FUNGAL CONTAMINATION IN THE WORKING ENVIRONMENT OF WASTE SORTING FACILITIES: A REVIEW

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In recent years, many studies have pointed to a relationship between the working activity in waste sorting facilities and the occurrence of health problems (respiratory, gastrointestinal, musculoskeletal, skin and eye irritations). Employees in these facilities are simultaneously exposed to many biological, chemical and physical factors. Due to the repeated detection of high concentrations of airborne fungi (reaching up to 1.8 x 10^6 CFU m^{-3}) in the working environment involving potentially allergenic, infectious and toxigenic fungal species, it can be assumed that fungi may play an important role in the development of health problems. In terms of minimizing health risks, it is necessary to take several preventive and protective measures to reduce contamination of the working environment by biological agents. The basic recommendation is the consistent use of protective equipment as well as the observance of personal hygiene by the employees. Other necessary measures are the frequent air exchange inside the facility, educating the employees about health risks associated with waste sorting and establishment of regular medical check-ups.

fungi, waste, occupational exposure, health problems

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INTRODUCTION

In recent years, waste production has grown worldwide. Due to the excessive production of waste, there is an increasing pressure on its recycling. In April 2018, the European Parliament, in agreement with the European Council, supported new recycling targets under the legislation on waste and the circular economy. The new Directive (EU) 2018/851 orders the Member States to increase the proportion of the municipal waste destined for reuse and recycling to a minimum of 55 % of weight by 2025, to increase this proportion to at least 60% of weight by 2030, and to 65% of weight by 2035. Thus, waste treatment is going to be a still more important topic.

Waste in waste sorting plants is very often contaminated with organic residues that serve as a nutrient substrate for the growth of many microorganisms (Pahren, Clark, 1987), including an important group of microscopic fungi. Microscopic fungi are heterotrophic organisms capable of feeding and proliferating on various substrates – not only on the organic residues adhering to the waste, but also the surfaces of various interior equipment of waste sorting facilities (e.g. wood, gypsum boards, plywood, chipboard, cellulose, wallpaper, textiles made of natural fibres, and also insulation materials) (Raper, Fennell, 1977; Pasanen et al., 1992; Karunasena et al., 2000). Owing to the external factors (air velocity, air humidity) and mechanical handling of waste, the microscopic fungi particles from these sources are released into the air (Pasanen et al., 1991), where they become part of bioaerosol and can further sediment and recontamine the surfaces of the interior equipment, or they can cling to the exposed parts of workers' bodies as well as their clothing (Ivens et al., 1999; Park et al., 2011; Viegas et al., 2014a).

In the waste sorting facilities, high concentrations of airborne fungi have repeatedly been measured – up to 4 orders of magnitude higher than those measured in office buildings or home interiors (Gorny, Krysinska-Traczyk, 1999; Klanova, 2000;

P a s t u s z k a et al., 2000). The relationship between the occurrence of health problems and the high concentrations of airborne fungi has not been clarified yet; however, it is assumed that microscopic fungi play an important role in this case. I v e n s et al. (1999) documented the connection between the exposure of garbage men to microscopic fungi and the development of gastrointestinal problems.

The aim of this paper is to summarize the existing knowledge about fungal contamination of working environment in waste sorting facilities. Particular emphasis is placed on the species composition of the fungal community inside waste sorting facilities as well as on the health problems associated with occupational exposure to microscopic fungi.

Fungal composition in waste sorting facilities

In general, indoor fungi include a mixture of those that have entered from outdoors (L a c e y, 1981; B u r g e et al., 1982) and those from indoor sources. *Aspergillus* spp. and *Penicillium* spp. are usually considered the major groups of indoor fungi (G o r n y, D u t k i e w i c z, 2002). These fungal genera were the most prevalent fungi isolated from working environment of waste sorting facilities too. However, the percentage represented by each genus varied between the studies.

V i e g a s et al. (2014a) detected in the air samples from waste sorting facilities almost exclusively species of *Aspergillus* genus, whereas in L e h t i n e n et al. (2013) 93% of all identified species of the captured fungi were constituted by the genus *Penicillium*. Pinto et al. (2015) detected the genus *Penicillium* in 95% of all captured fungi. Similar percentages of the genera *Aspergillus* (44%) and *Penicillium* (40%) were detected in the samples by T o l v a n e n et al. (1999). Apart from the fungi of the genera *Aspergillus* (*A. candidus, A. flavus, A. fumigatus, A. glaucus, A. nidulans, A. niger, A. ochraceus, A. phoenicis, A. versicolor*) and *Penicillium* (*P. brevicompactum, P. camemberti, P. chrysogenum, P.citrinum, P. commune, P. corylophilum, P. crustosum, P. digitatum, P. expansum, P. glabrum, P. italicum, P. lanosum, P. nalgiovense, P. olsonii, P. pramulosum, P. roqueforti, P. rugulosum, P. variables, P. verrucosum*), other fungal genera were isolated from the air of the waste sorting facilities: *Absidia, Alternaria, Botrytis* (*B. cinerea*), *Chrysonilia, Cladosporium* (*C. cladosporioides, C. herbarum,Cladosporium* sp.), *Epicoccum* (*E. nigrum*), *Fusarium, Geotrichum* (*G. silvicola, Geotrichum* sp.), *Hemicarpenteles, Humicola, Hyalodendron, Monilia, Mucor, Paecilomyces, Rhizopus, Sporobolomyces* (*S. roseus*), *Trichoderma, Trichophyton, Ulocladium, Wallemia* (N e r s t i n g et al., 1991; W u r t z, B r e u m, 1997; K i v i r a n t a et al., 1999; R e i n t h a l e r et al., 1999; T o l v a n e n et al., 1999; L e h t i n e n et al., 2013; V i e g a s et al., 2014a; P i n t o et al., 2015; C e r n a et al., 2017; D e g o i s et al., 2017; S a n t o s et al., 2018, M a d s e n et al., 2019, B r a g o s z e w s k a, 2020).

So far, surface contamination of indoor environment in waste sorting facilities has been dealt with by only a few studies (P a r k et al., 2011; V i e g a s et al., 2014a). V i e g a s et al. (2014a) identified eight different species of microscopic fungi in the samples taken from the surface of the waste sorting facility equipment and faces of the employees. In the analysed samples, the most frequent species included *Aspergillus niger* (66.1%), *A. flavus* (14.2%) and *A. fumigatus* (13.8%). These species of microscopic fungi were at the same time the most numerous species captured in the samples taken from the air in the same working environment. The remaining 5.9% included *A. candidus, A. terreus, Neosartorya fumigata*, *Eurotium herbarium* and *Absidia* spp. The identification of captured microscopic fungi was not performed in the study by P a r k et al. (2011).

Occupational exposure to fungi

Employees of waste sorting facilities can be exposed to particles of microscopic fungi in three ways: inhalation, gastrointestinal, and dermal exposure (Park et al., 2011). Inhalation is the easiest to measure and therefore also the most frequently rated type of exposure. Table 1 overviews the concentrations of airborne fungi particles measured in the working environment of waste sorting facilities.

Airborne fungi sampling has revealed that the employees of waste sorting facilities are exposed to a wide range of airborne fungi concentrations reaching up to 1.8×10^6 CFU m^{-3}. The employees of the other types of waste treatment facilities (e.g. composting plant, landfill, waste incineration plant, sewage treatment plant) are exposed to similar concentrations of airborne fungi (R a h k o n e n, 1992; M a r c h a n d et al., 1995; I v e n s et al., 1999; K i v i r a n t a et al., 1999; R e i n t h a l e r et al., 1999; K r a j e w s k i et al., 2002; T o l v a n e n, H a n n i n e n, 2006; T e i x e i r a et al., 2013).

The potential health risks to employees of waste sorting facilities result mainly from their long-term exposure to high concentrations of microscopic fungi particles. Ivens et al. (1999) found out that during a single workday the waste collectors inhaled approximately 1.2×10^5–1.8×10^7 (2.8×10^6 on the avarage) CFU of airborne fungi at a concentration of 10×10^3–4.9×10^5 CFU m^{-3}. On the basis of the obtained results, they created a three-level classification of the employees' weekly inhalation exposure to airborne fungi: (1) low exposure level (1×10^5–1×10^6 CFU of microscopic fungi), (2) medium exposure level (1×10^6–1×10^7 CFU of microscopic fungi), and (3) high exposure level ($> 1 \times 10^7$ CFU of microscopic fungi).

Table 1. An overview of measured concentrations (in CFU per 1 m^3) of airborne fungi in working environment of waste sorting facilities depending on the type of sampling device used

Literary source	CFU m^{-3}	Type of sampling device	Type of sorted waste
Nersting et al. (1991)	1.0×10^2–1.5×10^4	A	unspecified
Nersting et al. (1991)	4.0×10^2–1.4×10^5	I	unspecified
Malmros et al. (1992)	3.5×10^2–1.8×10^4	A	unspecified
Rahkonen (1992)	6.5×10^2–2.5×10^4	A	unspecified
Sigsgaard et al. (1994)	5.2×10^3 (5.4×10^3)*	I	paper
Sigsgaard et al. (1994)	1.4×10^4 (3.1×10^4)*	I	unspecified
Marchand et al. (1995)	8.0×10^2–7.2×10^3	A	unspecified
Wurtz, Breum (1997)	9.6×10^2–2.3×10^5	F	paper
Reinthaler et al. (1999)	3.0×10^4–1.6×10^5	A	unspecified
Tolvanen et al. (1999)	3.6×10^3–1.4×10^5	F	unspecified
Tolvanen et al. (1999)	1.0×10^4–1.3×10^5	A	unspecified
Tolvanen (2001)	3.3×10^2–2.0×10^5	A	unspecified
Tolvanen (2001)	0–1.2×10^4	F	unspecified
Krajewski et al. (2002)	8.4×10^4–1.3×10^5	F	unspecified
Kozajda et al. (2009)	1.9×10^3–1.6×10^5	A	unspecified
Park et al. (2011)	2.4×10^4–1.1×10^5	F	unspecified
Breza-Boruta (2012)	0–5.3×10^4	S	unspecified
Lehtinen et al. (2013)	1.5×10^3–2.9×10^5	A	unspecified
Kozajda et al. (2015)	1.9×10^3–3.4×10^4	A	unspecified
Cerna et al. (2015)	2.6×10^3–3.9×10^4	S	paper
Pinto et al. (2015)	1.5×10^4*	S	glass
Cerna et al. (2016)	2×10^2–1.7×10^6	F	plastics
Cerna et al. (2016)	3×10^2–6.4×10^4	S	plastics
Cerna et al. (2017)	2.0×10^2–1.8×10^6	F	plastics
Santos et al. (2018)	2.0×10^1–2.8×10^4	S	unspecified
Bragoszewska (2019)	2.1×10^2–1.2×10^3	A	unspecified
Madsen et al. (2019)	6.3×10^2–6.5×10^3	F	cardboard

CFU = colony forming unit, A = 6-stage Andersen cascade impactor, F = membrane filter sampler, I = impinger, S = single head impaction air sampler

*mean (SD)

Microscopic fungi particles that cling to clothing and faces of the employees as well as particles inhaled by mouth can become a source of gastrointestinal exposure. Park et al. (2011) found out in their study that during one work shift an average of 1.6×10^4 CFU of microscopic fungi per 1 cm^2 adhered to the waste sorting facility employees' faces. In comparison, an average of 3.7×10^5 CFU of microscopic fungi per 1 cm^2 adhered to the waste collector's face. The study also showed that during work shift a large amount of microscopic fungi particles can cling to various parts of the employees' clothing (average values for trousers: 4.2×10^6 CFU cm^{-2}, gloves 6.5×10^6 CFU cm^{-2}, sleeve 3.2×10^6 CFU cm^{-2}, shoulders 1.6×10^5 CFU cm^{-2}, handkerchief 3.3×10^5 CFU cm^{-2}).

The sources of employees' dermal exposure are the sedimentation of airborne fungi particles on their exposed skin or direct touching the contaminated waste. As stated by Park et al. (2011), a significant amount of microscopic fungi particles was detected on the exposed parts of garbage collectors' bodies (average values for face: 3.7×10^5 CFU cm^{-2}, back of the hand: 2.6×10^6 CFU cm^{-2}, palm: 6.4×10^6 CFU cm^{-2}).

Health risks of the occupational exposure

In recent years, an increasing number of studies have given evidence of the relationship between the working activity in waste sorting facilities and the occurrence of health problems (Marth et al., 1997;

Chan, Leung, 2011; Eker et al., 2012). In spite of the large number of studies, it is very difficult to link a specific health problem with a particular factor, since the employees of waste sorting facilities are exposed to the simultaneous interaction of biological agents (microscopic fungi, bacteria, viruses) (Wurtz, Breum, 1997; Kiviranta et al., 1999; Reinthaler et al., 1999; Tolvanen et al., 1999; Park et al., 2011; Carducci et al., 2013; Lehtinen et al., 2013), chemical agents (microbial volatile organic compounds, endotoxins, mycotoxins) (Rahkonen, 1992; Kiviranta et al., 1999; Degen et al., 2003; Tolvanen, Hanninen, 2006; Park et al., 2011; Lehtinen et al., 2013; Viegas et al., 2014b) and physical factors (noise, unsatisfactory light conditions, vibrations, extreme temperatures) (Krajewski et al., 2002; Tolvanen, Hanninen, 2006). Neglecting the synergistic effects of these factors represents a major limitation of many available studies (e.g. Marth et al., 1997; Athanasiou et al., 2010; Chan, Leung, 2011; Eker et al., 2012). Another methodological problem of some studies is that their authors neglected not only the health condition of the employees before entering the job (e.g. Ivens et al., 1999; Heldal et al., 2003), but also the time elapsing from an employee's entry into the job and the first occurrence of the symptoms (e.g. Ivens et al., 1999; Krajewski et al., 2002; Heldal et al., 2003; Athanasiou et al., 2010). Additionally, some authors even omitted the identification of the measured biological factors. But in fact, allergenic, infectious and toxigenic fungal species may also be present among the microorganisms occurring in the environment of waste sorting facilities (Wurtz, Breum, 1997; Kiviranta et al., 1999; Tolvanen, Hanninen, 2006; Lehtinen et al., 2013; Viegas et al., 2014a, b; Cerna et al., 2017).

The most important genera causing allergic reactions isolated from the environment of waste sorting facilities are *Alternaria, Aspergillus, Cladosporium, Penicillium, Mucor* and *Rhizopus*. These genera of microscopic fungi are characterised by a fast asexual reproduction cycle giving them the ability to quickly produce a huge amount of conidia or spores, which are easily released into the environment (Gravesen, 1979). Threshold values for allergic reaction are not known exactly; however, Bagni et al. (1977) state in their study that an allergic reaction of humans can occur in the presence of only 100 particles (conidia) of the genus *Alternaria* in 1 m^3 of air, or 3 000 particles (conidia) of the genus *Cladosporium* in 1 m^3 of air.

The most common infectious disease caused by microscopic fungi is dermatomycosis (an infectious disease of the skin, skin derivatives and mucous membranes). The potential originators of this disease can be microscopic fungi of the genera *Alternaria* (Robb et al., 2003), *Aspergillus* (Ozcan et al., 2003), *Cladosporium* (Vieira et al., 2001), *Fusarium* (Nucci, Anaissie, 2007), *Paecilomyces* (Hall et al., 2004) and *Ulocladium* (Badenoch et al., 2006). Most of these genera were repeatedly detected in working environment of waste sorting facilities (Nersting et al., 1991; Wurtz, Breum, 1997; Kiviranta et al., 1999; Reinthaler et al., 1999; Tolvanen et al., 1999; Lehtinen et al., 2013; Viegas et al., 2014a).

In addition to an increased risk of allergic reactions and dermatomycosis, the employees of waste sorting facilities were more susceptible to the organic dust toxic syndrome (cough, chest tightness, dyspnea, flu-like symptoms such as fever, muscle and joint pain, fatigue, headache) and a higher risk of gastrointestinal (diarrhoea, stomach cancer), respiratory (hoarseness, cough, upper respiratory tract inflammation) and musculoskeletal problems (musculoskeletal and joint disorders) (Sigsgaard et al., 1994; Marth et al., 1997; Ivens et al., 1999; Krajewski et al., 2002; Kozajda, Szadkowska-Stanczyk, 2009; Chan, Leung, 2011). Furthermore, Eker et al. (2012) found out that 40% of the employees in a large-scale waste treatment facility suffered from metabolic syndrome (insulin resistance and glucose intolerance, diabetes mellitus, obesity, abdominal fat accumulation, dyslipidemia and hypertension). Employees of waste sorting facilities are further exposed to the risk of acute infectious diseases due to inhalation of bioaerosols containing infectious particles released from waste (Alonso et al., 2015).

An important feature of some fungal species is the production of mycotoxins. Mycotoxins are the product of secondary metabolism of toxigenic fungal species that have adverse effects on humans (Chelkowski, 1991). The presence of several mycotoxins has been detected in the environment of waste sorting facilities. Degen et al. (2003) detected the presence of ochratoxin A in the blood of the workers handling waste, and Viegas et al. (2014b) detected aflatoxin B1 in the blood of waste sorting facility employees. Occupational exposure to ochratoxin A and enniatin B in the working environment of a waste sorting plant was also reported (Viegas et al., 2018). The most significant toxigenic microscopic fungi that have been isolated from the working environment of waste sorting facilities include the following genera: *Alternaria, Aspergillus, Cladosporium, Eurotium, Fusarium, Neosartorya, Paecilomyces, Penicillium, Stachybotrys* and *Trichoderma* (Chelkowski, 1991; Jarvis et al., 1998; Brase et al., 2009; Marin et al., 2013). Thus, the exposure to other mycotoxins could be expected.

Preventive and protective measures

To minimise health risks, both the employees and employers are encouraged to take a number of technical and organizational measures to help reduce the contamination of the working environment by biological agents. The basic recommendation is the consistent use of protective working tools (thick rubber gloves, respiratory mask, working clothes) and increased personal hygiene during and after working shift (Sigsgaard et al., 1990; Marchand et al., 1995; Kozajda, Szadkowska-Stanczyk, 2009; Viegas et al., 2014b). Another necessary measure is regular air exchange inside the waste sorting facility and thorough daily cleaning of workspaces (Marchand et al., 1995; Marth et al., 1997). The employees should be also informed about the occupational safety and health risks they are exposed to during work. At the same time, they should have regular medical check-ups, and in the case of health problems they should be immediately transferred to another position (Marchand et al., 1995; Kiviranta et al., 1999; Kozajda, Szadkowska-Stanczyk, 2009; Athanasiou et al., 2010; Viegas et al., 2014b). Finally, within the spatial layout of waste sorting facilities, the workspaces should be separated from common spaces and sanitary facilities (Marchand et al., 1995; Marth et al., 1997).

CONCLUSION

In recent years, several studies have illustrated the relationship between the working activities in waste sorting facilities and the occurrence of health problems in employees. Despite the large number of studies, it is very difficult to connect a specific health problem with a particular agent as the employees of waste sorting facilities are exposed to the simultaneous interaction of biological, chemical and physical agents. On the account of high concentrations of fungi repeatedly measured in the air of some waste sorting plants and due to the identification of toxigenic, allergenic and infectious species, microscopic fungi probably play an important role in this respect. In order to thoroughly assess the influence of high concentrations of microscopic fungi on the health condition of the employees, it is necessary to implement a uniform method for sampling microscopic fungi that will ensure both their quantification and exact identification. At the same time, future studies should consider the employees' health condition as well as other factors that can affect employees in the work environment. Last but not least, a crucial step in decreasing the health risks to the employees in waste sorting facilities is the compliance with the proposed preventive and protective measures as well as the implementation of occupational exposure limits.

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