detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

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IMPACT OF DIFFERENT SCREENING TECHNOLOGIES ON THE SEPARATION OF PLASTIC, METAL AND GLASS IMPURITIES FROM COMPOSTS

Erwin Binner, Peter Beigl, Benedikt Vay, René Schwarzl, Marion Huber-Humer and Christian Zafiu *

Department of Landscape, Water, and Infrastructure (LAWI), Institute of Waste Management and Circularity, BOKU University, Muthgasse 107, 1190 Vienna, Austria

Article Info:
Received:
29 November 2025
Revised:
8 March 2026
Accepted:
8 April 2026
Available online:
5 May 2026

Keywords:
Compost
Plastic
Microplastic
Physical contaminants
Impurities

ABSTRACT

The application of compost is regulated in the EU member states mainly based on the quantity of hazardous chemical elements and compounds and on physical contaminants, such as glass, metals and plastics. A large fraction of impurities is removed by screening of the rotting material usually before the composting process is started or at the end of the process. Different screening technologies are used to obtain high quality composts. However, the removal efficiency of impurities for frequently used screening technologies was not thoroughly studied so far. In this study raw compost (rotting duration 6 weeks) from a composting plant, was treated by 6, 8, and 10 mm flip-flop screens and 12 and 25 mm drum screens. The produced composts were analyzed on their properties as well as quantities of impurities. In addition, plastic impurities in fraction down to 0.63 mm were investigated for their quantity in mass, the particle number, polymer, and form type (fiber, film and fragments). The results show that all investigated screening technologies were able to remove plastic-impurities to a level below the thresholds (limit-value 0.3% DM in the fraction > 2 mm) for composts according to the EU fertilizer regulation. The deeper analysis, however, showed that plastics of different form types were separated with different efficiencies by flip-flop and drum screens. Additionally, microscopic analyses of the separated plastics indicated that film and fiber materials that were larger than the mesh sizes were not entirely separated by screening.

1. INTRODUCTION

In the EU in 2022, 42 million tons of biowaste were composted (European Compost Network, 2022) and converted to valuable and renewable soil conditioners that can be applied in farming or to remediate soils (Cogger, 2005; Heyman et al., 2019). Moreover, composts are applied in organic farming (Martínez-Blanco et al., 2013) in place of mineral fertilizers leading also to a reduction of greenhouse gas emissions (Chojnacka et al., 2020). However, compost quality is important for becoming a product and be marketed. Compost quality is determined, among other parameters, by its quantity of contaminants composing hazardous materials, such as certain chemical elements (e.g., heavy metals), and so-called physical contaminants that are not considered hazardous, but do not add any benefits to the compost, such as particles of other metals, glass, stones and plastics (>2 mm). Although, source separation of biowaste helped to reduce the contamination level of composts, massive quantities of these contaminations are still entering the composting process. The main sources of contamination are littering in case of green waste inputs or mis-directed disposal of impurities into bio-bins, with plastics as dominating fraction (Le Pera et al., 2023). The acceptable contamination levels of the output materials are regulated at the EU level by the EU Fertilising Products Regulation 2019/1009 (EC, 2019), as well as at the national regulations in the member states, or voluntary quality assurance schemes (ECN 2021). The EU Fertilising Products Regulation (EC, 2019) for composts and digestates defines an upper threshold of 5 g kg^{-1} DM (or 0.5% DM) for the sum of impurity particle types glass, metals, and plastics. Moreover, individual thresholds of 0.3% DM for each type of impurity are defined too, whereas a further reduction of the limit value for plastics to 0.25 g kg^{-1} DM is planned for 2026 (ECN 2021). However, these thresholds apply to impurities of particle sizes above 2 mm for practical reasons. The improved restrictions towards plastics originate from the dis-

* Corresponding author:
Christian Zafiu
email: christian.zafiu@boku.ac.at

Detritus / Volume 35 - June 2026 / pages 72-81
https://doi.org/10.31025/2611-4135/2026.19590

cussions on the (micro-)plastic pollution and their potential negative impacts on soil health (Souza Machado et al., 2019). In particular, microplastic pollution was shown to cause harm to soil organisms (Huerta Lwanga et al., 2017, 2016; Prendergast-Miller et al., 2019) and crops (Rillig et al., 2019), and to be transferred to the humans via consumption of contaminated food (Cox et al., 2019). Various publications show that composts are contaminated with (micro-)plastics which are transferred to soils (Braun et al., 2021; Weithmann et al., 2018; Zafiu et al., 2023; Zafiu et al., 2020). Plastic contaminations cannot be removed from soil, which leads to their accumulation and the particles remaining there for an unforeseeable time due to the persistence of most plastics (Albertsson and Karlsson, 1988; Allen et al., 1994) to degradation (Bläsing and Amelung, 2018). Although efforts have been already undertaken to reduce the plastic contamination in the preprocessing of biowaste (Alessi et al., 2020; do Carmo Precci Lopes, Alice et al., 2019; Ferreux et al., 2020; Jank et al., 2017), plastics still remain in the input materials for the rotting process.

Plastics that enter the composting process become a source of plastic contaminant > 2 mm as well as microplastics < 5 mm due to their disintegration during the composting processes (Zafiu et al., 2023). Due to the very high water content of the collected biowastes, a mechanical separation of impurities prior the rotting process appears to be feasible only at considerable effort and therefore mitigation strategies of plastic during and before collection are desirable.

In Austria source separation of biowastes at household level is obligatory since 1995 (BGBl. 68/1992, 1992). Although local authorities made huge efforts to reduce incorrect disposal into biogenic waste bins, analyses of the input material at Austrian composting plants still show sometimes high levels of contamination with impurities. The draft of the new Composting Ordinance takes this into account: for the first time in Austria, the impurity content in the input material is to be limited (limit value for impurities in the initial composting mixture < 2% FM). The main factor for high impurities in biowaste is the settlement structure. The degree of urbanisation (higher anonymity of the residents) correlates with higher contaminant content in the collected biowaste.

For composts, the remaining plastic contamination can cause negative economic impacts, when the contaminated compost is not accepted for utilization and, e.g., must be landfilled or thermally treated (Le Pera et al., 2023). On the other hand, composts represent a major source of plastic and microplastic pollution (Bertling et al., 2018). Thus, methods for separation of impurities from final compost must be evaluated and developed. After composting, impurities and bulking materials are usually separated during the final treatment step (mostly screening, sometimes additional use of wind shifters, ballistic separators etc.). Screening typically is made after the end of the thermophilic phase and before maturation. Besides the removal of impurities, the screening step is made also to homogenize the compost for maturation. Although different technologies are available to screen compost efficiently, no information is available so far that thoroughly reports the efficiency of compost homogenization and impurity separation. Comparative studies on final screening can help in optimizing the removal efficiency of impurities in composts.

To close this knowledge gap, this study was conducted on raw compost from one treatment plant operated according to the Austrian state-of-the-art. The compost was treated using different types of screens and different meshes (6, 8, and 10 mm flip-flop screens as well as 12 and 25 mm drum screens). The composition and the quantity of physical contaminants > 2 mm in the produced composts were investigated, to answer the question whether the currently mostly used screening technologies enable compliance with actual quality requirements in principle, or whether requirements beyond those currently defined will be necessary (e.g. with regard to microplastics < 2 mm, which are not yet regulated in composts). Thus, plastic contaminations were objected to a deeper analysis determining also particles < 2 mm and the polymeric composition of particles > 2 mm which were categorized too. This investigation was also undertaken to broaden the understanding of the type of plastic morphology and size that can be separated by different screening technologies.

2. MATERIALS AND METHODS

2.1 Raw compost sampling and screening

For this investigation rotting material from an industrial open windrow composting plant in Austria was used. Rotting technique uses triangular windrows with frequent turning by a commercial windrow turning machine. The duration of the rotting process (until screening step prior to maturation of rotting material) is approx. 6 weeks. The final mechanical treatment in the plant is made using drum screens with mesh sizes of 25 and 12 mm (Figure 1). The rotting material first is screened to < 25 mm. Compost < 12 mm is produced from the screen passage (= throughflow) in a second screening step.

This two-stage process was retained for the study. Raw-compost ready for final treatment to separate the compost from undegraded coarse particles was screened < 25 mm by the drum screen. During the whole screening process subsamples (triplicates) from raw-compost, fraction > 25 mm (overflow) and fraction < 25 mm (throughflow) were taken and brought to the laboratory (Figure 1). From the fraction < 25 mm 4 sub-samples were generated for further screening tests with different screening technologies.

Directly in the composting plant (as reference) one of the four sub samples was separated by the existing drum screen at 12 mm mesh size. The further three sub-samples were filled into big bags and transported to a company operating flip-flop screening. The samples were separated there six days later using 10, 8, and 6 mm mesh screens. From each of these fractions (throughflows and overflows) two representative samples were taken and brought to the laboratory (Figure 1).

Additionally, the final composts were analyzed on some relevant parameters describing the compost quality according to the Austrian Compost Ordinance (BGBl. II 292/2001): organic matter, inorganic carbon, nitrogen,

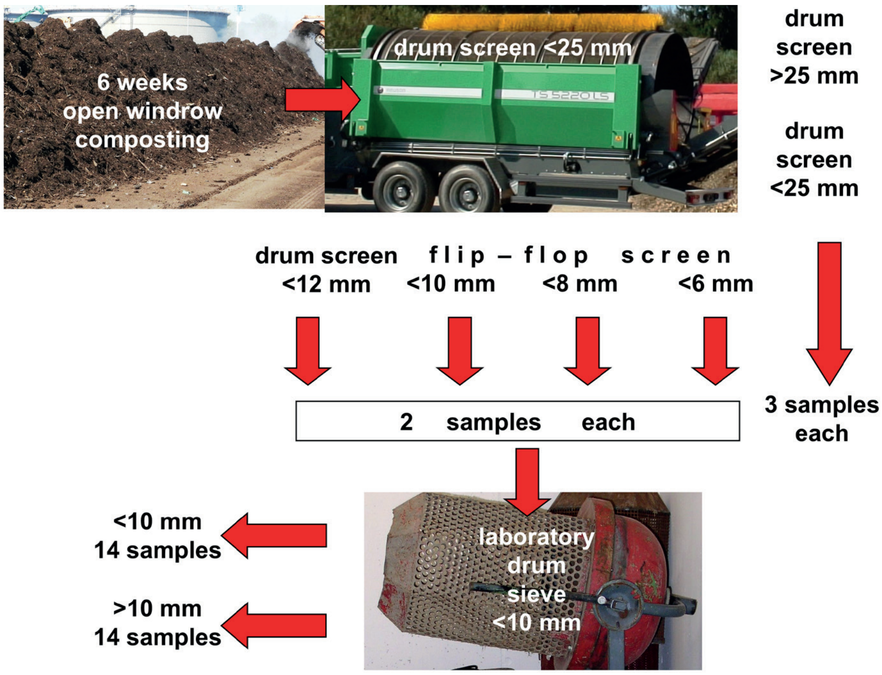

FIGURE 1: Screening and sampling for impurity analyses (triplicates of fractions > 25 mm and < 25 mm and duplicates of fractions 12 mm, 10 mm, 8 mm and 6 mm). Prior analyses of impurities, all samples were sieved by laboratory drum sieve to fractions > 10 mm and < 10 mm.

C/N-ratio, AT_4 (respiration activity within four days) and physical contaminants > 2 mm (particles of glass, metals, plastics).

2.2 Impurity analyses

Each sample consisted of approx. 6.4 to 31.4 kg wet matter (WM) (10 to 50 litres), whereby raw composts before screening had larger sample sizes than those in the final composts after screening. In the laboratory, the entire sample masses were sieved (regardless of the sample size) by a laboratory drum screen equipped with a 10 mm mesh. The dry mass (DM) was determined from a subsample by drying at 105°C. After the fractionation sub samples of 1.0 - 3.8 kg > 10 mm and 1.0-4.5 kg < 10 mm were taken for further sieving. The fraction < 10 mm was further sieved by a vibratory sieve shaker (AS 200, Retsch) using sieves with 6.3, 2 and 0.63 mm mesh sizes, which was operated in wet sieving mode using tap water. Fractions < 0.63 mm were not analysed to their impurity content. Statements about microplastics therefore refer only to particles > 0.63 mm. The fractions were transferred to aluminium trays and dried at 60°C for at least 2 days. Impurities (particles of metals, glass, and plastics) were separated manually in the fraction > 6.3 and 2 - 6.3 mm, while the fractions 0.63 - 2 mm were separated under a stereomicroscope (SZX-ILLD 200, Olympus Optical) with tweezers. The separated particles were then weighted, photographed, and identified by diamond ATR-FTIR Spectroscopy (Attenuated total reflection Fourier transform infrared Alpha, Bruker) using a DTGS (Deuterated triglycine sulphate) sensor. The spectra of the plastic particles were compared to a commercial ("Know it all", Biorad) and a custom-made polymer spectral database, which contained also biodegradable plastics recorded in earlier investigations. Particles were classified as plastics when the hit quality exceeded 40% and characteristic peaks for the identified polymer were observable. This threshold was chosen based on experience with the data bases. While most of plastics reached hit qualities >70%, low hit qualities were obtained in rare cases of small and/or thin and colored polymers with attachments that cannot be entirely removed.

Quantitative data was processed and presented by Microsoft Excel 365. Means were made from triplicates and error bars represent standard deviations of the replicates. Pearson linear correlation was calculated also in Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1 Compost separation efficiency

As described, composts were screened by different techniques (drum or flip-flop screening) using different mesh sizes (25, 12, 10, 8, 6 mm). The efficiency of these separation techniques was assessed by drum sieving in the laboratory into the fractions > 10 mm and < 10 mm (Figure 2). Different to the on-site screening, the laboratory separation was maintained as long as no particles visibly passed the sieve anymore, which means that more aggregates were disassembled allowing more material to pass the screen. Therefore, a larger quantity of finer fractions can be separated in the laboratory.

For screen cutoff-sizes of 10, 8 and 6 mm flip-flop screens were used, while 12 mm screening by drum screen was performed by the standard screening method available at the composting plant. The input, which was the raw compost before screening, was almost evenly distributed

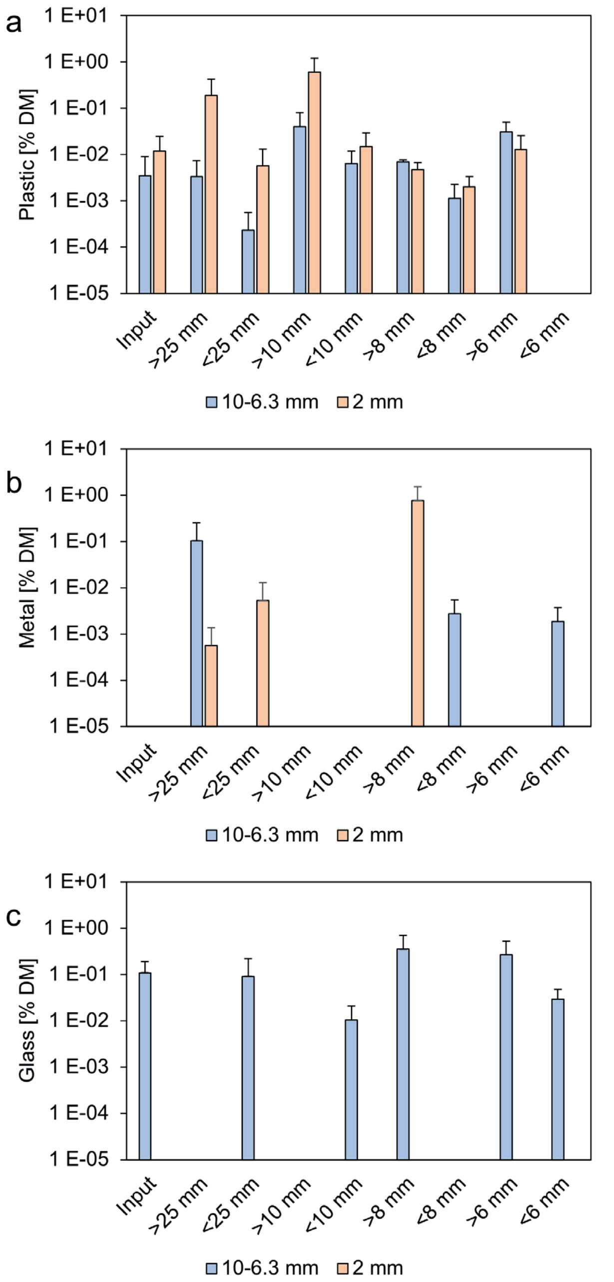

FIGURE 2: Mass fractions of differently separated rotting material after fractionation at 10 mm in the laboratory by a drum sieve. Screening in the composting plant at 25 and 12 mm (from fraction < 25 mm) was made by the facility's own drum screen system. Flip-flop screening (from fraction < 25 mm) at 10, 8, and 6 mm was made in another facility.

between > 10 mm (44.4% WM) and < 10 mm (56.4% WM) fractions. Within the fractions that were larger than or the same size as the screen size of the drum screen (10 - 25 mm) 17 - 28% WM of the total share had a particle size that was < 10 mm. This is remarkable, as it would have been expected that particularly in the fraction > 25 mm the share would not be measurable, yet it was found to contribute to about a quarter of the total fraction, which indicates that a large fraction of fine material is still aggregated in larger particles and gets rejected by the standard screening. The minimal quantity of < 10 mm grain size was found in the fraction > 10 mm after flip-flop screening, which appears to be the optimal separation method of this particle size. As expected, the screening by 8 and 6 mm flip-flop screening rejects more > 10 mm fraction - 32 and 59% WM respectively. In the fractions < 25 mm and < 12 mm the mass of > 10 mm fraction is larger than in the fractions > 25 mm and > 12 mm.

3.2 Efficiency of separation of impurities

The quantity of impurities was analyzed in all available fractions in the size ranges > 10 mm, 6.3 - 10 mm, and 2 - 6.3 mm, whereas no impurities > 10 mm were found in any sample. Figure 2 shows that the plastic quantities found after separation in the overflow (Figure 3 a) and in the throughflow fraction (Figure 3 b) varied strongly for both investigated size ranges (where physical contaminants were found). However, the pollution level correlated well with the plastic quantity in the size range 6.3 - 10 mm, with a Pearson linear correlation coefficient (ρ) of 0.656 and highly for the fraction 2 - 6.3 mm (0.989), thus showing that the variation originated from the individual pollution levels in the single samples used for the individual screening procedures. This finding is expressed by the large error bars in Figure 3. Therefore, an interpretation of the removal of impurity relative to the individual pollution level must be applied, to draw conclusion on the separation efficiency. In addition, the analysis shows that the majority (by mass) of plastics could be removed from the compost by the screening step. A comparison of the quantities of plastics in the overflow and throughflow fraction shows that in the size range of 6.3 - 10 mm screening by 25, 12, 10, 8, and 6 mm screens separated 93.6%, 100%, 86.3%, 85.9%, and 100% of the plastics from the throughflow. In the smaller size range of 2 - 6.3 mm 97.0%, 97.7%, 97.6%, 70.4%, and 100.0% of the plastics were removed by screening at 25, 12, 10, 8, and 6 mm. The results show that smaller particles than the cutoff were removed too by the screening step, because they were aggregated with other matrix components, as also observed in an earlier study (Zafiu et al., 2020). Remarkably the screening by the finest screen (6 mm) removed the entire plastic impurities in both investigated size ranges. The threshold for the highest quality class of composts, which is 0.2% DM of particles > 2 mm, and allows the application of the compost as soil conditioner, was achieved by all screening procedures. However, it must be noted that the raw compost before screening already showed a low plastic contamination. The other regulated impurities, glass and metals did not exceed the threshold of 0.2% DM of particles > 2 mm. Interestingly, the drum screening (12 mm) processes removed metal impurities in size ranges of 6.3 - 10 mm entirely, while the flip-flop screens failed to do so (Figure 3 d). However, due to the low level of contamination of metals, the difference may have been caused due to the inhomogeneous distribution of the metals in the material. In case of glass, the drum screens did not remove the impurities, but the flip-flop screens.

Table 1 shows the influence of the different final treatments (screenings) on some selected compost parameters. Organic matter content was hardly influenced by

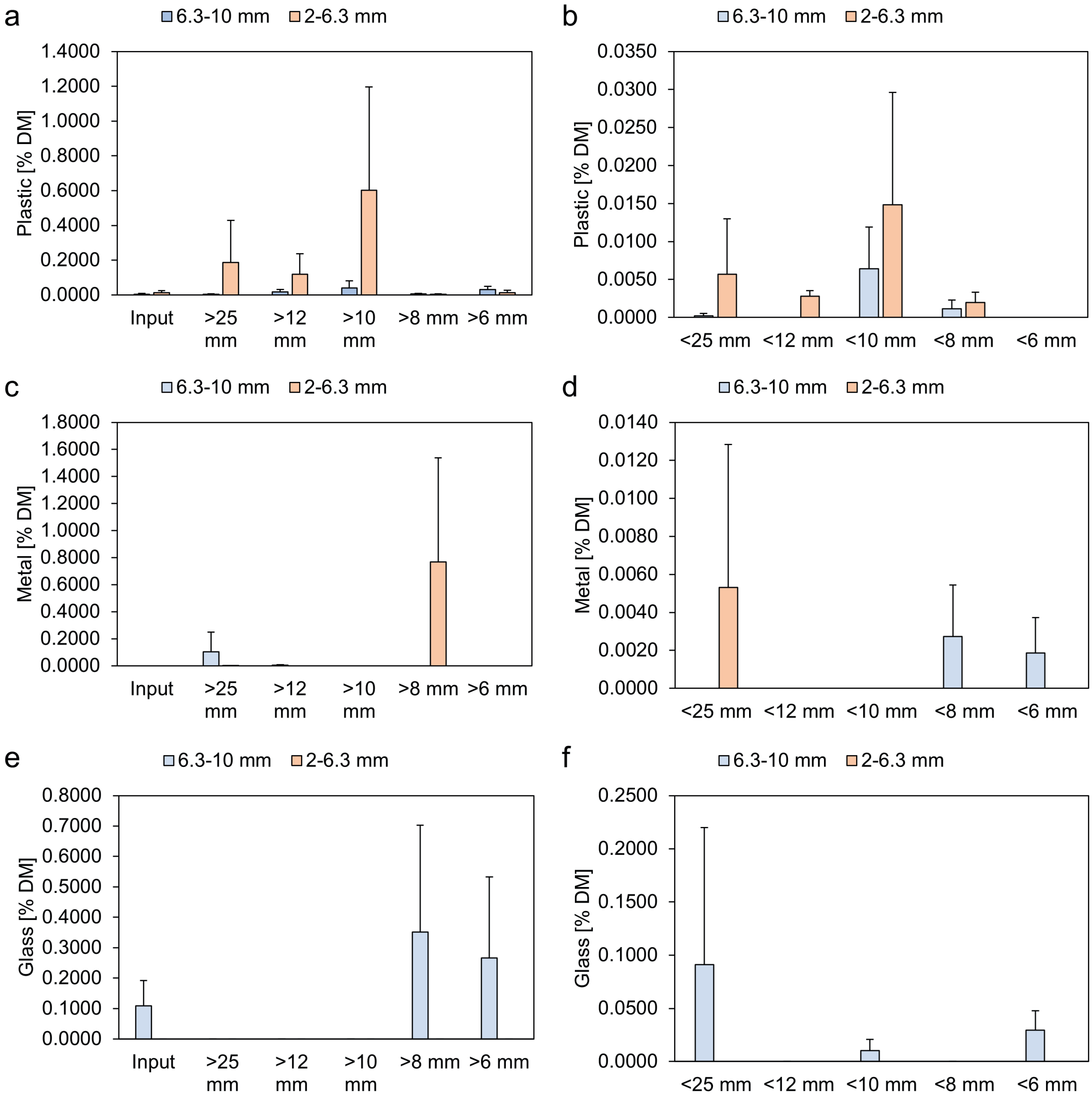

FIGURE 3: Quantity of impurities in raw composts before (input) and in the throughflow (drum screen) < 25 mm and composts after screening the material < 25 mm by different screening techniques and cut-offs. Plastics in the fractions are larger and smaller than the screening cut-off are shown in a) and b), respectively. Metals in the fractions larger and smaller than the screening cut-off are shown in c) and d), respectively. Glass in the fractions larger and smaller than the screening cut-off are shown in e) and f), respectively. The error bars represent the standard deviation of duplicate samples.

screening. The slightly larger value after flip-flop screening at 8 mm was rather caused by sample inhomogeneity. Inorganic carbon content was slightly reduced by smaller screen mesh. Nitrogen content appeared slightly increasing by smaller screen mesh. The much lower respiration activity (AT_4) (as well as the slightly lower C/N-ratio) in the "flip-flop screen composts" was most probably caused by a much longer interval between drum screening < 12 mm and flip-flop screening. The big bags were stored for 6 days before flip-flop screening was performed – samples arrived at the laboratory 19 days after the drum screen samples. Thus, it is strongly assumed that further degradation (stabilization) took place in case of the flip-flop screened samples. The time delay in screening could influence the formation of aggregates during storage, but we didn't observe a trend confirming this effect.

Already after 6 weeks of intensive rotting all four compost materials met the requirements of the Austrian Compost Ordinance (BGBl. II 292/2001) for use in agriculture – the other applications allow the same or even higher impurity content (if the limit values of the draft of the NEW Compost Ordinance will be used as a reference, the AT_4 in drum screened compost < 12 mm would have exceeded the limit value – maturation would be necessary). The content of impurities can generally be described as very low. A clear tendency between screen cutoff and plastics content > 2 mm could not be determined (the order from lowest to highest plastics content is 6 mm = 8 mm < 12

TABLE 1: Organic matter (LOI, C_{org}), inorganic carbon, total nitrogen, C/N-ratio, respiration activity and impurities in final composts after different screening procedures.

	< 12 mm drum screen	< 10 mm flip-flop screen	< 8 mm flip-flop screen	< 6 mm flip-flop screen
Loss on ignition (LOI) [% DM]	32.5	32.6	34.1	31.5
C_{Org} [% DM]	17.4	17.4	18.3	16.1
C_{Inorg} [% DM]	1.4	1.5	1.6	1.8
N_{Dumas} [% DM]	1.19	1.45	1.46	1.38
C/N	15	12	13	12
AT_4 [mg O_2 g^{-1} DM]	15,9	4.2	4.7	4.4
Impurities > 2 mm (glass, metals plastics) [% DM]	0.03	0.07	0.16	0.02
Plastics > 2 mm (mass) [% DM]	0.007	0.036	0.003	0.003
Plastics > 2 mm (area) [cm^2 / l]	2.5	4.0	1.3	1.0

mm < 10 mm). Mass evaluation and area evaluation for plastic impurities correlate well with each other (ρ=0.929). Due to the low initial contamination and the high variability, the results on the separation efficiency cause a limited significance on the comparability of the separation efficiency between the screen sizes. Nevertheless, the results show that even in the worst case scenarios presented here separation efficiency > 70% are achieved in all investigated fractions.

3.3 Composition of plastic impurities

The plastic particles of the investigated size fractions were classified into fibers, films and fragments based on morphological features and quantified by numbers and mass for each class (Table 2). The classification shows that most of the particles found were films (58%), followed by fibers (41%) and only to a small extent of fragments (4%) in terms of numbers. As expected, fibers made a very small fraction in mass (9%) compared to the few fragments that contribute to 37% of the total mass. 10 different polymers were identified by ATR-FTIR spectroscopy, whereas by the majority of the particles consisted of PE (33%), PP (20%), PET (16%) and PS (9%) (Figure 4 a). 7% of the particles could not be identified by the ATR-FTIR databases (< 40% hit quality) but were qualitatively identified as plastics due to their mechanical properties (e.g. flexibility). These particles were films and fibers found in all three fractions. Although the quantity of such objects is small, they add uncertainty to the data, showing the limits of the detection method. In terms of mass fraction PS (51%) was dominant followed by PET (17%) and PE (15%).

3.4 Separation of fibers, films, and fragments

The separation of the single categories (fibers, films and fragments) by the different screening methods is shown in Figure 5. The analysis was made on a fraction of the materials that were received by the 10 mm laboratory sieve (for the distribution see Figure 2). The smallest number of fibers in the investigated fractions was found after screening at 12 mm (Figure 5 a). In the input and the 25 mm drum screened fraction almost similar quantities of fibers were found in all investigated fractions, which indicates that the 25 mm drum screening processes removed similar amounts of the matrix compounds and fibers. This suggests that the fibers are aggregated to particles < 25 mm. The 12 mm drum screen could separate more fibers, which were only found in the smallest size fraction. In case of the flip-flop screening a maximum quantity of fibers was observed in the fraction screened at 8 mm, which suggests that this screening represents the least efficient choice for the removal of fibers. Only screening at 6 mm resulted in similar quantities of fibers as those that were found in the input and after 25 mm drum screening, which suggests that the fibers were mainly aggregated to matrix material > 6 mm. The difference for the minimum quantity of the 12 mm drum screening was the dilution effect, as drum screening breaks up aggregates efficiently and allows therefore more matrix material to pass through the screen, compared to flip-flop screens. Therefore, increased quantities of fibers in the smallest screening sizes are caused by the small size of the particles that accumulate as larger matrix materials are removed. Screening increased also the relative quantity of film materials in the separated fraction (Figure 5 b), except for the 25 mm drum screen, that

TABLE 2: Numbers and mass of classes (fibers, films and fragments) of microplastics in different size fractions of the final composts after screening.

	number of plastic particles [number kg^{-1} DM]			mass of plastic particles [mg kg^{-1} DM]		
fraction [mm]	fibers	films	fragments	fibers	films	fragments
0.63 - 2	19	20	0	7	11	0
2 - 6.3	26	34	2	34	171	20
> 6.3	12	24	3	15	175	220
sum	57	78	5	56	357	240

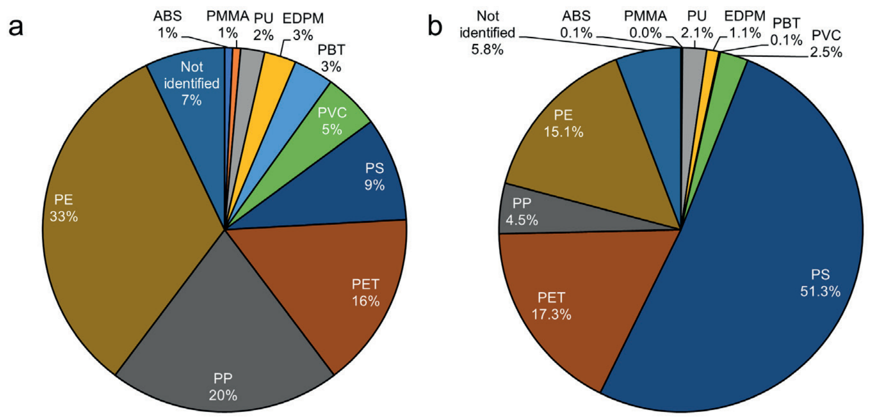

FIGURE 4: Polymeric composition of plastics found in the final composts. a) fractions by numbers and b) fractions by mass.

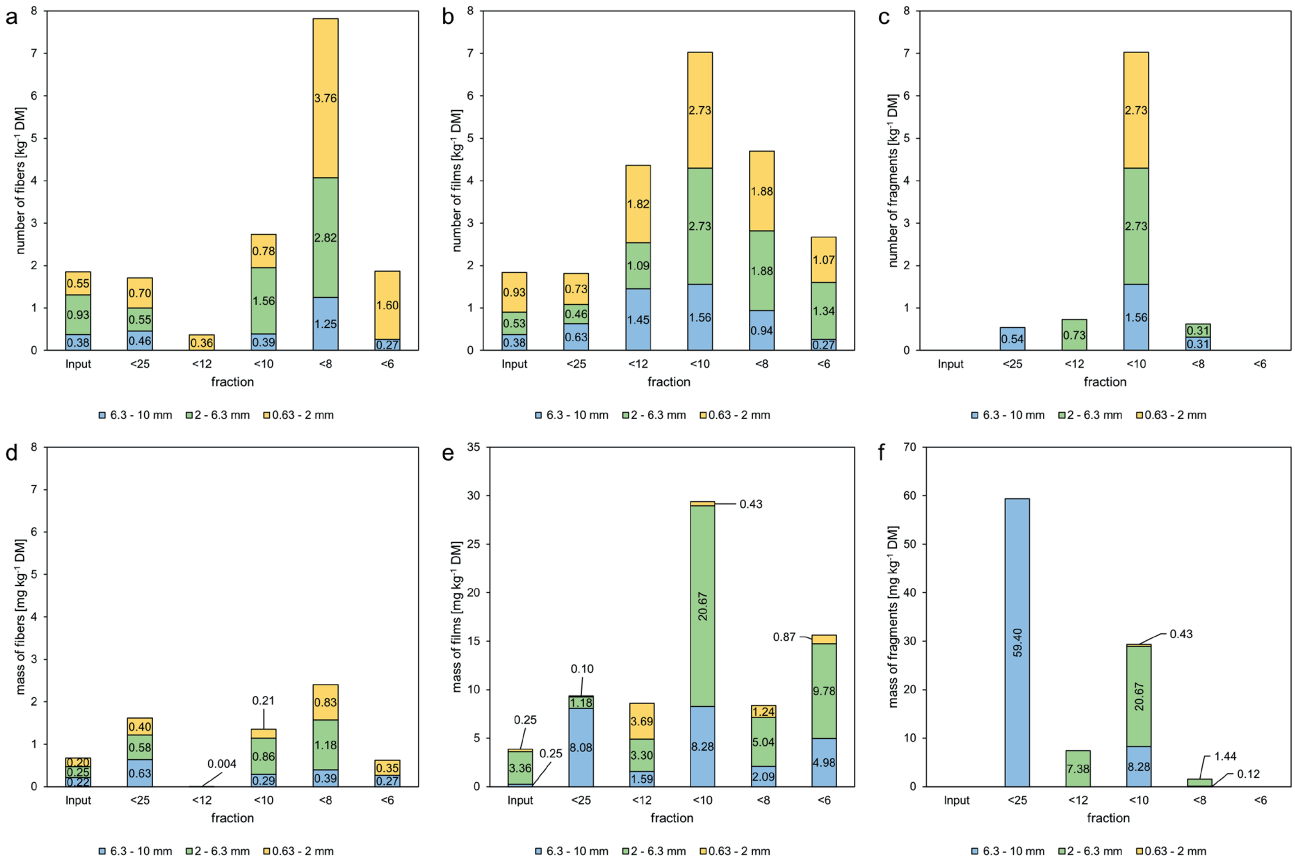

FIGURE 5: Fragments in the input, the on-site drum screening at 25 and the following screening steps 12 mm drum screening, as well as 10, 8 and, 6 mm flip-flop screening. Number of a) fibers, b) films, and c), mass of d) fibers, c) films, and e) fragments. Fibers, films and fragments were analyzed in the fractions 6.3-10 mm (blue), 2-6.3 mm (green), and 0.63-2 mm (yellow).

was equally contaminated as the input. However, for films, 12 mm drum screening did not yield the lowest contamination. That suggests that films were not aggregated to matrix particles and separated almost exclusively according to their size. The lowest efficiency was found for the 10 mm flip-flop screen, while 12 mm drum and 8 mm flip-flop screening yielded the same quantity of films in the separated fraction. The size distribution indicates that flip-flop screening removes the largest fraction (6.3 - 10 mm) more efficiently than the smaller ones, particular in case of 6 mm screening. However, also in the case of films the dilution effect of the removal of less polluted larger matrix materials is visible. This effect was also visible for fragments (Figure 5 c), that were not found in the input samples as well as after 6 mm flip-flop screening, while after drum screening (25 and 12 mm) and 8 mm flip-flop screening almost no particles were found. The reason for not finding fragments in the input could be that this type of contaminant is rare (4% of all microplastics) and probably too diluted in the input, and that the sample size of the input was too small to quantify it. The largest number of fragments were found in the flowthrough of the 10 mm flip-flop screen. The mass of the particles was also recorded (Figure 5 d-f). For fibers, the determined mass correlated to the particle number well (Figure 5 a), as most of the fibers were found in the fraction < 8 mm and the lowest in < 12 mm after drum screening. In contrast, the mass of films and fragments did not show a correlation with their number, whereas the largest mass of films was found in the fraction < 10 mm after flip-flop screening. In case of fragments the largest contamination by mass was found after drum screening at 25 mm. Such a variation, particularly in case of fragments, was already observed earlier (Zafiu et al., 2020). In general, the cumulative (sum of all fractions and all types) plastic impurities were very low with 4 - 17 particles per kg DM over all fractions, in comparison with data published by Zafiu et al. (2023) of 9 composts, who shows approximately 60 particles per kg DM in a comparable size range.

The evaluation of the size of each plastic object was made after separation and placing each sample on a glass slide and recording an image. This evaluation leads to different results than that by the cut-off mesh size of screen. Particles that were analyzed after screening are often still bound to aggregates and appear large. Films and fibers may be folded and pass mesh sizes that they would exceed in one or two dimensions. For the evaluation of the absolute object sizes the area and the Feret's diameter, which corresponds to the largest (maximum) diameter of the projection of a particle on a microscopic image, were determined (Figure 6). The histogram in Figure 6 a shows that particles as large as 4 cm were still found after sieving. Most of the objects in all screened fractions had the largest diameter around 0.5 - 0.75 cm, which was around the cut-off size of the smallest mesh size of the screens that were used (6 mm) and around the limit for being considered as microplastics. This means that most of the objects must have strongly differing aspect ratios, such as fibers, that allow them to pass through a mesh in one dimension. The distributions over all screening techniques show no large differences, which suggest that the removal efficiency of plastic objects was independent from the screening technique or the mesh size. The reason for this is that plastics in this size range are mainly bound to larger aggregates that are retained by the screens. Interestingly, the histograms made from the area of the object show that flip-flop screening was mostly contaminated with particles with an area of ca. 0.05 cm², while in the input and drum screened samples particles of areas of 0.5 cm² and 0.05 cm² were found in almost equal quantities (Figure 6 b). The results suggest that flip-flop screening is more selective for retaining larger

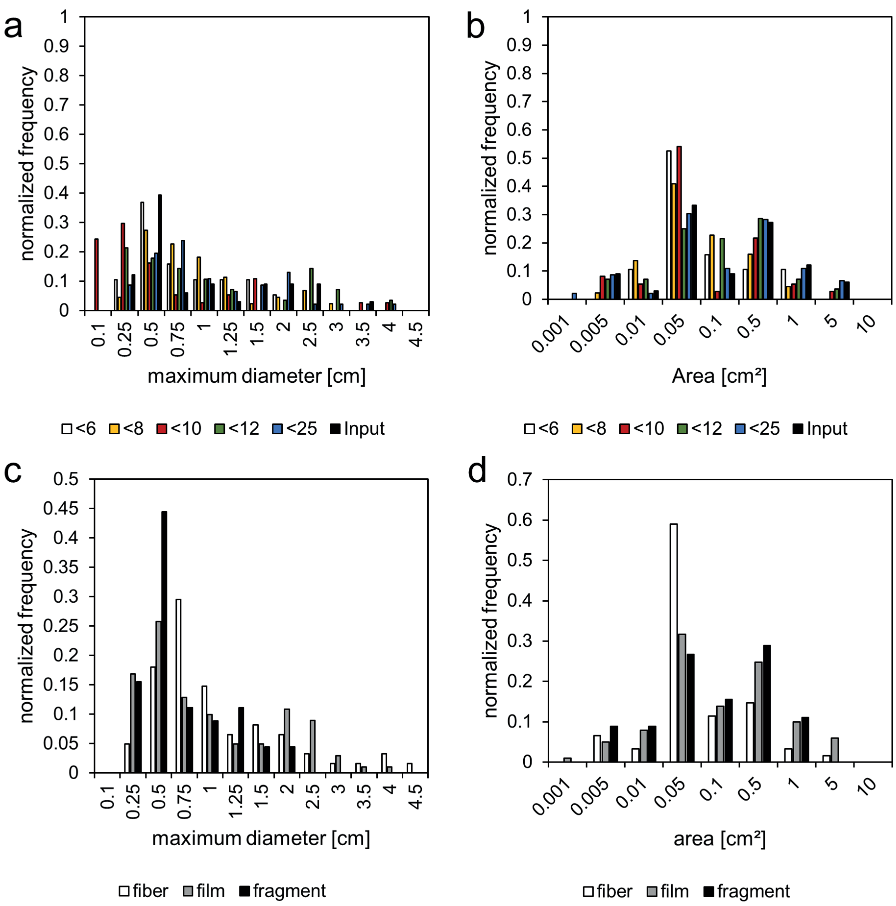

FIGURE 6: Normalized frequency histograms of plastic objects found in rotting material before and after screening. a) maximum diameter (Feret's diameter) and b) area of plastic objects found in different fractions. c) maximum diameter (Feret's diameter) and d) area of the objects depending on the category (fiber, film or fragment).

particles that have a larger area. This would suggest that films are more effectively removed by these techniques as the vibration during flip-flop screening would allow a film to spread and increase its surface, while in case of fibers it could assist in moving it through a mesh. The evaluation of maximum diameter and type of object shows that fibers and films exhibited a flat distribution that peaked at 0.75 cm, while fragments were only found between 0.25 - 2 cm, with a peak at 0.5 cm (Figure 6 c). The distribution of the area of different types of objects exhibited a strong peak at 0.05 cm² for fibers, while most films and fragments had areas between 0.05 - 0.5 cm² (Figure 6 d).

4. CONCLUSIONS

Screening rotting material after processing is necessary to remove undegraded structural material. Removing impurities during this process depends strongly on the screen type, the screen mesh and the method for removing macroscopic objects. Small plastics are usually bound to larger aggregates of matrix materials and can also be partially removed by screening, but with the effect that larger amounts of organic materials must be rejected, thus increasing the quantity of material that must be disposed of. It can be expected that factors influencing the formation of aggregates between impurities and matrix materials play the key role for the separation efficiency. The water content could be the main influencing factor to foster the aggregation and influence the separation efficiency. Composting operations in closed vessels may have a different impact on aggregate formation compared to the case of open windrow composting, which is shown in this study. However, the conclusions of this work are limited to the humidity of the compost sample when the separations were made in the plant. Changes in the degree of separation may be possible at higher or lower water content, which was not studied here and would need further investigation. In addition, input materials and the quantity of bulking agents can play a role in the formation of aggregates or attachment and removal of flexible impurities (such as film material or fibers), as well as on the quantity of impurities. Moreover, composting duration and operations can influence the formation of fragments and their aggregation with matrix materials.

Therefore, the study is limited with respect to compost's humidity, operation time and composition, but general findings that aggregates are formed, and drive separation can be deduced from it. Further studies, analysing impurity removal depending on the humidity and eventually on operational time (duration and number of turns and in vessel compared to open windrow) of the compost before screening could add valuable information in choosing the ideal conditions for screening of composts to obtain the lowest microplastic impurities in composts at the end of the process. Due to the variability of the impurities, caused also by their low number, recommendation on the best performing screening technology based on separation efficiency cannot be given by this study, but may be investigated in future by applying defined spiking experiments.

Although the different screening techniques remove different types of plastics, the benefit remains small and depending on the object type (fiber, film, or fragment) even objects as large as 10 mm in at least one dimension are not retained even by the smallest state-of-the-art screening technologies. The facts that smaller plastic objects are formed during composting process, that cannot be removed at the final screening step, and that no methods exist today to remove plastics from soils, where the composts are used, lead to the conclusion that more plastics need to be avoided or removed before entering the composting process. Optimization of screening may be used as a contribution to further reduce impurities. Finally, novel methods that are tailored for removing particularly microplastics to a higher degree from composts still have to be developed to drastically reduce the transfer of plastics to agricultural soils.

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