Fate of microplastics during composting and their leachability

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Plastics are among the most widespread contaminants of aquatic, terrestrial and atmospheric environments (Zhang and Chen, 2020). The presence and accumulation of microplastics lead to a series of ecological risks to animals and humans. Plastics present in soils enter the food chain and thus potentially end up in human food. Composting removes up to 50% of the plastics, but monomers and additives remain in the biogenic matrix (Watteau et al., 2018). In composts from biowaste composting plant, where only “green bins” are used as a raw material source, styrene-based polymers are represented by up to 60%, while PE and polyester form about 30%(Weithmann et al., 2018). The visible plastic particles in the compost are present in amounts from 2.38 to 180 mg/kg (Yang et al., 2021). As a result of organic matter loss, the concentrations of non-biodegradable substances may increase. Plastics in soils and composts are broken down by photodegradation and release additives and unreacted monomers (Bach et al., 2013) into the environment. There is very little information on the transfer of organic compounds released from the microplastics contained in composts into the aqueous leachate. Organic compounds leached from plastics affect ecotoxicity. The contribution of this text is the identification and quantification of organic compounds, additives and monomers of plastics that pass into aqueous leachate from composts, depending on the process of composting.

Organic compounds in the aqueous leachate were prepared using solvent assisted-stir bar sorptive extraction (SA-SBSE), and subsequently, after thermal desorption, they were analysed by gas chromatography with mass detection (TD-GC/MS). SA-SBSE analysis allows the determination of polar and non-polar compounds in aqueous leachates. Organic compounds in the dry matter of composts have been identified and quantified using TD-GC/MS. Samples of input material and compost during the composting process (after three and six months) were taken at the composting plant of OZO Ostrava, Czech Republic. The composting plant only processes waste from the maintenance of urban greenery and the “brown bins” containing biowaste from households.

Organic compounds have been found in the dry matter of composts to indicate PET (polyethylene terephthalate), PS (polystyrene), PP (polypropylene), and PE (polyethylene). PET and PS are the plastics that were present in the highest amounts in dry matter and compost leachate. The highest amount of plastic was identified in the feedstock for compost production (471.6 mg/kg). The concentrations of organic compounds indicating plastic in composts decrease with the composting length and the compost maturity.

PET in compost dry matter is indicated by organic compounds such as 1,3-dioxolane, 2-ethyl-1-hexanol, diethylene glycol, 1,2-ethanediol, benzoate-containing compounds (2-chloroethyl benzoate, 2-ethylhexyl benzoate, 2-methylpropyl benzoate, and benzyl benzoate), and terephthalates – methyl hydrogen terephthalate, ethyl methyl terephthalate, and methyl vinyl terephthalate (Dümichen et al., 2017)

The highest concentrations of compounds indicating PET were found in the composting feedstock (136.8 ± 27.7 mg/kg). The concentrations of compounds indicating PET decrease during composting. After six months of composting, the concentrations of compounds indicating PET decreased by 73% to 37.5 ± 4.5 mg/kg. The observed concentration range of compounds indicating PET in composts corresponds to the range (10.2 – 102 mg/kg) reported by Müller et al. (2020)

Benzoic acid and its esters are among the main breakdown products of PET. Benzoic acid esters in composts include 2-ethylhexyl benzoate (2-ethylhexyl ester benzoic acid), 2-methylpropyl benzoate (2-methylpropyl ester benzoic acid), and decyl benzoate (2-decyl ester benzoic acid). 2-ethylhexyl benzoate is leached from the dry matter of composts. The highest leaching value (around 47%) was found in feedstock (743.8 µg/kg). Th transition of 2-ethylhexyl benzoate into the leachate decreases with the age of the composts. Only 6.55% (68.8 µg/kg) of 2-ethylhexyl benzoate was extracted from mature compost.

1,3-dioxolane ($C_3H_6O_2$) has been identified as a breakdown product of PET. Concentrations of 1,3-dioxolane in composts range from 2.14 to 22.02 mg/kg. 18.2 to 41.8% is extracted from the dry matter of the composts, depending on the length of the composting process.

1,2-ethanediol (ethylene glycol, $C_2H_6O_2$) is a raw material for PET production; it is a PET monomer. The highest concentration of 1,2-ethanediol was found in the feedstock (4.3 ± 1.1 mg/kg). 1,2-ethanediol is a toxic compound that is miscible with water without limits. Up to 45% of the feedstock was leached; the measured

concentration in the extract was 1920 ± 452 µg/kg. The 18.7 per cent of 1,2-ethanediol was leached from the matured compost; the measured concentration in the extract was 590 ± 56 µg/kg, which was about three times lower than the feedstock.

2-ethyl-1-hexanol ($C_8H_{18}O$) is used to produce plasticisers from a group of phthalates and adipate such as di(2-ethylhexyl) phthalate (DEHP). At the same time, it is the breakdown product of 2-ethylhexyl benzoate. The concentration of 2-ethyl-1-hexanol in the matured compost is 4.45 ± 0.80 mg/kg, while the concentration of 10.26 ± 2.20 mg/kg was found in the feedstock.

Polystyrene has been identified in composts and soil by the presence of styrene, dimer styrene (2,4-diphenyl-1-butene), and trimer styrene (2,4,6-triphenyl-1-hexene)(Duemichen et al., 2019). The highest concentrations of compounds indicating polystyrene were found in the feedstock (175.6 ± 28.4 mg/kg), which gradually decreases depending on the maturation period. Dimer and trimer of styrene occur in the aqueous leachate of composts. The feedstock extract contained 6.03 mg/kg of styrene dimer, while the matured compost extract contained 0.3 mg/kg. In a higher concentration, styrene trimer was present. The feedstock leachate contained 12.5 ± 3.4 mg/kg, and the matured compost leachate contained 0.34 ± 0.08 mg/kg.

Polypropylene was identified in composts by the occurrence of dimer (2-methyl-1-pentene), trimer (2,4-dimethyl-1-heptene), and tetramer polypropylene (2,4,6-trimethyl-1-nonene). The highest PP concentration was found in feedstock (0.72 mg/kg). After six months, concentration decreases by 50% to 0.35 mg/kg. No PP-indicating compounds were identified in the aqueous leachate. PE can be identified in composts by occurrences of 1,12-tridecadiene, 1,13-tetradecadiene, 1,14-pentadecadiene, and 1,15-hexadecadiene. The highest concentrations of compounds indicating PE were found in feedstock (86.6 ± 24.7 mg/kg). After six months, the concentration decreases approximately by 70% (27.2 ± 6.4 mg/kg). These compounds were not identified in the aqueous leachate.

Plastics in compost are accompanied by additives. Identified additives include plasticisers, UV stabilisers, antioxidants, flame retardants, adhesives, binding agents, and their breakdown products. The antioxidant butylated hydroxytoluene (BHT) concentration in the sludge dry matter decreased by only 20% to 5.69 ± 0.70 mg/kg during the 6-month composting process. The concentration of BHT in the aqueous leachate from the mature compost reached 0.871 mg/kg. Antioxidants include 2,4-di-tert-butylphenol, which is used as a PVC stabiliser. In feedstock, it occurs at a high concentration of 3325 mg/kg, which decrease to 85 mg/kg after six months. It was not determined in the aqueous leachate.

Of the fillers used for plastic production, the feedstock contains 2,5-di-tert-butyl-1,4-benzoquinone. The highest concentration of 2,5-di-tert-butyl-1,4-benzoquinone was found in mature compost (11.2 ± 2.4 mg/kg). In this case, there is an increase in concentration during the composting process, but it is not transferred into the aqueous leachate.

Phthalates, such as dibutyl phthalate (DBP), diisobutyl phthalate (DIBP), and diethyl phthalate (DEP), have been identified from plasticisers in the dry matter of composts. DIBP and DBP are classified as carcinogenic, mutagenic or toxic. From phthalates, DEP is most easily leached from the dry matter of composts, at around 25 to 45% and DIBP around 17 to 37%. Phthalate concentrations decrease with the age and maturity of composts. Dibutyl phthalate (3.7 to 31%) has the smallest transfer from compost dry matter. Dry matter of composts contains the degradation products of phthalates and their precursors, e.g., phthalimide and phthalic anhydride. From the precursors, phthalic anhydride passes partially (13-33%) to the aqueous leachate of the composts.

A decrease in concentrations during composting has been observed for the greater part of additives and organic compounds derived from the degradation of plastics. The exception is fillers, which concentrate in the dry matter of composts during composting. The leachability of additives and organic compounds indicating plastics decreases with the age of composts.

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