

# OCCUPATIONAL EXPOSURE TO ORGANIC DUST ASSOCIATED WITH MUNICIPAL WASTE COLLECTION AND MANAGEMENT

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**Abstract.** The aim of the study was to assess the occupational exposure of workers employed in the municipal waste collection and management industry. Air samples were collected in the workers' breathing zone; two samples were collected parallelly. The assessment concerned exposure to organic dust, endotoxins, bacteria and fungi.

The questionnaire data showed that workers found themselves in good or very good health. They also regarded noise, dustiness, odor, physical effort and changeable atmospheric conditions as the most strenuous factors.

The highest dust concentrations were observed on the sites of waste collection (mean, 7.7 mg/m<sup>3</sup>) and composting (mean, 4.6 mg/m<sup>3</sup>). Samples collected on the composting site contained the largest amount of endotoxins (mean concentration, 76 ng/m<sup>3</sup>). This was followed by sorting facility (61 ng/m<sup>3</sup>) and waste collection area (36 ng/m<sup>3</sup>).

Gram-negative rods (primarily intestinal) were found in all samples collected at workposts, which justified the adoption of the air concentrations of endotoxins as a criterion for assessing their hygienic conditions.

Taking MAC for total suspended dust (4.0 mg/m<sup>3</sup>) and the concentration of 10 ng/m<sup>3</sup> for endotoxin as the criteria for the exposure evaluation, it must be considered that waste collectors and composting site workers are working in poor hygienic conditions.

Workers employed at the most hazardous workposts did not use personal protective equipment (glasses, antirespirators), thus infringing a fundamental condition for limiting health hazards (Directive 2000/54/EC).

**Key words:**

**Municipal waste, Organic dust, Occupational exposure**

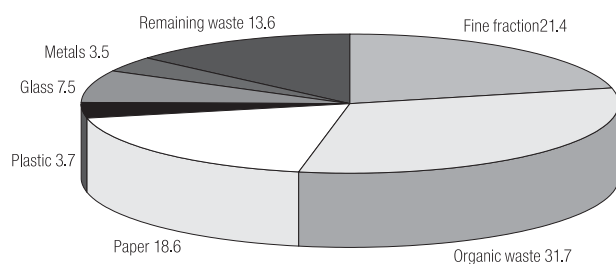
## INTRODUCTION

In Poland, a large group of workers (about several dozen thousand) is involved in municipal waste collection and utilization. The process of waste management starts already in the place of its origin, namely in households. From there, waste is directly transported to a dumping

ground or it is treated by sorting, composting, burning and storing. In Poland, waste sorting and recycling are carried out on a large scale. Municipal waste is usually collected, transported and stored without preliminary separation. Fig. 1 shows an average morphological composition of non-separated municipal waste [1].

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**Fig. 1.** Morphological composition of municipal waste in Poland (%).

The incidence and type of agents hazardous to human health that are released from wastes are firmly linked with the waste morphology, form and conditions of its utilization. The scientific literature, published in Poland and in other countries, is rich in publications devoted to technical aspects of waste collection [2–4], separation [3–5], composting, burning [6,7] and storage with special attention focused on the construction and exploitation of landfills [8,9]. A number of papers on the qualitative composition and incidence of hazardous agents emitted during the whole process of waste management have also been published [2,5,10–14]. Mechanical traumas, chemical poisoning, allergic diseases of the respiratory system, as well as pulmonary, respiratory, musculoskeletal, digestive, skin and infectious diseases have been observed in workers employed in waste collection and management [2,5,15–23].

In Poland, exposure and hygienic conditions at workposts associated with waste collection and management, have not been assessed. Neither studies on harmful health effects of biological and chemical agents emitted by municipal waste have been carried out.

Łódź has not as yet established its own landfill, so that all waste is directed to two reloading areas, and then transported in containers to landfills outside the Łódź region (voivodship).

Five municipal sanitation units, operating in Łódź, employ 250 workers. They can be divided into the following groups according to their jobs performed:

- waste collectors (drivers and loaders);
- waste reloaders (machine operators and site workers);
- waste composting workers (machine operators and site workers);

- waste sorters; and
- waste landfill sites workers (machine operators and site workers).

The study aimed at defining the magnitude of the organic dust exposure and assessing the hygienic conditions at municipal waste collection and management workposts, based on the determination of the air concentrations of dust, total number of microorganisms, viable bacteria (mesophilic, thermophilic), fungi and endotoxins. In addition, the characteristics of the population of workers and the jobs performed by them were carried out using questionnaires.

## MATERIALS AND METHODS

### A questionnaire used to obtain the characteristics of waste collectors

The questionnaire contained 39 questions grouped in the following four blocks: personal data, job description, life style and general information on the health condition.

Some of the questions required descriptive responses, others just a simple answer "Yes" or "No". The version of the questionnaire used in the study was a compilation of several other questionnaires employed previously.

### A questionnaire used to obtain the job description

The questionnaire was elaborated according to Okón [24]. It was composed of the following sections:

- general information on the work site, work time, tools and machines used;
- qualifications required to perform the job at a particular workpost;
- work conditions; this section included questions that allowed to determine the period of time spent in particular conditions during a working day;
- physical work performed by employees at a particular workpost;
- physical and mental traits necessary to perform successfully individual tasks (43 traits), including the indication how far a given trait should be developed to assure good performance;

■ potential occupational hazards and related responsibilities of workers.

### Sampling strategy

The material collected served to identify microorganisms, as well as to determine: the concentration of dust; the total number of microorganisms; the concentration of endotoxins and viable microorganisms, including mesophilic (Gram-positive and Gram-negative) and thermophilic bacteria, and the concentration of fungi. Two air samples were collected parallelly, using two pumps (two filters) worn by each worker. One sample collected on one filter was used to determine the mass of the dust and the endotoxin concentration, the other to determine the mass of dust and the total number of viable microorganisms divided into three groups: mesophilic bacteria, thermophilic bacteria, actinomycetes and fungi. Table 1 summarizes the parameters of the measurement strategy.

The study, performed in three plants of municipal works and municipal sanitation, included 61 workers who performed jobs described above (five groups). Samples were collected during at least six hours of a given shift. If the number of workers was too small, air samples were collected at a stationary sampling points using also personal samplers. In addition, samples were collected in the streets of the city center, and in the workers' dwellings. In

the city center, the samples were collected by students who were wearing personal samplers for a defined number of hours.

### Determination of the number of viable microorganisms

Filters with collected samples of the dust were placed in containers; 10 ml of buffered NaCl solution (PBS) was added to each container and shaken for 45 min. Eluate was tenfold diluted in PBS. Dilutions ( $10^{-1}$ – $10^{-5}$ ) of extraction fluid were inoculated into specific media on three parallel plates, 100  $\mu$ l on each (Table 2). The number of colony forming units (cfu) in a sample was determined using standard methods. Due to high sensitivity of the method it was feasible to determine at least 100 cfu in the sample.

### Identification of microorganisms

Colonies of mesophilic bacteria from the culture media, listed in Table 2, were isolated on TSA plates for further identification. Fungi species were not identified, but only distinguished between yeast and molds according to the colonial morphology. Thermophilic actinomycetes were determined after staining with Gram method using light microscopy and according to the colonial morphology without a detailed identification of their group.

**Table 1.** Basic parameters of the measurement strategy

Strategy elements	Parameters
Sample collection:	
personal sampling in breathing zone	2 Cassela or SKC samplers
stationary sampling	2 Cassela or SKC samplers
Apparatus:	
personal samplers	Cassela; SKC
a number of measuring heads	2; $\varnothing$ 25
filters	GF/A Whatmann $\varnothing$ 25 mm
Time of sample collection:	
of one sample	~ 6 h
during work shift	8:00–14:00
in a year	June
Number of samples:	
for assessing individual exposure	1 sample
for assessing occupational group exposure	4–10 samples

**Table 2.** Media and conditions for determining the number of culturable microorganisms

Medium	Application	Incubation		Medium particular properties
		Temp.	Time	
Trypticase Soy Agar (TSA)	General determination of mesophilic bacteria	37°C	48h	Lack of selectivity
KRANEP Agar (Merck)	Determination of Gram-positive rods and cocci	37°C	48h	Stimulates growth of Staphylococci; inhibits growth of Gram-negative bacteria
Enterococcosel Agar (BBL)	Determination of enterococci	37°C	24h	Some Gram-positive and Gram-negative rods may grow
McConkey Medium (Biomed)	Determination of Gram-negative rods	37°C	24h	Inhibits the growth of Gram-positive bacteria
CLED Agar (BBL)	Determination of Gram-negative rods	37°C	24h	Lower selectivity than that of McConkey Medium; some Gram-negative rods grow better
Trypticase Soy Agar (50% concentration of components) – TSA 50%	Determination of thermophilic actinomycetes	55°C	5–7 days	Thermophilic <i>Bacillus</i> also grows
Malt Extract Agar (BBL) with added 0.01% chloramphenicol	Determination of mesophilic and thermophilic fungi	24°C and 55°C	3–7 days	Lack of bacteria growth

The identification of mesophilic bacteria was based on the morphology of cells in Gram-stained microscopic preparations, morphology of colonies cultured on appropriate media, as well as on biological, biochemical and serological properties. The bacteria properties described in Bergey's manual [25] and in other handbooks of diagnostic microbiology [26,27] were used to construct relevant identification schemes. Diagnostic and diagnostic-selective media prepared from dry commercial preparations (Biomed, Difeo, bioMerieux, BBL), and according to our own compositions were used, as well as diagnostic tests (commercial preparations): API (bioMerieux), diagnostic and antibiotic disks (BBL) and diagnostic sera for slide agglutination test (Biomed).

#### Determination of endotoxin concentrations

Filters with adsorbed dust were placed in sterile containers; 10 ml of pyrogen free water was added and shaken [28,29]. The suspension was then centrifuged and supernatants diluted in nonpyrogenic water 5 to 500 times, depending on the mass of the dust. Some samples were investigated without dilution.

The LAL quantitative test, termed COATEST Endotoxin, with S-2423 chromogenic substrate (Charles River Endosafe, USA) was used to determine the concentration of endotoxins. The determination was conducted strictly according to the producer's instruction. The size distribu-

tion of endotoxins in samples was read-out from the calibration curve, prepared each time on the day of determination, and calculated for the concentration expressed in cubic meters. In the analysis, the pyrogen-free laboratory equipment was utilized.

#### Determination of the total number of microorganisms

The count of the total number of microorganisms in a sample was conducted using the epifluorescence method [27,30]. The preparation was analyzed using fluorescence microscope with an immersion oil objective. Microorganism cells were counted in the whole preparation using a netted ocular.

## RESULTS AND DISCUSSION

The questionnaire survey of the waste handling workers covered 61 persons (mean age, 38 yr; mean duration of employment, 6 yr). Table 3 gives the characteristics of the study population. According to the workers' self-assessment, waste collection requires physical effort, especially during the wintertime. Odor, and then dustiness, noise and unfavorable atmospheric conditions were most frequently reported as hazardous factors. The evaluation of hazards occurring at workposts and recognized by respondents as the most arduous is summarized in Fig. 2.

**Table 3.** Characteristics of the study population (selected features)

Characteristics	Workplaces			
	Drivers and machine operators (n = 22)	Loaders (n = 15)	Site workers (n = 16)	Sorters (n = 8)
Age (yr):				
20–30	4	2	7	2
31–40	10	6	3	1
41–50	3	6	4	5
51–60	5	1	2	0
Gender:				
females	-	-	4	6
males	22	15	12	2
Marital status (married):	19	13	12	3
Education:				
primary	5	3	6	2
vocational	13	8	7	1
secondary	4	4	3	5
Duration of employment in the waste collection and disposal (yr):				
<1	4	6	6	4
>1	7	2	7	3
>5	11	7	3	1
Working time:				
one shift work	12	15	10	4
two-shift work	10	0	6	4
Work satisfaction:				
satisfied	21	13	15	8
unsatisfied	1	2	1	0
Absence from work (last year):				
number of days	5	2	6	6
total absence from work (in days)	318	21	112	208
Accidents at work:				
number of accidents	4	3	0	0
total sick absenteeism (in days)	161	49	0	0
Housing:				
good	18	11	12	6
poor	4	4	4	2
Stimulants:				
cigarettes > 20	17	13	11	5
alcohol > 100 g/week	13	8	7	1
Self-assessment of health condition:				
good	18	13	12	6
moderate	4	2	4	2
Way of spending leisure time:				
TV	18	9	10	4
social life	9	8	9	3
walking	9	7	3	2
other	12	6	1	3

The majority (48) of respondents assessed their health condition as good or very good; twelve as moderate and only one respondent reported poor health. Twelve persons from the study population suffered from chronic ill-

ness, including cardiovascular, musculoskeletal and digestive diseases; there were also single cases of diabetes, epilepsy and viral hepatitis B. Seven accidents at work were recorded, in which loaders and drivers were

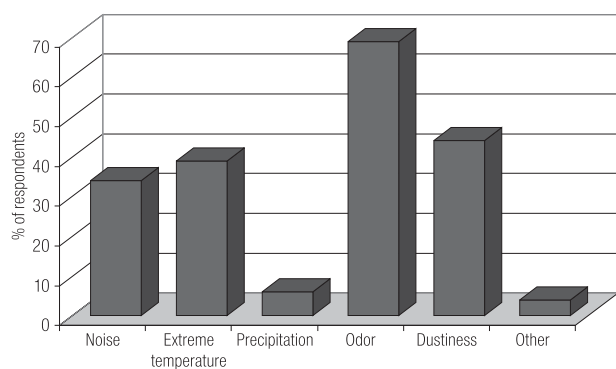


Fig. 2. Factors occurring at workposts regarded as noxious by respondents.

involved. The most serious accident was a crushing injury of two hand fingers when emptying a container. Almost 80% of respondents smoked about 20 cigarettes per day for 10–20 yr on average.

The characteristics of workposts, including jobs performed and harmful factors, is presented in Table 4.

The number of individual groups of microorganisms in the air samples is given in Fig. 3. The majority of viable mesophilic bacteria and thermophilic actinomycetes were found in dust emitted in the composting facility, the only location where thermophilic molds were found. The conditions in composting facilities (humidity and relatively high temperature) favor the growth of thermophilic

microorganisms; the optimal temperature for their multiplication falls within the range of 50–75°C [31,32].

The workposts of waste collectors occupied the second place in respect to the number of viable microorganisms in the air. Mesophilic bacteria and mold spores predominated in this occupational environment, although yeast could also be found. A considerable amount of fungi, among which yeast was also present, occurred in samples collected in the waste sorting facility. Much lower concentrations of viable microorganisms were found in samples collected in the city streets and in dwellings of waste handling workers, and some samples were completely free from them. This means that the number of cfu/m<sup>3</sup> was below  $2-7 \cdot 10^1$ . There were significant differences between the values of cfu/m<sup>3</sup> in individual samples, ranging from  $2.8 \cdot 10^4$  to  $6.3 \cdot 10^6$ , and they were not associated with a particular workpost.

Mesophilic bacteria were subjected to a very thorough analysis. Primarily, they were divided into the following groups: Gram-positive bacteria, including cocci, endospore forming and nonsporing rods, and Gram-negative bacteria with distinguished facultatively anaerobic and aerobic rods.

Table 4. Characteristics of waste collection and disposal workplaces

Workplace	Post	Job description	Hazards
Compactor truck	Driver	Driving in municipal traffic, handling of compactor truck near rubbish chutes, waste bins and containers	Noise, vibration, odor, dustiness, stress
	Loader	Pulling, pushing, tilting, lifting and emptying of waste bins and containers	High physical load, odor, dustiness, bioaerosols, changeable atmospheric conditions
Reloading facility	Machine operator	Operation of bulldozer-excavator, reloading of waste brought by compactor trucks to lorries, waste dislocation, ground leveling	Noise, vibration, odor, dustiness, bioaerosols, stress
	Site worker	Regulation of traffic of compactor trucks in reloading facility, preliminary separation of waste (separation of large metal and plastic elements), site arrangement	Physical load, odor, dustiness, bioaerosols, changeable atmospheric conditions
Sorting facility	Sorter	Separation of plastics, metals and glass on a moving conveyor belt	Odor, dustiness, bioaerosols, work at standing position
Composting plant	Machine operator	Operation and loading of large elements of waste on a crusher, dislocation and gathering of waste on compost windrows using a loading machine	Dustiness, bioaerosols, noise, changeable atmospheric conditions, stress
	Site worker	Separation of waste unfit for compost, regulation of vehicle traffic, keeping the site in order	Dustiness, bioaerosols, unfavorable atmospheric conditions, odor.
Dumping ground	Machine operator	Operation of the machine used to communitate waste, and bulldozer-excavator to level and ram the ground	Noise, odor, unfavorable atmospheric conditions.
	Site worker	Arrangement of waste dumping ground	Odor, unfavorable atmospheric conditions.

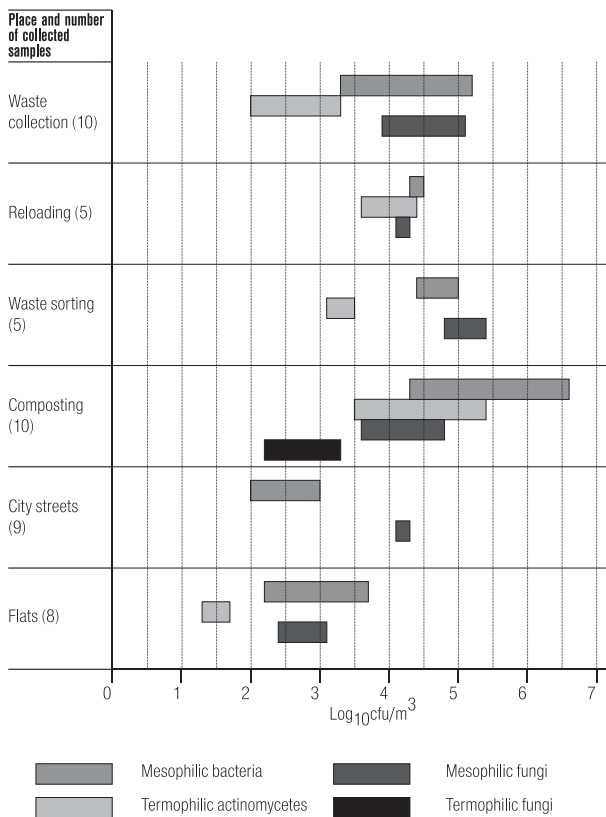


Fig. 3. The size of individual microorganism groups in air samples.

The values of  $\text{cfu/m}^3$  of these bacteria groups were determined, and the isolated strains were identified. The identification was oriented mainly towards detection of genus and species of potential or opportunistic pathogens, and those regarded as indicators of the hygienic conditions of the investigated environment.

The occurrence of microorganisms of individual groups in the air samples collected at different workplaces is shown in Fig. 4. It can be noted that the majority of Gram-positive cocci and endospore forming rods (*Bacillus*), and Gram-negative cocci, as well as of thermophilic actinomycetes originated from the dust generated in the composting facility, whereas fungi were mainly found in samples collected in the areas where waste was collected and sorted.

Endospore forming rods of *Bacillus* genus were found in almost all study material. This is associated with their common occurrence in the nature and high resistance of endospores to the influence of physicochemical factors. Only two species among all are pathogenic. One of them,

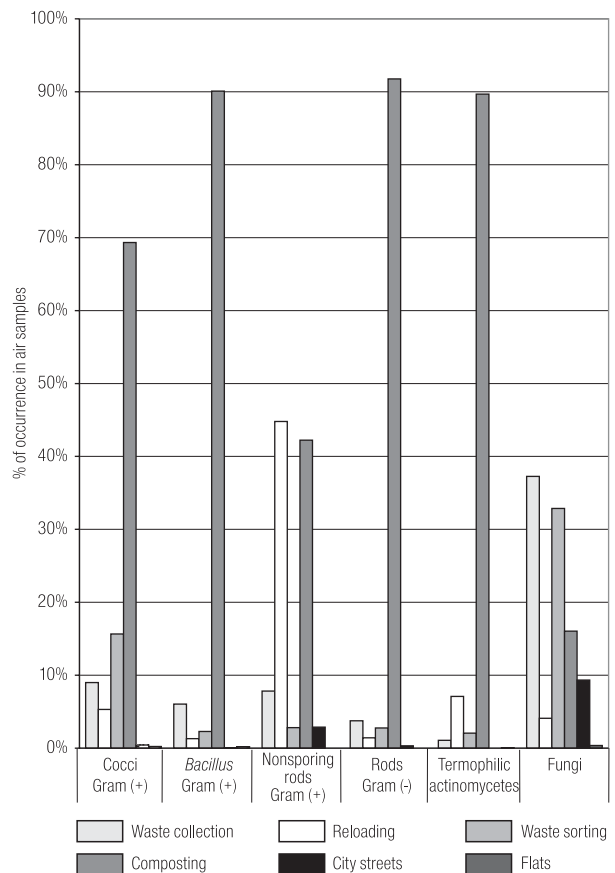


Fig. 4. The occurrence (%) of the representatives of individual microorganism groups in air samples collected at different workplaces.

*Bacillus anthracis* is very rare in Poland, the other are saprophytes. The latter may be pathogenic in very specific conditions [33,34].

Among Gram-positive cocci, coagulase-negative staphylococci of the saprophyticus group were most common, although numerous staphylococci of the epidermidis group for which human organism is the natural host, and *Staphylococcus aureus* were also isolated. Coagulase-negative staphylococci very rarely induce diseases in healthy persons.

It is interesting to note that *Enterococcus faecalis* and *Enterococcus faecium* were present in the air at all workplaces (mostly in the areas of waste collection and storage). The presence of these bacteria in dust provided evidence that it was contaminated by intestinal contents of humans and other mammals. Other Gram-positive bacteria were detected in single samples.

**Table 5.** The incidence of mesophilic bacteria, classified in the European Union Directive as biologic agents hazardous at workplace, was found in air samples.

Mesophilic bacteria	Place of sample collection						Risk acc. to EU
	Waste collection	Reloading	Waste sorting	Composting	City streets	Flats	
Gram-positive cocci:							
<i>Staphylococcus aureus</i>	2/10	0/5	2/5	1/10	2/9	0/8	2
<i>Enterococcus spp.</i>	7/10	3/5	4/5	3/10	0/9	0/8	2
<i>Enterococcus faecalis</i>	4/10	3/5	4/5	0/10	0/9	0/8	2
<i>Enterococcus faecium</i>	2/10	0/5	2/5	3/10	0/9	0/8	2
Nonsporing Gram-positive rods:							
<i>Listeria spp.</i>	1/10	1/5	0/5	1/10	1/9	0/8	2
<i>Corynebacterium spp.</i>	0/10	1/5	0/5	2/10	2/9	0/8	2
Nocardioform actinomycetes:							
<i>Rhodococcus spp.</i>	0/10	0/5	0/5	0/10	1/9	0/8	2
Facultatively anaerobic Gram-negative rods: Family <i>Enterobacteriaceae</i> :							
<i>Enterobacter spp.</i>	9/10	5/5	5/5	9/10	0/9	0/8	2
<i>Escherichia coli</i>	9/10	4/5	5/5	5/10	0/9	0/8	2
<i>Klebsiella spp.</i>	0/10	0/5	0/5	1/10	0/9	0/8	2
<i>Morganella spp.</i>	0/10	1/5	0/5	0/10	0/9	0/8	2
<i>Proteus spp.</i>	3/10	0/5	3/5	1/10	0/9	0/8	2
<i>Shigella spp.</i>	0/10	0/5	0/5	2/10	0/9	0/8	2
Gram-negative aerobic rods:							
<i>Chryseobacterium (Flavobacterium) spp.</i>	1/10	3/5	0/5	2/10	0/9	0/8	2
<i>Pseudomonas spp.</i>	3/10	2/5	3/5	7/10	2/9	0/8	2

Table 5 shows the incidence of Gram-negative rods in the air samples. According to EU Directive 2000/54/EC [35] only microorganisms classified as biological agents hazardous to human health are mentioned here. The *Enterobacteriaceae* family is of particular interest. Numerous representatives of this family are obligatory or opportunistic pathogens, and commensals e.g., non-pathogenic strains: *Escherichia coli*, *Proteus mirabilis*, *Enterobacter cloacae* or *Citrobacter* are present mainly in large intestine of humans and animals. The presence of these bacteria in the dust emitted at workposts proved its fecal contamination.

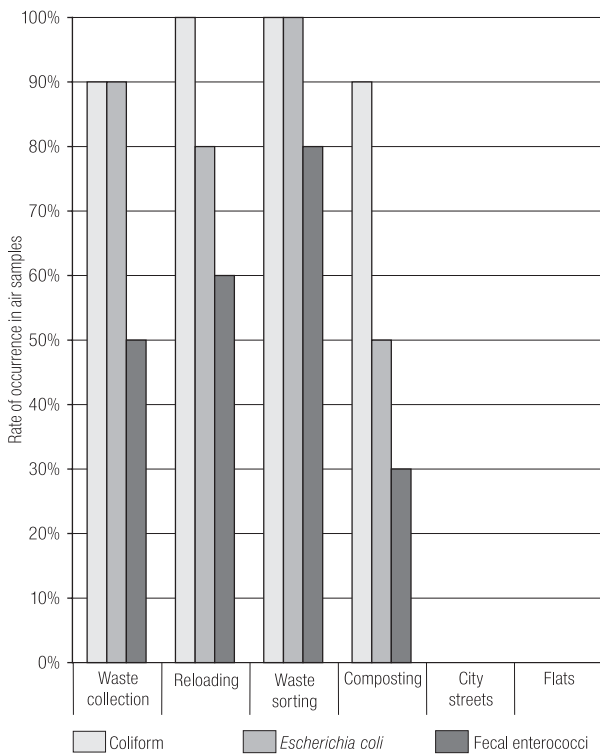
The rate of occurrence of bacteria regarded as indicators of hygienic conditions at workposts is shown in Fig. 5. The *Coli* form rods: *Escherichia*, *Enterobacter* and *Citrobacter*, were found in the samples collected at all workplaces. In the sorting facility, *Escherichia Coli* was isolated from all

samples, in the 9 of 10 samples gathered during waste collection. Genus *Enterobacter* with *E. cloacae* and *E. sakazaki* as predominating species, was also very often detected; in some samples, strains belonging to other *Enterobacter* species were present as well.

The classification of biological agents is presented in the Appendix III to Directive 2000/54/EC on the protection of workers against the occupational risk of exposure to biological agents [35]. The list of agents includes almost all genera of intestinal rods. They are classified in two groups of risk: pathogenic to humans and hazardous at workplace.

The presence of *E. coli* and fecal enterococci in the air at workposts suggested that other dangerous pathogens transmitted through the alimentary tract, such as viruses, certain bacteria, protozoonic cysts and eggs of worms might also occur there.





**Fig. 5.** The rate of occurrence (%) of indicator bacteria taken as a criterion for assessing the hygienic conditions at workplaces.

Gram-negative aerobic nonfermentative rods: *Acinetobacter*, *Alcaligenes*, *Bulkholderia*, *Brevundimonas*, *Comamonas*, *Flavimonas*, *Sphingomonas* and *Stenotrophomonas*, found in the samples, are not included in the list of biological agents hazardous at workplace, as they generally live in the natural environment and are not pathogenic to humans (healthy persons). However, it should be noted that rods originated from the natural environment and intestinal rods are both the source of endotoxins (lipopolysaccharides) as a component of their cell walls. The effects of bacterial endotoxins on the human body have been discussed in numerous publications [21,23,36,37]. Endotoxins inhaled with polluted air may lead to toxic pneumonitis and finally to adult respiratory distress syndrome (ARDS) [36].

Table 6 summarizes the exposure of workers to bioaerosols present in the air at workposts (medium and extreme values) during the collection and management of municipal solid waste. The air concentrations of determined components of organic dust at individual workposts are characterized by a long span reaching two orders

of magnitude. But it is not surprising because the majority of workposts are in the open air.

Among possible criteria for assessing hygienic conditions at workplaces, a hygiene standard that regulates the highest permissible concentration of organic dust in the air has been first adopted in Poland [38]. Bearing in mind the measurement procedures, the value of  $4 \text{ mg/m}^3$  was adopted as a standard for the total dust containing less than 10% of silica. The highest individual exposure levels were found in waste composting and collecting workers. The concentrations exceeded significantly the set standard (a tenfold excess in the composting facility). The mean values for other occupational groups also exceeded the value of  $4 \text{ mg/m}^3$ . Dust concentrations at other workposts were significantly lower and in the city center and dwellings were found at the level of about  $0.1 \text{ mg/m}^3$ .

The endotoxin concentration is another possible criterion for assessing occupational exposure to organic dust. The ICOH Committee for Organic Dust has presented a Criteria Document [37]. In this Document, the Committee justifies the use of endotoxin concentration as a measure of occupational exposure. It also recommends to adopt  $200 \text{ ng/m}^3$  for endotoxins as a no effect guideline value for toxic pneumonitis;  $10 \text{ ng/m}^3$  for respiratory inflammation; and  $100 \text{ ng/m}^3$  for systemic effects. In the Netherlands, the Expert Group for Occupational Standards proposed the maximum allowable endotoxin concentration of  $4.5 \text{ ng/m}^3$  in the air as time weighted average per shift. In Poland, the facultative value of  $200 \text{ ng/m}^3$  has been proposed by Dutkiewicz [40].

In our study, the value of  $200 \text{ ng/m}^3$  was exceeded only in one case ( $324 \text{ ng/m}^3$ ) in the composting facility (site worker). The remaining values were significantly lower.

The concentration of  $100 \text{ ng/m}^3$ , protecting against systemic effects, was exceeded in individual cases (in the composting utility and during waste collection), but the mean concentration of endotoxins calculated for any of study groups was below this value.

The concentration of  $10 \text{ ng/m}^3$ , protecting against pulmonary inflammation, also in person with atopy, was exceeded in the majority of the measurements (over 50%), contributing at the same time to higher than 10

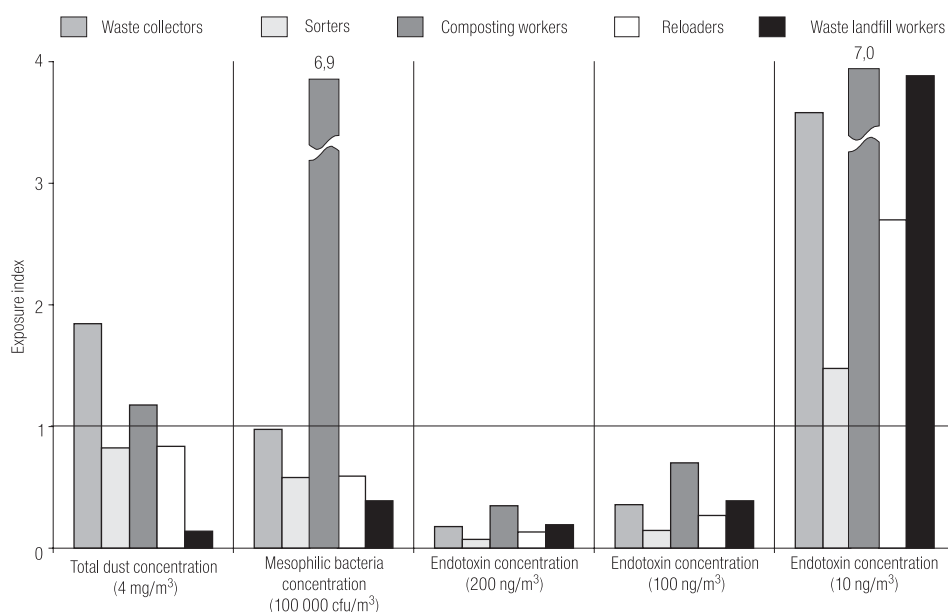
**Table 6.** Workers' exposure to bioaerosols present in the air at workposts (mean and extreme values) during waste collection and management, including background value

Sampling point	Workpost	Dust concentration (mg/m <sup>3</sup> )	Total number of microorganisms (10 <sup>7</sup> /m <sup>3</sup> )	Mesophilic bacteria (10 <sup>3</sup> cfu/m <sup>3</sup> )	Thermophilic bacteria (10 <sup>3</sup> cfu/m <sup>3</sup> )	Fungi (10 <sup>3</sup> cfu/m <sup>3</sup> )	Endotoxins (ng/m <sup>3</sup> )
Waste collectors	Driver	6.3 (1.1–16)	0.4 (0.2–0.5)	267 (22–750)	1.7 (0.3–3.3)	30 (6.2–61)	36 (0.9–101)
	Loader	7.7 (0.6–24)	0.4 (0.04–1.2)	59 (3.8–190)	1.4 (0.13–6.3)	63 (6.8–132)	36 (1.8–109)
Sorting utility	Machine operator	6.3	1.1	29	4.6	126	20
	Sorter	2.6 (1.9–3.2)	0.9 (0.3–1.7)	65 (37–105)	3.7 (2.4–4.9)	102 (84–138)	13 (5.0–23)
Composting utility	Machine operator	4.9 (2.3–10)	41 (0.11–190)	323 (19–540)	257 (9.8–890)	27 (5.8–69)	61 (9.1–114)
	Site worker	4.6 (0.8–10)	14 (0.17–48)	919 (26–6278)	64 (4.4–390)	19 (1.6–56)	76 (10–324)
Reloading facility	Machine operator	2.5 (1.9–3.2)	15 (0.16–29)	78 (31–170)	29 (6.1–59)	16 (11–26)	14 (9.2–20)
	Site worker	3.8 (1.4–7.4)	17 (0.05–37)	48 (24–83)	10 (3.8–21)	12 (5.4–19)	34 (9.1–104)
Waste landfill	Machine operator	0.9 (0.2–1.9)	0.1 (0.02–0.2)	40 (21–81)	25 (0.8–110)	25 (0.4–110)	40 (0.9–120)
	Site worker	0.3 (0.11–0.6)	0.06 (0.03–0.09)	37 (9.5–95)	6.4 (0.02–25)	3.1 (0.3–7.9)	38 (0.9–150)
City streets	Background	0.03 (0.01–0.1)	0.3 (0.06–1.5)	1.1 (0.1–2.3)	0	17 (12–22)	0.5
Dwellings	Background	0.05 (0.01–0.2)	0.2 (0.08–0.5)	1.3 (0.13–6.7)	0.02 (0.04–0.07)	0.8 (0.2–1.8)	1.5 (0.8–2.1)

ng/m<sup>3</sup> mean concentration in occupational groups. In samples collected in the city center and dwellings, endotoxins were at the level of 1 ng/m<sup>3</sup>.

The facultative threshold concentrations of microorganisms in the organic dust: 100 000 cfu/m<sup>3</sup> for total mesophilic bacteria; 20 000 cfu/m<sup>3</sup> for Gram-negative bacteria; 20 000 cfu/m<sup>3</sup> for thermophilic actinomycetes; and 50 000 cfu/m<sup>3</sup> for fungi, proposed by Dutkiewicz [40] as permissible in the work environment. were also applied

for evaluating the magnitude of exposure at individual workposts. Based on the measurements performed in our study, it may be concluded that the proposed highest permissible concentrations of mesophilic bacteria (10<sup>5</sup> cfu/m<sup>3</sup>) were exceeded (mean values for workposts) during waste collection and in composting facility, whereas at other workposts they were below the proposed value. The concentrations of thermophilic actinomycetes in samples collected in the city center and dwellings were also lower

**Fig. 6.** Assessment of workers' exposure to aerosols occurring in the air at workposts; various criteria applied.

than  $10^5$  cfu/m<sup>3</sup>, but higher at workposts, particularly in the composting facility among machine operators (mean,  $2.57 \cdot 10^5$  cfu/m<sup>3</sup>). The lowest concentration of fungi was found in dwellings and the highest in the sorting facility ( $1.0 \cdot 10^5$  cfu/m<sup>3</sup> on average), which could have been expected.

The results are summarized in Fig. 6. The figure presents the workers' exposure expressed by the exposure index (exposure index 1 = recommended MAC) for bioaerosols present in the air during waste collection, assessed using the following criteria: concentration of total suspended dust, concentration of mesophilic bacteria and concentration of endotoxins. As shown in Fig. 6, the mean concentrations at waste collection and composting workposts exceeded the exposure index by 1.75 and 1.18 times, respectively if the total mass of dust was taken as a criterion. At other workposts, admissible levels were not exceeded.

The exposure index for mesophilic bacteria was significantly exceeded (6.90 times) in the composting facility. At other workposts it was below the reference value.

When the endotoxin concentration at the level of 10 ng/m<sup>3</sup> was used as a criterion, this admissible value was exceeded at all workposts, reaching even a sevenfold excess in the composting facility. But in the case of the concentration of 200 ng/m<sup>3</sup> or 100 ng/m<sup>3</sup>, at the permissible highest concentration, the work hygienic conditions could be regarded as acceptable.

When the total number of bacteria, the concentration of thermophilic bacteria and the concentration of fungi were considered in terms of compliance with the reference value, proposed by Dutkiewicz [40] and used as the exposure evaluation criteria, the interpretation of obtained results led to quite different conclusions with regard to hygienic conditions.

Among the criteria used to assess hygienic conditions at workposts in question, two of them are really important: the concentration of total dust – 4 mg/m<sup>3</sup>, and the concentration of 10 ng/m<sup>3</sup> for endotoxins. In Poland, the maximum permissible concentration of organic dust is established at the level of 4 mg/m<sup>3</sup>, and therefore all measurements should be compared with it. In view of the sanitary

inspection, the assessment of exposure based on the measurement of the total dust is easier and cheaper than that of endotoxin. However, the latter one is based on scientifically sound health criteria.

The concentration of endotoxins at the level of 10 ng/m<sup>3</sup> as a criterion is well documented by the ICOH Committee for Organic Dust [37], but the high cost of analyses may be disadvantageous for applying this criterion.

Measurements conducted in the city center and dwellings render it possible to become familiar with concentrations in the municipal environment, however, they should be taken only as a background. Nevertheless, it is an important information that should be considered when setting maximum admissible concentrations at workposts.

It should be stressed that the workers employed at all workposts, covered by the study did not use any individual devices to protect the respiratory tract and eyes, which according to the results obtained substantially contributed to the increased exposure at certain workposts.

The study was carried out in the period of year characterized by enhanced air concentrations of bioaerosols due to high temperature and humidity. It is likely that during the wintertime, the workers' exposure will be considerably lower.

## CONCLUSIONS

The highest dust concentrations were found at the waste collecting sites (mean, 7.7 mg/m<sup>3</sup>) and in the composting unit (mean, 4.6 mg/m<sup>3</sup>). Samples collected in the composting unit showed the highest endotoxin levels (mean concentration, 76 ng/m<sup>3</sup>); the corresponding values for other workplaces were, in the descending order: sorting (61 ng/m<sup>3</sup>), and waste collection (36 ng/m<sup>3</sup>).

Gram-negative bacteria (intestinal in particular) were found in all samples collected at the workplaces, therefore it seems reasonable to use the air endotoxin concentration as the criterion for the hygiene assessment of the working conditions.

Assuming the total dust concentration of 4.0 mg/m<sup>3</sup> (Polish MAC value) and the endotoxin concentration at the level of 10 ng/m<sup>3</sup> as the reference criteria, the hygien-

ic conditions of collecting waste and at the waste composting unit cannot be considered as satisfactory. The requirement of using protective means (goggles, dust masks) by individual workers in the areas of high exposure should be enforced.

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