Organic dust and gaseous contaminants at wood working shops

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Airborne dust bioaerosols, ammonia and formaldehyde levels were determined inside two different (ventilated and unventilated) wood working shops. Airborne dust was found at mean values of 4.3 and 3.01 mg m^{-3}. These levels were higher than that recommended by Egyptian environmental law [1 mg m^{-3} indoor maximum allowable concentration (MAC) for hard wood]. The highest frequency of aerodynamic size distribution of airborne wood dust was detected at a diametre of 4.9 μm which was recorded during a machining operation. Total viable bacteria were recorded at a mean value of 10^4 colony-forming units (cfu) m^{-3}, whereas Gram-negative bacteria were found at very low counts (10^1 cfu m^{-3}). Fungi levels were recorded at mean values of 10^3 and 10^2 cfu m^{-3} in ventilated and unventilated shops, respectively. *Penicillium*, *Aspergillus*, *Cladosporium* and yeast species were dominant isolates. Moreover, actinomycetes were found at a mean value of 10^3 cfu m^{-3} at both workshops. Ammonia was detected in relatively low concentrations (mean values of 457 and 623 μg m^{-3}), whereas formaldehyde was found in relatively moderate concentrations (mean values of 0.42 and 0.64 ppm).

Introduction

A number of industrial environments, such as cotton mills, textiles plants, woodshops and sewage plants, contain organic dust and gases, which may cause health hazards. Many investigators[1–3] have found that mucociliary function is impaired in workers exposed to wood dust in the furniture industry for more than 10 years. Acheson *et al.*[4] found a relationship between adenocarcinoma of the paranasal sinuses of workers and exposure to wood dust in the furniture industry. The incidence of adenocarcinoma was about 1000 times greater in wood workers than in other people.[5] Moreover, exposure to wood dust produced pathological changes in the lung,[6] and certain types of wood produced dermatitis, rhinitis, asthma and allergenic responses.[7]

The exposure to airborne bacteria, fungi, endotoxins and viruses causes potential biological hazards.[8] Wood and wood products in saw mills, wood working shops and the furniture industry yield both airborne bacteria and fungi.[9] Saw dust containing different types of fungi causes sequoiosis.[10] *Aspergillus fumigatus* was reported to cause tremorgenic mycotoxins in saw mills.[11] Alveolitis and respiratory diseases among wood timber workers were attributed to exposure to *Rhizopus microsporus* var *rhizopodiformis*[12] and *Penicillium* species.[13] Gram-negative bacteria of plant origin are sources of endotoxins and allergens.[9,14] Rylander[15] suggested that dyspnoea among workers at cotton mills is due to invasion of the airway by leucocytes in response to inhalation of Gram-negative bacteria. A positive relation was found between acute effects of lung function and the level of endotoxins.[16] In addition, *Pseudomonas*, *Klebsiella*, *Alcaligenes* and *Acinetobacter* are common in organic dust and pose potential hazards to exposed workers.[17]

Formaldehyde is found throughout the environment. It originates from many sources, such as incinerators, photochemical smog and engine exhaust.[1] Formaldehyde is used to produce synthetic resins, adhesives, cosmetics, dyes, fibrewood, plastic, rubber, textiles and insulation foam.[18] Irritation of the respiratory tract, eyes and skin is the principal hazard in humans exposed to formaldehyde.[19] Moreover, formaldehyde must be handled as a potential carcinogen[20] and as a mutagen.[21] In contrast, ammonia occurs in body metabolites and in breath, and is a strong toxin to the eyes.[22]

The present study aims to evaluate the levels and characters of airborne dust, bioaerosols (bacteria, Gram-negative bacteria, fungi and streptomycetes), ammonia and formaldehyde in work zones of wood working shops, and to determine the population of microorganisms that have potential toxic effects or emit volatile organic compounds.

Materials and methods

Description of wood working shops

Two wood working shops were selected. They differ in area, location, number of workers, load of work and ventilation conditions. The first workshop (located at the National Research Centre) has natural and mechanical (fans) ventilators, whereas the second shop (located at Elharam Street) has neither natural nor mechanical ventilators. Both workshops use a wide range of soft and hard woods. They produce a range of wood products, such as desks, chairs and furniture.

Air sampling

Air samples for dust, microbial and chemical indicators were collected indoors, 2 h after starting work, during working and after stopping of the wood machines. These samples were collected at a height of 1.5 m above ground level.

Dust sampling

The mass concentrations of airborne dust in the work zone were collected on conditioned preweighed cellulose nitrate filter membranes (pore size, 0.45 μm; diameter, 25 mm). Sequential half-hour samples were obtained using an open face holder and sampling pump calibrated to draw 5 l min^{-1}. The filters were conditioned in a desiccator before weighing and the concentrations of airborne dust was calculated in mg m^{-3}.

Microbial analysis

Air samples were collected using a slit sampler (Model TVπ 818N° 5587, CAEπAHO B CCCP) at a flow rate of 25 l min^{-1}. The sampling periods ranged between 1–4 min. Trypticase soya agar, 3% malt extract agar, MacConkey agar and starch casein agar (Difco, Detroit, MI) media plates were used for the

counting of total viable bacteria, fungi, Gram-negative bacteria and actinomycetes, respectively. Bacteria/environmental plates were incubated at 25–30 °C for 48 h, whereas Gram-negative bacterial plates were incubated at 37 °C. Fungi and actinomycetes plates were incubated at 28 °C for 7 days. Fungi isolates were identified microscopically, whereas bacterial isolates were identified according to Bausum *et al.*[23] The aerodynamic diameter (*ad*) of the dust and fungi spores was calculated from the density, shape and physical diameter of the particles (physical diameter measured microscopically).

Chemical analysis

Sequential 1 h air samples for formaldehyde and ammonia were collected using a pump calibrated to draw 1 l min^{-1} at the breathing zone. The indoor air concentration of total aliphatic aldehyde (as formaldehyde) was determined using the 3-methyl-2-benzothiazolone hydrazone hydrochloride (MBTH) method.[24] Ammonia levels were determined using dilute sulfuric acid as an absorbing reagent, followed by reaction with Nessler's reagent and colorimetric estimation.[25]

Statistical analysis

The linear correlation coefficient (r) and Student's t test ($p = 0.05$) were used to examine the relationships between viable agents and airborne dust and gases.[26] Logarithmic transformation ($\log x+1$) was used to normalize microbial data.

Results

A total of 14 trials were carried out at both workshops. High airborne levels were found at both wood workshops. The highest concentration was found during a machining operation (8.9 mg m^{-3}), whereas the lowest was detected when machines were inoperative (0.65 mg m^{-3}) (Table 1). The aerodynamic diameters of airborne wood dust ranged between 1.2 and 20 μm. The highest frequency (17%) of aerodynamic size distribution was 4.9 μm, which was detected during a machining operation. Moreover, phase contrast microscopy showed that dust particles are fibrous, flaky and cylindrical in shape.

Bioaerosol concentrations

Total viable bacterial counts ranged between 10^3 and 10^4 colony-forming units (cfu) m^{-3}, with a mean value of 10^4 cfu m^{-3} in both workshops (Table 1). Gram-negative bacteria were found in the range 0–3.12×10^2 cfu m^{-3} (with a mean value of 70 cfu m^{-3}) and 0–66 cfu m^{-3} (with a mean value of 38 cfu m^{-3}) in ventilated and unventilated workshops, respectively (Table 1).

The identification of bacterial isolates is summarized in Table 2. Gram-positive bacteria (cocci and bacilli) constituted 92.85%, whereas Gram-negative bacteria comprised 7.15% only. *Bacillus*, *Diplococcus*, *Staphylococcus* and *Micrococcus* were dominant, whereas *Sarcina* and *Tetrads* were isolated but in lower counts. *Acinetobacter* was the dominant Gram-negative bacteria, and *Alcaligenes*, *Flavobacterium* and *Pseudomonas* were also isolated (Table 2).

Table 2 Identification of bacterial isolates

Type	No.	%
Gram-positive		
Diplococcus	54	17.53
Micrococcus	36	11.69
Staphylococcus	44	14.28
Sarcina	36	11.69
Tetrads	16	05.2
Bacillus	100	32.46
Gram-negative		
Acinetobacter	10	3.25
Alcaligenes	4	1.3
Flavobacterium	6	1.95
Pseudomonas	2	0.65
Total isolates	308	100

Fungi levels averaged between 9.2×10^2 and 3.5×10^3 cfu m^{-3} and between 80 and 3.6×10^2 cfu m^{-3} in ventilated and unventilated woodshops, respectively (Table 1). The mycological examination of 222 isolates is recorded in Table 3. *Penicillium* spp., *Aspergillus* spp., *Cladosporium* and yeasts were the predominant fungi. *Alternaria*, *Helminthosporium*, *Mucor*, *Rhizopus*, *Spicaria*, *Fusarium* and *Scopuloriopsis* were found, but in lower counts. *Penicillium* spp., *Aspergillus niger*, *Asp. versicolor*, *Cladosporium* and yeasts were found in higher counts in the ventilated workshop than in the unventilated one. In contrast, *Asp. flavus*, *Spicaria* and *Scopuloriopsis* were detected in the unventilated workshop only.

Table 3 shows the physical and measured aerodynamic diameters of the fungal isolates. The aerodynamic size is a critical factor for evaluating respiratory exposure to fungal spores. *Penicillium*, *Aspergillus* spp., *Cladosporium* (short axis diameter), *Spicaria* and *Scopuloriopsis* have aerodynamic diameters (*ad*) of less than 5 μm, and can enter the gas exchange tissues of the lung. On the other hand, *Helminthosporium*, *Mucor*, *Alternaria* and *Rhizopus* have aerodynamic diameters greater than 5 μm, and may be deposited in the nasal region.

Actinomycetes (streptomycetes) were found in relatively high counts (a mean value of 10^3 cfu m^{-3}) in both workshops. Streptomycetes spores are well suited for deep penetration into the lung on inhalation (*ad* between 1 and 1.5 μm).

Gas concentrations

Ammonia was found at relatively low levels in both workshops. It was detected at a relatively higher mean value, 623 μg m^{-3}, in the unventilated workshop than in the ventilated workshop (a mean value of 457 μg m^{-3}). Formaldehyde levels ranged

Table 1 The range and mean concentrations of air indicators at two wood working shops

	Ventilated workshop (site 1)		Unventilated workshop (site 2)	
Indicator	Range	Mean	Range	Mean
Suspended particulate/mg m^{-3}	0.65–8.928	4.307	0.66–8.930	3.01
TVBC/cfu m^{-3}	3.1×10^3–2.3×10^4	1.3×10^4	6.9×10^3–3.5×10^4	1.39×10^4
Gram-negative/cfu m^{-3}	0–3.12×10^2	7.0×10	1.6×10–6.6×10	3.8×10
Total fungi/cfu m^{-3}	9.2×10^2–3.5×10^3	2.3×10^3	8×10–3.6×10^2	2.01×10^2
Actin/cfu m^{-3}	6.4×10–8.23×10^3	3.36×10^3	0–6.78×10^3	1.72×10^3
Ammonia/μg m^{-3}	300–630	457	528–714	623
Formaldehyde/ppm	0.28–0.54	0.42	0.48–0.84	0.64

TVBC, total viable bacterial count; Actin, actinomycetes.

Table 3 The predominant fungi genera and their physical and aerodynamic diameters[a]

Type	Site		Physical diameter/ μm	Aerodynamic diameter/μm
	No. 1	No. 2		
Penicillium spp.	75	25	1.7–3.5	1.6–3.1
Aspergillus niger	17	1	3.5–4.9	3–4.5
Asp. versicolor	18	—	2.5–3.5	2–3.5
Asp. flavus	—	6	2.5–3.5	2.3–3.1
Cladosporium spp.	25	1	(2.8–5) × (5–14)	2.5–4.5
Alternaria	2	1	(7–10) × (10–17)	6–10
Helminthosporium	1	—	(4.6–10) × (9–17)	4.6–9
Mucor	4	—	10–14	10–12
Rhizopus	2	1	4.9–14	4.6–12
Spicaria	—	1	2.5–4.9	2.4–4.5
Scopuloriopsis	—	2	3–4	2.5–3.5
Fusarium	1	—	(2–3.1) × (4.6–17)	2–3.1
Yeasts	32	3	2.8–3.5	2.8–3.8
Non-sporulating mycelia	4	—	—	—

[a]—, not detected.

between 0.28 and 0.84 ppm. It was detected at mean values of 0.63 ppm and 0.42 ppm in the unventilated and ventilated workshops, respectively (Table 1).

Table 4 shows the correlation coefficients (r) between bioaerosols and airborne dust and gases. There are positive and sometimes significant relationships between bacterial and actinomycetes counts and airborne dust, ammonia and formaldehyde (Table 4). In contrast Gram-negative bacteria were insignificantly and negatively related with airborne dust, ammonia and formaldehyde. A positive relation ($r = 0.37$) and a negative relation ($r = -0.53$) were detected between fungi and airborne dust in ventilated and unventilated workshops, respectively. Moreover, negative relations were recorded between fungi and gases in both shops.

Discussion

There are few publications concerned with the levels of airborne dust, aerosols and gases inside wood working shops. A wide range of values of airborne dust were obtained in the present study. The detected levels were higher than the industrial maximum allowable concentration (MAC) recommended by the Egyptian Environmental Affairs Agency (EEAA)[27] (1 mg m^{-3} for hard wood). Hounam and Williams[28] found airborne dust in the range 1–25 mg m^{-3}, with a median of 4.2 mg m^{-3} and a mean value of 5.9 mg m^{-3}, in five large wood factories. Al-Zuhair *et al.*[29] found airborne dust at an average of 0.72–4.4 mg m^{-3} in a wood working zone. The coarsest dust size was produced during machining operations, whereas the finest was detected when machines were inoperative due to the removal of the coarser fractions by gravity. The dust samples of the ventilated workshop (site 1) were greyer in colour than those of the unventilated workshop (site 2). This indicated that general atmospheric pollution rather than wood dust had infiltrated from outdoors to indoors. Wood particles are fibrous and flaky in character and have a large area, which could facilitate the leaching of soluble toxic constituents.[30]

Table 4 The correlation coefficients between bioaerosols and suspended particulate and gaseous indicators at the two wood working shops

Agent	SPM		NH_3		HCHO	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
TVBC	0.91[a]	0.89[a]	0.75	0.74	0.81	0.74
Total fungi	−0.53	0.37	−0.51	−0.1	−0.197	−0.022
Gram-negative	−0.36	−0.24	−0.55	−0.21	−0.62	−0.181
Actin	0.87[a]	0.94[a]	0.73	0.78	0.92[a]	0.73

[a]Significant ($p = 0.05$). SPM, suspended particulate matter; TVBC, total viable bacterial count; Actin, actinomycetes.

In the present study, total viable bacterial counts exceeded the average (3.4×10^3 to 10^4 cfu m^{-3}) recommended for indoor environments.[31] However, Gram-negative bacteria were found in low counts. Airborne Gram-negative bacteria were detected at a mean concentration of 33 cfu m^{-3} in a saw mill and ranged between 870 and 1020 cfu m^{-3} at a large wood furniture factory.[29] Gram-positive (cocci and bacilli) and Gram-negative (*Acinetobacter*, *Alcaligenes*, *Pseudomonas* and *Flavobacterium*) types were dominant isolates. Gram-positive cocci (*Staphylococcus* and *Micrococcus*) are normally predominant indoors.[32] However, the presence of Gram-positive bacteria indicates overcrowding and inadequate ventilation, whereas Gram-negative bacteria indicate the presence of a contamination source.[33] *Acinetobacter calcoaceticus*, Gram-negative and coccoid bacteria are common in airborne dust, and cause pulmonary infections.[34] Moreover, *Bacillus* species are numerous in organic dust and are related to allergic alveolitis.[35] Milanowski[36] found cocci in high counts in dusts of plant origin.

The observed fungi counts are in agreement with Al-Zuhair *et al.*,[29] who detected fungi at a mean concentration of 1.1×10^3 cfu m^{-3} at a wood workshop. Fungi were recorded in higher counts in the ventilated than in the unventilated workshop due to the large release of spores by the effects of the air current.[37] *Penicillium* and *Aspergillus* species were dominant in both workshops in the present study. *Aspergillus* and *Penicillium* are normal indoors, whereas *Cladosporium* and *Alternaria* are of outdoor origin.[38] In the present study, *Cladosporium* and yeasts were detected in relatively high counts in the ventilated workshop. This indicates that the outdoor air contaminants are infiltrated indoors. Reponen[39] found *Cladosporium* and yeasts in higher counts outdoors than indoors. Moreover, *Penicillium*, *Aspergillus*, *Cladosporium*, *Fusarium*, *Mucor* and *Rhizopus* were dominant in cotton mills,[40] while *Penicillium* and *Rhizopus* were dominant in wood workshops.[11] Aflatoxin inhalation was reported as a problem for workers exposed to corn and peanut dusts,[41] and mycotoxins are produced by *Penicillium* and *Aspergillus*.[42]

The relatively high counts of streptomycetes may be due to their presence at large levels in dusts of plant origin. Their presence in indoor environments is an indication of contamination.[33] Actinomycetes are important air contaminants in agriculture and waste composting plant.[43] Several types of actinomycetes are associated with allergenic alveolitis.[44] Also, streptomycetes species stimulate lung macrophage reactions, which lead to inflammation and tissue injury.[45]

In the present study, formaldehyde was detected at relatively moderate levels. Volatile metabolites produced by fungi can cause a musty odour in mouldy buildings.[46] Aldehyde, butanol, short chain alcohols and 1-octen-3-ol-but-ethylacetate are dominant volatile materials produced by fungi.[10] In contrast, ammonia was detected at low levels. The threshold limit of ammonia is 25 ppm.[27] Continued exposure to formaldehyde at concentrations ranging between 0.1 and 0.5 ppm is irritating to humans.[20] However, a very low occupational threshold level of formaldehyde (0.75 ppm) is recommended in the USA (value given by the Occupational Safety and Health Administration, OSHA) and 0.5 ppm in Germany.[47]

The positive relationships between the viable fraction (bacteria and fungi) and airborne dust may be due to the fact that the viable fraction is mainly associated with large dust particles.[48] Natural volatile gases from vegetation, such as α-pinene and terpenes from shrubs and herbs, act as aerial disinfecting agents against air microorganisms.[49] Reynolds *et al.*[50] found a negative relation between Gram-negative bacteria and NH_3. Formaldehyde, CO, and O_3 are known to damage

cell wall membranes.[51] However, the outer sheath of streptomycetes is protected against physical damage and drying.[52]

Conclusions

(1) Airborne dust varied between 0.66 and 4.4 mg m^{-3}, and the highest frequency of dust size distribution was 4.9 μm, during machining operations.

(2) High levels of fungi, bacteria and actinomycetes were recorded, whereas Gram-negative bacteria were found in low counts.

(3) Low levels of formaldehyde and ammonia were detected, and long exposure to these gases can be very dangerous.

(4) Most of the wood workers are exposed to a complex biological and chemical mixture.

(5) Chemical gas may preserve or kill airborne organisms.

(6) The present levels of bioaerosols, airborne dust and gases are an indication of the inadequate ventilation and overcrowding of both shops.

(7) An occupational hygiene study must be carried out to assess the potential health risks arising from exposure to airborne contaminants in the wood working shops under investigation.

References

1 A. Black, J. C. Evans, E. H. Handfield, R. C. Macbeth, A. Morgan and M. Walsh, *Br. J. Ind. Med.*, 1974, **31**, 10.
2 C. B. Mckerrow, M. McDermott, J. C. Gilson and R. S. F. Schilling, *Br. J. Ind. Med.*, 1958, **15**, 75.
3 M. A. El Batawi, R. S. F. Schilling, F. Valic and J. Walford, *Br. J. Ind. Med.*, 1964, **21**, 13.
4 E. D. Acheson, R. H. Cowdell, E. Hadfield and R. G. Macbeth, *Br. Med. J.*, 1968, **2**, 587.
5 International Labour Office, *Encyclopaedia of Occupational Health and Safety*, International Labour Office, Lyon, 3rd edn., 1983.
6 L. Michaels, *Can. Med. Assoc. J.*, 1967, **96**, 1150.
7 L. J. Findley, *Br. J. Ind. Med.*, 1972, **29**, 343.
8 S. Clark, R. Rylander and L. Larsson, *Am. Ind. Hyg. Assoc. J.*, 1983, **44**(7), 537.
9 J. Lacey and J. Dutkiewicz, *J. Aerosol Sci.*, 1994, **25**(8), 1371.
10 H. I. Cohen, T. C. Merigan, J. C. Kosek and F. Eldridge, *Am. J. Med.*, 1967, **43**, 785.
11 C. J. Land, K. Hult, R. Fuchs, S. Hagelberg and H. Lundstrom, *Appl. Environ. Microbiol.*, 1987, **53**(4), 787.
12 W. Eduard, Ph.D. Thesis, Agriculture University, Wageningen, The Netherlands, 1993.
13 A. H. W. Van Assendelft, M. Raitio and V. Turkia, *Chest*, 1985, **87**, 394.
14 J. Dutkiewicz, in *Biodeterioration Research 2*, ed. G. C. Llewellyn and C. E. O'Rear, Plenum Press, New York, 1989, pp. 533–547.
15 R. Rylander, in *XIX International Conference on Occupational Health, Dubrovnik, Yugoslavia, 1978*, Institute of Medical Research and Occupational Health, Zagreb, 1978, p. 272 (Abstracts).
16 R. M. Castellan, S. A. Olenchock, K. B. Kinsley and J. L. Honkinson, *N. Engl. J. Med.*, 1987, **317**, 605.
17 J. Dutkiewicz, in *Proceedings of the International Symposium on Work-Related Respiratory Disorders Among Farmers, Kuopio, Finland, 11–16 August 1985*, ed. E. O. Terho, K. Husman and T. Kauppinen, *Eur. J. Respir. Dis.*, 1987, **71** (Suppl. 154), 71.
18 G. M. Marsh, *Br. J. Ind. Med.*, 1982, **39**, 313.
19 N. H. Proctor and J. P. Hughes, *Chemical Hazards of the Workplace*, J. B. Lippincott, Philadelphia, 1978.
20 R. W. Hart, A. Terturro and L. Neimeth, *Environ. Health Perspect.*, 1984, **58**, 323.
21 C. Auerbach, M. Moutschen-Dohmen and J. Moutschen, *Mutat. Res.*, 1977, **39**, 317.
22 N. J. Smith, *Handbook of Ocular Toxicity*, Publishing Sciences Group, Acton, MA, 1976.
23 H. T. Bausum, S. A. Schaub, M. J. Small, J. A. Highfill and C. A. Sorber, Bacterial aerosols resulting from spray irrigation with waste water, US Army Medical Bioengineering Research and Development Laboratory, *Technical Report 7602*, ADA 028359, 1976, Fort Detrick, Frederick, MD.
24 R. M. Harrison and R. Perry, *Handbook of Air Pollution Analysis*, Chapman and Hall, London, New York, 2nd edn., 1986.
25 L. L. Morr and M. S. Cresser, *Environmental Chemical Analysis*, International Textbook Company, NY, 1985.
26 S. Gregory, *Statistical Methods and the Geographer*, Longmans, London, 1st edn., 1963.
27 Egyptian Environmental Affair Agency (EEAA), Environmental Protection Law, No. 4, 1994, EEAA, Cairo, 1995.
28 R. F. Hounam and J. Williams, *Br. J. Ind. Med.*, 1974, **31**, 1.
29 Y. S. Al-Zuhair, C. J. Whitaker and F. F. Cinkotai, *Br. J. Ind. Med.*, 1981, **38**, 339.
30 L. Hanslian and K. Kadlec, *Pracovni Lekarstvi*, 1964, **16**, 276.
31 A. Nevalainen Bacterial aerosol in indoor air (dissertation), *NPHIA3/1989*, National Public Health Institute, Helsinki, Finland, 1989, pp. 66–69.
32 P. Morey, J. Otten, H. Burge, M. Chatigny, J. Feeley, F. M. La Force and K. Peterson, *Appl. Ind. Hyg.*, 1986, **1**, R19.
33 American Conference of Governmental Industrial Hygienists (ACGIH), Step two, on-site investigation, pp. 1–8, fungi, pp. 1–10, bacteria, pp. 1–7, in *Guidelines for the Assessment of Bioaerosols in the Indoor Environment*, ed. Committee on Bioaerosols, ACGIH, Cincinnati, OH, 1989.
34 L. G. Cordes, E. W. Brink, P. J. Checko, A. Lentnek, R. W. Lyons, P. S. Hayes, T. C. Wu, D. G. Tharr and D. W. Frozer, *Ann. Int. Med.*, 1981, **95**, 688.
35 C. L. Johnson, I. L. Bernstein, J. S. Gallagher, P. F. Benventre and S. M. Brooks, *Am. Rev. Res. Dis.*, 1980, **122**, 339.
36 J. Milanowski, *Pneum. Pol.*, 1988, **56**, 100 (in Polish).
37 P. H. Gregory, *The Microbiology of the Atmosphere*, Leonard Hill Books, Plymouth, 1973.
38 J. D. Miller, *Atmos. Environ.*, 1992, **26A**, 2163.
39 T. Reponen, *Aerosol Sci. Technol.*, 1995, **22**, 11.
40 J. Lacey and M. E. Lacey, *Ann. Occup. Hyg.*, 1987, **31**, 1.
41 W. R. Burg and O. L. Shotwell, *J. Assoc. Off. Anal. Chem.*, 1984, **67**, 309.
42 V. Betina, in *Mycotoxins. Production, Isolation, Separation and Purification*, ed. V. Betina, Elsevier Biomedical Press, Amsterdam, 1984, pp. 415–442.
43 J. Lacey, in *Bergey's Manual of Systematic Bacteriology*, ed. S. T. Williams, M. E. Sharpe and J. G. Holt, Williams & Wilkins, Baltimore, MD, 1989, vol. 4, pp. 2573–2585.
44 D. Che, S. Liu and X. Huang, *Chinese Med. J. (Beijing)*, 1989, **102**, 563.
45 M. R. Hirvonen, A. Nevalainen, M. Makkonen, J. Monkkonen and K. Savolainen, *Environ. Toxicol. Pharmacol.*, 1997, **3**, 57.
46 R. A. Samson, *Eur. J. Epidemiol.*, 1985, **1**, 54.
47 Deutsche Forschungsgemeinschaft, *MAK- und BAT-Werter Liste 1997*, Wiley, Weinheim, 1997.
48 W. C. Noble, O. M. Lidwell and D. Kingston, *J. Hyg. Camb.*, 1963, **61**, 385.
49 J. C. Maruzzella, *J. Pharm. Sci.*, 1963, **52**(6), 601.
50 S. J. Reynolds, D. Parker, D. Vesley, K. Janni and C. Medilton, *Appl. Occup. Environ. Hyg.*, 1994, **9**(7), 493.
51 W. P. Won and H. Ross, *Appl. Microbiol.*, 1969, **18**(4), 555.
52 T. A. Reponen, S. V. Gazenko, S. A. Grinshpun, K. Willeke and E. C. Cole, *Appl. Environ. Microbiol.*, 1998, **64**(10), 3807.

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