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ORIGINAL ARTICLE

Effects of bioaerosol exposure on work-related symptoms among Swiss sawmill workers

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Abstract

Objective Exposure to bioaerosols in the occupational environment of sawmills could be associated with a wide range of health effects, in particular respiratory impairment, allergy and organic dust toxic syndrome. The objective of the study was to assess the frequency of medical respiratory and general symptoms and their relation to bioaerosol exposure.

Method Twelve sawmills in the French part of Switzerland were investigated and the relationship between levels of bioaerosols (wood dust, airborne bacteria, airborne fungi and endotoxins), medical symptoms and impaired lung function was explored. A health questionnaire was distributed to 111 sawmill workers.

Results The concentration of airborne fungi exceeded the limit recommended by the Swiss National Insurance (SUVA) in the twelve sawmills. This elevated fungi level significantly influenced the occurrence of bronchial syndrome (defined by cough and expectorations). No other health effects (irritations or respiratory effects) could be associated to the measured exposures. We observed that junior workers showed significantly more irritation syndrome (defined by itching/running nose, snoring and itching/red eyes) than senior workers. Lung function tests were not influenced by bioaerosol levels nor dust exposure levels.

Conclusion Results suggest that occupational exposure to wood dust in a Swiss sawmill does not promote a clinically relevant decline in lung function. However, the occurrence of bronchial syndrome is strongly influenced by airborne fungi levels.

Keywords Airborne fungi · Endotoxin · Lung function · Occupational health · Sawmill workers · Wood dust

Introduction

Wood dust is a potential health hazard in the wood processing industry. Wood dust is an organic vector for aeroallergens, fungi, bacteria and endotoxins. Dust from soft wood (fir, spruce white or red cedar) can be responsible for occupational asthma (reviewed in Demers et al. 1997) and can also cause simple irritation by action of fine particles resulting in non-allergic inflammation of eyes, nose, upper respiratory tract or skin. Working in the wood industry may therefore promote allergic and non allergic diseases, including rhinitis, conjunctivitis, dermatitis, chronic bronchitis, organic dust toxic syndrome, asthma and asthma-like syndrome (Pisaniello et al. 1992; Hessel et al. 1995; Halpin et al. 1994; Chan-Yeung et al. 1978; Wimander and Belin 1980; Vedal et al. 1986; Brooks 1981).

Respiratory symptoms among woodworkers can be explained by others factors than wood dust only. Airborne microorganisms may also contribute to the development of respiratory symptoms among wood workers (Eduard et al. 1994). The main biohazards associated with wood dust in sawmills are endotoxins (lipopolysaccharide protein complexes of the cell wall of Gram negative bacteria) and allergenic fungi (Douwes et al. 2000; Belin 1980). Airborne endotoxins have been suggested to cause respiratory

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symptoms (Vogelzang et al. 1998; Thorn et al. 1998). An endotoxin threshold limit value of 20 ng/m^3 described by Rylander (1997) is considered as the required level for triggering an effect on the airways. Clinical signs after endotoxin inhalations are non-specific: transient fever, chills, malaise, dry cough, mild dyspnea, chest tightness, myalgia, fatigue, headache and nausea. This self-limiting flu-like syndrome beginning within hours after exposure to high concentration of organic dust is known as organic dust toxic syndrome (ODTS) (Seifert et al. 2003).

Industrial use of wood is of significant importance in Switzerland. According to the Swiss Statistic Office 2001 data, 6,503 firms and 38,810 workers are registered in the wood industry. Most of the wood businesses are small family businesses: 87.3% of the firms count less then 10 employees. Less and less sawmills are still in activity in Switzerland: 450 sawmills were registered in 2001 against 970 sawmills in 1991. The annual Swiss sawing production reaches 1.5 million m^3 of wood. Coniferous trees represent 90% of the processed wood and broad-leaved trees 10%. Exploited species are mostly spruce and fir provided by the local forest.

At this point in time, occupational exposure limits for non-infectious microorganisms have not been established in Switzerland and very few studies in the wood industry have been able to show a relationship between exposure level to bioaerosols and respiratory impairment. The objectives of the study were to assess the frequency of several symptoms (itching/running nose, snoring, itching/red eyes; chronic cough, expectoration, wheezing, difficulty to breath, thoracic oppression, fever, joint pain, fatigue and malaise) and their relation to bioaerosol exposure on one hand, to correlate a possible lung function decline with exposure levels on the other hand.

The study was designed for workers exposed to the same species of fresh wood before any use of biocide or chemical agents. Working processes in the selected sawmills include sawing up barks into planks, planing and piling up the planks. Barks are generally stored outdoors for several months and regularly watered before being sawn.

Materials and methods

Study design

The study design is a cross sectional survey of male employees working in sawmills processing spruce and fir species. Nineteen sawmills geographically spread over the French part of Switzerland were first contacted for participation in the study. Ten (52.6%) responded positively. The main reason given for not participating was "no time to loose" or "technically not possible to stop the machine even for a short time". A written consent had to be obtained by the direction of the company and by volunteer employees. Participation was based on free consent and reached 91.4% (117/128). Ten wood companies represented by 12 geographically separated sawmills were visited between June 2002 and October 2002. They were of different importance in matter of volume of production (range 1–140 × 10^3 m^3) and number of employees (range 4–40): eight sawmills were small-scaled traditional firms in which production volume was not over 10,000 m^3. One sawmill had an annual production of 80,000 m^3 and the largest one had an annual production of 140,000 m^3.

Inclusion factors were male gender, working for at least 1 year in the company, working full time and not being exposed to organic dust outside the sawmill. Six volunteers have been excluded (3 women, 1 men working for less then a year, 1 men working part time, 1 absent), reducing the study population to 111 male woodworkers. The study was approved by the Ethics Committee at the University of Lausanne.

Occupational hygiene survey

Temperatures and relative air humidity were measured at each sampling site with an ECOLOG apparatus (Ecolog TH1, Elpro-Buchs). The mean summer temperature during sampling was 22 ± 1.0°C (17–28) and relative humidity was 55 ± 2.3% (45–66). At each sawmill air sampling was carried out at four or five different workstations, i.e. debarking, sawing, sorting, planing and in the sawing cockpit. All microorganism samples were taken in duplicate, twice in the morning and twice in the afternoon, for a total of 8 samples. For the filter-sampling devices, endotoxins and dust were sampled continuously for 4 h at stationary points.

Dust and bioaerosols assessment

All details about dust and bioaerosol (endotoxin, fungi and bacteria) sampling and analyses have been published elsewhere (Oppliger et al. 2005). Briefly, inhalable dust was sampled on glass fibre filters at a flow rate of 2.0 l/min using pocket pumps (MSA Escort Elf, Mine Safety Appliance Company, Pittsburgh, USA or SKC pocket pump 210-1002, SKC Inc., USA) and IOM heads (SKC Inc.). The filters were pre and post-weighed on an analytical balance (Mettler, 0.001 mg sensitivity). Bioaerosol measurement consisted of collecting bioaerosols in the work area in the same place as dust samples. Airborne bacteria and fungi were sampled with an impactor (MAS-100 Eco, MBV; Vevey, Switzerland) at a flow rate of 100 l/min. We sampled 20 l for fungi, 50 L for non-specific bacteria and 100 l for gram-negative bacteria. Total cultivable bacteria were impacted onto Tryptone soja agar plates, gram-negative bacteria onto MacConkey and fungi onto Dichloran glycerol plates (all from Oxoïd, Basel Switzerland). All plates were checked daily for colony counts. Results are expressed in Colony Forming Units (CFU) per cubic meter of air. Endotoxins were sampled onto polycarbonate filters (37 mm diameter, 0.4 um pore size) placed into a ready to use polystyrene cassette (endofree cassette, Aerotech Laboratories, Inc., Phoenix, USA). We sampled with a pocket pump (MSA Escort Elf, Mine Safety Appliance Company, or SKC pocket pump 210-1002, SKC Inc.) calibrated at 1.5 l/min. Endotoxins were extracted by shaking the filters at room temperature for 1 h in 10 ml of non-pyrogene water in a 50 ml conical polypropylene tube. Filter extraction solutions were vortexed vigorously prior to drawing a sample for endotoxin analysis using the kinetic Limulus amoebocyte lysate assay (LAL).

Questionnaire survey and lung function testing

General health was assessed at the workplace during the morning shift between 8 and 12 a.m. Workers were called one by one in a separate room and a health questionnaire directed at organic dust exposure and respiratory symptoms was given. The questionnaire included items from the British Medical Research Council respiratory questionnaire as well as a French translation of the Rylander et al. questionnaire (1990) modified for additional questions regarding seniority, allergy, asthma, medication and occupational history related to wood dust. Smoking habits were assessed by classifying subjects into non-smokers and current smokers; ex-smokers were subjects having stopped smoking for more than one year. Cigarette pack-years unit was calculated.

Height and weight were measured at the end of the interview. Lung function tests were performed using a dry spirometer (Vitalograph—Compact N°4200, Maids Moreton House, Norme: C.E.C.A, Communeauté Européenne pour le Charbon et l'Acier, 1983, polgar). The best value of at least three reproducible assays was chosen to assess the lung functions. Predicted value of forced vital capacity (FVC%) and forced expiratory volume in the 1st second (FEV1%) were calculated. Calibration of the spirometer according ambient temperature was performed before the first test in the morning using 2 l syringe Spirometry measurements.

Statistical analysis

To test the relationship between bioaerosol concentration and occurrence of medical syndromes in workers, we have used a generalized linear model (GLM) with a probit link (STATA). The effect of bioaerosol on the following syndromes was tested: (1) irritation syndrome was defined by the presence of at least one of the following symptoms: itching/running nose, snoring and itching/red eyes; (2) bronchial syndrome was defined by chronic cough and expectorations; (3) asthmatic syndrome was defined by wheezing and at least one complaint of difficulty to breathe and/or thoracic oppression; (4) flu-like syndrome was defined by fever and joint pain and fatigue/or malaise. Independent variables introduced in the GLM were seniority (defined as the duration of employment in the wood industry); smoking; atopic disposition (atopy was defined by medical diagnosis of allergic skin disease; hay fever; hypersensitivity to animal hair; acaridae; food allergy; drug allergy); mean wood dust exposure level and mean fungi and total bacteria exposure level. The influence of bioaerosols, dust exposure and smoking habits on lung functions were analysed using GLM with an identity link.

Results

Dust and bioaerosols

In all sawmill, mean levels of total dust were below the legal limit value of 5 mg/m^3 for the wood species (Fig. 1). The concentration of dust was in the range of 0.2–8.5 mg/m^3 with a mean of 1.7 mg/m^3. In two sawmills dust levels were over half of the limit, and even over the limit itself in certain workstations. Dust levels show a positive correlation with production volume ($r = 0.65$, $P = 0.01$) (Oppliger et al. 2005).

Global results showed that endotoxin levels were well below the 1,000 UE/m^3 of air value recommended by the Swiss National Insurance (SUVA) (Fig. 1). Bacteria levels (Gram negative and total bacteria) everywhere were under the recommended value of 10^4 CFU/m^3 except for two sawmill (Fig. 1). Fungi levels were very high and exceeded the SUVA recommended limit of 10^3 CFU/m^3 in every sawmill (Fig. 1). On average, the concentration of airborne fungi was in the range of 4,318–35,130 CFU/m^3 air with a mean of 14,776 CFU/m^3. No correlation between dust level and fungi level was found ($r = 0.19$; $P = 0.54$).

Workers and medical characteristics

Workers characteristics are listed in Table 1. Groups 1, 2 and 3 were compared according to seniority. Group 1 was defined as woodworkers with less then 5 years of employment in the wood industry; workers with 5–20 years of seniority in the wood industry were Group 2, workers with more than 20 years of seniority in the wood industry were Group 3. Mean age differed in the three groups as the senior workers were also the older. Groups were comparable for height. Workers in group 2 and 3 were more likely to be

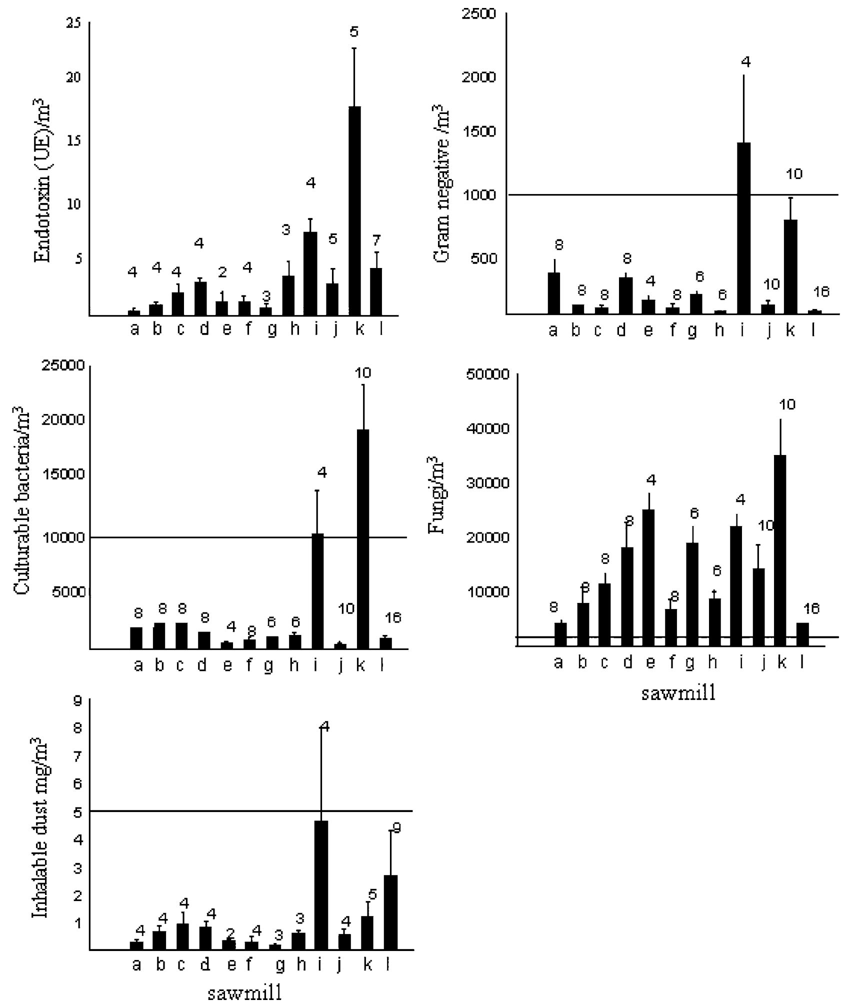

Fig. 1 Mean amount + SE of different bioaerosols and inhalable dust per cubic meter of air sampled in different work sites (see details in text) in 12 sawmills. *Numbers beside the bars* indicate the sample size. The *horizontal line* shows Swiss recommendations

overweight than group 1 workers with a mean BMI of 27 Kg/m^2. Smoking patterns were similar in the three groups with more or less one third of current smokers in each group. In the studied population we did not find any medical diagnosis of asthma. Flu-like-syndrome, even if rare, was reported more frequently by junior workers. Group 1 workers complained twice as much of ocular, nasal and upper airways tract irritations when exposed to wood dust.

About 56% of the 111 questioned workers complained of having bronchial syndrome and the concentration of airborne fungi influenced significantly the occurrence of this, while cigarette pack year has no effect (Tables 1, 2; Fig. 2). The proportion of workers who complained of bronchial syndrome is slightly higher for smokers (64%; 22/34) than for non-smokers (51%; 37/72) and bronchial syndrome was reported more frequently in the senior workers group There was no other significant relationship between the medical syndromes and the concentrations of bioaerosol or dust (Table 2). About 67% of workers complained of suffering irritation syndrome and we observed that seniority had a significant effect on irritation syndrome with junior worker suffering more often of irritation (Tables 1, 2). Atopic disposition is associated with an increased risk of suffering from asthmatic syndrome, which is reported in about 50% of workers (Tables 1, 2).

As expected, current smokers were at increased risk of suffering from asthmatic syndromes whereas irritation or flu-like attacks did not seem to be more frequent in this group (Tables 1, 2).

Concerning lung function tests, FEV1% is neither influenced by bioaerosol or dust exposure nor by cigarette pack-years unit or seniority (Table 2).

Discussion

The analysis of association between prevalence of self-reported bronchial syndrome and airborne fungi concentration among sawmill workers revealed a strong positive dose–response relationship according to cough and expectoration. Other studies have observed that chronic cough was

Table 1 Demographic characteristics, self-reported respiratory symptoms and lung functions in regard to seniority

	Seniority ≤ 5 years (n = 20)	Seniority 5–20 years (n = 49)	Seniority > 20 years (n = 42)
Age (years; mean ± SD)	26.5 ± 9.5 (range 17–51)	36.7 ± 8.5 (range23–63)	47.7 ± 8.2 (range 32–67)
Seniority[a] (years; mean ± SD)	3.3 ± 0.9	13.3 ± 3.9	27.9 ± 6.7
Height (cm; mean ± SD)	174.4 ± 5.7	173.5 ± 6.5	171.2 ± 6.3
Weight (Kg; mean ± SD)	71.6 ± 12.5	81.5 ± 12.7	80.3 ± 10.6
BMI (Kg/m^2; mean ± SD)	23.4 ± 3.6	27.0 ± 3.8	27.2 ± 3.1
Smokers (*n*/%)	7 (35.0%)	15 (30.6%)	12 (28.5%)
Non-smokers (*n*/%)	12 (60%)	32 (65.3%)	28 (66.6%)
Ex-smokers (*n*/%)	1 (5.0%)	2 (4.0%)	2 (4.7%)
Cigarette pack-years[c] (mean ± SD)	3.6 ± 3.5	19.7 ± 10.9	23.5 ± 12.2
Atopy[b] (*n*/%)	6 (30%)	8 (16.3.0%)	3 (7.1%)
Irritation syndrome	17 (85%)	38 (77%)	19 (45%)
Asthmatic syndrome (*n*/%)	8 (40%)	36 (73%)	14 (33%)
Bronchial syndrome (*n*/%)	2 (10%)	31 (63%)	29 (69%)
Flu-like-syndrome (*n*/%)	3 (15%)	4 (8.1%)	1 (2.3%)
Predicted FEV1% (mean ± SD)[d]	96.6 ± 8.5	103.4 ± 18.0	104.4 ± 12.4
Predicted FVC %(mean ± SD)[d]	97.7 ± 13.2	104.7 ± 18.2	105.6 ± 13.2
Predicted FEV1/FVC (mean ± SD)[d]	84.6 ± 9.8	82.3 ± 6.8	81.3 ± 7.7

[a] Seniority = duration of occupational exposure to wood dust

[b] Atopy = medical diagnosis of allergic eczema; hay fever; hypersensitivity to animal hair or acaridae; food allergy, drug allergy

[c] Cigarette pack year unit for current smokers and former smokers

[d] Results are corrected for height and cigarette pack-years

Table 2 Generalized linear model: partial regression coefficients

	Bronchial syndrome	Asthmatic syndrome	Irritation syndrome	Flu-like syndrome	FEV1%
Source	Z	Z	Z	Z	Z
Seniority	0.03	−0.14	−2.41*	−1.19	1.65
Atopy	−0.92	−2.29*	−1.88	−1.50	
Pack-year unit	0.38	2.26*	1.91	1.22	−1.19
Bacteria	−1.61	−1.041	−0.501	1.22	−0.04
Dust	0.41	1.02	1.38	0.58	−0.90
Fungi	2.76*	1.15	0.49	−0.66	−1.59
intercept	−0.19	−0.19	2.62	1.60	35.42

* $P < 0.05$

the most consistent symptom related to wood dust exposure (Holness et al. 1985; Shamssain 1992; Norrish et al. 1992; Schlünssen et al. 2002; Douwes et al. 2001; Whitehead et al. 1982) but none of those studies has measured the airborne fungi exposure. A correlation between dust and fungi level could be suspected but was not demonstrated in our study. Few studies in sawmills have investigated health effects and fungi exposure. Mandryk et al. (1999; 2000) have carried out a very comprehensive study in Australian sawmills, they have measured exposure levels of all bioaerosols (endotoxin, fungi, bacteria, β(1,3)-glucan) and lung function but correlation between respiratory parameters and fungi level was not tested. However, they showed an effect of β(1,3)-glucan (fungal cell wall component) on cross-shift decrease in lung function tests. High prevalence of regular cough, phlegm and chronic bronchitis among woodworkers was demonstrated and levels of airborne fungi in these sawmills were as elevated as levels in Swiss sawmills (40,000 and 35,000 CFU/m^3, respectively). In Norway, Eduard et al. (1994) have shown that exposure levels exceeding 10^6 spores/m^3 were related to increased prevalence of respiratory symptoms. Another study reporting fungi exposure of

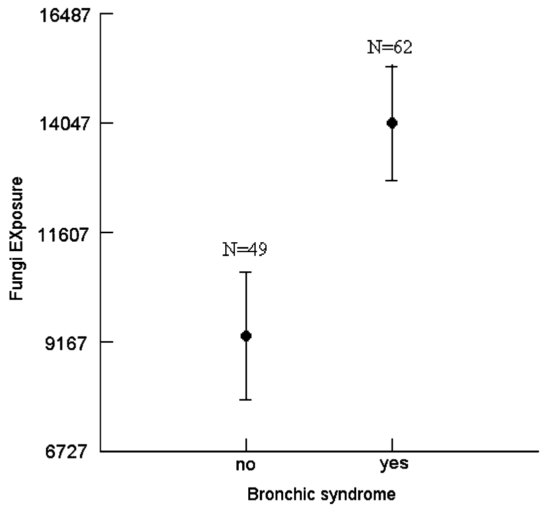

Fig. 2 Mean ± SE of fungi exposure in regard to the occurrence of bronchial syndrome in sawmill workers

only 4,200 CFU/m^3 shows an increased prevalence of cough and breathlessness and a reduction in FEV1 in wood trimmers in Sweden (Dahlqvist et al. 1992). Heterogeneity of exposures make it difficult in eliciting causal relationships between different agents present in the Swedish sawmills (mostly chemical agents). These results suggested that airborne fungi in the sawmill environment are potential agents for occupational health effects.

Several studies have shown a positive dose–response relationship between exposure to wood dust and impaired lung functions, which are obstructive in nature (Schlünssen et al. 2002; Shamssain 1992; Mandryk et al. 1999; Carosso et al. 1987; Ahman et al. 1996; Alwis et al. 1999). Our results and theses of a Canadian study (Cormier et al. 2000) did not show such an association. Levels of inhalable dust measured in the Swiss and Canadian sawmills were slightly higher or similar to those found in the above cited sawmills and in several other studies (Mandryk et al. 1999; Teschke et al. 1999; Demers et al. 2000; Douwes et al. 2000). Thus the levels of wood dust exposure should not be responsible for those discrepancies. Wood dust species may play a role, or probably the high levels of endotoxin, which are well known to have strong effect on lung function decline (Vogelzang et al. 1998). The level of endotoxin measured in Swiss sawmills were very low compared with results from other studies (Duchaine et al. 2000; Douwes et al. 2000; Mandryk et al. 1999).

Workers with a short-term of employment reported more irritation syndrome than long duration employees suggesting that the work environment, especially the dust loaded atmosphere in sawmills, was no longer perceived as causing itching nose or snoring by the senior workers. Moreover, flu-like-syndrome, even if rare, is more frequently reported by junior workers. In this respect, we have seen the result of a probable healthy worker selection as suggested by Hessel et al. (1995). In a recent cross-sectional study in Danish sawmills, a negative association between morning cough, daily coughing and seniority was found (Schlünssen et al. 2002) suggesting also a healthy worker selection. Young workers affected by the work environment tend to seek work elsewhere.

We also have observed that current smokers reported more wheezing, difficulty to breathe and thoracic oppression, a group of symptoms that we called asthmatic syndrome. It has been demonstrated that prevalence of respiratory symptoms, included asthma related symptoms, was higher among smokers (Urrutia et al. 2005). Smoking increases the incidence of obstructive lung diseases (see review: King et al. 2004, Lindberg et al. 2006) and asthma severity (Siroux et al. 2000) but the relationship between smoking and asthma remains unclear.

We noticed that no case of medically diagnosed asthma was observed in our population of wood workers. An explanation would be that working in a dusty workplace does not suit to asthmatic condition: asthmatic people are more likely to be advised not to start working in a sawmill.

To conclude, despite the small sample size of this study, these findings indicate that airborne fungi associated with wood dust could represent a potential health hazard in sawmills. The need to specifically evaluate the composition of the fungi population and its potential health effects on exposed workers should be considered in further studies. Wood workers should be aware of the potential respiratory health effect of occupational exposure to bioaerosol and preventive measures should be taken despite the lack in limit level values concerning this biological hazard.

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