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ORIGINAL ARTICLE

# A 5-year follow-up study on respiratory disorders and lung function in workers exposed to organic dust from composting plants

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**Abstract**
*Objectives* To evaluate acute and chronic effects of long-term exposure to organic dust on respiratory disorders and lung function among employees at 41 composting facilities in Germany.
*Methods* A total of 218 compost workers and 66 control subjects were enrolled in the cohort. They were evaluated using a standardized questionnaire, a clinical examination, and spirometric measurements. Changes of symptoms, respiratory disorders, and lung function were determined in a first survey after 5 years of exposure in 123 compost workers and 48 controls. Exposure measurements were performed at six composting facilities for respirable dust, cultivable microorganisms, and endotoxins.
*Results* Exposure measurements revealed high concentrations of thermo-tolerant/thermophilic actinomycetes and filamentous fungi in the bioaerosols at the composting sites. A significantly higher job fluctuation was observed among the compost workers compared to control subjects (95 vs. 18; $p < 0.05$). Compost workers reported a significantly higher prevalence of mucosal membrane irritation (MMI) of the eyes and upper airways than control subjects. Conjunctivitis was diagnosed significantly more often in compost workers. Forced vital capacity in percent of predicted (FVC%) of the non-smoking compost workers declined significantly (−5.4%) during the observation period compared to control subjects. The decline of FVC% in 16 compost workers exceeded 10% of initial values. A significant increase was observed in the number of compost workers suffering from chronic bronchitis (RR = 1.41; 95% CI = 1.28–1.55). Allergic alveolitis was diagnosed clinically in two compost workers.
*Conclusions* The exposure to organic dust at workplaces of composting facilities is associated with adverse acute and chronic respiratory health effects, including MMI, chronic bronchitis, and an accelerated decline of FVC%. The pattern of health effects differs from those at other workplaces with exposures to organic dust possibly due to high concentrations of thermo-tolerant/thermophilic actinomycetes and filamentous fungi at composting plants.

**Keywords** Bioaerosol exposure · Organic dust · Lung function · Chronic bronchitis · Hypersensitivity pneumonitis

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## Introduction

Handling of organic waste (biowaste), which is used for the production of compost in many countries, is a source of exposure to bioaerosols. Composting sites in various countries were investigated and bioaerosols containing a complex mixture of components with possible effects on health were identified at the workplaces. Peak concentrations of inhalable dust reach 10 mg/m$^3$ (Clark et al. 1983; Streib et al. 1996), but mean levels are below 1 mg/m$^3$ (Clark et al. 1983; Sigsgaard et al. 1994; Streib et al. 1996; Hryhorczuk et al. 2001). In the Netherlands, dust exposures up to 3 mg/m$^3$ are observed in operators of domestic waste composting plants (Wouters et al. 2006). The mean levels of respirable dust range from 0.34 to 2.1 mg/m$^3$ in a German study (Streib et al. 1996). Gram-negative bacteria reach $10^5$ cfu/m$^3$ (Clark et al. 1983; Hryhorczuk et al. 2001). In a German multi center study (Stalder and Bünger 1996), numbers of total airborne bacteria amount up to $10^8$ cfu/m$^3$ (Schmidt and Philipp 1994), actinomycetes up to $10^5$ cfu/m$^3$ (Kutzner and Kempf 1994), and fungal spores (molds) up to $10^7$ cfu/m$^3$ (Göttlich et al. 1994). Levels for *Aspergillus fumigatus* exceed $10^6$ cfu/m$^3$ at Swedish and German composting sites (Clark et al. 1983; Göttlich et al. 1994). Since atmospheric concentrations of *A. fumigatus* were also very high in most other investigations on airborne molds, this fungus may generally serve as an indicator of mold exposures in composting plants (Sanchez-Monedero et al. 2005). Levels of endotoxins regularly do not exceed 50 ng/m$^3$ (Clark et al. 1983; Hryhorczuk et al. 2001; Wouters et al. 2006). Exposure to other organic air pollutants such as β-1,3-glucans (Hryhorczuk et al. 2001; Wouters et al. 2006) and mycotoxins (Bünger et al. 2004) is apparent, but measurement data is scarce. The highest exposures occur during dumping of biowaste from the collecting trucks into bunkers, manual sorting of biowaste, filling or emptying reactors for intense pretreatment of biowaste, heaping up or turning the windrows, and sifting the compost before delivery.

The primary health effect of exposure to organic dust is an inflammatory response of the upper airways with congested nose, sore throat, and dry cough frequently in connection with symptoms of the eyes like redness and lacrimation—the so-called mucous membrane irritation (MMI)—subsiding several hours after cessation of exposure (Richerson 1990; do Pico 1992; Rylander 1994). High concentrations of organic dust are capable of inducing toxic reactions such as the organic dust toxic syndrome (ODTS), also called toxic pneumonitis (Lacey and Crook 1988; Rylander 1994). Endotoxins from Gram-negative bacteria were identified as a cause of these toxic symptoms and were also associated with acute (Donham et al. 1989; Rylander et al. 1989) and chronic (Post et al. 1998; Simpson et al. 1998) impairment of lung function. An increased prevalence of airway symptoms was reported among US-American, Scandinavian, and German compost workers in cross sectional studies (Clark et al. 1984; Sigsgaard et al. 1994; Bünger et al. 2000).

This prospective cohort study investigates the health risks of compost workers due to long-term exposure to organic dust with special focus on respiratory disorders and the course of lung function parameters.

## Methods

### Study design

The study was performed at 41 composting sites in Northern Germany from 1996 to 2001. Of a total number of 231 full-time employees, 218 participated in the study. Sixty-six full-time office employees who were not exposed to organic dust served as control group. All study participants were physically examined by the same occupational physician. They answered occupational, environmental, and symptom orientated questions in a standardized questionnaire. Symptoms and diseases in the previous 12 months were registered.

Study participants who did not participate in the second survey since they had quit the work during the 5 years of follow-up were asked to answer a questionnaire delivered by mail containing items about the reasons for giving up the employment.

All spirograms (Flowscreen, Jäger, Höchstadt, Germany) were performed prior to work shifts according to the recommendations of the American Thoracic Society (American Thoracic Society 1995) by the same experienced technician. The best of three acceptable spirograms with a good reproducibility (FVC and $FEV_1$ within 0.2 l of each other) was used for further analysis. The lung volumes and forced ventilatory flows of the ECSC study served as reference values (Quanjer et al. 1993).

The study design and the protocol were reviewed and approved by the ethics committee of the Georg-August-University of Göttingen in accordance with the Declaration of Helsinki. All study participants gave written informed consent to the study protocol.

### Handling and treatment of biowaste in the study region

Biowaste is collected from private households (curbside collection) in a two-week-schedule, transported to composting plants, and dumped into bunkers for further processing. At the composting sites, non-compostable materials are removed from the organic material by manual sorting. The biowaste is mixed with shredded garden waste or hay and straw and piled up in windrows by shovel loaders or specially designed vehicles (windrow turners). Modern composting plants provide reactors for intense treatment (tunnels, large containers, and revolving drums) prior to heaping up the windrows. Prior to delivery, the compost is sifted to exclude non-biological compounds, which had not been removed during manual sorting.

### Exposure measurements

Exposure measurements were performed for respirable dust, cultivable microorganisms, and endotoxins at 6 of 41 composting facilities representing the different processing techniques and sizes of the composting plants. Personal air sampling was conducted from workers on machinery platforms, drivers of shovel loaders, and workers at manual sorting cabins according to German guidelines. Determination of endotoxins was performed with the chromogenic Limulus-Amoebocyte-Lysate-assay (LAL-assay; Charles River Laboratories, Wilmington, MA, USA). Detailed information on the methods has been published previously (Schappler-Scheele et al. 1999).

### Statistical analyses

Data were stored using Access 97, Microsoft, Seattle, WA, USA and tabulated for further analysis. All analytical calculations were performed with nonparametric procedures using Statistica 6.0 for Windows (StatSoft Inc., Tulsa, OK, USA). Differences of continuous variables between the two groups were analyzed with the Mann–Whitney *U*-test. Since small numbers had to be calculated in the contingency tables, statistics of categorical variables were calculated using Fisher's exact test, two-sided. The significance level for all statistical procedures was set at $p < 0.05$.

## Results

Of the initial 284 study participants (218 compost workers and 66 control subjects), 16 were female (11 compost workers and five control subjects). No separate statistical evaluation was performed due to the small number of women. A total of 113 subjects had left the workplaces (drop outs). A significantly higher job fluctuation was observed among the compost workers compared to control subjects (95 vs. 18; $p < 0.05$, Fisher's exact test, two-sided).

The drop out questionnaire was answered by 84 compost workers and 16 control subjects. Most employees left the workplaces for socioeconomic reasons. However, symptoms and diseases of the airways were reported by 12 compost workers (nine of them with regular pharmacological treatment) and one office employee (no treatment).

Complete data sets of 123 compost workers and 48 control subjects participating in both surveys are available for further analysis. An overview of the group characteristics and smoking habits is given in Table 1. Since the number of current and former smokers was higher in compost workers compared to the control group, lung function data of never smokers was analyzed separately.

The mean duration of follow up for compost workers was 4.8 years and for control subjects 4.9 years with a range of less than 3 months in both groups. Forty three compost workers and one control subject was exposed to organic dust from working on farms, in cattle, swine, and poultry confinement buildings, or at other workplaces in waste treatment industries prior to working at composting sites; yet none of the study participants had a concurrent occupational bioaerosol exposure from other sources than composting during the course of the follow up.

Symptoms frequently reported by the compost workers concern the eyes as well as the upper and lower airways (Table 2). In 2001, symptoms of the eyes indicative of MMI had a significantly higher frequency in compost workers than in the control group. Nasal congestion was reported significantly oftener by the control subjects in 2001.

The number of compost workers with chronic bronchitis (according to WHO criteria) doubled during the

**Table 1** Demographic characteristics and confounding factors of study participants

| | Age in years | | Body mass index | | Smoking habits (%) | | |
|---|---|---|---|---|---|---|---|
| | Mean | Range | Mean | Range | Never | Ex | Current |
| Compost ($n = 123$) | 42.3 | 27–61 | 26.7 | 18.5–39.7 | 49 (39.8) | 30 (24.4) | 44 (35.8) |
| Control ($n = 48$) | 48.2 | 35–61 | 25.2 | 18.5–35.4 | 29 (60.4) | 9 (18.8) | 10 (20.8) |

**Table 2** Frequency of reported symptoms from mucosal membranes or airways and medically treated respiratory diseases in the last 12 months

| | | Compost workers ($n$ = 123) | | Control subjects ($n$ = 48) | |
|---|---|---|---|---|---|
| | | 1996/1997 | 2001 | 1996/1997 | 2001 |
| Reported symptoms | | | | | |
| Burning eyes | % | 11.4 | 16.5 | 12.5 | 20.8 |
| | (n) | (14) | (20) | (6) | (10) |
| Watering eyes | % | 7.3 | *11.4 | 4.2 | 0.0 |
| | (n) | (9) | (14) | (2) | (0) |
| Itching eyes | % | 8.1 | *13.0 | 2.1 | 2.1 |
| | (n) | (10) | (16) | (1) | (1) |
| Congested nose | % | 13.0 | 12.4 | 10.4 | *29.2 |
| | (n) | (16) | (15) | (5) | (14) |
| Chest tightness | % | 4.1 | 6.6 | 2.1 | 4.2 |
| | (n) | (5) | (8) | (1) | (2) |
| Cough | % | 21.1 | 18.7 | 14.6 | 14.6 |
| | (n) | (26) | (23) | (7) | (7) |
| Reported medically treated respiratory diseases | | | | | |
| Chronic bronchitis | % | 4.1 | 8.1 | 0.0 | 0.0 |
| | (n) | (5) | (10) | (0) | (0) |
| Asthma | % | 2.4 | 2.4 | 2.1 | 2.1 |
| | (n) | (3) | (3) | (1) | (1) |
| Allergic alveolitis | % | 0.0 | 1.6 | 0.0 | 0.0 |
| | (n) | (0) | (2) | (0) | (0) |
| ODTS | % | 0.8 | 0.8 | 0.0 | 0.0 |
| | (n) | (1) | (1) | (0) | (0) |

Significance level: *$p > 0.05$, Fisher's exact test, two-sided

observation period and this increase was significant (relative risk = 1.41; 95% confidence interval = 1.28–1.55). The five compost workers already suffering from chronic bronchitis at the beginning of the study were smokers or ex-smokers, respectively. Three of the additional five cases of chronic bronchitis after 5 years were non-smokers.

Two cases of allergic alveolitis (AA) were reported for compensation as occupational diseases. Both compost workers were non-smokers. The diagnosis was based on the typical onset of flu-like symptoms more than 4 h after exposure and the identification of precipitating IgG-antibodies to actinomycetes and filamentous fungi regularly found in the air of composting sites.

One compost worker had repeatedly been treated for ODTS by his pulmonologist. He had similar complaints as the two workers with AA. The symptoms lasted less than 48 h in each phase of the disease and no precipitating antibodies could be determined.

According to the physical examinations, compost workers suffered more often from health complaints of the eyes, the upper airways, and the skin than the control subjects (Table 3). Compost workers had a significantly higher prevalence of conjunctivitis. Severe infections of the airways were not observed or reported.

The control group reported a non-significant higher prevalence for allergic rhinitis diagnosed by a physician than the compost workers, while the reported frequency of all allergic symptoms was significantly higher (20.5% vs. 35.4%, $p < 0.05$; Fisher's exact test, two-sided). However, since both results differ from the answers to the question "Have you ever had a positive skin prick test?", the reliability of these results is questionable. The prevalence of atopic diseases in the family members of the workers reported by the employees was not significantly different in the control group and the compost workers.

Spirometric maneuvers were performed at the beginning of the work shifts and had an excellent acceptability and reproducibility according to the ATS recommendations of 1995. The FVC% of the non-smoking compost workers decreased significantly during the observation period compared to control subjects ($p < 0.05$, Mann–Whitney $U$-test). Current and former smokers already had an initially lower FVC%, which then declined also but not significantly (Fig. 1). The decline of FVC% in 16 compost workers exceeded 10% of the initial value. Six of them were current smokers or had quit smoking during the follow-up period. A decrease of $FEV_1$ was also observed, although it was neither significant in smoking nor in non-smoking compost workers. In one compost worker, the severe loss of lung function was caused by ∝01-antitrypsin deficiency.

Exposure measurements are not representative for all workplaces since only 6 of 41 composting sites were investigated. Nevertheless, the results should allow orientation about the kind and magnitude of exposures in these industries. Respirable dust did not exceed 1 mg/m$^3$ at all workplaces. Median concentrations of endotoxins were 16 ng/m$^3$ (range 0.8–34 ng/m$^3$). One measurement at a shredder revealed an outlier value of 304 ng/m$^3$.

**Table 3** Results of clinical examination of compost workers and control subjects

| | | Compost workers ($n$ = 123) | | Control subjects ($n$ = 48) | |
|---|---|---|---|---|---|
| | | 1996/1997 | 2001 | 1996/1997 | 2001 |
| Conjunctivitis | % | *21.1 | 13.8 | 6.3 | 8.3 |
| | (n) | (26) | (17) | (3) | (4) |
| Pharyngitis | % | 23.6 | 22.0 | 12.5 | 10.4 |
| | (n) | (29) | (27) | (6) | (5) |
| Skin lesions | % | 28.5 | 30.1 | 25.0 | 16.7 |
| | (n) | (35) | (37) | (12) | (8) |

Significance level: *$p > 0.05$, Fisher's exact test, two-sided

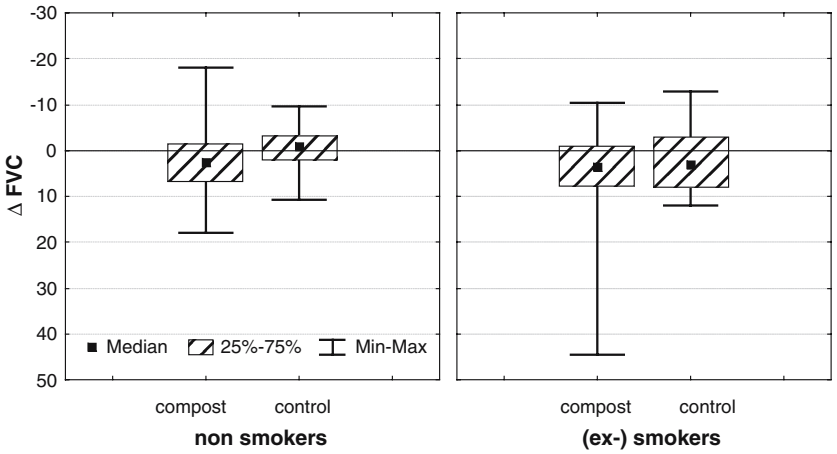


**Fig. 1** Forced vital capacity in percent of predicted (FVC%), stratified for smoking status. Changes from 1996/1997 to 2001 ($p < 0.05$ in Mann–Whitney $U$-test)

Concentrations of cultivable microorganisms varied extremely at different workplaces and during the shifts. Since reliable time weighted averages were not calculable, results are given as ranges (Table 4). Predominant fungal species belonged to the genera aspergillus and penicillium. Species of actinomycetes varied widely.

## Discussion

Generally, the high job fluctuation of compost workers raises some uncertainty concerning the interpretation of the results described above. A comprehensive statistical analysis including the evaluation of all confounding variables was limited due to loss of statistical power. The elevated but non-significant number of 12 compost workers quitting their employment due to airway complaints and the significantly higher frequency of allergic symptoms in the control group indicate a healthy worker effect possibly leading to an underestimation of health effects.

Up to now, scientific information on health risks of compost workers is scarce. In a cross sectional study, Clark and coworkers investigated employees who composted sludge of US waste water treatment facilities. The exposed workers reported burning eyes and skin irritation significantly more often than workers without exposure to organic dust. In the physical examination, a significantly higher prevalence of diseases of the skin, mainly due to infections, and of the upper airways was diagnosed in the exposed workers (Clark et al. 1984). In European cross sectional studies, different patterns of acute symptoms and diseases were reported by biowaste composting workers. Four of 11 Swedish compost workers experienced nausea, headache, and diarrhea (Lundholm and Rylander 1980). A Danish study investigated 68 employees of the recycling industries including eight compost workers, who had an elevated prevalence of respiratory and gastrointestinal symptoms compared to controls, although the results were not significant due to the small number of subjects exposed to compost dust (Sigsgaard et al. 1994). An examination of 58 German compost workers revealed a significantly higher prevalence of acute dermal and respiratory symptoms and diseases. An increased prevalence of gastrointestinal symptoms was not observed. A significant association was observed between the diseases and increased specific IgG antibodies against molds and actinomycetes occurring in high amounts in the compost dust (Bünger et al. 2000).

In this longitudinal study, workers reported significantly increased symptoms of MMI like watering and itching eyes. Furthermore, symptoms of the upper airways and skin lesions occurred more often in compost workers compared to the control group; yet, these

**Table 4** Ranges of airborne cultivable microorganisms at several workplaces in six composting plants *CFU* colony forming units

| | Filamentous fungi Range ($\times 10^3$ cfu/m$^3$) | Actinomycetes Range ($\times 10^3$ cfu/m$^3$) |
|---|---|---|
| Machinery platforms | 200–2,800 | 300–3,500 |
| Driver cabins with filtered air | 2–40 | 4–125 |
| Driver cabins without filtered air | 20–900 | 30–1,800 |
| Manual sorting cabins with ventilation | 10–380 | 10–600 |
| Manual sorting cabins without ventilation | 1,600–11,000 | 700–3,500 |

differences were not significant. Although the reported symptoms of the eyes were often confirmed in the clinical examination and diagnosed as conjunctivitis, some symptoms of MMI were more frequently reported by the control group. Watering and itching eyes seem to be associated with bioaerosol exposure, while burning eyes and congested nose also may be provoked by other circumstances, e.g., dry air at offices with central heating or air condition.

Antigens of fungi and actinomycetes can cause AA, which is also called hypersensitivity pneumonitis. Two newly developed cases of AA in our study demonstrate that compost workers are at risk of this occupational disease. Singular cases of AA in subjects handling compost have been reported in Belgium (Vincken and Roels 1984) and the USA (Brown et al. 1995).

The frequency of medically treated chronic bronchitis in the compost workers increased significantly during the observation period. However, this result should be handled with caution due to the different prevalence of smokers in the study groups and the fact that only three of the compost workers with chronic bronchitis were never smokers.

The disease is probably caused by inflammatory effects of organic dust. Unfortunately, further longitudinal studies concerning health effects due to dust exposure in composting plants or other waste treatment facilities are not available for comparison of health effects and loss of lung function. Nevertheless, similar bioaerosols including high amounts of microorganisms occur in other industries, e.g., textile industries, saw and paper mills, farms, poultry, and swine confinement buildings.

Increasing current personal exposures to organic dust at these workplaces were found to be predictive of upper and lower respiratory tract symptoms and chronic bronchitis (Simpson et al. 1998; Wang 2005; Rylander and Carvalheiro 2006). In an international multi center study, an increased risk of chronic bronchitis has been observed even in young agricultural, textile, paper, wood, and food processing workers (Zock et al. 2001).

Chronic impairment of pulmonary function due to organic dust exposures was observed among cotton textile workers, farmers, swine confinement operators, and animal feed processing workers, and it was associated with high dust and endotoxin concentrations (Smid et al. 1992; Schwartz et al. 1995; American Thoracic Society 1998; Wang et al. 2005). However, in contrast to our results, the decline of $FEV_1$ in all of these studies was more pronounced compared to FVC, indicating a different pathogenic mechanism of organic dust from composting plants.

At the composting facilities, median concentrations of respirable dust and endotoxins did not exceed 1 mg/m$^3$ and 20 ng/m$^3$, respectively. Additionally, the decrease of FVC in compost workers was stronger than the decline in $FEV_1$, indicating a restrictive lung disorder rather than an obstruction. Thus, organic dust exposures underlying these effects on lung function at workplaces in composting facilities seem to differ from effects among cotton textile workers, farmers, swine confinement operators, and animal feed processing workers. This may be caused by exposure to different species of microorganisms in the dust. Since compost piles heat up to 60–70°C during the biodegradation process, high amounts of thermo-tolerant and thermophilic bacteria (actinomycetes) and filamentous fungi are found in bioaerosols at composting sites (Göttlich et al. 1994; Kutzner and Kempf 1994; Schappler-Scheele et al. 1999) but low concentrations of Gram-negative, endotoxin producing bacteria which are often high at cotton manufacturing industries, poultry and swine confinement buildings, and farms. Fungal species of the genera aspergillus and penicillium are prominent in bioaerosols from composting plants (Göttlich et al. 1994; Schappler-Scheele et al. 1999), many of them producing secondary metabolites such as mycotoxins (Bünger et al. 2004). The influence of these microorganisms and their components on the upper and lower airways should be evaluated in further studies.

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