



Review

Domestic waste composting facilities: A review of human health risks

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ABSTRACT

In the management of municipal solid waste (MSW), the sorting–composting approach presents many advantages. However, since MSW contains a number of chemical and biological agents, the compost should not be necessarily a harmless product. These contaminants may expose different populations to health hazards, ranging from the composting plant workers to the consumers of vegetable products grown in soils treated with compost. Recent information concerning health risks derived from occupational exposure to organic dusts, bioaerosols and microorganisms in MSW composting plants is here reviewed. An evaluation of the potential health risks of volatile organic compounds (VOCs) released during composting is also included. Taking into account the potential biological and chemical risks, an exhaustive control of the workers employed in MSW composting facilities is clearly recommendable. Moreover, because the compost derived from the organic fraction of MSW can contain a number of metals and persistent organic pollutants, as well as microbial and fungi toxins, any compost that may mean a health risk for the population should not be commercialized.

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1. Introduction

Currently, the major methods of waste management are: a) recycling—the recovery of materials from products after they have been used by consumers, b) composting—an aerobic, biological process of degradation of biodegradable organic matter, c) sewage treatment—a process of treating raw sewage to produce a non-toxic liquid effluent which is discharged to rivers or sea, and a semi-solid sludge, which is used as a soil amendment on land, incinerated or disposed in a landfill, d) incineration—a process of combustion designed to recover energy and reduce the volume of waste going to disposal, and e) landfill—the deposition of waste in a specially designated

area, which in modern sites consists of a pre-constructed ‘cell’ lined with an impermeable layer (man-made or natural) and with controls to minimize emissions (Rushton, 2003).

Because of the operative easiness and the low economic costs in most cases, during many years landfills have been among the most extended forms of disposal of municipal solid waste (MSW). Until recent years, it was still considered that about 95% of the generated MSW on world-wide scale was still being deposited in landfills (El-Fadel et al., 1997). However, it is well known that generation of gas and leachates mainly due to microbial decomposition, climatic conditions, and the own characteristics of the waste, are inevitable consequences of the disposal in landfills. The risks for the public health due to the potential exposure to pathogenic agents, toxic substances, and gases, together with the annoyances derived from the bad odors, the migration of gases and leachates outside the limits of the landfill, and their release to the surrounding environment, raise a number of important environmental questions including the possibility of fires

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and explosions, damages to the vegetation, groundwater contamination, atmospheric pollution, etc.

In recent decades, industrialized countries also included the thermal treatment (incineration, pyrolysis, or gasification) of MSW as an important option for its management. Within thermal treatments, incineration has reached a great interest. However, although this process notably reduces the space required for the disposal of the same amount of residues in landfills (typically by a factor from 4 to 10) (Magrinho et al., 2006; Moy et al., 2008; Sharholy et al., 2008), MSW incinerators (MSWI) have been very questioned because of the atmospheric emissions of acid gases, heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and especially by the emission of the potential carcinogenic agents polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) (Domingo, 2002; Meneses et al., 2004; Magrinho et al., 2006; Schuhmacher and Domingo, 2006; Moy et al., 2008; Zheng et al., *in press*). As a direct consequence of the concern raised by MSWI among the public opinion, in recent years a number of countries have decided to carry out a new global planning for the management of MSW. It means a selective collection, whose classification presents/displays unquestionable advantages such as separating recyclable and compostable material, and diminishing significantly the volume of waste to be incinerated or to be deposited in landfills. In turn, the organic fraction of the MSW is reduced during the composting process, being the final item, the compost, potentially used in various agricultural applications depending on its quality and maturity (Deportes et al., 1995; Ahmad et al., 2007; Alvarenga et al., 2007; Hargreaves et al., 2008). Prime quality compost is suitable for the production of high quality agricultural products, and the secondary quality compost has utility for the improvement of landscape and forests, an essential element for the development of agro-tourism and tourism in general (Manios, 2004). Although in principle compost is not basically a product that can be considered like potentially detrimental or dangerous for the environment or the public health, the MSW with which it has been elaborated can contain various pollutants that can mean environmental or health risks (Harrad et al., 1991; Deportes et al., 1995; Veeken and Hamelers, 2002; Brändli et al., 2007).

The European waste sector is undergoing a period of unprecedented change driven by business consolidation, new legislation and heightened public and government scrutiny (Pollard et al., 2006). In the management of MSW, the sorting–composting approach presents many advantages. However, different populations may be exposed to the health hazards of the compost, a product that should not be necessarily harmless, taking into account the potential chemical and biological contaminants contained in the original MSW. These health hazards include from workers of composting plants to consumers of vegetables treated with compost fertilizers. The importance that the disposal of the MSW currently has and is going to have in an immediate future, as well as the interest raised by the selective collection, the partial recycling and the composting of the organic fraction of MSW, are unquestionable.

The objective of the present paper has been to review, from a scientific point of view, the state-of-the-art of one of these important issues: the health risks of the composting process of the MSW organic fraction. Reduction of waste to dispose to landfill and incineration, recovery of useful organic matter for use as soil amendment, and employment opportunities are among the main advantages of this waste management option. By contrast, odors, noise, vermin nuisance, bioaerosol (organic dust containing bacterial or fungal spores) generation and emissions, emission of volatile organic compounds (VOCs), and potential pathway from use on land for contaminants to enter food chain, are among the most remarkable disadvantages of this option (Rushton, 2003; Müller et al., 2004a,b; Harrison, 2007). We have here reviewed both occupational risks and health risks for the general population living near to waste composting facilities. Recent information concerning health risks derived from exposure to organic dusts, bioaerosols, and microorganisms in MSW composting plants, as well as

an evaluation of the health risks of VOCs released during composting has been also included. The scientific literature on human health risks of domestic waste composting facilities has been reviewed using the databases Medline (available at: <http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed>) and Scopus (available at: <http://www.scopus.com/scopus/home.url>).

## 2. Composting facilities and chemical risks

With respect to the health risks of compost, three are the main exposure routes for the population: a) ingestion of soils treated with compost, very specially for pica children, b) contamination through the food chain by consumption of products cultivated in soils where compost has been applied, which could (with time) suppose a certain toxic accumulation, and c) dispersion of atmospheric dust of compost that transports microorganisms and toxicants susceptible of being inhaled (Fig. 1). The human health risks can be divided according to their nature in chemical and biological. Because of their potential toxicity, metals, especially arsenic, cadmium, chromium, lead, mercury and nickel, pesticides, and organochlorinated compounds such as PCDD/Fs and PCBs, PAHs and halogenated hydrocarbons are among the chemical agents of a greatest interest. In the composting process, the aerobic or anaerobic decomposition of the organic solid matter by the action of microorganisms is the crucial step. An important problem in the facilities that operate under aerobic conditions is the odor due to the VOC emissions, beginning with the arrival of fresh material (Santa Coloma et al., 2000). Most VOCs generated in aerobic composting plants are already emitted in the initial steps of the process (Eitzer, 1995). It has been described that mainly under anaerobic conditions and due to insufficient or incomplete ventilation, sulfured compounds of intense odor are generated, whereas the incomplete processes of aerobic degradation produce emissions of alcohol, organic ketones, esters and acids (Pöhle and Kliche, 1996; Santa Coloma et al., 2000). While the odors in the zones next to the plants can be eliminated or at least significantly reduced, the workers at these facilities undergo an inevitable exhibition to VOCs. These compounds constitute an important class of polluting chemicals commonly found in the atmosphere at terrestrial level in different urban and industrial atmospheres. It is well known that they are ubiquitous, having even been detected in vegetation of the proximities of the Everest, in marine waters of any part of the planet, as well as in sediments and air of the Antarctica (Ciccioli et al., 1993; Hiatt, 1999). In fact, the existing hundreds of atmospheric VOCs derive so much from anthropogenic activities such as the traffic, the hydrocarbon fuel evaporation, different industrial processes, petroleum storage and distribution and refineries, landfills and agricultural activities, as from natural biogenic processes such as emissions from trees and vegetation, forest fires produced by natural causes, or anaerobic marshy bog processes, among others. The main environmental problems raised by VOC emissions are: reduction of stratospheric ozone, photochemical formation of ozone at terrestrial level, adverse effects on health, and both general toxicity and carcinogenicity. These effects are a consequence of their great mobility and capacity to be inhaled by people working or living in places with high concentrations. The increase of the global greenhouse effect is another serious problem. It is also important to add the environmental persistence and accumulation. Concerning the adverse health effects of VOCs, an especial emphasis on the following compounds must be done: benzene and 1,3-butadiene, as potentially inductive agents of leukemia; formaldehyde, as a nasal carcinogen potential; certain PAHs as compounds potentially inductive of cancer, and the carcinogenic PCDD/Fs. Although numerous VOCs have not been classified as cancerigen agents by the International Agency for Research on Cancer (IARC), many of them they have an important toxic, non-carcinogenic, potential. Among the adverse effects of VOCs, the bad odors must be also included, as can be cause of diverse indirect health effects such as nausea and vomits, reactions of hypersensitivity, and even alterations

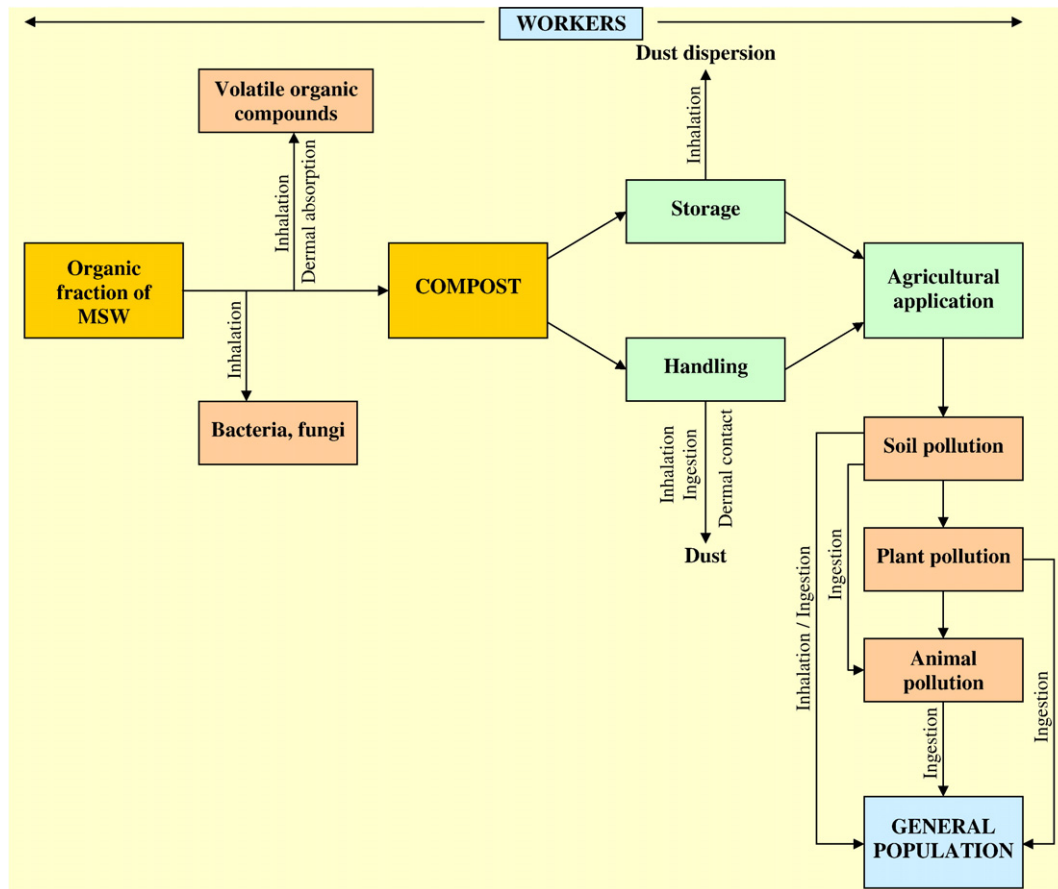


Fig. 1. Exposure pathways to pollutants derived from the production and utilization of compost derived from the organic fraction of MSW.

in the respiratory model. Anyhow, the systemic toxic effects of VOCs are relevant. Among these, renal, hematological, neurological and hepatic alterations, as well as mucosal irritations are the most common (Curtis et al., 2006; Rumchev et al., 2007; Kampa and Castanas, 2008). Thus, it is well known that benzene can cause aplastic anemia and polycythemia, dichloromethane produces carboxyhemoglobin, dichloromethane, toluene, styrene, trichloroethylene and tetrachloroethylene are neurotoxic, while naphthalene and styrene produce irritations of the mucosal membranes.

In spite of the potential toxicological importance of VOCs, information concerning their levels in composting facilities of organic material from MSW is scarce. First data on VOC emissions by composting facilities corresponding to a wide study were reported by Eitzer (1995). This author determined the VOCs emitted and their approximate concentrations in the air during the process of composting inside 8 facilities in the USA. Eitzer (1995) analyzed the VOC with a greater potential impact on health. The following conclusions were drawn: 1) there was a great similarity of results, independently of the operating characteristics of each facility, 2) most VOCs were concentrated in the deposits of fresh material, the crushing machines, and the initial zone of the composting process, and 3) from a point of view of occupational health, the concentrations of most VOCs remained below the allowable exposure limits of exhibition according to the American Conference of Governmental Industrial Hygiene (ACGIH, 1992). The total concentrations of VOCs (sum of all identified compounds) oscillated between  $<10$  and  $>150$   $\text{mg}/\text{m}^3$  of air (Eitzer, 1995).

Smet et al. (1999) compared two different techniques of composting for organic biomaterial from MSW with respect to the total emission of VOCs during the period of active composting. In the process of aerobic composting, the material was aired during 12 weeks, while the combined process aerobic/anaerobic consisted of a sequence of 3 weeks of

anaerobic digestion (phase I) and a period of 2 weeks of ventilation (phase II). The total emission of VOCs,  $\text{NH}_3$  and  $\text{H}_2\text{S}$  during the process of aerobic composting was 742 g/tm of biowaste, whereas the total emissions during phases I and II of the combined aerobic/anaerobic composting were 236 and 44 g/tm, respectively. In that study, the occupational exposure to VOCs was not evaluated. On the other hand, Leach et al. (1999) determined the occurrence and temporal distribution of VOCs in the air of 9 sampling points located in the neighborhood of a center of MSW collection, a MSW incinerator, and a sewage treatment plant in a suburban environment on the edge of the coastline of the Southampton Water estuary, located on the coastline of central southern England. More than 100 different VOCs were detected, being aromatic, chlorinated and sulfurated compounds the most abundant, with smaller proportions of alkanes, alkenes and cycloalkanes. The rank of these outdoor concentrations corresponding to total VOCs oscillated between 0.1 and 1.3  $\text{mg}/\text{m}^3$  of air. These values were sensibly lower than the indoor levels reported in the study of Eitzer (1995). For comparison purposes, we here include data from Pérez-Pastor et al. (1999), who analyzed during a year in 4 urban and suburban points of the Community of Madrid, Spain, the distribution and concentrations of VOCs. Around 140 compounds were identified, with an annual average concentration of total VOCs between 0.14 and 0.20  $\text{mg}/\text{m}^3$  of air, which were of the same order as those found in other European cities. These outdoor levels were again notably lower to the indoor concentrations reported by Eitzer (1995).

### 3. Composting facilities and biological risks

Occupational biorisks are those derived from the presence of micro and macroorganisms, and/or substances generated by them in occupational atmospheres, which can cause adverse effects on workers, leading

to occupational diseases. In comparison to the effects caused by chemical and physical agents, those of biological origin are less known and not so well defined. However, in humans they can act as infectious, allergenic, toxic, and carcinogenic (Schlosser and Huyard, 2008). The MSW contains great amounts of organic materials derived from animals, residues of vegetables, rest of foods process, etc. For humans, the implied biological degradation in the processing of this waste means multiple opportunities of exposure to organic dusts (van Tongeren et al., 1997), which can be of vegetal, microbiological, or animal origin. The individuals who handle MSW can be also exposed to infectious viruses, microorganisms, bacteria that generate allergenic endotoxins, fungi, and parasitic protozoa. The workers of MSW composting facilities are not only potentially subjected to this exposure, but also to that concerning organic dusts, being cause of several general health problems. Among these, pulmonary inflammation (acute inflammation, hypersensitive pneumonitis), occupational asthma, and chronic bronchitis are included. Moreover, the following adverse effects can also occur specifically by exposure to organic dusts derived from the MSW: gastrointestinal disturbances, fevers, and infections and irritations of eyes, ear and skin (van Tongeren et al., 1997). For workers of composting facilities in which the organic fraction of MSW is involved, as well as for the employees in operations of selection/classification of MSW, the biological agents that mean a potential threat infectious are the following: bacteria and/or endotoxins produced by them, allergenic fungi, and parasitic protozoa. Most fungi detected in the previous activities are allergenic agents that can lead to occupational diseases.

*Aspergillus fumigatus* (*A. fumigatus*) is an especially well known opportunistic pathogenic fungus in nose and throat, susceptible of causing infections. Other fungi such as *Aspergillus flavus*, *Stachybotrys atra*, and different species of *Fusarium* and *Penicillium* produce mycotoxins (Reijula and Tuomi, 2003). There are strong indications that the occupational exposure to breathable mycotoxins increases the risk of cancer in workers, which can be due at least partly, to the deleterious effects of the mycotoxins on the alveolar macrophages. Among the mycotoxins, the aflatoxins produced by several strains of *A. flavus* and *A. parasiticus* have been catalogued as mutagenic and hepatocarcinogenic by the IARC (1993). In the processing of the MSW and in the composting of their organic matter, certain biological agents reach the air. For these kinds of occupational atmospheres, some investigators proposed TLVs (threshold limit values) of 10,000 colony-forming units by cubic meter (CFU/m<sup>3</sup>) of air for the total bacteria, and 1000 CFU/m<sup>3</sup> of air for the Gram-negative bacteria (Marchand et al., 1995). It is known that the endotoxins produced by the Gram-negative bacteria cause fever and respiratory problems, as well as gastrointestinal disturbances and diarrheas (Douwes et al., 2000). Long periods of exposure to MSW combined with elevated temperatures, provide excellent conditions for the bacteria development, reason why a number of people implied in the composting process can be sensitized to microorganisms through inhalation of bacteria and spores of fungi. As result of a case occurred in Germany a few years ago, concerning allergic bronchopulmonary aspergillosis occurred in an atmosphere, in which the presence of *A. fumigatus* showed a concentration superior to 10<sup>6</sup> CFU/m<sup>3</sup> of air, Allmers et al. (2000) recommended that this disease should have an occupational character, as it was due to exposure to spores of fungi occurring in the biodegradable MSW. Anyhow, the potential occupational health risks associated with exposure to biological aerosols (bioaerosols), are due to microorganisms (actinomycetes, bacteria and fungi), arthropods, protozoa, and organic components of microbial and vegetal origin. Among these, those meaning a greater risk are *A. fumigatus*, the cellular walls of the Gram-negative bacteria (endotoxins), as well as the glucans  $\beta$ -1,3 of the cellular walls of fungi and mycotoxins.

Taking into account that there are not established TLVs for bioaerosols, a potential method to obtain an estimation relative of the occupational exposure to them is to compare the concentration of bioaerosols in the composting facilities with the background concen-

trations in different areas. For biological risks, it is necessary to consider two kinds of microorganisms: 1) the pathogenic agents present in the fresh organic material, susceptible to disappear during the composting process, and 2) the microorganisms that are developed during the formation of compost, which play an important role in the degradation of the organic matter (mesophilic fungi and thermophilic bacteria). Microorganisms such as the Gram-negative bacteria (including actinomycetes), Gram-positive bacteria and fungi suppose a potential respiratory risk much more frequent that the derivative of their ingestion through the digestive tract. However, if the compost is used in zones of grass, those animals ingesting until 6% of ground (when they graze) can be significantly contaminated (Fries, 1995). The contact hand–mouth can also mean ingestions of soils/compost between 60 and 100 mg/day. A very well documented revision on the human and environmental risks derived from the agricultural use of compost was published by Deportes et al. (1995) some years ago.

There is little available information on the health risks of compost workers. Büniger et al. (1999) found concentrations of 10<sup>7</sup> CFU/m<sup>3</sup> in air of composting facilities in Germany, whereas exposures of biowaste collectors were two orders of magnitude lower, with exposure peaks up to 10<sup>6</sup> CFU/m<sup>3</sup> of air. The exposure data from the workplaces indicated a higher exposure of compost workers compared to biowaste collectors. This corresponded with significantly increased health complaints of the upper airways and the skin, and higher concentrations of specific antibodies against molds and actinomycetes in the compost workers. In turn, in a cross-sectional study, in which 58 compost workers and 53 biowaste collectors were investigated (and compared with 40 control subjects), Büniger et al. (2000) observed that the high exposure to bioaerosols of compost workers was significantly associated with a higher frequency of health complaints and diseases. Higher concentrations of specific antibodies against moulds and actinomycetes were also noted. A healthy worker effect was indicated by the under representation of atopic diseases among the compost workers compared with biowaste collectors and the control group. In a recent survey also performed in Germany by Büniger et al. (2007), acute and chronic effects of long-term exposure to organic dust on respiratory disorders and lung function were evaluated among employees at 41 composting facilities. A total of 218 compost workers and 66 control subjects were enrolled in a cohort. The exposure to organic dust at workplaces of composting facilities was associated with adverse acute and chronic respiratory health effects, including mucosal membrane irritation (MMI) of the eyes and upper airways, chronic bronchitis, and an accelerated decline of forced vital capacity in percent of predicted (FVC%). The pattern of health effects differed from those at other workplaces with exposures to organic dust, which was possibly due to high concentrations of thermo-tolerant/thermophilic actinomycetes and filamentous fungi at composting plants (Büniger et al., 2007). This same research group had previously concluded that mycotoxins might be involved in the etiology of lung diseases due to the inhalation of organic dust (Büniger et al., 2004).

Tolvanen et al. (2005) determined bioaerosols (microbes, dust and endotoxins) in the working air of a drum composting plant treating source-separated catering waste of Finland. The average (arithmetic) endotoxin concentration was over the threshold value of 200 endotoxin units (EU) per m<sup>3</sup> in 2 measurement locations. In all working areas, the average (arithmetic) dust concentrations were in a low range of 0.6–0.7 mg/m<sup>3</sup>, being below the Finnish threshold value of 5 mg/m<sup>3</sup>. In the receiving hall and drum composting hall, it was found that the concentrations of airborne microbes and endotoxins might rise to levels hazardous to health during prolonged exposure. Therefore, the authors recommended using a respirator mask (class P3) in these areas. In a subsequent study of the same research group, occupational hygiene was investigated in two Finnish combined-drum-and-tunnel composting plants, Plant A (composting sewage sludge) and Plant B (composting source-separated biowaste). There were more problems with microbes

in Plant B, where the working areas were not aired. Endotoxins were also a problem in Plant B being the threshold value of 200 EU/m<sup>3</sup> exceeded in several measurements (Tolvanen and Hänninen, 2007).

In Germany, Ostrowski et al. (1997) performed a preliminary study on airborne microorganisms at places of work in a compost plant and in the surrounding villages in order to estimate potential health risks for workers in composting facilities, and to monitor a possible drift of spores emitted from the plant. The study revealed high numbers of CFU up to  $5 \times 10^5/\text{m}^3$  at almost all sites within the facility, exceeding all national and international threshold limit values recommended. On the other hand, Marth et al. (1997) subjected to medical examination to 137 employees from 2 composting facilities and 3 waste sorting plants from Germany. No statistically significant increase of allergic diseases was found. Although immunoglobulin E (IgE) levels of employees in sorting facilities were increased, no causality between IgE concentrations and the length of employment in the facility could be established. Spirometry did not show differences in the lung function. Among the workers, subjective complaints such as hoarseness (38%), cough (35%), infections of the respiratory organs (23%), diarrhea (18%), disorders in joints and muscles (13%) and conjunctivitis (12%) were found. Ivens et al. (1997) reported an association between level of exposure to fungal spores and self-reported diarrhea among waste collectors of Denmark. It was concluded that this should be taken into account in surveillance programs of compost workers. From March 1996 to April 1997, Haas et al. (1999) sampled airborne microorganisms in and around two different USA composting facilities (open and closed system) using Andersen 6-stage viable cascade impactors. The maximum value was 4356 CFU/m<sup>3</sup> air for thermophilic actinomycetes, but pathogenic species were detected at all sampling locations in the area of the composting facilities. In a suburban yard-waste composting facility in northern Illinois (USA), Hryhorczuk et al. (2001) assessed worker and community exposure to bioaerosols. On-site concentrations of total spores, *Aspergillus/Penicillium* spores, total bacteria, Gram-positive bacteria, Gram-negative bacteria, actinomycetes, total particulates, endotoxin, and  $\beta(1 \rightarrow 3)$ -glucans were higher than off-site concentrations. Off-site concentrations of bacteria were also significantly higher during periods of activity compared to no activity. The highest concentrations of total particulates, endotoxin, and  $\beta(1 \rightarrow 3)$ -glucans were observed in the personal samplers worn by workers at the facility.

Krajewski et al. (2002) assessed the occupational exposure of individuals employed in the municipal waste collection and management industry in Poland. 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>). Taking maximum allowed concentration (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 exposure evaluation, it was concluded that waste collectors and composting site workers were working in poor hygienic conditions. On the other hand, in an overview of personal occupational exposure levels to inhalable dust, endotoxin,  $\beta(1 \rightarrow 3)$ -glucan, and fungal extracellular polysaccharides in the waste management chain in the Netherlands, Wouters et al. (2006) concluded that bioaerosol exposure was lower for outdoor handling of waste and higher when waste was handled indoors. However, exposure variability was found to be large, with greater within-worker than between-worker variance. Occupational exposure limits for organic dust and endotoxins were frequently exceeded, suggesting workers were at risk of developing adverse health effects. Recently, Albrecht et al. (2007) reported that according to data from the literature, inactive or even dead cells can also have the potential to cause adverse health effects. Therefore, in composting facilities, a risk assessment based only on measuring colony-forming units may, in some cases, not be sufficient. There is enough evidence of an association between exposure to bioaerosols in composting plants and mucus membrane irritation of the airways and eyes, but not yet sufficient data to assess the risk of allergic diseases or the effects of long-term exposure on respiratory function. It was concluded that although frequently men-

tioned, severe mold infection, especially invasive pulmonary aspergillosis, was unlikely to occur in the occupationally exposed population (Schlosser and Huyard, 2008).

A personal sampling campaign for culturable bacteria and fungi in the breathing zones of waste collectors in a variety of typical work settings (scenarios) was performed in the province of Quebec, Canada (Lavoie et al., 2006). Total culturable bacterial and fungal counts were analyzed and compared to ambient environmental levels (background) to determine the degree of incremental exposure among workers. In several scenarios, worker exposure counts were significantly ( $p < 0.05$ ) higher than ambient levels measured upwind, with the highest personal exposures to bacteria observed for urban compostable waste collectors. Similar exposures to culturable bacteria and fungi have shown adverse health effects such as nausea, diarrhoea, upper respiratory tract irritation, and allergy. In order to minimize exposure, the authors' recommendations included automation of waste and compost collection, use of personal protective equipment including goggles, gloves, and disposable masks, and meticulous personal hygiene (Lavoie et al., 2006).

#### 4. Composting facilities and the surrounding environments

Composting facilities are known to release odorous VOCs due to biodegradation of waste. Although odor perception and its grading are influenced by experience, attitude and adaptation, these emissions have created a lack of acceptance for residents in the vicinity of composting facilities. Enclosure of compost pile halls, ventilation systems and bio-filters are often insufficient to minimize the burden of compost-derived compounds in the air. Moreover, economic considerations have forced small communities to establish less sophisticated facilities with open storage areas and other relevant sources for wind-borne dispersal of bioaerosols. Müller et al. (2004a,b) investigated the emission to volatiles in the environment at two composting facilities in Germany. Air samples were taken at distances ranging from 50 to 800 m in a downwind direction from each facility. Compost-derived and microbial volatile organic compounds (MVOCs) were found at distances of up to 800 m from the composting facilities. Concentrations of single compounds belonging to alcohols, ketones, furans, sulfur-containing compounds and especially terpenes, ranged from 10<sup>2</sup> up to nearly 10<sup>6</sup> ng/m<sup>3</sup>, depending on the sampling sites and the process engineering. Although exposure concentrations were not of toxicological relevance, the authors concluded that sensory irritation and psychohygienic effects due to an annoyance potential of such compounds should not be dismissed (Müller et al., 2004a,b).

In order to assess source emissions and dispersal of airborne culturable microorganisms from composting plants, measurements at three German facilities were carried out (Schilling et al., 1999). The downwind concentrations of dispersed microorganisms differed greatly, depending on the type of plant design. Hryhorczuk et al. (2001) assessed community exposure to bioaerosols emitted from a suburban yard-waste composting facility in northern Illinois, USA. Evaluation of the impact of the facility on community bioaerosol concentrations was undertaken by comparing on- and off-site measurements by sampling locations, wind direction and site activity. Total fungal spores averaged 13,451 spores/m<sup>3</sup> (range 5223–26,067) on-site and 8772 spores/m<sup>3</sup> (range 243–18,276) off-site, while viable bacterial airborne concentrations (in CFU/m<sup>3</sup>) averaged 11,879 on-site (range 480–78,880) and 3204 off-site (range 160–17,600). In turn, mean levels of endotoxins (in ng/m<sup>3</sup>) were 1.94 on-site (range 0.12–6.06) and 0.14 off-site (range 0.01–0.41), whereas mean total viable fungi were higher off-site than on-site (8651 vs 3068 CFU/m<sup>3</sup>). Herr et al. (2003) investigated the prevalence of somatic symptoms in three study samples of people living in the vicinity of composting plants in Germany. Microorganisms were measured in the air of the residential areas closest to the facilities. At the same time, an epidemiological investigation was performed in the neighborhood near (150 to 1500 m) to the three plants, and in corresponding control

residential areas of the same district. Nine hundred and seventy-nine residents were questioned about the odor annoyance in their vicinity. The percentages of study population reporting somatic symptoms were higher in all six samples in comparison with those reported for the German population (Rief et al., 2001), and in samples of population living near composting sites compared to the corresponding control samples. The type of somatic symptoms reported most often was scarcely influenced by environmental odors and medically relevant bioaerosol concentrations, except for nausea in context with annoying residential odors. As expected, the frequency of reporting general somatic symptoms was influenced by the perceived environment near the three composting sites (Herr et al., 2003).

Recer et al. (2001) investigated viable *A. fumigatus* and thermophilic actinomycete levels upwind and downwind of a large yard-waste composting facility in Long Island, NY, USA. It was also determined whether levels in a residential neighborhood near the facility were elevated above background concentrations due to facility bioaerosol emissions. It was noted that mean bioaerosol levels at the composting facility were significantly higher than the mean background levels, exceeding the background means by roughly 20-fold. There was a significant temporal correlation between bioaerosol levels at the composting facility and the downwind sampling site. The authors concluded that bioaerosol emissions from that large yard-waste composting facility could significantly increase bioaerosol exposure levels at least 500 m downwind from the facility. The same research group conducted also a study involving the collection of health symptom data and environmental monitoring data near a 40-acre grass and leaf composting facility in USA. Analyses were based on symptom diary data from 63 individuals from the study area, and 82 individuals from a reference area. The results did not support an association between allergy and asthma symptom incidence and *A. fumigatus* spore levels. Although the risk was not directly assessed, it seemed that severe illnesses among very sensitive individuals could occur (Browne et al., 2001). Recently, pseudomyiasis was detected in a two year old boy from South Moravia (Czech Republic). Contamination was caused by larvae of family *Calliphoridae* (Diptera), accidentally consumed with half-rotten fruits from bio compost (Borkovcová and Veselý, 2008). According to the authors, this has been the first documented case of pseudomyiasis in the Czech Republic, being closely connected with bio waste and ecological waste disposal.

In a study aimed at relating self-reported health complaints to bioaerosol pollution in the residential outdoor air and to duration of storing organic waste indoors, Herr et al. (2004a) found an elevation of reports of irritative airway complaints. These complaints were associated with residency in an area with a higher bioaerosol exposure, but not with odor annoyance. It was concluded that exposure to organic dust in residential air affects airways of residents, while exposure at homes due to organic wastes affects the skin. This same research group (Herr et al., 2004b) investigated the health effects associated with indoor storage of organic waste. In a cross-sectional study performed in Hesse, Germany, in 1997, doctors collected 384 questionnaires in three neighborhoods without industrial sources for microbial contamination. Self-reported

prevalence of airway, skin and general health complaints during the last year, lifetime diagnoses by a doctor, and home hygiene (storage of garbage, private composting, pet contact, indoor mould growth), were assessed in the home for several days, especially as far as skin irritation was concerned. The associations possibly resulted from indoor microbial contamination (e.g., endotoxins due to waste). Atopic disposition was a possible risk factor for health impairment.

On the other hand, Sanchez-Monedero et al. (2005) reported that major risks for local residents due to bioaerosol generation at large-scale green waste composting plants in UK were not expected. It was based on the fact that the concentrations recorded at distances of 200 and 300 m downwind of the operational area were not significantly different from background levels. In turn, in a recent report, Rosenfeld et al. (2007) presented data relating the human odor detection limit to human health threshold criteria developed by the National Institute for Occupational Safety and Health, Occupational Safety and Health Administration, the US EPA Region 9, and the WHO. This comparison indicated that: (1) the human odor threshold concentrations (OTC) for most compost odorants were far lower than their respective human health risk (regulatory) threshold values, (2) several compost odorants had OTC that were below some of their respective regulatory thresholds and above others (i.e. dimethyl amine, formic acid acetone, ethyl benzene and toluene), and (3) only the VOCs probably presented as contaminants in the raw composting material had OTC greater than all of its regulatory thresholds (i.e. benzene). The authors concluded that benzene was the most hazardous VOC associated with composting, and therefore, it should be monitored (Rosenfeld et al., 2007).

## 5. Summary and research directions

The diversion of biodegradable waste from landfill is of key importance in developing a sustainable waste strategy for the next decade and beyond (Sykes et al., 2007). The selective collection and the recycling of biosolids and the organic fraction of the MSW are essential factors for the success of a modern policy of global management of MSW. Therefore, the composting process, whose ecological and economic advantages are evident, plays and must play an essential role in the global management of domestic waste. However, some disadvantages in the elaboration of compost at industrial scale also exist. In this sense, it is necessary to refer to occupational problems for the individuals implied in this activity, without forgetting those for the general population, some of them derived from the elaboration of compost and others potentially derived from its direct applicability in agriculture. From a point of view of occupational health, the results of epidemiological studies are the best evidence to establish a correlation between the potential risks and the current situations. Consequently, we recommend that in the composting facilities, exhaustive controls of the biological risks are carried out. These controls should include measurements in the compost (in its different phases from elaboration) and in the air (different zones of the facility) of the concentrations of bioaerosols above commented, paying special attention to the Gram-negative bacteria and the fungus *A. fumigatus*.

**Table 1**  
Domestic waste composting facilities: A summary of recommendations to prevent human health risks

Potentially affected populations	Health risks	Recommendations
Individuals working at composting facilities	<i>Biological risks:</i> bacteria (mainly Gram-negative), fungi (mainly <i>A. fumigatus</i> ), endotoxins, parasitic protozoa <i>Chemical risks:</i> volatile organic compounds (VOCs) (mainly benzene)	<ul style="list-style-type: none"> <li>– Exhaustive control of biological risks</li> <li>– Measurement of microorganisms in the compost and in the air (indoor)</li> <li>– Measurement of indoor concentrations of VOCs</li> <li>– Biological monitoring of VOCs in workers</li> <li>– Protective measures to prevent exposure to VOCs and bioagents</li> </ul>
Individuals non-occupationally exposed	<ul style="list-style-type: none"> <li>– Metals (mainly As, Cd, Cr, Hg, Ni, Pb), pesticides, PAHs, persistent organic pollutants (PCDD/Fs, PCBs, etc.)</li> <li>– VOCs</li> <li>– Microorganisms</li> </ul>	<ul style="list-style-type: none"> <li>– Environmental (outdoor) monitoring of microorganisms and VOCs in the surrounding of the facilities</li> <li>– Periodic analytical quality of compost in order to reject any compost containing concentrations of biological or chemical agents with potential health risks</li> </ul>

Moreover, the environmental concentrations of VOCs should be also determined, and the personnel should be biologically monitored with certain regularity. A summary of recommendations is shown in Table 1.

It must be noted that, to date, the available information referring to occupational risks, and/or to the factors that produce those risks, is scarce. For that reason, we suggest to develop surveillance programs focused on relating occupational exposure and health effects. It should provide data that might be also used for the elaboration of administrative regulations and to concrete recommendations for the establishment of limits of occupational exposure. It should allow preventing potential adverse health effects. There is no doubt that in the near future, an important number of composting facilities of MSW will be built.

On the other hand, taking into account that the compost derived from the organic fraction of MSW can contain metals, persistent organic pollutants, as well as microbial and fungi toxins, whose exposure in certain scenarios might mean health risks for the general population, rigorous periodic analytical controls of quality accompanied by the corresponding evaluations of risk of the mentioned components seem to be clearly recommendable. The compost must be rejected for those uses that potentially may mean any significant increase of the human health risks.

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