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EXPOSURE TO AIRBORNE MICROORGANISMS IN FIBERBOARD AND CHIPBOARD FACTORIES

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Abstract: Microbiological air sampling was performed in one fiberboard factory and two chipboard factories located in south-eastern Poland. It was found that the levels of bacteria, fungi, dust and bacterial endotoxin in the air of examined facilities were high during initial stages of the production cycle (shredding of waste wood, storing of chips) and then sharply decreased during further stages of this cycle (forming and formatting of the boards). In the fiberboard factory, the concentration of airborne microorganisms at the initial stages of production cycle was 71.8–95.2 × 10^3 cfu/m^3 and dropped in further stages to the level of 8.4–17.5 × 10^3 cfu/m^3. Fungi (mostly *Aspergillus fumigatus* and *Penicillium* spp.) were prevailing microorganisms in the air of the fiberboard factory, forming 46.0–87.3% of the total airborne microflora. The concentrations of microorganisms in the air of the chipboard factories were significantly lower compared to the fiberboard factory ($p < 0.05$). During initial stages of production cycle they were within the range of 12.9–101.5 × 10^3 cfu/m^3, while during forming and formatting of boards within the range of 5.3–12.4 × 10^3 cfu/m^3. On average, the most common microorganisms in the air of the chipboard factories were corynebacteria (mostly *Arthrobacter* spp. and *Corynebacterium* spp.) which formed 24.4–64.6% of the total microflora. The values of the respirable fraction of airborne microflora in the fiberboard and chipboard factories varied within a fairly wide range and were between 20.5–91.1%. Altogether, 38 species or genera of bacteria and 16 species or genera of fungi were identified in the air of examined factories, of which respectively 14 and 9 species or genera were reported as having allergenic and/or immunotoxic properties. The concentration of bacterial endotoxin in the air of examined factories was greatest, similarly to the concentration of microorganisms, during the initial stages of the production cycle: 103.1–1974.0 EU/m^3 in the fiberboard factory, and 3.2–217.4 EU/m^3 in chipboard factories. In conclusion, the workers of fiberboard and chipboard factories may be exposed during the initial stages of the production cycle (shredding of waste wood, storing of chips) to high levels of airborne microorganisms and endotoxin posing respiratory hazard.

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INTRODUCTION

Workers processing wood are under increased risk of lung function impairment, bronchial hyperresponsiveness and respiratory disorders of allergic, immunotoxic and neoplastic etiology [10, 30, 64]. This is due to the inhalation of various hazardous components of wood dust, comprising wood derivatives (e.g. resin acids,

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monoterpenes) and microorganisms developing in wood [10, 12, 14, 20, 32, 51].

The pollution of the air of wood processing facilities with microorganisms results from the primary or secondary infection of timber [20, 29, 58]. The primary infection, initially with bacteria and then with fungi, develops in timber logs stored in the forest and in lumber yards [31, 36, 47, 59]. A study performed in the USA has shown that the microflora of the apparently undecayed timber may reach high levels and may contain allergenic and/or toxic species which pose a potential risk for woodworkers [22, 63]. Secondary infection of wood proceeds on chopped wood (chips, planks) which are stored and/or kiln dried in wood processing facilities in conditions favoring microbial growth. It is characterized by an abundant growth of molds and often causes respiratory illnesses in workers [5, 28, 29, 34, 38, 58, 66].

The workers exposed to wood dust containing microorganisms and their products may develop allergic disease (allergic alveolitis, asthma) caused by protein or glycoprotein allergens produced by bacteria and fungi, or immunotoxic disease (mostly organic dust toxic syndrome) caused by biologically potent microbial substances such as bacterial endotoxins or fungal (1→3)-β-D-glucans which induce inflammatory reaction in lungs [2, 10, 11, 12, 14, 15, 20, 21, 26, 50, 51, 54, 55, 61].

In an earlier work we described airborne microflora of Polish sawmills [26]. The aim of the present work was to study the concentration and species composition of the microflora of air of fiberboard and chipboard factories which, to the best of our knowledge, have so far not been investigated. The production cycle in these facilities is totally different compared to sawmills: the boards are manufactured from waste wood which is shredded and subjected to thermal and chemical processing.

MATERIALS AND METHODS

Examined facilities. Air sampling was performed in three factories located in south-eastern Poland on the territory of the Sub-Carpathian Province, of which one (plant "A") was a fiberboard factory and the other two ("B" and "C") were chipboard factories. In both types of factories three basic stages of production cycle could be distinguished:

a) Initial stage: shredding waste wood (branches, poles, shavings, etc.) into chips. In the chipboard factories, chips were repeatedly cut into very small pieces. Before further processing, the chips were stored either indoors in tanks or outdoors in piles.

b) Mid-stage: forming boards with the use of thermal, mechanical and/or chemical processing. Fiberboards were made by steaming chips under high pressure for getting fiber mass, which was followed by mechanical milling and glueing of the mass, and subsequent forming of boards and compressing them at high temperature. Chipboards were made by sticking together small wood chips in appropriate forms, with the use of glue containing urea and formaldehyde, chemical fixation with ammonium chloride, and subsequent compression at high temperature.

c) Final stage: in which boards are finished by trimming and sanding.

In fiberboard factory "A", the air samples were taken in the sequence of the production cycle, on the following 6 sites, marked A1-A6: • small chipper shredding mixed waste wood from European alder (*Alnus glutinosa*) and silver fir (*Abies alba*) (A1); • big chipper shredding waste wood from Scots pine (*Pinus sylvestris*) (A2); • chip tanks (A3); • forming of raw fiberboards on a conveyor belt (A4); • machine trimming of fiberboards (A5); • machine sanding of fiberboards (A6).

In chipboard factory "B", the samples were taken at the following 3 sites, marked B1-B3: • chipper shredding mixed waste wood (B1); • turboslicers shredding chips from mixed waste wood (B2); • slicer shredding silver fir shavings (B3).

In chipboard factory "C", the samples were taken at the following 5 sites, marked C1-C5: • chipper shredding mixed waste wood from silver fir and Scots pine (C1); • two-stage shredding of Scots pine blocks into chips with band saw and slicer (C2); • turboslicers shredding silver fir waste wood into chips (C3); • forming of chipboards on a conveyor belt (C4); • machine trimming and sanding of chipboards (C5).

All samples in examined factories were taken indoors. The samples were always collected during uninterrupted work of machinery and full activity of all workers engaged at the workplace. At each site, a full series of 20 double samples for viable microorganisms (as described below) and samples for dust and endotoxin were collected on the same day.

Microbiological examination of the air. The examination was performed as described earlier [26]. Air samples were taken in fiberboard and chipboard factories with a custom-designed particle-sizing slit sampler [16] enabling estimations of both total and respirable fractions of the microbial aerosol. Each air sample was a duplicate, taken at a flow rate of 20 l/min. It consisted of two parallelly exposed agar plates: one "a" sampled directly for all organisms and used for the estimation of total concentration of cfu per m^3; and the other "b" sampled through a pre-selector for the respirable fraction. The value of respirable fraction was expressed as a percent (%) of the total count.

At each sampling site, series of 5 double samples were taken on each of the following agar media: blood agar for total mesophilic Gram-negative and Gram-positive bacteria, whey agar for lactobacilli, half-strength tryptic soya agar for thermophilic actinomycetes, and malt agar for fungi. The blood agar plates were subsequently incubated for one day at 37ºC, then three days at 22ºC and finally three days at 4ºC. The malt agar plates were

Table 1. Microorganisms in the air of fiberboard factory “A”: concentrations and respirable fractions (Rf).

Sampling site	Mesophilic bacteria		Fungi		Total microorganisms[a]	
	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)
A1. Small chipper (mixed waste wood from alder and silver fir)	27.9 ± 8.0	69.5	43.9 ± 9.6	30.1	71.8 ± 7.9	45.4
A2. Big chipper (waste wood from Scots pine)	21.4 ± 8.7	63.2	52.8 ± 11.0	28.6	74.2 ± 6.0	38.6
A3. Chip tanks	12.1 ± 3.1	50.0	83.1 ± 13.0	64.5	95.2 ± 13.4	62.6
A4. Forming of raw fiberboards	2.5 ± 1.1	40.5	5.8 ± 3.5	56.3	8.4 ± 3.3	51.4
A5. Trimming of fiberboards	6.5 ± 0.9	32.4	5.5 ± 2.8	30.4	12.0 ± 1.9	31.5
A6. Sanding of fiberboards	7.4 ± 1.5	34.1	10.1 ± 2.1	19.5	17.5 ± 2.9	25.7
Mean	13.0 ± 9.1	48.3	33.5 ± 29.5	38.2	46.5 ± 35.4	42.5

[a]Included are thermophilic actinomycetes which were detected in small concentration only at one sampling site A4 (mean± S.D. = 0.1 ± 0.2 cfu/m^3 × 10^3, Rf = 0). Lactobacilli were not detected at any of examined sampling sites.

subsequently incubated for four days at 30ºC and four days at 22ºC [17]. The prolonged incubation at lower temperatures was aimed at isolating as wide a spectrum of bacteria and fungi as possible. The whey agar plates were incubated the same as the blood agar plates, and the tryptic soya agar plates were incubated for five days at 55ºC. The colonies grown were counted and differentiated and the data reported as cfu per one cubic meter of the air (cfu/m^3). The total concentration of microorganisms in the air was obtained by the addition of the concentrations of total mesophilic bacteria, lactobacilli, thermophilic actinomycetes and fungi. Then, the percent composition of the total microflora of the air was determined.

Bacterial isolates were identified by microscopic and biochemical methods, as recommended by Bergey’s Manual [39, 62, 68] and Cowan & Steel [8]. Additionally, the selected isolates were identified with microtests: API Systems 20E and NE (bioMérieux, Marcy l’Etoile, France) and BIOLOG System (Biolog, Inc., Hayward, CA, USA). Fungi were classified by microscopic methods, according to Barron [4], Larone [45], Litvinov [48], Ramirez [56], and Raper & Fennell [57].

The concentration of dust and endotoxin in the air was determined at all sampling sites except for sites A2 and B1. Air samples were collected on the polyvinyl chloride filters by the use of a AS-50 one-stage sampler (TWOMET, Zgierz, Poland). Two samples were taken on each sampling site. The concentration of dust in the air was estimated gravimetrically.

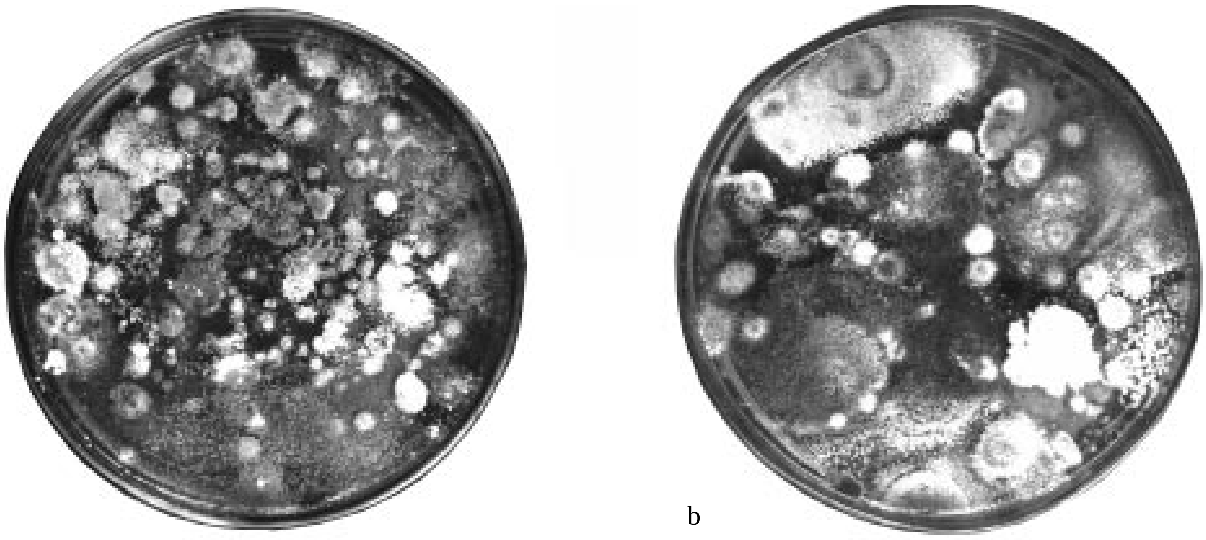
The concentration of bacterial endotoxin in the airborne dust was determined by the *Limulus* amebocyte lysate (LAL) test [46]. The filters were extracted with 5 ml of sterile non-pyrogenic water (Travenol Laboratories Inc., Deerfield, IL, USA) by rocking for 60 min at room temperature. The suspension was centrifuged at 1,000 g for 10 min to remove particulate debris, and the supernatant fluid was separated for further analysis. Quantification of endotoxin content was performed in duplicate by a chromogenic modification of the LAL test (QCL-1000; Whittaker Bioproducts, Walkersville, MA, USA). Results were reported in terms of Endotoxin Units (EU) per 1 m^3 of air. To convert to nanograms the value was divided by 10 [15].

Most of the study was performed in the years 1986–1989 and continued in 1998–2001. All the sampling and determinations of the concentration and species composition of the airborne microflora was completed in all facilities during the first phase of the study (1986–1989). In the second phase of the study (1998–2001), the detailed taxonomic studies of the bacterial and fungal isolates and statistical analyses of the results were carried out. Preliminary results of this work have been reported elsewhere [20].

RESULTS

The concentration of microorganisms in the air of fiberboard factory “A” was large at the initial stages of production cycle (shredding of waste wood, storing of chips) ranging from 71.8–95.2 × 10^3 cfu/m^3 (Tab. 1, Fig. 1). In further stages of production cycle (forming and formatting of fiberboards), the concentration of airborne microorganisms sharply decreased to the level of 8.4–17.5 × 10^3 cfu/m^3 (Tab. 1). Fungi were the prevailing microorganisms in the air of the fiberboard factory, forming 61.1–87.3% of the total airborne microflora during initial stages of production cycle and 46.0–69.1% during later stages of the cycle (Fig. 2). The group second to fungi, but much less numerous, were corynebacteria which constituted 6.6–15.9% of the total airborne microflora during initial stages of production cycle and 22.3–36.0% during later stages of the cycle (Fig. 2). The other morphological types of microorganisms occurred in relatively low proportion.

During shredding of waste wood with chippers, *Penicillium* and *Cladosporium* strains were most often recovered from the air, forming respectively 46.2–75.2%



a b

Figure 1. Photographs of air samples for fungi taken in fiberboard factory “A” at big chipper shredding pine waste wood (sampling site A2). Samples taken by use of particle-sizing sampler on malt agar plates (a - total airborne fungi; b - respirable fraction of airborne fungi) each in volume of 3.33 l. It may be seen that the concentration of fungi in the air at the initial stages of fiberboard and chipboard production (shredding of waste wood) is large, posing a risk to workers. At the presented site, the potentially allergenic *Penicillium* strains prevailed among airborne fungi.

and 9.1–15.3% of the total fungal strains isolated from the air. By contrast, in the air of the room where wood chips were stored, strains of *Aspergillus fumigatus* distinctly prevailed which constituted 79.7% of total fungal isolates. *Aspergillus fumigatus* was also the most common species during forming and formatting of fiberboards, forming 35.9–82.8% of total fungal isolates.

The concentrations of microorganisms in the air of chipboard factories “B” and “C” were, on average, lower compared to fiberboard factory “A” and the difference proved to be statistically significant (t-test, $p < 0.05$). Out of eight sampling sites in two chipboard factories, only at one site, at the chipper shredding waste wood in factory “B”, a large concentration of airborne microorganisms was found equal to 101.5×10^3 cfu/m^3 (Tab. 2). Of this number, 65.2×10^3 cfu/m^3 (64.2%) were fungi, among which *Penicillium* strains distinctly prevailed that made up 77.2 % of total fungal isolates. At the remaining seven

Table 2. Microorganisms in the air of chipboard factories “B” and “C”: concentrations and respirable fractions (Rf).

Plant, sampling site	Mesophilic bacteria		Fungi		Total microorganisms[a]	
	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)	Concentration (mean ± S.D., cfu/m^3 × 10^3)	Rf (%)
Chipboard factory “B”						
B1. Chipper (mixed waste wood)	36.3 ± 6.9	35.4	65.2 ± 24.9	12.2	101.5 ± 21.8	20.5
B2. Turboslicers shredding chips (mixed waste wood)	12.7 ± 3.5	61.8	5.3 ± 2.5	46.6	18.0 ± 4.3	57.3
B3. Slicer shredding fir shavings	32.1 ± 18.2	37.0	2.1 ± 0.6	25.7	34.8 ± 16.0	36.3
Chipboard factory “C”						
C1. Chipper (mixed waste wood from silver fir and Scots pine)	17.5 ± 1.7	35.3	2.6 ± 2.9	25.0	20.9 ± 3.8	34.1
C2. Two-stage shredding of pine blocks into chips with band saw and slicer	10.9 ± 3.0	67.0	2.7 ± 0.7	53.3	14.3 ± 2.3	62.3
C3. Turboslicers shredding fir waste wood into chips	11.6 ± 3.6	96.4	1.3 ± 0.3	42.9	12.9 ± 3.2	91.1
C4. Forming of chipboards on a conveyor belt	11.6 ± 2.6	76.8	0.8 ± 0.3	38.5	12.4 ± 2.8	74.4
C5. Trimming and sanding of chipboards	4.1 ± 0.9	42.6	1.1 ± 0.9	26.3	5.3 ± 1.4	38.4
Mean	17.1 ± 10.6	56.5	10.1 ± 21.1	33.8	27.5 ± 29.4	51.8

[a]Included are thermophilic actinomycetes and lactobacilli, detected in small concentration only at four sampling sites. Thermophilic actinomycetes were detected on sites C2 (mean ± S.D. = 0.1 ± 0.2 cfu/m^3 × 10^3, Rf = 0) and C5 (mean ± S.D. = 0.1 ± 0.2 cfu/m^3 × 10^3, Rf = 0). Lactobacilli were detected on sites B3 (mean ± S.D. = 0.6 ± 0.0 cfu/m^3 × 10^3, Rf = 50.0), C1 (mean ± S.D. = 0.8 ± 0.2 cfu/m^3 × 10^3, Rf = 40.0), and C2 (mean ± S.D. = 0.6 ± 0.0 cfu/m^3 × 10^3, Rf = 25.0).

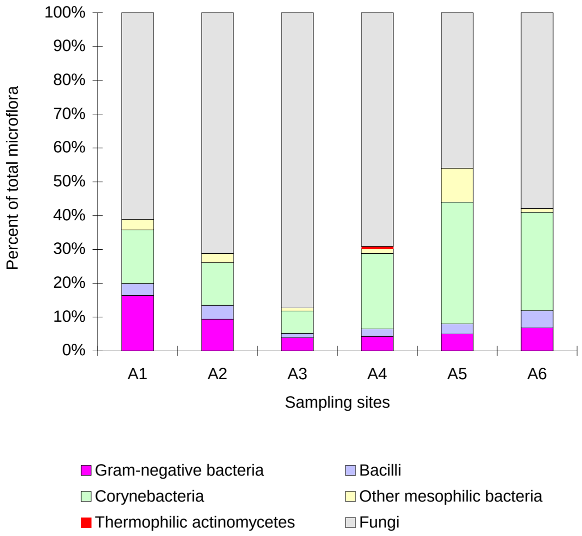


Figure 2. Composition of airborne microflora in a fiberboard factory (total count, including mesophilic bacteria, thermophilic actinomycetes and fungi).

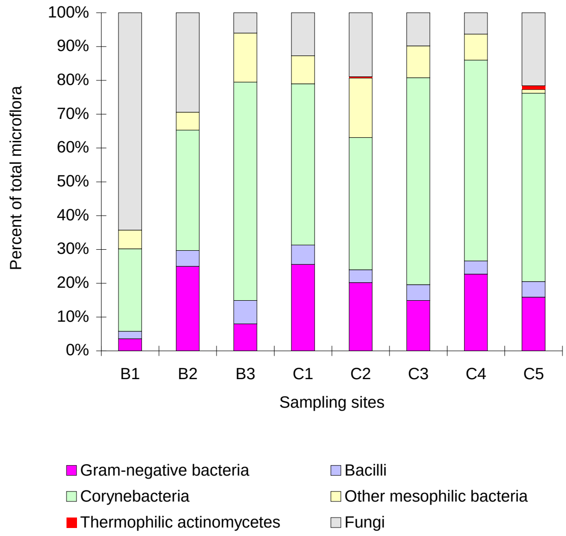


Figure 3. Composition of airborne microflora in chipboard factories (total count, including mesophilic bacteria, thermophilic actinomycetes and fungi).

sampling sites in chipboard factories, the concentrations of airborne microorganisms were much lower, ranging from 5.3–34.8 × 10^3 cfu/m^3 (Tab. 2). Similar to the fiberboard factory, the smallest concentrations of airborne microorganisms were noted during forming and formatting of boards (respectively 12.4 and 5.3 × 10^3 cfu/m^3) compared to initial stages of production cycle, comprising shredding of waste wood and chips (12.9–101.5 × 10^3 cfu/m^3 at six sampling sites) (Tab. 2).

The composition of airborne microflora in the examined chipboard factories differed from that found in the fiberboard factory. In seven out of eight sampling points the commonest microorganisms were corynebacteria (mostly *Arthrobacter* spp. and *Corynebacterium* spp.) ranging from 24.4–64.6% of the total airborne microflora, while fungi, ranging from 6.0–64.3% of the total count, prevailed at only one out of eight sampling points (Fig. 3). The third commonest microorganisms were Gram-

Table 3. List of microbial species and genera identified in samples of air from fiberboard and chipboard factories.

Gram-negative bacteria: ***Acinetobacter calcoaceticus****+ (A1-A4, B, C2-C5), ***Alcaligenes faecalis****+ (C3)**,** ***Enterobacter aerogenes*** + (C2), ***Enterobacter cloacae*** + (A1, C2, C3), ***Klebsiella pneumoniae* ssp. *ozaenae*** + (C4), ***Pantoea agglomerans******+ (synonyms: *Erwinia herbicola, Enterobacter agglomerans*)** (B2-B3, C2), ***Proteus vulgaris*** + (A1), *Pseudomonas fluorescens* (C3), *Pseudomonas* spp. (A1, A6, B2, C2, C3, C5), ***Rahnella* spp.**+ (A2-A5, B).

Bacilli: *Bacillus cereus* (A, B, C1-C4), *Bacillus megaterium* (A1-A3, A6, C1-C4), ***Bacillus subtilis**** (A, B, C), *Bacillus* spp. (A, B, C).

Corynebacteria: ***Arthrobacter globiformis**** (A2, A3, A5, A6, B2, C1, C2), *Arthrobacter* spp. (A, B, C), ***Brevibacterium linens**** (A, B, C), *Brevibacterium helvolum* (B3), *Corynebacterium nitrophilus* (C3), *Corynebacterium thomssenii* (C2), *Corynebacterium* spp. (A, B, C), *Jonesia denitrificans* (B1), *Microbacterium imperiale* (C5), *Microbacterium lacticum* (A, B, C).

Other mesophilic bacteria: *Aerococcus viridans* (B1, B3), *Carnobacterium divergens* (B1), *Lactobacillus* spp. (B3, C1, C2), *Micrococcus luteus* (A5, B3), *Micrococcus roseus* (A4, A5, C2), *Micrococcus* spp. (A1-A3, A5, B, C2-C4), *Staphylococcus epidermidis* (A1-A3, A5, B2, B3, C1, C2), *Staphylococcus* spp. (A, B, C1-C4), *Streptococcus pneumoniae* (A2), *Streptococcus* spp. (A1-A3, A5, B, C1-C4), ***Streptomyces albus**** (A1, B1), *Streptomyces* spp. (A1, A6, B, C1-C4).

Thermophilic actinomycetes: ***Saccharopolyspora rectivirgula**** **(synonyms: *Faenia rectivirgula, Micropolyspora faeni*)** (A4), ***Thermoactinomyces vulgaris**** (C2).

Fungi: ***Alternaria alternata**+** (A5, A6), ***Aspergillus fumigatus**+** (A3-A6, B, C)**,** ***Aspergillus niger****+ (A3, B2, C2, C3), *Aspergillus repens* (A3, A6), ***Candida* spp.*** (A, B, C), *Cladosporium brevi-compactum* (A, B1, B2, C1), *Geotrichum candidum* (A6, C3), ***Mucor* spp**.* (A, B, C2, C4, C5), *Paecilomyces* spp. (A3, B1, C4), ***Penicillium citrinum****+ (A1-A3, B1, B2, C1), ***Penicillium* spp.*+** (A, B, C), ***Rhizopus nigricans*** * + (A3), *Rhodotorula graminis* (A1-A5, B1, C3), *Trichoderma album* (A1-A4, B1, B2, C5), ***Trichoderma viride**** (A1-A4, B, C1, C3), *Trichothecium roseum* (A1, C4).

Sites of isolation are given in parentheses. Quoting only the letter attributed to a particular factory ("A", "B" or C", without numbers) means that the species was isolated from all sampling sites within the factory. Names of species reported as having allergenic and/or immunotoxic properties (see text) are in bold and marked as follows: * allergenic species; + immunotoxic species. The species *Klebsiella pneumoniae* ssp. *ozaenae, Proteus vulgaris, Streptococcus pneumoniae* and *Aspergillus fumigatus* may be a cause of infectious disease.

Table 4. Concentrations of dust and bacterial endotoxin in the air of fiberboard and chipboard factories.

Plant, sampling site	Concentration of dust (mean, mg/m^3)	Concentration of endotoxin (mean, EU/m^3)
Fiberboard factory "A"		
A1. Small chipper (mixed waste wood from alder and silver fir)	35.6	1,974.02
A3. Chip tanks	2.2	284.53
A4. Forming of raw fiberboards	0.4	103.05
A5. Trimming of fiberboards	2.3	16.26
A6. Sanding of fiberboards	2.4	16.15
Chipboard factory "B"		
B2. Turboslicers shredding chips (mixed waste wood)	3.4	66.78
B3. Slicer shredding fir shavings	1.1	6.32
Chipboard factory "C"		
C1. Chipper (mixed waste wood from silver fir and Scots pine)	6.2	89.16
C2. Two-stage shredding of pine blocks into chips with band-saw and slicer	29.1	217.38
C3. Turboslicers shredding fir waste wood into chips.	1.3	3.22
C4. Forming of chipboards on a conveyor belt	1.1	<0.125
C5. Trimming and sanding of chipboards	1.2	<0.125

negative bacteria which formed 3.6–25.6% of the total count. The other types of microorganisms were less numerous.

The values of the respirable fraction of airborne microflora in the fiberboard and chipboard factories varied within a fairly wide range, respectively between 25.7–62.6% and 20.5–91.1%. At 12 sampling sites out the 14 examined, the values of respirable fraction were greater for bacteria than for fungi.

In the air samples taken in the examined fiberboard and chipboard factories, 38 species or genera of bacteria and 16 species or genera of fungi were identified, of these, respectively 14 and 9 species or genera were reported as having allergenic and/or immunotoxic properties [21, 24, 27, 32, 35, 41, 42, 52] (Tab. 3). These figures are certainly underestimated, as a number of bacterial and fungal strains could be identified only to the generic level.

The concentration of dust in the air of the fiberboard factory ranged from 2.2–35.6 mg/m^3 during initial stages of production cycle (shredding of waste wood, storing of chips), and from 0.4–2.4 mg/m^3 during forming and formatting of the boards, while in chipboard factories the corresponding figures were 1.1–29.1 mg/m^3 and 1.1–1.2 mg/m^3 (Tab. 4). Only at two sampling sites (A1, C2), denoted values exceeded the Polish OEL value equal to 4 mg/m^3 [60].

The concentration of bacterial endotoxin in the air of the fiberboard and chipboard factories was greatest, similar to the concentration of microorganisms, during the initial stages of the production cycle. In the fiberboard factory, a very distinct decrease of endotoxin concentration with the progress of the production cycle could be observed: this was 1,974.0 EU/m^3 during shredding of waste wood, 284.5 EU/m^3 at chip tanks, 103.1 EU/m^3 during forming of raw boards, and 16.2–16.3 EU/m^3 during final trimming and sanding of the boards (Tab. 4). Similar to the case of microbial concentrations, the concentrations of endotoxin in the air of chipboard factories were lower, ranging from 3.2–217.4 EU/m^3 during shredding of waste wood and chips. During forming and formatting of chipboards, the concentration of endotoxin was below detection limit (0.125 EU/m^3).

DISCUSSION

The greatest risk of exposure to hazardous bioaerosols in fiberboard and chipboard factories occurs in the initial stages of the production cycle during shredding of waste wood, mostly with the use of chippers, and during handling of wood chips. The concentrations of airborne microorganisms at these places were of the order 10^4–10^5 cfu/m^3, due mostly to the abundant presence of mold fungi. These figures, on average, were higher compared to those recorded in the Polish sawmills [26] and in wood working shops in Egypt [1], and similar to those recorded in wood processing facilities located in Australia and North America [2, 11, 14, 50, 51], but lower compared to the concentrations of airborne microorganisms reported from Scandinavian sawmills where stored or kiln dried wood products were heavily infected by molds [28, 29, 34].

During the further stages of the production cycle in fiberboard and chipboard factories (forming and final formatting of the boards), the concentrations of airborne microorganisms notably decreased, being in the order of 10^3–10^4 cfu/m^3. This may be explained by the sterilizing effect of the thermal processing of chips, and by the microbicidal effect of formaldehyde used for glueing boards. Generally, the levels of microorganisms in the air of the examined fiberboard factory were higher than in the chipboard factories.

To date, there are no internationally recognized Occupational Exposure Limit (OEL) values for bioaerosols, and thus the results obtained in the present work could be compared only to the proposals raised by particular authors. The OEL value of 10×10^3 cfu/m^3 for total airborne micoorganisms proposed by Malmros *et al.* [49] was exceeded at 12 out 14 sampling sites examined, while the OEL value proposed for this component by Dutkiewicz and Jabłoński (50×10^3 cfu/m^3 if respirable fraction equals to or exceeds 50% of the total count, 100×10^3 cfu/m^3 if respirable fraction is below 50% of the total count) [21, 23] was exceeded at only 2 sampling sites out of 14 examined. The OEL value proposed by the latter authors [21, 23] for fungi (25×10^3 cfu/m^3 if respirable fraction equals to or exceeds 50% of the total count, 50×10^3 cfu/m^3 if respirable fraction is below 50% of the total count) was exceeded at 3 sampling sites out 14 examined.

Airborne fungi pose a major biohazard in the fiberboard and chipboard factories. They distinticly prevailed at sites where the pollution of the air with microorganisms was the greatest: at chippers shredding waste wood and at the tanks with wood chips. *Penicillium* strains, growing as a primary infection on various waste wood shredded by chippers, formed a major component of the airborne microflora in the vicinity of these machines. At tanks with wood chips, the most common species was *Aspergillus fumigatus* which abundantly developed on stored chips as a secondary infection. The latter observation conforms with reports of earlier authors who noted the abundant occurrence of *A. fumigatus* on wood chips and in the air near chip piles [18, 33, 34, 66].

Both *Aspergillus fumigatus* and *Penicillium* spp. possess allergenic and immunotoxic properties and are known risk factors of occupational respiratory disease [41, 42]. *Aspergillus fumigatus* may cause allergic alveolitis, asthma, pulmonary aspergillosis, and possibly mycotoxicoses [13, 40, 44]. *Aspergillus* and *Penicillium* strains were reported as causative agents of allergic alveolitis or organic dust toxic syndrome in woodwoorkers [3, 27, 65] and in people exposed to wood chips while performing other occupations [37] or using chips as a fuel [38, 67]. Minárik *et al.* [53] reported cases of a novel form of allergic alveolitis described as “beech chips disease” among the workers of a cellulose factory exposed to dust from stored beech chips.

Corynebacteria prevailed among bacterial strains isolated from the air of examined facilities, having been particularly numerous in chipboard factories. So far, little is known about the potentially pathogenic properties of corynebacteria associated with organic dusts. Cases of allergic alveolitis caused by *Arthrobacter globiformis* and *Brevibacterium linens* have been reported [52] and the involvement of peptidoglycan produced by these bacteria in causing organic dust toxic syndrome (ODTS) cannot be excluded.

The levels of Gram-negative negative bacteria found in the air of fiberboard and chipboard factories were lower compared to those recorded earlier in sawmills [26]. Nevertheless, at 9 out of 14 examined sampling points their concentration exceeded the value of 1×10^3 cfu/m^3 proposed by Clark [7] and Malmros *et al.* [49] as the OEL value, and many isolated strains (*Rahnella* spp., *Pantoea agglomerans, Proteus vulgaris, Alcaligenes faecalis, Acinetobacter calcoaceticus*) are known to possess strong endotoxic and/or allergenic properties [19, 21, 52].

A potential health hazard created by endotoxin-producing bacteria for sawmill workers has been confirmed by finding substantial exposure to airborne endotoxin during shredding of waste wood and handling of wood chips at the initial stages of production cycle. A relatively high concentration of endotoxin has been found also at the forming of raw fiberboards. At the final formatting of the boards, the concentration of endotoxin in the air was low and did not pose any health hazard for the workers. Altogether, at 4 out of 12 sampling sites in the examined facilities, concentration of 9 ng/m^3 (90 EU/m^3) - reported by Castellan *et al.* [6] as the threshold value causing decrease of lung function in exposed men - was exceeded, and the OEL value of 50 EU/m^3 - proposed by the Dutch Expert Committee on Occupational Standards (DECOS) [15], was exceeded at 6 out of 12 sampling sites. At 3 sites the OEL value of 25 ng/m^3 (200 EU/m^3) - proposed by Laitinen [43] was exceeded, and on one site the OEL value of 0.1 μg/m^3 (1000 EU/m^3) - proposed by Clark [7], Rylander [61] and Malmros *et al.* [49]. Compared to earlier studies on endotoxin pollution in wood processing facilities, the values recorded in the present work are higher compared to those obtained by Dahlqvist *et al.* in Sweden [9], Laitinen in Finland [43], Dennekamp *et al.* in Canada [12] and Alwis *et al.* and Mandryk *et al.* in Australia [2, 50], but similar to those obtained by Duchaine *et al.* in Canada [14]. They were lower, however, than those noted in Polish sawmills [26], and distinctly lower compared to those recorded during the performing of various agricultural activities associated with high exposure to grain dust and other dusts of plant origin [21, 25, 43, 54, 55]. Nevertheless, the results of endotoxin determination by *Limulus* test may vary to a great extent between laboratories and thereby all the comparisons are only of limited value.

CONCLUSION

In conclusion, during the initial stages of the production cycle (shredding of waste wood, storing of chips), the workers of fiberboard and chipboard factories may be exposed to high levels of airborne microorganisms and endotoxin, posing risk of respiratory disease. The greatest potential hazard is presented by the allergenic fungi of the genera *Penicillium* and *Aspergillus*.

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