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A study of the potential release of bioaerosols from containers as a result of reduced frequency residual waste collections

Toni L. Gladding *, Ceri L. Gwyther

Open University, Department of Mathematics, Computing and Technology, Walton Hall, Milton Keynes, Buckinghamshire MK7 6AA, UK

HIGHLIGHTS

- Extended residual waste collection frequencies are proposed to encourage recycling.
- Bioaerosols from bins could contain biological material in concentrations that are hazardous to health.
- Endotoxin concentrations during missed collections may be a risk to householders.
- Glucan concentrations during bin tipping may be a risk to waste collectors.
- Local authorities should risk assess the effects of a missed extended collection.

GRAPHICAL ABSTRACT

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ABSTRACT

Microorganisms have the potential to grow within waste containers if waste is stored for longer periods as a result of an extended residual waste collection cycle. Release of microorganisms as bioaerosols during waste collection and processing may be an occupational risk to workers within the industry. There may be many constituents of the bioaerosol that may be of concern, however, there are currently only workplace exposure limits proposed for endotoxin (90 EU m^{-3}). A field-scale trial was established to determine the concentration of mesophilic bacteria, Gram-negative bacteria, *Listeria monocytogenes*, thermotolerant fungi, *Aspergillus fumigatus*, and endotoxin and (1 → 3)-β-D-glucan in air within bins containing either bagged or loose residual waste, in warm (23 °C) or cold (7 °C) conditions, to simulate an extended collection cycle. Fresh waste was added during the first four weeks, with an additional 'missed collection' phase of a further four weeks where no more waste was added. A second trial examined the microbiological components of bioaerosols associated with 'tipping' the bins, simulating the moment when bins are emptied into waste collection vehicles. The majority of mesophilic bacteria, fungi and *A. fumigatus* concentrations were recorded when fresh material was added to the bins, with only mesophilic bacteria recorded up to week 6 during the 'missed collection' phase. (1 → 3)-β-D-glucan concentrations were variable throughout the first trial, (geometric mean range 0.4–13.8 ng m^{-3}). Perhaps the bioaerosol component of most interest was endotoxin (geometric mean range 0.52–1288 EU m^{-3}). Elevated endotoxin concentrations were recorded during the 'missed collection' phase of the extended collection cycle and during 'tipping'. This data demonstrates significant concentrations of bioaerosols and particularly endotoxin can be generated during prolonged residual waste storage and collection. As endotoxin is a bioaerosol component of concern it can be concluded there is the potential for workplace exposure hence identifying key areas for risk assessment.

* Corresponding author.
E-mail address: toni.gladding@open.ac.uk (T.L. Gladding).

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1. Introduction

Residual waste is all the material that is left after the recyclables have been removed, and may consist of organics (including kitchen waste), plastics, cans, glass and various other recyclable and non-recyclable components. Householders may deposit this material either loose or bagged, and the size of residual waste bins are often restricted to 120 l to encourage materials to be deposited in recycling containers. In a bid to bring the UK's household recycling rates in line with the European Union's target of 50% of household waste recycled by 2020 (Council of the European Union, 2008) many UK Councils have extended residual waste collection cycles to fortnightly or three-weekly (Gladding, 2009). Indeed, this practice is not uncommon within Europe, particularly in Germany. Within the UK devolved regions, more stringent local government targets of 70% by 2025 have also been introduced (Scottish Government, 2010; Welsh Assembly Government, 2010). Monthly bin collections of residual waste have also been suggested, although public opinion has hampered progress in this area (Yates, 2016). One reason for this lack of support is often due to the perception that bins would become a nuisance via odours but also because of public health fears regarding vermin. However, there is also concern they could also provide a breeding ground for microorganisms, particularly in bins where nappies and organic wastes are deposited.

The health effects of bioaerosols are of interest as they have the potential to be released whenever the bin is opened, such as when waste is added and when a bin is emptied. Bioaerosols potentially contain aerosolised biological material such as bacteria, fungi, viruses, endotoxins and (1 → 3)-β-D-glucan which may all have health impacts ranging from upper airways irritation, nausea, and fever to potential lung inflammation and respiratory illness (Gutarowska et al., 2015; Swan et al., 2003; Searl, 2008). However, only endotoxin, found in the cell walls of Gram-negative bacteria, has a demonstrable increased risk of symptoms alongside increased exposure (Searl, 2008). As a result, currently, there are no agreed upon workplace exposure limits for any bioaerosol components (Walser et al., 2015). In a recent comprehensive review no suitable exposure-response relationships could be found between the microbial component of bioaerosols and human health due to insufficient and comparable data in the literature, the range of health effects, and insufficient exposure assessment (Walser et al., 2015). It has also been noted that variability in response due to individual risk factors is also a barrier to the setup of reliable exposure-response relationships for inhaled biological agents (Searl, 2008). Various authors have reported exposure thresholds in the literature ranging from 10^3 cfu m^{-3} and 10^5 cfu m^{-3} for both general bacteria and total fungi (Eduard et al., 2012; Kuijer et al., 2010; Searl and Crawford, 2012). The Health council of the Netherlands has imposed a 30 EU m^{-3} limit on endotoxin released from livestock farms for the protection of the public and an occupational limit of 90 EU m^{-3} (Health Council of the Netherlands, 2010; Health Council of the Netherlands, 2012), whilst Rylander (1997) has suggested a 10 ng m^{-3} guideline value for exposure to (1 → 3)-β-D-glucan.

Although not occupational, the Environment Agency in the UK has applied precautionary environmental limits to bioaerosols that are emitted downwind of waste compost sites in order to protect the public (1000 cfu m^{-3} for bacteria, 500 cfu m^{-3} for *Aspergillus fumigatus* and 300 cfu m^{-3} for Gram-negative bacteria) (Environmental Agency, 2009). In the absence of validated occupational limits, data from this study was also assessed against these more stringent reference guidelines.

Whilst some work has been undertaken to assess the health risks associated with bioaerosols emitted from general waste collection (Neumann et al., 2005; Roodbari et al., 2013; Kuijer et al., 2010; Neumann et al., 2014; Neumann et al., 2015; Schantora et al., 2015), source separated recyclable collection (Heldal et al., 1997) and indoor storage of organic waste (Wouters et al., 2000) no studies to date have detailed the risks associated with storage and collection of containers (bins) containing only the residual fraction after recycling. Therefore, the aims of this study were three-fold:

1) To explore the potential for bioaerosol emissions arising from the extended storage of residual waste material,
2) To explore the link between these emissions and potential health impacts on householders and waste collectors, and,
3) To provide further evidence to support the development of guidance to local authorities that may be considering extended waste collections in the future.

2. Material and methods

2.1. Experimental setup

Household-sized wheeled bins (240 l) were stored under 'simulated waste disposal' and 'tipping' conditions at a dedicated indoor field site facility at the Open University (52°1′27″N, 0°42′20″W). The facility space was in two parts, and was approximately 5 m × 5 m at 23 °C in one part, with a separated refrigerated container measuring 5 m × 10 m at 7 °C in the other. Data were collected between July and September 2013. 'Simulated waste disposal' bins were divided by waste addition method, e.g. bagged (black plastic refuse sacks tied at the top) and loose (waste material emptied straight into the bin). Each waste treatment was further subdivided into summer (warm) and winter (cold) groupings in the separated field site facility areas (23 °C and 7 °C respectively). Temperatures were checked in the airspace of the bins and in the atmosphere of these areas daily utilising calibrated digital thermometers. This culminated in four subgroups ($n = 6$ in each) namely, bagged, warm (BW); loose, warm (LW); bagged, cold (BC), and loose, cold (LC). Mixed residual waste (4.5 kg; see Section 2.2, Table 1) was added to each bin once a week for four weeks and subsequently left for a further four weeks to simulate householder deposition and subsequent missed collection on an extended frequency. Therefore, results from week 2 could be used to assess the risk to householders and collectors after a fortnightly waste collection, week 4 could be used to assess the risk to householders and collectors after an extended four-weekly collection, and results at week 8 could be used to assess the risk to householders and collectors after a missed collection of an extended four-weekly collection cycle.

To further simulate the risks posed to waste operators involved in bin emptying, a 'tipping' scenario was established. 'Tipping' was standardised by laying the bins on their side and agitating them for 10 s to replicate the disturbance caused when wheeled bins are emptied or moved. Bins ($n = 6$) containing loose, warm waste (23 °C) (expected to be the 'worst case scenario') were left undisturbed for four weeks (LW4) and then agitated as described to mimic the activity of tipping bins into a waste collection vehicle. Subsequently, the bins used in the eight-week 'simulated waste disposal' trial were left for a further week before tipping and agitating (week 9; LW9, BW9, LC9 & BC9). In this instance, waste was added at time 0 and 1 day prior to tipping for LW4. The last addition of waste to the other treatments was as for the 'simulated waste disposal' scenario, i.e. in week 4.

2.2. Waste properties

Waste was chosen to reflect typical waste compositions (Table 1) and were taken from Parfitt and Bridgewater (2010) with slight modifications to account for 'fines' and 'other organics' which were not defined, and to remove glass and replace it with other packaging in the interests of safe handling. The following assumptions were made to determine the quantity of material to be added to the bins per week: On average, one person generates 428 kg of waste a year which, with a 43% recycling rate (DEFRA, 2013) results in approximately 4.7 kg of residual waste per person a week. Previous scoping studies from Zero Waste Scotland (ZWS) (Gladding, unpublished) on an extended waste