FEV_1 when inhaled by affected farm workers [34]. In another study doctor-diagnosed asthma among school children was strongly associated with high IgG levels to *Trichoderma citrinoviride* [68], and in a study of farm workers in England 35% reacted to *Verticillium lecanii* when given skin tests [85]. In another study, extracts of *V. lecanii* produced immediate weal reactions in skin tests, precipitin reactions with sera, and rapid decrease in FEV_1 when inhaled by affected farm workers [34]. In a lung epithelial cell assay, *T. harzianum* was shown to be an inflammogen [7]. Furthermore in a sperm-assay *T. harzianum* has been shown to damage the cell membrane barrier function of sperm cells [106] and the sperm cell motility [107]. On the other hand, short-term human exposure to *T. harzianum* did not result in more clinical effects than placebo exposure [93]. In skin prick tests, patients visiting an allergy clinic have shown immediate skin reactions to the genus *Ulocladium* [6]. In addition to the direct health effects, fungi may also have an adjuvant effect on the allergic response to other allergens. Thus *Metarhizium anisopliae* is seen to have an adjuvant effect on a standard allergen [71].

Fungi selected for biocontrol are not infectious in mammals but case stories indicate that some of the fungi may to some extent be infectious, or at least prevalent, in weakened and immunodepressed persons. For example, *Beauveria bassiana* has been isolated from the pleural fluid of a patient with lung adenocarcinoma [56], it has infected a patient who had acute lymphoblastic leukaemia [131] and it has caused keratitis [77]. *T. harzianum* has been identified as the causal agent of peritonitis in a dialysis patient [55]. *Paecilomyces* sp., *Trichoderma* sp., and unidentified *Ulocladium* species have been found to be responsible for onychomycoses cases [64, 117]. Furthermore, *U. atrum* has been reported as a casual agent of keratitis [11] and cutaneous granulomas [8]. On the other hand, a *P. fumosoroseus* isolate administered intragastrically in mice, has been recovered in the liver, spleen, kidney, brain and lung without any pathological tissue reaction [96]. As regards species belonging to the same genera as some biocontrol agents, *P. variotii* has caused an infection in the central nervous system of a cancer patient [74] and *U. chartarum* a cutaneous infection in a heart transplant recipient [35].

Respiratory disorders caused by microorganisms are dependent on the exposure levels [39, 119]; yet, there are no internationally accepted threshold limit values (TLV) for microorganisms. A Dutch study group has suggested that fungal concentrations above 10^4 cfu/m^3 should be considered a threat to workers' health [61]. Furthermore, Eduard *et al.* have shown that symptoms in the eyes and nose increased after exposure to fungal spores at the level 2×10^4 to 5×10^5 cfu/m^3, and cough symptoms increased after exposure to concentrations of 5×10^5-17×10^5 fungal spores/m^3 [39]. For single fungal species such as *A. fumigatus*, Heida, Bartman and Van der Zee have suggested a TLV of 500 cfu/m^3 [61]. Assessment of exposure to fungi by counting the spores by microscopy seems to be the most suitable method, according to a Nordic expert group [38]. The total numbers of fungal spores counted by microscopy are often a factor 10-100 higher than the numbers of cfu (colony forming units) of fungi. However, there is no conversion factor between total numbers of fungal spores and cfu of fungi. In this review, exposure levels will be related to the suggested TLV of 500 cfu/m^3 as the fungi in the studied papers were measured as cfu. In addition, the exposures will be related to the exposures to other species of the same genera. In some papers, mainly about settled dust, concentrations of fungi have been measured as cfu/mg dust. There are no standard categories for which fungal concentrations in dust can be considered as high or low. However, measurement of culturable fungi exceeding 100 cfu/mg dust collected from carpet or furniture surfaces have been considered by some as evidence that a building has been contaminated with mould [65]. In indoor studies, the median contents of total cultivable fungi per mg sedimented dust seem often to be around 10-200 cfu/mg dust [66, 72, 136]. In agriculturally related environments, the median contents of total cultivable fungi per mg dust seem to be very variable, thus concentrations between about 5 to 1000 cfu/mg dust have been found [36, 46, 122]. In this review paper, concentrations of a single species higher than 35 cfu/mg dust are considered as high and a concentration of 15-34 cfu/mg dust as a medium level.

The aim of this review, based on an extensive literature survey, is to provide an overview of the current knowledge of human exposure to the following fungi, also found in biocontrol products: *T. harzianum*, *T. polysporum*, *T. viride*, *P. fumosoroseus*, *V. lecanii*, *U. oudemansii*, *U. atrum* and *B. bassiana*. The exposures and concentrations are related to the exposures to other species of the same genera and to the exposures and concentrations discussed above. It is important to know which fungus species or genus data refer to, and authors have treated this differently. Due to the rapid development of fungal taxonomy and methods for diagnosis, we pay special attention to discussing these elements throughout the paper.

The taxa of fungal pathogens used in biocontrol of insect pests represent anamorphic or asexual life stages. This means that they are haploid and can replicate by the production of mitosporic conidia. It is these conidia that represent the infective stages of the fungi and can be found in the commercially available products for biocontrol. The taxonomy used for these fungi in relation to biocontrol products is therefore based on the anamorphs. A review of published reports of findings of these fungi in the air has potentially the bias that the identification to species level is not based on current taxonomy.

METHODS

The fungal genera *Beauveria*, *Paecilomyces*, *Trichoderma*, *Ulocladium* and *Verticillium/Lecanicillium* are seldom mentioned explicitly in the titles or in the key words of papers concerning exposure to fungi. Papers about exposure to these fungi are therefore difficult to find. For this paper we have reviewed 383 randomly selected papers concerning exposure to airborne fungi. We compiled and standardized literature data in Tables 1-5. In some papers, the fungi are identified to species level, while in other papers the genus name is used, in some cases followed by sp. or spp. indicating the occurrence of "one" or "more than one species", respectively. In other papers, the name of the genera are not followed by sp. or spp. and therefore do not indicate whether more than one species occurred. In all cases we have chosen to retain the original names used in the studied literature.

To accommodate for variations in methods used for quantification of fungal exposure level in the reviewed literature we have grouped all findings into categories of exposure. The "Exposure level" is the numbers of colony forming units (cfu) of the fungus taxon per m^3 of air. The "Concentration in dust" is cfu of the fungus taxon per mg of dust. In some papers the measure was per mg dry dust, and in others per mg dust and it is not possible to convert, e.g. mg dust to mg dry dust, as the humidity content of dust is very different. In contrast, we have converted all gram dust to milligram dust. The "Frequency of presence in samples" is the frequency of samples with the studied fungus. Finally, "% of all fungi" is the percentage of cfu of the fungi of interest for biological control relative to the total number of cfu of fungi.

The studied fungi are only found in papers where quantification is based on cultivation methods, thus only viable and cultivable spores were quantified. In some studies, sampling methods such as, e.g. the Anderson sampler or Impingers were used and the exposure level was measured as cfu/m^3. In other papers, sedimented dust has been studied and in these papers concentrations have been measured as cfu/mg dust. In other studies, the agar settle method was used and the results from these studies were often presented as frequency of occurrence in the samples or the percentage of the studied fungus in relation to all fungi. In some studies, several different types of agar media were used for plate dilution and the results presented for each respective agar medium. We have chosen only to present the results from the most successful agar medium which gave the highest cfu of fungi. The level of detailed description of the methods used for sampling and cultivation differed between the papers. We chose to use a standard set of key words useful to describe all data with a similar level of precision.

RESULTS AND DISCUSSION

***Beauveria* spp.** Several commercial biocontrol products based on *B. bassiana* are marketed around the world [20]. These products are targeted at various pest insects, including aphids, thrips, whiteflies, and outdoor pests e.g. Colorado potato beetles, European corn borer, and army worms. In addition, products based on the species *B. brongniartii* are also available for control of cockchafers *Melolontha melolontha* in Central Europe.

Airborne *Beauveria* spp. was only found in 9 studies and half of these were associated with hospitals. In a horse stable the exposure to *Beauveria* was found to be 250 cfu/m^3 (Tab. 1). This is a medium exposure level compared to the suggested TLV for a single species. In one study, the concentration of *Beauveria* was measured in indoor dust and it was low (Tab. 1). In most studies *Beauveria* constituted only 0.01-4% of total fungi (Tab. 1). In spite of the apparent low occurrence of *B. bassiana* in the air, an intracutaneous skin test of patients with recurrent bronchial obstructive complaints, showed that 6.8% of the patients had strong reactions to *B. bassiana* while, e.g. only 2.3% showed reaction to the more common fungus *Cladosporium* [16].

The genus *Beauveria* consists exclusively of species that infect insects and mites. By far the most common species is *B. bassiana* which is known to infect more than 700 host species, and is therefore often isolated from insects [126]. *B. bassiana* is also commonly isolated from soil samples [94] but it has also been found in the lung of an alligator [43]. It is assumed that one dispersal pathway of conidia of the fungus is by air currents [57, 95] and *Beauveria* spp. should thus be expected to occur in air samples collected in environments where potential insect hosts occur. However, from Table 1 it is evident that the genus is also found in indoor environments and the origin of the isolated propagules remains elusive. It is currently unknown to what extent conidia are released from mycosed cadavers upon exposure to air currents. The low prevalence of *Beauveria* spp. in air samples could therefore be due to limited release of conidia to the air. Alternatively, the limited occurrence in air samples could be caused by the slow growth of the species in the genus and may be overgrown by opportunistic fungal taxa on agar media. Selective agar media containing fungicides have been used successfully to isolate *B. bassiana* [95].

The current authoritative phylogeny of the genus is presented by Rehner & Buckley [115]. This study showed that the morphological species *B. bassiana* consists of 2 unrelated clades that should be separated taxonomically. Despite this, there are good morphological characters available, mostly conidial dimensions, to make valid identification to the species level in *Beauveria*; the taxonomy of the morphological species is also presented in Rehner & Buckley [115]. The separation of the morphological species *B. bassiana* in each of the 2 clades is only possible using DNA sequence data.

***Paecilomyces* spp.** The fungus *P. fumosoroseus* is marketed for whitefly control in different countries [20]. The species occurs naturally as a pathogen of different host insects [21], and can also be isolated from soil samples [94].

Table 1. Exposure to *Beauveria* in different environments.

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m^3]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
B. bassiana	Indoor	Nose of a new-born baby			3.3*		Nasal mucus	Sterile cotton swabs, agar	Austria	86
B. bassiana	Indoor	Nose of a 2 month old baby			3.3*		Nasal mucus	Sterile cotton swabs, agar	Austria	86
B. bassiana	Indoor	Hospital				Low	Airborne	Sartorius Gelatine Disposables, DG18, MEA	Austria	112
B. bassiana	Indoor	Homes				<0.1	Airborne	RSC centrifugal sampler, MEA	Argentina, 2002-2003	14
B. bassiana	Outdoor	Forest					Airborne	Agar settle plates, D0B50 medium	Japan, 1996-1999	123
Beauveria sp.	Agriculture	Horse stable	250				Airborne	Surface air sampler, MEA	Italy, 2001-2002	102
Beauveria	Indoor	Low-traffic carpets in homes		Range 0-6.7, GM: 0.025#		4	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Beauveria	Outdoor	Rooftop of a hospital	18			0.01*	Airborne	Andersen sampler, YMA	The Netherlands, 1981-83	16
Beauveria	Outdoor	Coastal area	Av: 2.6		28		Airborne	AGI-30 Impinger, MEA	Lithuania, 1999	132
Beauveria-like fungus	Indoor	Hospital				Predominant	From air filters	Collection of air filters, MYA	USA	124

Abbreviations used in the Tables:
Cultivation agar: CA: Cellulose Agar, CZ: Czapek agar, CZD: Czapek-Dox agar; DG18: Dichloran Glycerol agar; MYA: Mycological Agar; PDA: Potato Dextrose Agar; RBA: Rose Bengal Agar; SA: Sabourad's Agar, SBA: Sheep Blood Agar; SDA: Sabourad Dextrose Agar; SGA: Sabourad Glucose Agar, YMA: Yeast Morphology Agar; *Number followed by a * are values calculated from the data presented in the original papers or read from figures. #The concentration is converted from per gram dust to per milligram dust. Av – values mentioned as averages or means in the original papers, GM as geometric means and Med as medians. †dry dust.

A product based on the species *P. lilacinus* has recently been developed for control of soil borne plant pathogenic nematodes [76]. Another important insect pathogenic fungus is *P. farinosus* that can be isolated from the soil environment [94].

In contrast to *Beauveria* spp., airborne *Paecilomyces* species were found in many environments and countries. In some cases it was the dominant genus (Tab. 2). The insect pathogenic species *P. fumosoroseus* and *P. farinosus* were not reported from air samples in any of the papers listed in Table 2. In an indoor (hospital) and an outdoor environment in Europe, low exposures to *P. lilacinus* have been found (Tab. 2). At a sawmill, a high exposure to *Paecilomyces* was measured (600 cfu/m^3) and a low exposure was measured in a bedroom (about 2.2 cfu/m^3) (Tab. 2). In agricultural dust, *Paecilomyces* constituted about 40% of the total number of fungal taxa and was a dominating genus. *P. variotii* was found to be dominating in two indoor studies. Most *Paecilomyces* species were not identified to species level; when identification was made, *P. variotii* was the species most commonly found (Tab. 2).

The low presence of *P. lilacinus* in the air and the fact that it was found outdoors and at a hospital (Tab. 2) is supported by the findings that *P. lilacinus* is mainly soil-borne [31], but has also been found in, e.g. infested building materials [49], in the soil of potted plants at a hospital [127] and in flax seeds [54]. *P. fumosoroseus* and *P. farinosus* were not reported from air samples in any of the papers listed in Table 2 and this may be because these fungi are mainly insect parasites. Other *Paecilomyces* species, including unidentified species, were often found in the air in different environments (Tab. 2). This may be because *Paecilomyces* species are able to grow on different agriculturally related materials, including poultry feeds [28, 83], compost [79], wood chips [37, 50], hay, straw and ensilage [114], and in soils [29], and can grow on indoor air related materials [118] and in drinking water [48].

The anamorphic genus *Paecilomyces* is separated in 2 sections of which the sect. *Isarioidea* contains mesophilic species which are mostly pathogens of invertebrates [70, 88]. The other section, sect. *Paecilomyces*, comprises termophilic species [88]. *Paecilomyces* species are often

Table 2. Exposure to *Paecilomyces* in different environments.

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m^3]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
P. lilacinus	Indoor	Hospital	Av: 0.6				Airborne	Sartorius gelatine disposables samplers, MEA, DG18	Austria	112
P. lilacinus	Outdoor	Urban	<5				Airborne	Volumetric sieve sampler, Dermasel Agar	Italy	4
P. terricola	Indoor	Air-conditioners		0.06[†]		5.4[*]	From air-conditioners	Dust samples from air-conditioners CZ, glucose	Saudi Arabia, 1986	13
P. terricola	Outdoor	Roof, urban			8.3[*]		Airborne	Agar settle plates, CZ, cellulose	Saudi Arabia, 1981-82	1
P. variotii	Agriculture/industry	Dairy				Low	Airborne	Surface Air System sampler, PDA, SA	Italy, 1987-88	27
P. variotii	Agriculture/industry	Dairy				Low	Settled	Contact plates, PDA	Italy, 1987-88	27
P. variotii	Agriculture/industry	Carpentries				Low	Airborne	Surface Air System sampler, PDA, SA	Italy, 1987-88	27
P. variotii	Agriculture/industry	Carpentries				Low	Settled	Contact plates, PDA	Italy, 1987-88	27
P. variotii	Indoor	Hospital	Av: 0.1				Airborne	Sartorius gelatine disposables samplers, MEA, DG18	Austria	112
P. variotii	Indoor	Buildings heated by wood chips				Predominant	Airborne	Agar settle plates, MEA	Sweden	130
P. variotii	Indoor	Floors at water damaged school				3	Settled	Vacuum cleaner with a Vacumark mouthpiece, DG18	Denmark	109
P. variotii	Indoor	Floors at schools without water damage				8	Settled	Vacuum cleaner with a Vacumark mouthpiece, DG18	Denmark	109
P. variotii	Indoor	Hospitals				Predominant	From air filters	Collection of air filters, MYA	USA	124
P. variotii	Indoor	Flats			100		Airborne	Agar settle plates	Lithuania	99
P. variotii	Indoor	Homes				<0.1	Airborne	RSC centrifugal sampler, MEA	Argentina, 2002-03	14
P. variotii	Indoor	Flats				<<7	Airborne	RSC centrifugal sampler, RBA	Canada	97
P. variotii	Outdoor	Roofs of houses and stationary cars		2.4[†#]	6[*]	0.2[*]	Settled	CZD, celluloses	Egypt	2
Paecilomyces spp. mainly *P. bacillosporus*	Agriculture/industry	Combine harvester			61		Airborne	Different samplers, MEA	England, 1970-72	34

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
Paecilomyces: *P. terricola* (50%), *P. variotii* (34%), *P. roseolus* (16%)	Outdoor	Urban	Moderate		60*	1	Airborne	Agar settle plates, MEA	Kuwait, 1974-75	101
Paecilomyces sp.	Agri-culture/ industry	Wood chips heating plant					Airborne	Nuclepore filter method	Sweden	81
Paecilomyces sp.	Agri-culture/ industry	Swine confinement building		0.75†		<0.1	Settled	Samplers with filters, MEA	USA	32
Paecilomyces sp.	Agri-culture/ industry	Hay			37		Dust blown from hay	Casella cascade Impactor, MEA	England	52
Paecilomyces sp.	Indoor	Wooden schools			12		Airborne	Andersen Sampler, MEA	Finland	92
Paecilomyces sp.	Indoor	Houses			20	0.3	From air ducts	Dust was collected from the ducts on a filter, MEA, DG18	Finland	105
Paecilomyces sp.	Indoor	Living room	GM: 1.7				Airborne	Andersen Sampler, MEA	Taiwan, 1993	87
Paecilomyces spp.	Indoor	School					Airborne and settled	Andersen sampler and surface samples with a swab, MEA, DG18	Finland	68
Paecilomyces	Agri-culture/ industry	Sawmill	600			20	Airborne	Agar settle plates and Andersen sampler	Finland, 1978	129
Paecilomyces	Agri-culture/ industry	Work with corn					Airborne	Andersen sampler, MEA	USA, 1979-82	63
Paecilomyces	Agri-culture/ industry	Swine farm: feeding and manure handling tasks				22	Airborne	Andersen Sampler, DG18	Finland	113
Paecilomyces	Agri-culture/ industry	Swine farm: turning sawdust composting bed				40	Airborne	Andersen Sampler, DG18	Finland	113
Paecilomyces	Agri-culture/ industry	Swine farm: turning of the peat composting bed				40	Airborne	Andersen Sampler, DG18	Finland	113
Paecilomyces	Agri-culture/ industry	Swine farm with peat composting bed, no activity				39	Airborne	Andersen Sampler, DG18	Finland	113
Paecilomyces	Indoor	Hospital	Av: 0.01				Airborne	Andersen Sampler DG18	Taiwan	135
Paecilomyces	Indoor	Concrete schools			2*		Airborne	Andersen Sampler, MEA	Finland	92

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
Paecilomyces	Indoor	Storey buildings undergoing renovation				3.4	Airborne	Filter sampling, SDA	Egypt	59
Paecilomyces	Indoor	5th floor corridor of the, Kuwait University			6	3.9	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Paecilomyces	Indoor	Bedroom	GM: 2.2				Airborne	Andersen Sampler, MEA	Taiwan, 1993	87
Paecilomyces	Indoor	Low-traffic carpets in homes		Range 0-25, GM: 0.051#		16	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Paecilomyces	Indoor	Bedspread/ furniture surfaces in homes		Range 0-0.91, GM: 0.027#		9	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Paecilomyces	Outdoor	Rooftop of a hospital	16			0.1*	Airborne	Andersen Sampler, YMA	The Netherlands, 1981-83	16
Paecilomyces	Outdoor	Balconies	GM: 1.9				Airborne	Andersen Sampler, MEA	Taiwan, 1993	87
Paecilomyces	Outdoor	Balcony of Kuwait University			5	1.3	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Paecilomyces	Outdoor	Coastal area	Av: 1.4		25		Airborne	AGI-30 Impinger, MEA	Lithuania, 1999	132
Paecilomyces-like	Indoor	Homes, winter time	Av: 3817 Med: 243			6.7	Airborne	Andersen Sampler, PDA.	USA	125

difficult to identify and in some studies are placed in a group called "other fungi with hyaline spores" [15]. Luangsa-Ard *et al.* [88] and Hodge *et al.* (2005) argue that the species *P. fumosoroseus* and *P. farinosus* should be assigned to the genus *Isaria* (as *I. fumosorosea* and *I. farinosa*) comprising the species found in the sect. Isarioidea. In contrast, the nematode pathogen *P. lilacinus* should not be included in *Isaria* based on the current data [88]. This taxonomical revision thus leaves species in the sect. *Paecilomyces* as members of the genus *Paecilomyces*, while most insect pathogens should be included in *Isaria*. Many studies presented in Table 2 only identify *Paecilomyces* to the genus level, it is therefore not possible to conclude whether these isolates belong to any taxa of relevance for biocontrol. However, since these taxa are relatively conspicuous morphologically and only 2 studies report of the occurrence of *P. lilacinus* in air samples and no study reports the occurrence of *P. fumosoroseus*, we conclude that the human exposure to the relevant taxa in the air is very limited.

***Trichoderma* spp.** Species from the genus *Trichoderma* (*T. harzianum*, *T. viride* and *T. polysporum*) have been developed for biocontrol of soil borne plant diseases from the genera *Fusarium*, *Pythium*, *Phytophthora*, *Rhizoctonia*, and others [134]. Products have been developed and are used in greenhouses in Europe.

Airborne *Trichoderma* species have been found in many and different environments and countries, and in a few studies as the dominant taxon (Tab. 3). *T. harzianum* was only found in airborne dust in two studies. In homes in Saudi Arabia, *T. harzianum* was found both in bedrooms, drawing rooms, living rooms, kitchens and bathrooms. The highest concentrations were found in the living room [18], and the found concentration of 36 cfu/mg dust can be considered as high for a single species in an indoor environment. However, the concentration of *T. hamatum* found in indoor dust in a home in Riyadh was 10 times higher (Tab. 3). *T. polysporum* was not found in any of the studied papers. In contrast, *T. viride* was often found in the air and in one investigation it was present in 53% of the studied samples (Tab. 3). Concentrations of *T. viride* were only investigated in two studies and were found to be low. In a few studies, the exposure to different airborne *Trichoderma* species was measured, and in these studies the exposures were low. For example, the exposure to *T. koningii* at a hospital was measured to be about 1.7 cfu/m³ (Tab. 3).

T. harzianum was very rarely found in the air (Tab. 3). However, *T. harzianum* is able to grow saprophytically on different materials. For example, *T. harzianum* has been isolated from thermal insulation [106], in soils [29] and in mushroom compost [22]. *T. polysporum* was not found in the air (Tab. 3) even though it is widely distributed globally [31]. This may be because, according Domsch, Gams & Anderson, it is mainly found in soils and because it is not found frequently anywhere [31]. *T. viride*, which was often found in the air, is also one of the most widely distributed of all soil fungi and it also occurs as a colonizer of numerous plant materials [31], e.g. it has been found in hay, straw [84], and seeds [54, 98]. Other *Trichoderma* species were often found in the air and *Trichoderma* species have also been found in very different materials such as soils [29], mushroom compost [22], hay, straw and ensilage [114], from the stem base of wheat [116], poultry feeds [28, 83] compost [79], wood chips [37, 50], infested building materials [49], and in olive and olive cake [118].

T. harzianum is according to Domsch, Gams & Anderson [31], often received at the Centraalbureau vor Schimmelcultures (CBS) for identification, but this study shows that it is only seldom found in the air. One reason could be that the conidia of *T. harzianum* may not be easily released from growth materials to the air. This idea is supported by different studies. One study shows that *T. harzianum* growing on building materials only released up to 0.03% of its conidia when exposed to an airflow, while *Penicillium chrysogenum* released up to 4% of its spores [90]. Another study has shown that *Trichoderma* was found on the wall (wall scrapes) but not in the air [103]. In a third study, *T. harzianum* was found to be in the top 30 of the most abundant fungi in floor dust, but not in the top 30 of airborne fungi [66].

Eight different *Trichoderma* species were reported in the studies listed in Table 3, but *Trichoderma* isolates were often not identified to the species level. When species identification was performed, *T. viride* was found in 11 studies. *Trichoderma* species are the anamorphic state of the genus *Hypocrea*, and increasing numbers of *Trichoderma* species are being linked to *Hypocrea* teleomorphs [120]. A useful key to the morphological species of *Trichoderma* is presented by Gams & Bissett (1998). However, as with many microfungi, morphological characters are limited and species delimitations are difficult to make. The use of sequence data has revealed 80 phylogenetic species in *Trichoderma* [120] and a combination of morphology and molecular tools would be valuable for future identification of *Trichoderma* species. Samuels [120] provides a list of correctly identified *Trichoderma* species accompanied with GenBank accession numbers of sequence data that can be used for comparison of collected material. Furthermore, the online key available at http://nt.ars-grin.gov/taxadescriptions/keys/TrichodermaIndex.cfm provided by the Systematic Botany & Mycology Laboratory, USDA-ARS is useful for morphological identification. This website also provides the current nomenclature for the genus.

***Ulocladium* spp.** Fungi positioned in the genus *Ulocladium* are soil saprophytes and some species, including *U. atrum* and *U. oudemansii*, have potential for use in biocontrol of foliar diseases in horticulture, such as species from the plant pathogenic genera *Schlerotina* and *Botrytis* [80].

Airborne *Ulocladium* species were found in indoor and outdoor environments in different countries but only seldom in agricultural environments (Tab. 4). *U. oudemansii* has been found in indoor settled dust in Saudi Arabia and outdoor airborne dust in Greece (Tab. 4). In one of these studies, the concentration was 16 cfu/mg dust which may be considered as a medium concentration. Airborne *U. atrum* was found in 7 studies and mainly in subtropical countries. In these studies, the fungus had a high frequency of presence in samples. Thus, e.g. in an outdoor environment it was found in 42% of the studied samples (Tab. 4). In a forest, *U. atrum* exhibited 3.5% of all the measured fungi (Tab. 4). The concentration of *U. atrum* in dust was at the same level as the concentrations of other *Ulocladium* species presented in Table 4. The concentration of *U. atrum* in outdoor air in Egypt and in indoor settled dust in Saudi Arabia was between 30 and 50 cfu/mg dry dust (Tab. 4). The concentration of 50 cfu/mg of a single species can be considered as high, in comparison with concentrations of total cultivable fungi in other environments.

Two studies have shown that *Ulocladium* was present on building materials but not in the air [69, 103]. This indicates that spores of some *Ulocladium* species growing in indoor environments may not be easily released to the air, but on the other hand, some *Ulocladium* species were found in indoor environments in several studies (Tab. 4).

U. atrum and *U. oudemansii* were not found in airborne or settled agricultural dust (Tab. 4). This was unexpected since both species have been found on agricultural materials which are often transported to different environments including homes: Thus, *U. oudemansii* has been found in flax seeds [54], barley seeds [24] and grains [89] and *U. atrum* has been found on oat seeds [98], in soil [53] and bird seeds [60]. In addition, unidentified *Ulocladium* species have been found in, e.g. olive and olive cake [118], on barley grain [23], poultry feed [83] and infested building materials [49]. *U. chlamydosporum* which was found in settled dust (Tab. 3) has also been found in, e.g. the Dead Sea [19]. *U. botrytis* and *U. consortiale* which were also found in settled dust (Tab. 3) have been found, e.g. on hairs of rabbits and camels [12].

In about half of the studies, *Ulocladium* was identified to the species level and in these cases *U. atrum* and *U. chartarum* were the species most often identified. The phylogeny of *Ulocladium* has not been as intensively studied as several other fungal genera used for biocontrol. Recent studies have shown that *Ulocladium* forms a large monophyletic clade together with the genus *Alternaria* [111]. However, taxonomic revisions are necessary for some *Ulocladium* species since the genus is polyphyletic within the clade [111]. Future molecular work will presumably result in a revision of the nomenclature of *Ulocladium*.

Table 3. Exposure to *Trichoderma* spp. in different environments.

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
T. album	Indoor	Hospital ward	<15				Airborne	Custom-designed particle-sizing slit Sampler, SDA	Poland, 1981-82	10
T. album	Indoor	Homes			5		Airborne	Andersen Sampler	Poland, 1990s	47
T. hamatum	Indoor	Air-conditioners		3[†]	60[*]		From air-conditioners	Dust samples from air-conditioners CZ, cellulose	Saudi Arabia, 1986	13
T. hamatum	Indoor	Homes Riyadh, west		Av: 449[†]			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. hamatum	Outdoor	Roofs of houses and stationary cars		1.2[†#]	8[*]	0.1[*]	Settled	CZD, glucose	Egypt	2
T. harzianum	Indoor	Homes Riyadh, central		Av: 26			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. harzianum	Indoor	Homes Riyadh, west		Av: 18			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. harzianum	Indoor	Homes Riyadh, East		Av: 36			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. harzianum	Indoor	Homes Riyadh					Airborne	Agar settle plates, SDA	Saudi Arabia	18
T. harzianum	Indoor	Floors in homes					Settled	Vacuum cleaner, DG18 and MEA	USA	66
T. inhamatum	Indoor	Homes, Riyadh, central		Av: 16			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. koningii	Agri-culture/ industry	Sawmill					Settled saw dust	Sawdust from beneath the saw, SA	England	58
T. koningii	Indoor	Hospital	Av: 1.7		Low[*]		Airborne	Sartorius Gelatine Disposables, MEA, DG18	Austria	112
T. koningii	Indoor	Homes, Riyadh, east		Av: 23			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. koningii	Indoor	Homes Riyadh, central		Av: 11			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
T. koningii	Outdoor	Roof, urban			8.3[*]		Airborne	Agar settle plates, CZ, glucose	Saudi Arabia, 1981-82	1
T. lignorum	Indoor	Homes			3.3		Airborne	Andersen Sampler	Poland, 1990s	47
T. sympodia-num	Indoor	Homes			12		Airborne	Andersen Sampler	Poland, 1990s	47
T. viride	Agri-culture/ industry	Hay			0.1[*]		Dust blown from hay	Casella cascade Impactor, MEA	England	52
T. viride	Agri-culture/ industry	Hop farms			53[*]		Airborne	AP-2A personal filter sampler, MEA	Poland, 2000	46

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m^3]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
T. viride	Agri-culture/ industry	Herb processing plants					Airborne	Particle-sizing slit sampler, MEA	Poland	36
T. viride	Agri-culture/ industry	Carpentries				2.6	Airborne	Surface Air System sampler, PDA, SA	Italy, 1987-88	27
T. viride	Agri-culture/ industry	Carpentries			66		Settled	Contact plates, PDA	Italy, 1987-88	27
T. viride	Indoor	Indoor air-conditioners		0.3[†]	16[*]		From air-condi-tioners	Dust samples from air-conditioners CZ, cellulose	Saudi Arabia, 1986	13
T. viride	Indoor	Hospitals			Predomi-nant		From air filters	Collection of air filters, MYA	USA	124
T. viride	Indoor	Clinical areas at a hospital				4.2[*]	Airborne and settled	Agar settle plates and swabbing of surfaces, different agars	Iraq, 1996-97	100
T. viride	Indoor	Flats			35		Airborne	Agar settle plates	Lithuania	99
T. viride	Outdoor	Pinus nigra forest				18	Airborne	Agar settle plates, SDA	Turkey, 2001	26
T. viride	Outdoor	Roof, urban			17[*]		Airborne	Agar settle plates, CZ, glucose	Saudi Arabia, 1981-82	1
T. viride	Outdoor	Roofs of houses and stationary cars		3.0[†#]	12[*]	0.2[*]	Settled	CZD, cellulose	Egypt	2
Trichoderma sp.	Agri-culture/ industry	Wood chips terminal					Airborne	Nuclepore filter method	Sweden	81
Trichoderma sp.	Indoor	Buildings heated by wood chips				Pre-dominant specie	Airborne	Agar settle plates, MEA	Sweden	130
Trichoderma sp.	Indoor	Schools without water damage				1	Settled dust	Vacuum cleaner with a Vacumark mouth-piece, DG18	Denmark	109
Trichoderma sp.	Indoor	Hospital	Av: 0.5			Low[*]	Airborne	Sartorius Gelatine Disposables, MEA, DG-18	Austria	112
Trichoderma sp.	Outdoor	Roofs of houses and stationary cars		2.4[†#]	10[*]	0.1	Settled	CZD, glucose	Egypt	2
Trichoderma sp.	Outdoor	Urban	Low		6.7[*]	0.1	Airborne	Agar settle plate, MEA	Kuwait, 1974-75	101
Trichoderma sp.	Outdoor	Pinus nigra forest				11	Airborne	Agar settle plates, SDA	Turkey, 2001	26
Trichoderma sp.	Outdoor	Quercus forest				14	Airborne	Agar settle plates, SDA	Turkey, 2001	26
Trichoderma spp.	Indoor	School					Airborne	Andersen Sampler, MEA, DG18.	Finland	68

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
Trichoderma spp.	Indoor	Homes					Airborne	Impactor FH2, SDA	Germany	121
Trichoderma spp.	Indoor	Homes, winter time	Low			Low	Airborne	Andersen Sampler, PDA.	USA, 1993	125
Trichoderma spp.	Indoor	Damp homes				6	Wall	Wall scrapes, SGA	Croatia, 2005	78
Trichoderma	Agri-culture/ industry	Work with corn					Airborne	Andersen Sampler, MEA	USA, 1979-82	63
Trichoderma	Agri-culture/ industry	Sawmill					Settled	Collection of dust under saws, SA	USA	25
Trichoderma	Agri-culture/ industry	Swine farm: feeding and manure handling tasks				11	Airborne	Andersen Sampler, Hagem agar	Finland	113
Trichoderma	Agri-culture/ industry	Swine farm with saw dust com-posting bed, no activity				10	Airborne	Andersen Sampler, Hagem agar	Finland	113
Trichoderma	Agri-culture/ industry	Swine farm: turning of the peat composting bed				60	Airborne	Andersen Sampler, Hagem agar	Finland	113
Trichoderma	Agri-culture/ industry	Swine farm with peat composting bed, no activity				44	Airborne	Andersen Sampler, Hagem agar	Finland	113
Trichoderma	Agri-culture/ industry	Combine har-vester			<10		Airborne	MEA	England, 1970-72	34
Trichoderma	Indoor	Storey buildings undergoing renovation				3.4	Airborne	Filter sampling, SDA	Egypt	59
Trichoderma	Indoor	Houses			20	0.2	From air ducts	Dust collected from ducts on filters, MEA, DG18	Finland	105
Trichoderma	Indoor	Low-traffic carpets in homes		Range 0-8.3, GM: 0.029#		4	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Trichoderma	Indoor	Bedspread/ furniture surfaces in homes		Range 0-4.0, GM: 0.025#		4	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Trichoderma	Indoor	Schools			10*		Airborne	Andersen sampler, MEA	Finland	92
Trichoderma	Indoor	Living room	GM: 1.0				Airborne	Andersen Sampler, MEA	Taiwan, 1993	87
Trichoderma	Indoor	Bedroom	GM: 1.0				Airborne	Andersen Sampler	Taiwan	87
Trichoderma	Indoor	Basement					Wall	Wall scrapes	USA, 1997	103

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
Trichoderma	Indoor	Homes				0.5	Airborne	Agar settle plates, RBA	Turkey, 2000-01	137
Trichoderma	Outdoor	Forest				7	Airborne	Agar settle plates, SDA	Turkey, 2001	26
Trichoderma	Outdoor	Rooftop of a hospital	13			<0.1*	Airborne	Andersen Sampler, YMA	Netherlands, 1981-83	16
Trichoderma	Outdoor	Coastal area	Av: 11		83		Airborne	AGI-30 Impinger, MEA	Lithuania, 1999	132
Trichoderma	Outdoor	At a balcony of Kuwait University			3	0.6	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Trichoderma	Outdoor	On balconies	GM: 1.2				Airborne	Andersen Sampler, MEA	Taiwan	87

***Verticillium* spp.** The fungus *Verticillium*/*Lecanicillium lecanii* is applied in biological control of aphids and other pests mainly in greenhouse crops and has been used successfully to keep cuttings free of pests in ornamental production [40]. Two commercial products are available based on *V. lecanii* [20]. These products are marketed for the control of whiteflies and thrips and aphids.

Airborne *Verticillium* species were only found in 11 studies, but in different environments and countries. *V. lecanii* was found in connection with harvest of cereals in agricultural settings (Tab. 5). In these studies, the frequency of presence of the fungus in samples was high (up to 100%). The exposure to airborne *Verticillium* spp. was only measured in 2 studies, and at a waste composting facility the exposure was measured to be 49 cfu/m³ [112], which cannot be considered as high. In homes exposure to *Verticillium* was measured to be 314 cfu/m³, on average. This exposure can be considered as medium to high if *Verticillium* only represents a single species because thresholds are generally lower in indoor environments where people often spend a lot of time. In agricultural dust *Verticillium* sp. was present in very high concentrations reaching 3.6×10^4 cfu/mg dust (Tab. 5).

V. lecanii is one of the most common entomogenous fungi [31] which e.g. has been isolated from e.g. cattle flies [126]. *V. lecanni* was only found in the air in two studies and therefore the fungus does not seem to be aerosolized to a high extent from attached insects. *V. lecanii* has also been found on agricultural materials. Thus, *V. lecanii* has been found on, e.g. the dying leaves bracts of wheat [42] and from the stem base of wheat [116]. This association with wheat is in accordance with findings in Table 5 showing that exposure to this fungus can occur during harvest work. *V. lecanii* has also been found in other environments such as in water pipes [48] and in the swimbladder of farmed Baltic salmon [3]. *V. lecanii* was the only identified airborne *Verticillium* species, but unidentified species were also found in agricultural, outdoor and indoor environments (Tab. 5). On some materials other *Verticillium* species have been found, e.g. in hay and straw [84], in infested building materials [49], in soil [29], humidifier water of a patient with a humidifier lung [41], and in mushrooms [44].

The fungi relevant for biocontrol of insect pests comprise the species formally named *V. lecanii*, but this species is now contained in the genus *Lecanicillium*. Two commercial products are available based on *V. lecanii* [20]. These products are marketed for the control of whiteflies and thrips (Mycotal), and aphids (Vertalec). However, the current taxonomy separates these two products into 2 distinct species, *L. muscarium* (= Mycotal) and *L. longisporum* (= Vertalec) [9, 139]. The current species *L. lecanii* described in Zare & Gams [139] only includes fungi previously called *V. lecanii* that occur in tropical or subtropical regions. Furthermore, all fungi previously grouped in the genus *Verticillium* have been reclassified into 6 genera [17, 139]. Thus the reports of *Verticillium* species in the studies in Table 5 can probably not be assigned to any of these new genera because no species name is given. In contrast, the presence of *V. lecanii* in 2 of the studies must represent entomopathogenic species now recognised in *Lecanicillium*. However, accurate identification to the species level in the former genus *Verticillium* is necessary in order to draw conclusions about which of the new genera was actually present in the samples.

CONCLUSION

Based on the reviewed literature, the entomopathogenic fungi *B. bassiana* and *V. lecanii* (synonyms: *L. lecanii*/*L. muscarium*/*L. longisporum*) were only infrequently present in the air, and therefore in general people seem to be exposed only seldom to these fungi. On the other hand, when

Table 4. Exposure to *Ulocladium* spp. in different environments.

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
U. alternariae	Outdoor	Roofs of houses and stationary cars		9.4†#	2*	0.6*	Settled	CZD, glucose	Egypt	2
U. atrum	Indoor	Clinical areas at a hospital				15*	Airborne and settled	Agar settle plates and swabbing of surfaces, different agars	Iraq, 1996-97	100
U. atrum	Indoor	Air-conditioners		7.2†	43*		From air-conditioners	Samples from air-conditioners, CZ, glucose	Saudi Arabia, 1986	13
U. atrum	Indoor	Flats			37		Airborne	Agar settle plates	Lithuania	99
U. atrum	Indoor	Homes, Riyadh, central		Av: 33			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. atrum	Outdoor	Quercus forest				3.5	Airborne	Agar settle plates, SDA	Turkey, 2001	26
U. atrum	Outdoor	Roofs of houses and stationary cars		48†#	34*	3.3*	Settled	CZD, glucose	Egypt	2
U. atrum	Outdoor	Roof, urban			42*		Airborne	Agar settle plates, CZ, cellulose	Saudi Arabia, 1981-82	1
U. botrytis	Indoor	Homes, Riyadh		Av: 18			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. botrytis	Outdoor	Roofs of houses and stationary cars		40†#	28*	2.4*	Settled	CZD, glucose	Egypt	2
U. botrytis	Outdoor	Roof, urban			33		Airborne	Agar settle plates, CZ, cellulose	Saudi Arabia, 1981-82	1
U. chartarum	Indoor	Bedroom		Gm: 0.033#	55		From floors	Vacuum cleaner with ALK allergen mouth-piece, DG18	The Netherlands	133
U. chartarum	Indoor	Bedroom		Gm: 0.079#	56		From mattress	Vacuum cleaner with ALK allergen mouth-piece, DG18	The Netherlands	133
U. chartarum	Indoor	Houses in suburban/urban areas	Av: 2.2			0.57	Airborne	RSC centrifugal sampler, MEA	Argentina, 2002-03	14
U. chartarum	Indoor	Homes, Riyadh		26			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. chartarum	Outdoor	Roof, urban			8.3*		Airborne	Agar settle plates, CZ, glucose	Saudi Arabia, 1981-82	1
U. chartarum	Outdoor	Roofs of houses and stationary cars		1.8†#	6*	0.14*	Settled	CZD, cellulose	Egypt	2
U. chlamydosporum	Indoor	Homes, Riyadh		Av: 49			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. chlamydosporum	Outdoor	Roofs of houses and stationary cars		25†#	28*	1.5*	Settled	CZD, glucose	Egypt	2

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m³]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
U. consortiale	Indoor	Hospital	Av: 0.1			Low*	Airborne	Sartorius Gelatine Disposables, MEA, DG18	Austria	112
U. consortiale	Indoor	Homes, Riyadh		Av: 32			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. consortiale	Outdoor	Roofs of houses and stationary cars		18†#	4*	1.1*	Settled	CZD, glucose	Egypt	2
U. microsporum	Outdoor	Roofs of houses and stationary cars		0.30†#	10*	0.6	Settled	CZD, sodium chloride	Egypt	2
U. oudemansii	Indoor	Homes, Riyadh		Av: 16			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
U. oudemansii	Outdoor	In Athens, urban					Airborne	Agar settle plates, SGA	Greece, 1971	104
U. tuberculatum	Indoor	Homes, Riyadh		Av: 46			Settled	Vacuum cleaner, SDA	Saudi Arabia	18
Ulocladium: *U. atrum* (39%), *U. chartarum* (13%), *U. consortiale* (4%), *U. botrytus* (45%)	Outdoor	Urban	High		100*	7.1	Airborne	Agar settle plates, MEA	Kuwait, 1974-75	101
Ulocladium sp.	Indoor	Water damaged school				2	Settled	Vacuum cleaner with a Vacumark mouthpiece, DG18	Denmark	109
Ulocladium sp.	Indoor	Schools without water damage				1	Settled	Vacuum cleaner with a Vacumark mouthpiece, DG18	Denmark	109
Ulocladium sp.	Indoor	Home					On walls	Wall scrapes, SA	Slovakia, 1997	108
Ulocladium spp.	Indoor	Damp homes				8	On walls	Wall scrapes, SGA	Croatia, 2005	78
Ulocladium spp.	Outdoor	Residential area during sandstorms			34*		Airborne	Agar settle plates, and sedimentation in empty Petri dishes, PDA, SBA, CZD	Saudi Arabia, 1991-93	82
Ulocladium	Agriculture/ industry	Swine farm during feeding and manure handling tasks				11	Airborne	Andersen Sampler, DG18	Finland	113
Ulocladium	Agriculture/ industry	Greenhouses				Low	Airborne	Surface Air System sampler, PDA, SA	Italy, 1987-88	27
Ulocladium	Indoor	Hospital				0.8	Airborne	Agar settle plates, SGA	Senegal, 1990-91	45

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m^3]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
Ulocladium	Indoor	Storey buildings undergoing renovation				0.4	Airborne	Filter sampling, SDA	Egypt	59
Ulocladium	Indoor	In a corridor of the 5th floor, Kuwait University			3	1.6	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Ulocladium	Indoor	Non-mouldy residence			5		Airborne	Allergenco Impaction sampler or Zefron slit bioaerosol cassette, acrylic substrate	USA	15
Ulocladium	Indoor	Mouldy residence			6		Airborne	Allergenco Impaction sampler or Zefron slit bioaerosol cassette, acrylic substrate	USA	15
Ulocladium	Indoor	Paint chips in the living room					On paint chips	Wall scrapes	USA	103
Ulocladium	Indoor	Low-traffic carpets in homes		Range 0-29 GM: 0.7#		64	Settled	Gast rotaryvane vacuum pump with a filter, MEA, DG18, CA	USA	62
Ulocladium	Indoor	Bedspread/ furniture surfaces in homes		Range 0-16, GM: 0.21#		48	Settled	Gast rotary-vane vacuum pump with a filter, MEA, DG18, CA	USA	62
Ulocladium	Indoor	Homes			0.25*		Airborne	Surface Air System, DG18 and MEA	USA	66
Ulocladium	Indoor	Floors in homes			3.0*		Settled	Vacuum cleaner, DG18 and MEA	USA	66
Ulocladium	Outdoor	Coastal area			1		Airborne	Allergenco Impaction sampler or Zefron slit bioaerosol cassette, acrylic substrate	USA	15
Ulocladium	Outdoor	Inland area			3		Airborne	Allergenco Impaction sampler or Zefron slit bioaerosol cassette, acrylic substrate	USA	15
Ulocladium	Outdoor	Rooftop of a hospital	6			<0.1*	Airborne	Andersen sampler, YMA	The Netherlands, 1981-83	16
Ulocladium	Outdoor	Outdoors, urban				5.2	Airborne	Burkard volumetric sampler.	Saudi Arabia	5
Ulocladium	Outdoor	Park				<0.1	Airborne	Intra-nasal air sampler	Australia, 2002	51
Ulocladium	Outdoor	At a balcony of Kuwait University			11	2.1	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Ulocladium	Outdoor	Coastal area	Av: 5		36		Airborne	AGI-30 Impinger, MEA	Lithuania, 1999	132

Table 5. Exposure to *Verticillium* in different environments

Microorganism	Environment category	Specification of environment	Exposure level [cfu/m^3]	Concentration in dust [cfu/mg]	Frequency of presence in samples [%]	Percent of all fungi [%]	Kinds of dust	Sampling method and cultivation agar	Country and year	Reference
V. lecanii	Agriculture/industry	Combine harvester			100		Airborne	Different samplers, MEA	England, 1970-72	34
V. lecanii	Agriculture/industry	Harvesting of cereal crops			≈67*	9	Airborne		England	85
Verticillium sp.	Agriculture/industry	Swine confinement building		500†		≈ 21*	Settled	Polyvinyl chloride membrane filters, MEA	USA	32
Verticillium sp.	Agriculture/industry	Rotation of organic grown straw		Av: 756-36000		Predominant	Airborne	Millipore filter samplers, DG18	Denmark	91
Verticillium spp	Agriculture/industry	Inside combine harvester	2.1×10^3				Airborne	Different samplers and media	England	128
Verticillium spp.	Indoor	Homes					Airborne	Impactor FH2, SGA	Germany	121
Verticillium spp.	Outdoor	Residential area during sandstorms			16*		Airborne	Agar settle plates, and sedimentation in empty Petri dishes, PDA, SBA, CZD	Saudi Arabia, 1991-93	82
Verticillium	Agriculture/industry	Suburban yard waste composting facility	Av: 49			0.6	Airborne	Andersen Sampler, MEA	USA, 1995	67
Verticillium	Indoor	Storey buildings undergoing renovation				0.4	Airborne	Filter sampling, SDA	Egypt	59
Verticillium	Indoor	Homes	Av: 314 Med: 21			6.7	Airborne	Andersen Sampler, PDA	USA	125
Verticillium	Outdoor	At a balcony of Kuwait University			1	0.2	Airborne	Andersen Sampler, RBA	Kuwait, 1995	75
Verticillium	Outdoor	Urban			Rare		Airborne	Agar settle plates, CZ	Romania	110

V. lecanii was present, high concentrations were measured. It remains unknown whether the reported *Verticillium* species belong to the entomopathogenic genus *Lecanicillium* or not. Of the entomopathogenic *Paecilomyces* species, *P. fumosoroseus* or *P. farinosus* were not recorded in any study, while the nematode pathogen *P. lilacinus* was found in two cases, however at low concentrations. Many fungi were reported to belong to *Paecilomyces*. However, the lack of species identification makes conclusions about taxonomical status impossible. Whether these taxa are among species used for biocontrol remains unknown.

T. harzianum, *T. polysporum* and *U. oudemansii* were only rarely registered in the air and people are therefore usually not exposed to these fungi. On the other hand, *Trichoderma* and *Ulocladium* were often not identified to the species level, and sometimes high concentrations were measured or high frequencies were reported of fungi from these genera. There could potentially be a background exposure to *T. harzianum*, *T. polysporum* and *U. oudemansii* that is not documented. *T. viride* and *U. atrum* were detected frequently in the air and in different environments, and sometimes with a high frequency of presence in samples. In addition, *T. viride* and *U. atrum* may also constitute some of the unidentified *Trichoderma* and *Ulocladium* species. Exposure to *T. viride* and *U. atrum* could be even more common.

The literateur included in this study covers a broad range of investigated environments where fungal genera used for biocontrol were observed. A few of the environments could possibly have been treated with a BCA product, e.g. in greenhouses [27] and forests [26]. However, none of the papers report the use of BCA in the environments concerned. The measured fungi are most likely to originate from natural sources rather then added BCA products. The data found in this paper is therefore a representation of the background level of the fungal genera used for biocontrol, and can assist in the risk assessment of workers' exposure to BCA during handling of the products.

Fungal taxonomy is currently under considerable revision due to the widespread implementation of molecular markers. In future studies of airborne fungi it is therefore important to specify the taxonomy used for identification, which will provide readers with a guideline to make comparative studies. Ideally, the identifications should be based on DNA sequences for an explicit verification of species identity.

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