The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility

Maarten van der Zee, Karin Molenveld

WAGENINGEN
UNIVERSITY & RESEARCH

The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility

Authors: Maarten van der Zee, Karin Molenveld

Institute: Wageningen Food & Biobased Research

This research project has been carried out by Wageningen Food & Biobased Research commissioned and funded by the Dutch Ministry of Economic Affairs and Climate Policy (EZK), in the context of 'Praktijkonderzoek industriële compostering' (project number BO-43-012.02-066).

Wageningen Food & Biobased Research
Wageningen, February 2020

Public

Report 2020
ISBN 978-94-6395-310-8

Version: final
Reviewer: Fresia Alvarado Chacon
Approved by: Arie van der Bent
Client: the Dutch Ministry of Economic Affairs and Climate Policy (EZK)
Sponsor: the Dutch Ministry of Economic Affairs and Climate Policy (EZK)

This report can be downloaded for free at https://doi.org/10.18174/514397 or at www.wur.eu/wfbr (under publications).

PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr. Wageningen Food & Biobased Research is part of Wageningen University & Research.

Contents

Samenvatting

Er is al enkele jaren een discussie gaande tussen de bedrijven die huishoudelijk groente-, fruit- en tuinafval (GFT) verwerken, georganiseerd in de Vereniging Afvalbedrijven (VA), en de fabrikanten van composteerbare plastics, georganiseerd in Holland Bioplastics (HB) over de toelating van composteerbare (verpakkings)materialen in GFT. Daarbij komt naar voren dat het nog steeds onduidelijk is of composteerbare producten (d.w.z. gecertificeerd volgens de Europese norm EN 13432) snel genoeg afbreken bij de huidige manier waarop GFT wordt verwerkt in Nederland. Daarover bestaat twijfel omdat de GFT-afvalverwerking tegenwoordig gericht is op een hoge doorvoer van GFT en bijbehorende korte composteertijden (korte verblijftijd).

VA en HB hebben samen een onderzoeksvraag gedefinieerd om duidelijkheid te verkrijgen over deze kwestie en meegeholpen met de onderzoeksopzet. Wageningen Food & Biobased Research heeft het onderzoek in opdracht van het ministerie van Economische Zaken en Klimaat (EZK) onafhankelijk uitgevoerd in de periode februari-oktober 2019.

De kern van het onderzoek is een praktijkproef op industriële schaal, waarbij is onderzocht wat er gebeurt met composteerbare verpakkingsproducten tijdens de GFT-afvalverwerking. De focus ligt op producten die voldoen aan de eisen voor composteerbare verpakkingen (volgens de norm EN 13432) en die bovendien een meerwaarde (‘co-benefit’) zouden kunnen bieden voor de GFT-afvalinzameling en verwerking. In het onderzoek werden negen verschillende composteerbare plastic producten van verschillende fabrikanten meegenomen, bestaande uit GFT-inzamelzakken, plantenpotten, theezakjes, koffiepads, koffiecapsules en fruitetiketten. Naast de praktijkproef is in detail gekeken naar de mate waarin GFT en compost tegenwoordig zijn verontreinigd met conventioneel niet-biologisch afbreekbaar plastic.

De praktijkproef is in overleg met HB en VA uitgevoerd bij Valor (Sint Oedenrode), een van de 21 bedrijven in Nederland die GFT-afval verwerken. De proef bestond uit twee afzonderlijke onderdelen:

(A) Het volgen van de gekozen composteerbare producten tijdens de verwerking van GFT en daarbij onderzoeken in welke (rest)fracties deze producten waarschijnlijk terechtkomen.
(B) Het onderzoeken van het uiteenvallen (desintegratie) van de gekozen composteerbare producten onder de normale verwerkingsomstandigheden en -duur (in relatie tot de resultaten uit de vereiste laboratoriumtests voor certificering volgens EN 13432)

Ongeveer 20 procent van het verwerkte GFT-afval dat na 11 dagen uit de composteerreactor kwam, passeerde de zeven van <10 mm waarmee het kon worden aangemerkt als compost. Het overige deel kwam voornamelijk terecht in twee zeeffracties, het grootste deel (ongeveer 70 procent) in de 10-40 mm-fractie, die bij het betreffende GFT-verwerkingsbedrijf normaalgesproken opnieuw wordt ingebracht in het composteerproces. De overige 10 procent kwam terecht in de >40 mm-fractie. Dit deel wordt meestal ook opnieuw ingebracht in het composteerproces als structuurmateriaal, maar als er zich te veel verontreinigingen in ophopen, wordt het afgevoerd (in de praktijk een paar keer per maand). De fracties die altijd worden afgevoerd (metaal en harde voorwerpen) waren relatief klein en hebben nauwelijks invloed op de totale massabalans.

De belangrijkste zeeffracties (10-40 mm en >40 mm) bestonden hoofdzakelijk uit organisch materiaal (wat in overeenstemming is met de korte composteertijd, d.w.z. een cyclus van in totaal 11 dagen waarvan slechts enkele dagen boven 50°C) en bevatten weinig plastic. De grootste zeeffractie (10-40 mm) bevatte ca. 1 gewichtsprocent plastic, dat vrijwel uitsluitend uit conventioneel, fossiel plastic bestond.

Een composteercyclus van 11 dagen was voor de meeste onderzochte producten, net als voor de referentiematerialen (sinaasappel- en bananenschillen), niet voldoende om volledig uiteen te vallen. Voor de plantenpot gemaakt van PLA was één composteercyclus van 11 dagen al wel voldoende om helemaal uiteen te vallen. Dat is sneller dan het meeste organische materiaal en papier. Dit wordt meer toegeschreven aan het materiaal waarvan het product is gemaakt (PLA) dan aan de dikte ervan.

Door de felle kleuren van de koffiecapsules (product G) zijn zelfs kleine fragmenten hiervan duidelijk zichtbaar en te herkennen in de over het algemeen donkerbruine compost. Donkerkleurige fragmenten zouden veel moeilijker te onderscheiden zijn, waardoor het aannemelijk is dat ze beduidend minder zouden bijdragen aan eventuele zichtbare verontreiniging van compost.

Volgens de bevindingen in deze praktijkproef draagt waarschijnlijk geen enkele van de onderzochte composteerbare plastic producten bij aan een significante toename van het residu dat moet worden afgevoerd bij de GFT-afvalverwerking bij Valor. Ze zullen namelijk verder afgebroken worden wanneer de zeeffracties opnieuw worden ingebracht (‘gerecirculeerd’) in het composteerproces. Ook is niet te verwachten dat de onderzochte composteerbare producten bijdragen aan zichtbare verontreiniging van de uiteindelijke compost. Mogelijk vormen de felgekleurde koffiecapsules een uitzondering hierop, omdat zelfs kleine fragmenten van dit product opvallen en herkenbaar zijn in de over het algemeen donkerbruine compost.

Wanneer deze resultaten worden doorgetrokken naar de andere GFT-afvalverwerkingsbedrijven in Nederland, is aannemelijk dat bij sommige processen een deel van de onderzochte composteerbare producten terecht kunnen komen in residu-fracties die worden afgevoerd. Dit zal echter afhankelijk zijn van de bij die bedrijven gebruikte voorbehandelingsprocessen, de verblijftijd in de composteringsfase, de keerfrequentie en de afschuifkrachten waaraan het afval tijdens het proces of de nabehandeling wordt blootgesteld.

Naast de praktijkproef op industriële schaal vond er in het kader van dit onderzoek ook een gedetailleerde analyse plaats van de samenstelling van de plastic verontreinigingen die worden aangetroffen in GFT. Uit de analyse bleek dat er meer niet-afbreekbaar plastic in GFT werd gevonden dan composteerbaar plastic, bijv. afkomstig van GFT-inzamelzakken. Het gehalte aan folies en plantenpotten in de aangetroffen plastics was vrij hoog, wat erop duidt dat een deel van de verontreiniging te verklaren is doordat het verpakte product een relatie heeft met organisch afval. Daarnaast is een aanzienlijk deel van de zichtbare plastic verontreinigingen in GFT niet duidelijk verklaarbaar en zal het per ongeluk of opzettelijk bij het GFT terecht gekomen zijn.

Er is ook geanalyseerd wat de samenstelling was van het conventionele plastic waarmee compost tegenwoordig zichtbaar verontreinigd is. Daarbij werd gekeken naar het type polymeer en (indien mogelijk) het type verpakking. In de compost zijn geen composteerbare plastics aangetroffen. Er is geen duidelijk verband gevonden tussen de samenstelling van de plastic fragmenten die zijn gevonden in compost, die zijn gevonden in GFT, en de gemiddelde samenstelling van plastic verpakkingsmaterialen gebruikt door de Nederlandse huishoudens.

Summary

For several years now, there has been debate between the (organic) waste treatment companies, organised in the Vereniging Afvalbedrijven (VA) and the companies producing compostable plastics, organised in Holland Bioplastics (HB) about the acceptance of compostable (packaging) products in source separated municipal organic waste (GFT). In this debate it is brought forward that it is still unclear whether the disintegration rate of compostable products (i.e. certified according to the current standard EN 13432) would be sufficient to be compatible with the current GFT treatment practice in the Netherlands. This is questioned because the current waste treatment practice has focussed more and more on high throughput of GFT and corresponding short composting cycles (low residence times).

VA and HB joined forces in defining the research question that could provide clarity to this matter and helped with project set-up. Wageningen Food & Biobased Research, commissioned by the Dutch Ministry of Economic Affairs and Climate Policy (EZK), independently carried out the research in the period February-October 2019.

The core of this research is an industrial organic waste treatment trial in which the fate of compostable packaging products is studied in a full scale organic waste treatment facility. The focus is on products that fulfil the requirements for compostable packaging (according to standard EN13432) ánd have a potential co-benefit for the waste collection and treatment. A set of 9 different compostable plastic products from various producers was selected, consisting of GFT collection bags, plant pots, tea bags, coffee pads, coffee capsules, and fruit labels. In addition, the present contamination of GFT and compost by conventional plastics is studied in detail.

The full scale organic waste treatment trial was performed at Valor, Sint Oedenrode, which is one of the 21 facilities treating source separated municipal organic waste (GFT) in the Netherlands. The trial consisted of two separate parts:

(A) Following selected compostable products during the organic waste treatment process and identifying in which (residual) fractions the products would likely end up.

(B) Evaluating of the disintegration of selected compostable products under the regular operation conditions and timeframe (in relation to the results obtained with laboratory testing required for certification according to EN13432)

In this trial, roughly 20% of the processed GFT that was unloaded from the tunnel after a waste treatment cycle of 11 days passed the sieves <10 mm and is the compost fraction. The rest mainly ended up in two residual fractions, the largest part (roughly 70%) in the 10-40 mm fraction which during normal operation at the selected facility is recirculated in the waste treatment process. The other 10% ended up in the >40 mm fraction which usually is also recirculated, but discarded when too much pollution accumulates, in practice a few times per month. The fractions that are always discarded (i.e. metals and hard items) are relatively small and have a marginal effect in the total mass balance.

The main residue fractions (10-40 mm and >40 mm) consisted predominantly of organic matter (which is consistent with the short composting time, i.e. a total cycle of 11 days with only a few days above 50°C) and contain only low amounts of plastics. The largest residue fraction (10-40 mm) contained approx. 1% of plastics by weight.

One waste treatment cycle of 11 days was for most selected products, including the reference materials orange peel and banana skin, not sufficient to completely disintegrate. For the full PLA plant pot, one waste treatment cycle of 11 days was sufficient for complete disintegration, which is significantly faster than paper and most organic matter. This is more attributed to the type of material the product is made of (i.e. PLA) than its thickness.

Due to the bright colours used in the coffee capsules (Product G), even tiny fragments are conspicuous and recognisable in the generally dark brown compost. If the particles would be dark coloured as well, they are indistinguishable from the compost, and recovery rates (visual contamination) would be much lower.

According to the observations in this trial, none of the selected compostable plastic products are likely to contribute significantly to the residue to be discarded in the waste treatment process operated at Valor because they will further decompose when the residue fractions are recirculated and composted in the next cycle. They are also not expected to cause visual contamination of the final compost with plastic residues, except for the brightly coloured coffee capsules because even tiny fragments of this product are conspicuous and recognisable in the generally dark brown compost.

When these findings are extrapolated to the other waste treatment facilities operating in the Netherlands, it is expected that in some processes, some of the selected compostable products will end up in fractions that are discarded, but this will depend on the pre-treatment processes installed, residence time in the composting phase, the turning frequency and the shear it encounters before or during post-treatment.

In addition to the industrial organic waste treatment trial, the research also involved detailed analysis of the composition of the current contamination of GFT by conventional plastics. The analysis showed that the amount of non-degradable plastic was higher than the amount of compostable waste bags used to collect GFT. Relatively high amounts of flexible packaging (films) and flower pots indicate that a part of the contamination can be explained by the association of the packed product with organic waste. Nevertheless, a substantial part of the plastic products is either accidentally or intentionally disposed of with GFT.

The composition of the current visual contamination of conventional plastics in compost was also analysed with regard to polymer type (and packaging type where possible). No compostable plastics were identified amongst the plastics found in compost. No clear relation was observed between the plastic fragments found in compost and the composition of plastic materials found in GFT or the composition of the packaging materials used by households.

1 Introduction

1.1 Motivation

In the Netherlands about 1.5 Mton organic waste is collected through separate collection systems provided by municipalities [1]. A considerable amount of organic waste is disposed of in residual waste and as a consequence residual waste consists of about 32% organic waste [2]. Within the VANG program (Van Afval Naar Grondstof) [3] the ambition is set to increase separate collection of municipal solid waste from 50% to 75% in 2020. Waste management companies and municipalities notice that with increasing collection volumes and changing policies the contamination of organic waste with metals, glass and plastic packaging products increases [4]. The organic waste stream of separately collected municipal waste (in the Netherlands indicated by the abbreviation GFT or GFTe, which stands for 'Groente-, Fruit- en Tuinafval, en etensresten) is used to produce compost and with increasing contamination levels the quality of the compost could deteriorate.

Allowing compostable packaging products that help to collect organic waste, can help to achieve the circularity goal of 75% separate collection of municipal solid waste. Typical products would be compostable waste bags, coffee and tea pads, coffee capsules, plant pots etc. However, there is a fear that allowing compostable packaging could also further increase plastic contamination in organic waste.

For several years now, there has been debate between the (organic) waste treatment companies, organised in the Vereniging Afvalbedrijven (VA) and the companies producing compostable plastics, organised in Holland Bioplastics (HB) about the acceptance of compostable (packaging) products in GFT. In this debate it is brought forward that it is still unclear whether the disintegration rate of compostable products certified according to the current standard EN 13432 [5] would be sufficient to be processed with the current GFT treatment practice in the Netherlands. This is questioned because the current practice has focussed more and more on high throughput of GFT and corresponding short composting cycles (low residence times).

VA and HB joined forces in defining a research project that could provide clarity to this matter and found the Ministry of Economic Affairs and Climate Policy (EZK) and the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) willing to sponsor the research. Wageningen Food & Biobased Research was commissioned to coordinate the experimental work and its researchers objectively and independently carried out the research in the period February-October 2019. The results and conclusions are presented in this report.

1.2 Objectives

The objective of the study is to determine:

- What is the composition of the current conventional plastics contamination in the organic waste (GFT) and in the compost produced from it? – i.e. in more detail than the regular analysis of waste and compost by the VA.
- What is the fate of (compostable) packaging products in the organic waste treatment process, in other words, do they finally end up in the compost or in one of the residue fraction.
- How fast do they disintegrate in current common practice in full scale commercial organic waste treatment facilities?

1.3 Scope of the study

The core of this research is an industrial organic waste treatment trial in which the fate of compostable packaging products is studied in a full scale organic waste treatment facility. The focus is on products that fulfil the requirements for compostable packaging (according to standard EN13432) ánd have a potential co-benefit for the waste collection and treatment. In addition, the present contamination of GFT and compost by conventional plastics is studied in detail. This is schematically presented in Figure 1. The effect of compostable (packaging) products on a possible increase/decrease of other contaminations (in Dutch also referred to as "insleep") is explicitly out of the scope of this project.

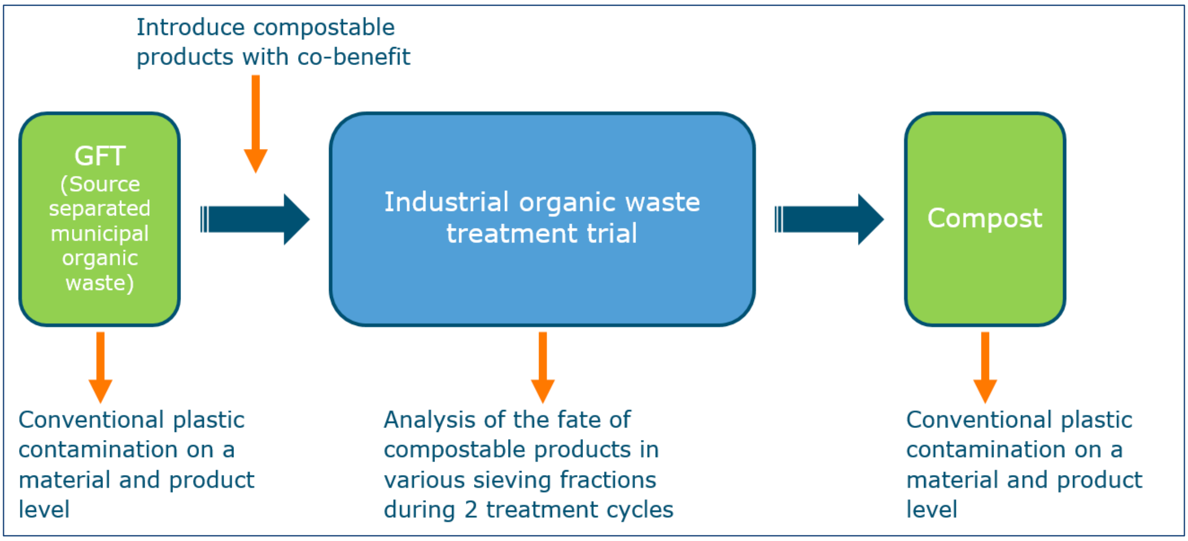


Figure 1 ***Schematic overview of the scope of the study***

1.4 Reader's guide

The report contains the following sections.

Section 2 covers the evaluation of the conventional plastic contaminants that are currently found in separately collected post-consumer solid organic waste – in this report referred to by its Dutch abbreviation 'GFT'.

Section 3 covers the results of a trial in which the fate of compostable packaging products is studied in a full scale organic waste treatment facility.

Section 4 covers the evaluation of the conventional plastic contaminants that are currently found in the compost that is produced by the 21 organic waste treatment facilities in the Netherlands.

Although each section comes to some conclusions, they are gathered in Section 5 'Overall conclusions' in which they are combined and integrated where possible.

A number of abbreviations are regularly used throughout the report. The main ones are listed in the next section for easy reference.

1.5 Abbreviations

GFT	'Groente, Fruit en Tuinafval', i.e. Dutch for vegetable, fruit and garden waste; the term established for source separated municipal solid organic waste in the Netherlands.
GFT/e	see GFT (where the /e stands for 'etensresten' to clarify that all food waste is also considered GFT).
HB	Holland Bioplastics – the Netherlands association of the Bioplastics producing industry.
NIR	Near Infrared Spectroscopy, a technique commonly used in waste management to sort plastic waste.
PA	Polyamide, engineering plastic used in various applications.
PC	Polycarbonate, engineering plastic used in various applications.
PE	Polyethylene, plastic used predominantly in flexible packaging and various bottles and rigid objects.
PET	Polyethylene terephthalate, plastic predominantly used in bottles, trays and sometimes flexible packaging.
PLA	Polylactic acid, compostable plastic used in films and trays.
PMD	'Plastic verpakkingen, Metaal verpakkingen (blik) en Drinkpakken', i.e. Dutch for plastics, metals and drinks packaging waste; the term established for source separated municipal plastic and metal packaging waste in the Netherlands.
PMMA	Polymethylene methacrylate, engineering plastic used in various applications.
PP	Polypropylene, plastic used in transparent flexible packaging, various wrappers, rigid packaging objects and caps & closures.
PS	Polystyrene, plastic used in trays and in disposables.
PUR	Polyurethane, engineering plastic used in various applications.
PVC	Polyvinyl chloride, plastic used in blisters and some flexible packages.
VA	Vereniging Afvalbedrijven – the Netherlands association of the waste processing industry.
WFBR	Wageningen Food & Biobased Research, a research institute part of Wageningen UR.

2 Conventional plastic contamination in separately collected post-consumer organic waste (GFT)

2.1 Introduction

This chapter describes the results of the analysis of plastic products that are found in organic waste collected by civilians (GFT). This is a separate part of the project that should give more insight in the causes of plastic pollution by civilians based on the type of packaging products found in GFT. The packaging products found in organic waste are compared with the plastic packaging products available on the market and found in light weight plastic packaging waste and/or residual waste [6]. This is to study what type of plastic packaging products are most frequently discarded with GFT (by accident or intentionally). The topic is relevant for the use of compostable plastics in packaging applications. With increasing (plastic) contamination, facilities are installing additional sieving processes that are likely to remove all plastics including compostable plastics.

The potential causes and effects of contaminations in GFT are addressed in a report prepared in 2018 by the Ministry of Infrastructure and Water management to support the VANG (from waste to raw materials) program [7]. This report presents the concerns and indications that pollution levels of GFT are increasing. Also, the report concludes that there is hardly any information on the contamination levels of GFT collected by civilians. To generate more systematic data on contaminations the Dutch Waste Management Association has started a systematic study in which contaminations in all 21 GFT treatment installation is measured regularly (4 times annually). Contaminations include stones, paper and board, textiles, glass and plastics. First findings of this study are [8]:

- GFT contains in total about 4.4% contaminants. Previous measurements in 2000 and 2008 showed contamination levels of 0.95 and 2.3% respectively.
- Plastic and glass contaminations have doubled as compared to measurements performed around 1998-2000.
- Due to increasing contamination, the percentage of residue that needs to be incinerated has increased.

Plastic contaminations may be not the largest contamination by weight, but are very visible due to their colours, size, and their large volume (low specific weight). The systematic study of the Dutch Waste Management Association was used as a source to provide a representative sample of plastics recovered from GFT.

2.2 Methods

2.2.1 Sampling of plastics from GFT

The Dutch Waste Management Association (VA) has commissioned Elsinga to measure contaminants in organic waste in all (21) Dutch organic waste treatment facilities 4 times per year. The plastics recovered from GFT in February 2019 (February 15th to March 7th, 16 installations) were sent to Wageningen Food & Biobased Research (WFBR) for detailed analysis. Upon arrival the plastics products were stored at 7°C in a cold storage room until they were analysed. All plastics collected in this period were processed as 1 batch of plastic packaging waste.

2.2.2 Plastic sorting

Whereas Elsinga only differentiates between a plastic film fraction and rigid plastic objects, at WFBR plastics are analysed on polymer type (NIR) and packaging type (using a list of about 50 different packaging types). The sorting protocol is described in detail in a public report available via the Wageningen UR website [9].

The protocol consists of the following steps;

1. Manual sorting on material type
2. NIR assisted sorting into main polymer type
3. Manual sorting into plastic packaging type

The objective of this study (step 3: manual sorting into plastic packaging type) is not possible without steps 1 and 2. After manual sorting pictures are taken to illustrate the findings.

2.2.2.1 Manual sorting on material type

The aim is to separate plastic packaging waste from other waste materials (organic, metals, paper & board, glass). In this study this first sorting step was mainly performed by Elsinga, but the sorted plastics still contained some other materials which were removed.

2.2.2.2 NIR assisted sorting into main polymer type

NIR assisted sorting is used to mimic industrial NIR sorting processes. The main polymer of the plastic object is determined (for instance the bottle material and not the label material). The NIR scanner identifies PE, PP, PET, PS, PVC, PLA, PC, PMMA, PA, PUR but also cellulose and several laminated films. Black and dark-coloured plastics, or plastics that are extremely dirty cannot be identified with NIR scanners and these are added to the category for ”non-NIR-detectable and residual plastics”. In this study additionally compostable waste bags were sorted using NIR combined with visual sorting using the seedling logo on the waste bags. After sorting the weight of all sorted fractions was determined.

2.2.2.3 Manual sorting into plastic packaging types

The NIR sorted plastics are manually sorted into the different packaging types. The following main categories are used: beverage bottles, non-beverage bottles, other rigid packages, flexibles, push-through strips, non-packaging plastics and a few specialties that differ per polymer type. The complete list is shown in Annex 1. Since the amount of bioplastic products (like for example PLA film) on the (Dutch) market is very low, there is no separate sorting category for these products. Commonly they are added to the category "other plastic". Nevertheless, for this study these bioplastics were identified and stored separately. During sorting specific attention was paid to the relation of the packaging product to organic waste. As a consequence some additional sorting categories were defined:

- An additional category was added for plant pots.
- An additional category was added for packaging products that still contained their original content.
- An additional category was used for compostable waste bags intended for collection of GFT and waste bin liners for organic waste.

As the plastic waste was very dirty and not all packaging objects could be sorted in detail further adaptations were made to the list:

- All PET bottles were combined into 1 category.
- 2 sizes PE carrier bags were combined into 1 category.
- Similarly for PE film, PET film and PP film, for each material 1 film category was used independent on size.
- Blisters and laminates were separated into 2 categories.

2.2.3 Analysis

The sorting results of the plastics retrieved from GFT were compared against plastics that are found in light weight packaging waste and plastic packaging mechanically recovered from mixed municipal waste as published by Brouwer et al. [6]. Analysis was performed on a material level (polymer type), on the relative amount of film as compared to rigid objects and on an object level. The (combined) categories were used as described in paragraph 2.2.2.3.

2.3 Results

2.3.1 Analysis on a material level

According to the sorting analysis of Elsinga 63.2 kg plastic waste (35.2 kg film and 28 kg rigid objects) was recovered from GFT during February and early March when sampling 16 different organic waste treatment installations. They found an average amount of plastic pollution of about 0.8% [10].

The sorting analysis of WFBR is based on 61 kg plastics delivered by Elsinga at the WFBR laboratory. The weight difference of about 2 kg can be due to weight loss due to drying, loss of organic material and sand that was originally attached to the plastic or maybe one of the samples got lost.

The rough composition of these plastic contaminants as determined by NIR and manual sorting is listed in Table 1.

Table 1 Composition of the 61 kg plastic contaminants found in GFT by Elsinga.

Material & Polymer type	Amount in kg
PP	9.3
PE	11.9
PET	3.8
PS	0.8
PVC	0.3
Black plastics	8.8
Other plastics (other & unidentified)	9.2
Laminates	0.2
Compostable waste bags	11.7
Other materials (paper, metal)	3.5
Agglomerates	0.2
Organic matter	1.3
Total	**61**

This first sorting step showed that of the 61 kg plastic contaminants found in GFT:

- 44 kg was identified as non-compostable plastics PP, PE, PET, PS, PVC, laminates, black plastics other plastics and unidentified plastics.
- almost 12 kg was identified as compostable waste bags that can be used to collect GFT
- 139 g PLA based packaging was found and added to the category other plastics (see picture in Annex 7.

The remaining 5 kg material (paper, metal, glass, textile and organic matter) was excluded from the study since it could not be identified as plastic material.

From Table 1 it can be concluded that the actual plastic pollution levels could be lower than reported because the plastic waste contains materials that belong in other pollution categories (paper, metals, organic matter, etc.) and since the recovered plastics are wet and covered with organic waste and dirt.

From Table 1 it can also be seen that a considerable amount of plastics found in GFT could not be identified into a specific polymer type, because they were black (garbage bags, plant pots) and often because they were too dirty.
Figure 2 presents an overview of these results. Figure 3 shows some pictures of examples of the compostable waste collection bags, and the plastics that could not be identified using NIR. More pictures of plastic products that were found in GFT are presented per category in Annex 3 to Annex 8.

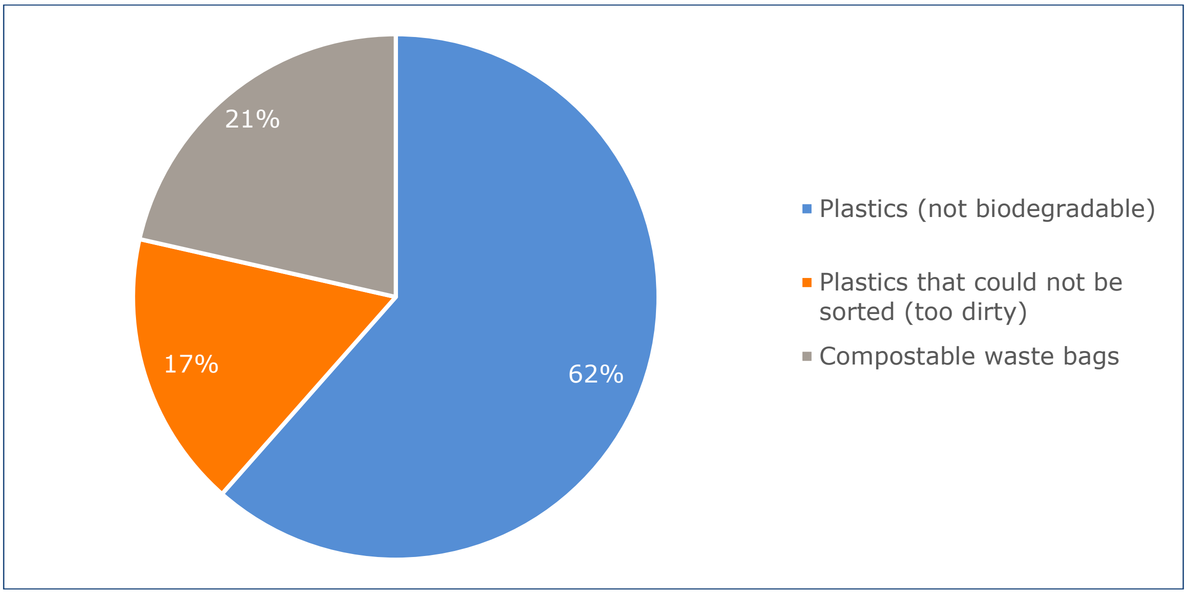


Figure 2 ***Rough composition of plastics found in GFT***

Figure 3 ***Examples of plastics found in GFT***
Left: Plastics that could not be sorted using NIR; Right: Compostable waste bags

Figure 2 shows that the amount of non-biodegradable plastics that were (accidentally or intentionally) disposed of in the organic waste bin is larger than the amount of compostable waste bags that are (intentionally) used to collect GFT. This would still be the case if all plastics that could not be identified turn out to be compostable products.

2.3.2 Analysis on packaging type

Using the complete list of packaging products as shown in Annex 1 all (packaging) products that could be identified were sorted into specific packaging types. Adaptations to the list are described in paragraph 2.2.2.3 and the overall results are listed in detail in Annex 2 (packaging types that were not found were removed from the list).

Figure 4 presents a schematic overview over the packaging products recovered from GFT.
The detailed analysis on packaging type presented in Figure 4 can be compared with the packaging products present at households shown in Figure 5).
The comparison shows:

- Relatively low amounts of bottles and flasks in GFT (5% as compared to 14%)
- Similar amounts of rigid packaging (~ 35%)
- Higher amount of flexible packaging in GFT (49% as compared to 32%)
- Slightly lower amount of non-packaging products (9% as compared to 12%)
- Within the flexible packaging fraction (film), the amount of PP found in GFT is relatively high (10% as compared to 5%).
- Relatively large amount of packaging is black and cannot be identified by NIR (25% as compared to 14%).

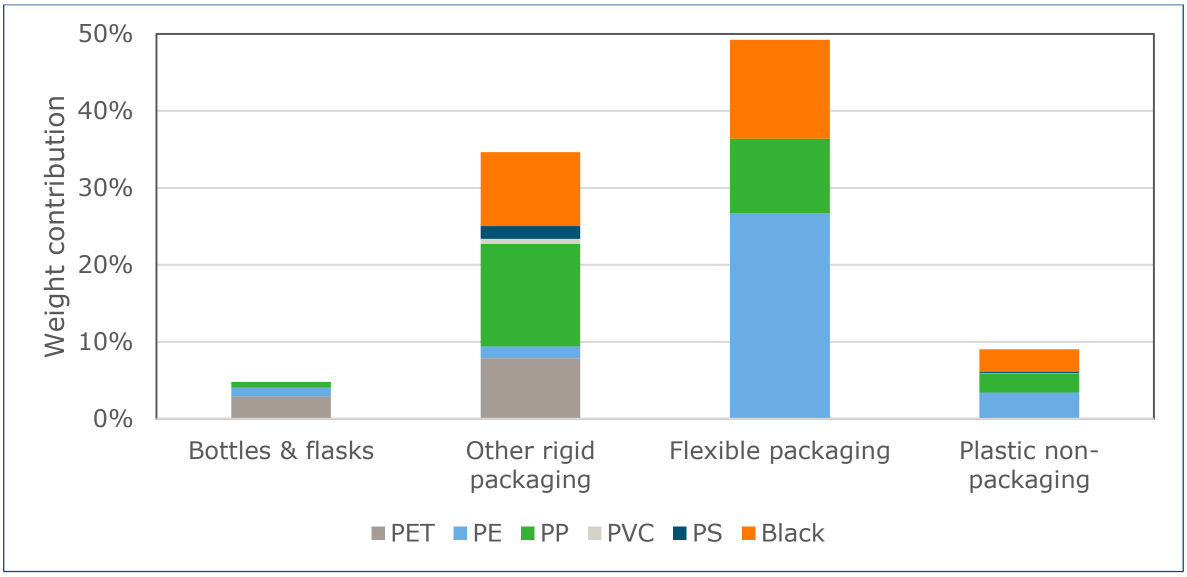


Figure 4 ***Detailed analysis of packaging products found in GFT[1] (black rigid packaging includes black bottles & flasks)***

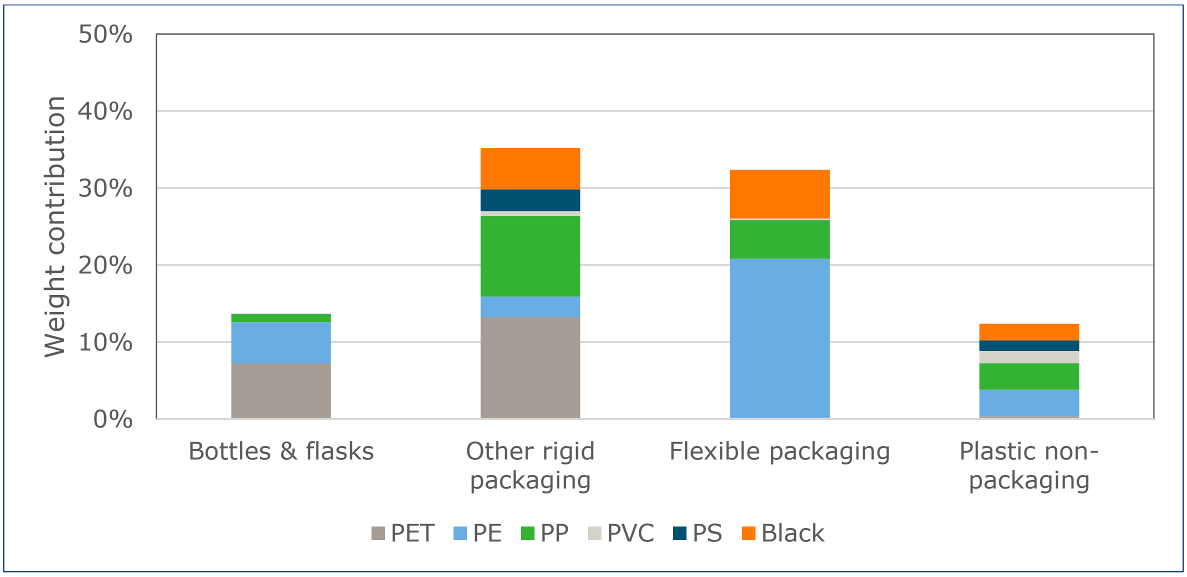


Figure 5 ***Detailed analysis of packaging products present at households (black rigid packaging includes black bottles & flasks)[2]. Including data from [1]***

In the following paragraphs results are discussed based on packaging type.

[1] Not shown in Figure 4 are 2% blisters and 0.4% other plastics.
[2] Not shown in Figure 5 are 4% blisters and 2% other plastics.

2.3.2.1 Bottles and flasks

A relative small amount of bottles and flasks was recovered from GFT. Details on these bottles and flasks are listed in Table 2 and pictures can be found in Annex 3. Additionally, the category “rigid packaging, not NIR identified” contains a black shampoo bottle (see Annex 4).

Table 2 Bottles and flasks found in GFT.

Type	Typical examples in the Netherlands	Gross weight (g)
PE beverage bottles	Milk and milk products, probiotic beverages	106
PE non-beverage bottles	Detergents, shampoo, toilet cleaner, cooking oil, mayonnaise	261
PP non-beverage bottles	Detergents, shower gels, shampoo, cooking oil, ketchup	260
PET bottles (all)	Soda & water bottles of various sizes and colours	581
PET non-beverage bottles	Shampoo, shower gels, hand soap, vinegar, oil, dressing	400
Total bottles and flasks		**1,608**

The presence of the bottles and flask in organic waste cannot be explained by their origin, content or use. A broad variety of bottles and flask was found based on material type and on packed product. Their occurrence is most likely due to ignorance, accidental or intentional incorrect disposal with GFT.

2.3.2.2 Rigid packaging

A considerable amount of rigid packaging was recovered from GFT. Details are listed in Table 3 and pictures can be found in Annex 4.

Table 3 Rigid packaging found in GFT.

Type	Examples in the Netherlands	Gross weight (g)
PE thermoforms & rigids	Chewing gum pots, toothpaste tubes, hair gel ports, caps and closures	508
PP thermoforms & rigids	Cookies trays, butter tubs, ice-cream trays, salad and fruit trays, yoghurt cups, mayonnaise buckets, hair gel pots, caps and closures	2,967
PET thermoforms & rigids	Trays for meat, fish, sliced cheese, cured meats, nuts, tomatoes, soft fruits, luxury salads	2638
PS thermoforms & rigids	Cookies trays, yoghurt beakers, sour cream beakers, champignon trays, egg trays, spray closures, pastry trays, coffee cup and ice cream closures, plant labels	562
PVC thermoforms & rigids	Toys packaging, medical packaging, general thermoformed packaging	214
PP flower pots	Flower pots	1,139
Other flower pots (not NIR)	Various flower pots	1,986
Rigid packages not NIR	Various black trays, pots, bottles and flasks	1,230
PP rigids with content	Packaging that still contained the original content	348
Total rigid packaging		**11,592**

Many objects found in this category are related to organic waste and food products. Over 3 kg flower pots were found that could be disposed of with garden waste or were still holding soil and plants. This is 9.3% of the plastic objects sorted into the different packaging categories. Likewise, various PS plant labels were found. A further observation is the presence of many small packaging parts like caps and closures based on PE or PP. Some, non-food packaging products could be identified mainly in the category PP thermoforms and rigids. The origin of many PET, PS and not NIR identified objects could not be assessed as they were too dirty or damaged.

2.3.2.3 Flexible packaging

Almost 50% of the plastics recovered from GFT is flexible packaging. This is higher than what would be expected based on packaging disposed of by consumers (about 32% flexible packaging). Details are listed in Table 4 and pictures can be found in Annex 5.

Table 4 Flexible packaging found in GFT

Type	Examples in the Netherlands	Gross weight (g)
Carrier bags PE (all)	Carrying bags, groceries bags, shopping bags	1,522
PE flexible packages (all)	Nets, small bags for nails, screws and fine iron ware, bread-bags, vegetables (potato, apple, carrot...) packaging, shrink film, bubble wrap foil, toilet paper wrap.	6,444
PE non-packaging bags	All the bags that are bought empty and don't fit in other categories (zip bags, freezer bags, ..)	734
PE waste collection bags	Trash bags without handle	275
PE film non-packages	Petrol station gloves, party flags, agricultural foil, camping foil	134
PE film with content	Packaging that still contained the original content	936
PP flexible packages (all)	Candy, sweets and pasta packaging, sliced fruits and vegetables, fresh flower sleeves	3,238
PET flexible packages (all)	Top seal film separated from trays for fruits and salads	24
Laminated flexible packages	Stand-up pouches, PET-PE, feed pouches, detergent pouch, etc	572
Flexible packages not NIR	Various black and dark coloured films, mainly trash bags	4,296
Total flexible packaging		**18,175**

The total amount of flexible packaging found in GFT is higher than the amount of compostable waste bags found (11.7 kg). The flexible packages are different types of bags (carrier bags, waste collection bags, zip bags, freezer bags) and actual packaging film. Figure 6 presents a schematic representation of the composition of the flexible packaging film fraction. From this figure it is clear that the contribution of PE and PP based flexible packaging is more than 50%. Assuming that the not NIR identifiable packaging are trash bags, the different type of bags add up to almost 40% of the flexible packaging category.

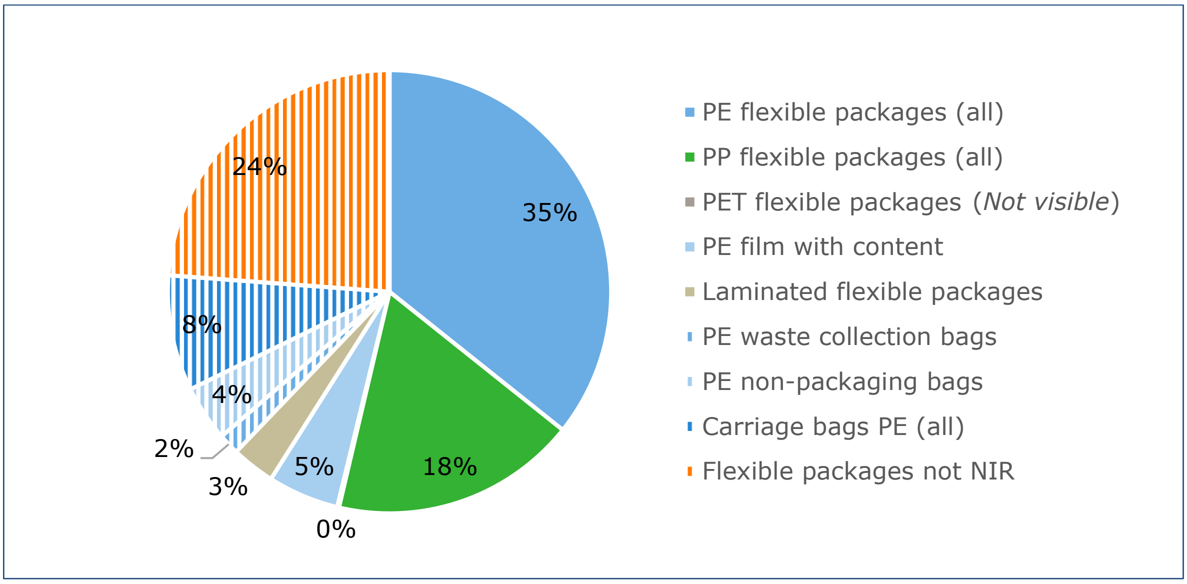


Figure 6 Schematic representation of the flexible packaging composition

The PE flexible packages are used to pack both food and non-food products. Still, visual observations indicate that most packages were used to pack food products (see Annex 5). PP flexible packages are typically used for food products like cut vegetables, but also for cookies and candy bars. The various types of bags (bags, trash bags) were empty and it is not possible to clarify how they ended up in organic waste.

2.3.2.4 Non-packaging plastics

The amount of non-packaging plastic found in GFT is slightly lower than commonly found in post-consumer packaging waste. Details are listed in Table 5 and pictures can be found in Annex 6.

Table 5 Non-packaging plastics found in GFT

Type	Examples in the Netherlands	Gross weight (g)
PE film non-packaging	Petrol station gloves, party flags, agricultural foil, camping foil	134
PP non-packaging	Fly swatter, toys, pipes, cutlery straws	840
PS non-packaging	Toys, coat hangers, frames, bicycle accessories, cassette, fridge shelf/drawer, pens, cutlery, plates, cups.	65
PVC non-packaging	Gloves, balloons, toys, inflatable swimming pool parts and accessories, piping and construction parts	6
Not-NIR identified non-packaging	Sunglasses, coat hangers, black cutlery, machine appliance parts, mulch film	973

Some articles found could be associated with food or garden waste like PS cups and cutlery and dark black film (looks like pond liner). Most other articles are damaged and their origin remains unclear. It could be that they were used or lost outdoor and collected with garden and landscaping waste, but this is a speculation. Clearly public transport cards should not end up in organic waste.

2.3.2.5 Biodegradable products

The biodegradable products found in GFT consist of 139 gram of PLA based packaging and 11.7 kg biodegradable bags for the collection of organic waste (see pictures in Annex 7). The small amount of PLA can be explained by the fact that PLA has a very low market share and that commonly consumers are instructed to dispose of compostable packaging with residual or PMD waste.

2.3.2.6 Other plastic packaging

Annex 8 shows pictures of 40 gram PVC blisters and 205 gram laminate packaging recovered from organic waste. These products do not have any relation with organic waste or food waste and there is no explanation for their presence other than ignorance, accidental or intentional incorrect disposal with GFT.

2.3.3 General results

A relatively high amount of flexible plastic packaging (film) as compared to rigid plastic packaging products was found in GFT (see Figure 4). This more than expected significant difference may have several possible causes:

- Fresh food is predominantly packed in flexible plastic packaging (film) products. It is possible that residues of fresh food are disposed of by civilians in the GFT-bin together with their packaging for various reasons (e.g. convenience, because they are unopened and contain a lot of organic waste, because they are associated with organic products and their waste).
- The surface area of plastic films is larger and therefore it is easier to detect and remove them from GFT than rigid packaging.

As a result of this relatively high amount of plastic film, the composition in plastic types is also significantly different from the plastics recovered from PMD and residual waste. This is illustrated in Figure 7 and Figure 8.

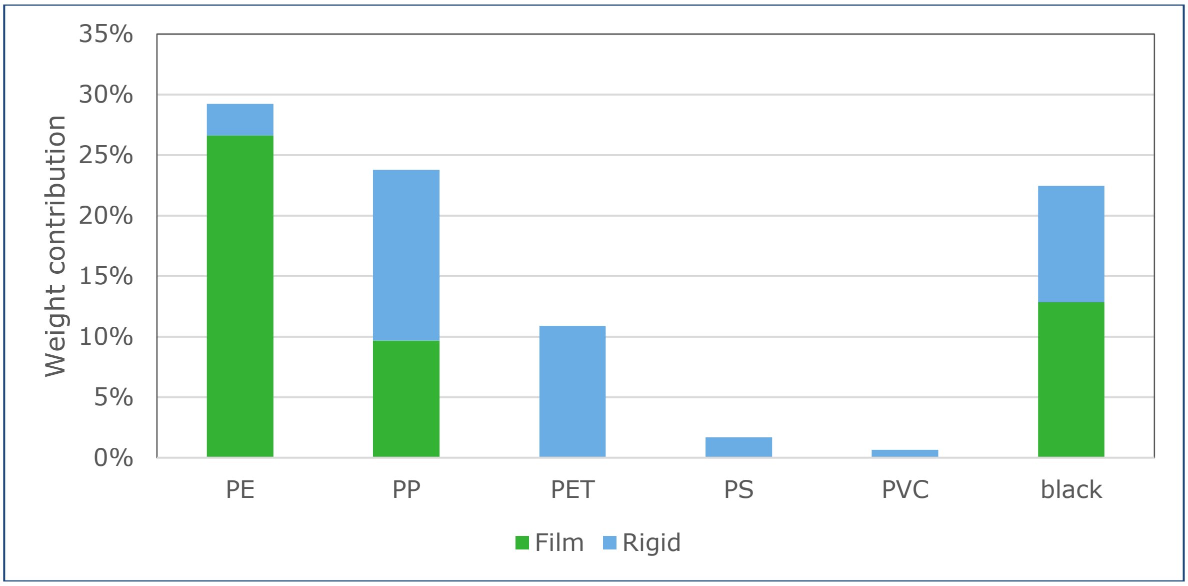


Figure 7 ***Analysis of packaging products recovered from GFT on plastic type***

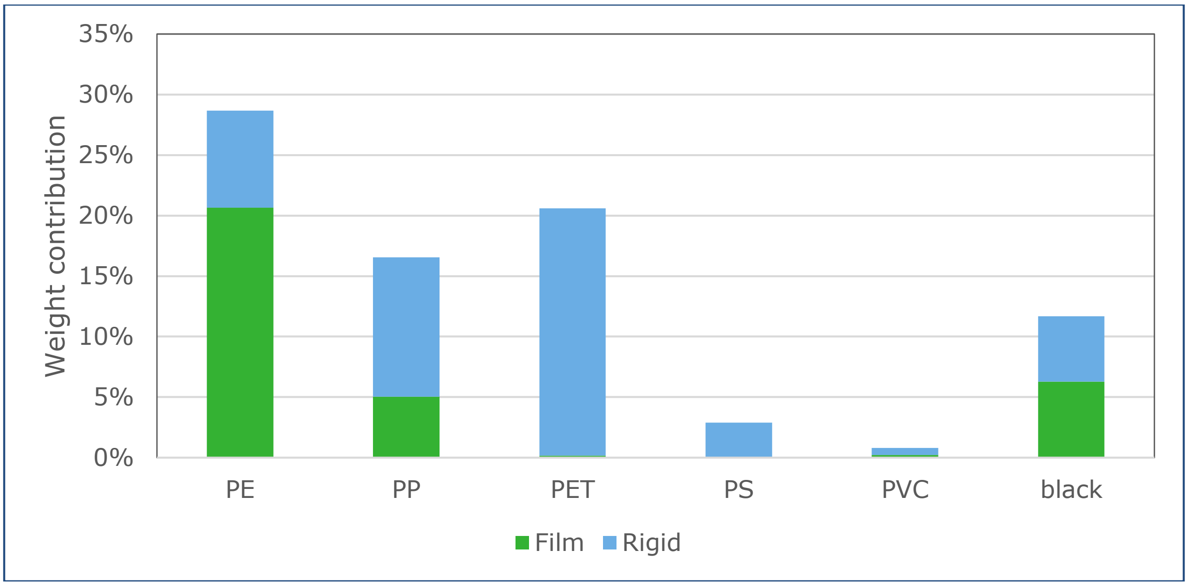


Figure 8 ***Analysis of packaging products present at households on plastic type***

The relatively low amount of PET, PVC and PS found in GFT may be explained by the fact that these materials are less frequently used in fresh food packaging. PP is predominantly used in food packaging and this could explain the relatively high amount of PP based packaging in GFT. Typical PP based packaging recovered from GFT is shown in Figure 9.

There is an indication that the plastic contamination in GFT is at least partly related to the origin of the product and the relationship with organic waste. It also needs to be addressed that a significant part of the plastic products found in GFT have no connection at all with organic waste. This is also obvious from the pictures shown in Annex 3 to Annex 8. These articles are either accidentally or intentionally disposed of with GFT. The substantial amounts of non-degradable plastics found in GFT clearly affects the discussion on acceptance of compostable products in GFT. The reason why these non-degradable plastics are accidentally or intentionally disposed of in the GFT was not investigated and out of the scope of this research. But looking at the plastic products found in GFT, for a substantial fraction there appears to be no obvious link with compostable products (bottles and flasks, PVC blisters, non-packaging plastics.....). It can be envisaged that the current policies of municipalities to encourage households to separate their waste more in specific by discouraging the collection of residual waste may also have effect on the pollution of the other specific waste streams, such as GFT and PMD. This will need further dedicated research to draw conclusions and was not investigated here.

Figure 9 ***Typical examples of PP based products recovered from GFT***
(top; PP film, bottom left; PP rigids, bottom right; PP plant pots and gardening objects)

2.4 Conclusions

The composition of the current contamination of conventional plastics in GFT was analysed with regard to polymer type and packaging type. The analysis showed that the amount of non-degradable plastic was higher than the amount of compostable waste bags used to collect GFT. Relatively high amounts of flexible packaging (films) and flower pots indicate that a part of the contamination can be explained by the association of the packed product with organic waste. Nevertheless, a substantial part of the plastic products found in GFT is either accidentally or intentionally disposed of with the organic waste.

3 Trial with compostable products in a full scale commercial municipal organic waste (GFT) treatment facility

3.1 Objectives

The objective of this part of the study is to determine the fate of (compostable) packaging products in the process currently in practice for the treatment of source separated municipal solid organic waste (i.e. GFT) in the Netherlands. In other words, in which compost or residue fraction do these compostable products finally end up.

3.2 Approach

3.2.1 Organic waste treatment facility

The aim is to execute the organic waste treatment trial in a facility that is representative for the current situation in the Netherlands. Selection of a representative facility, however, is not easy because there are many different processes for the treatment of GFT in place.

The general organic waste treatment process is shown in a simplified scheme in Figure 10

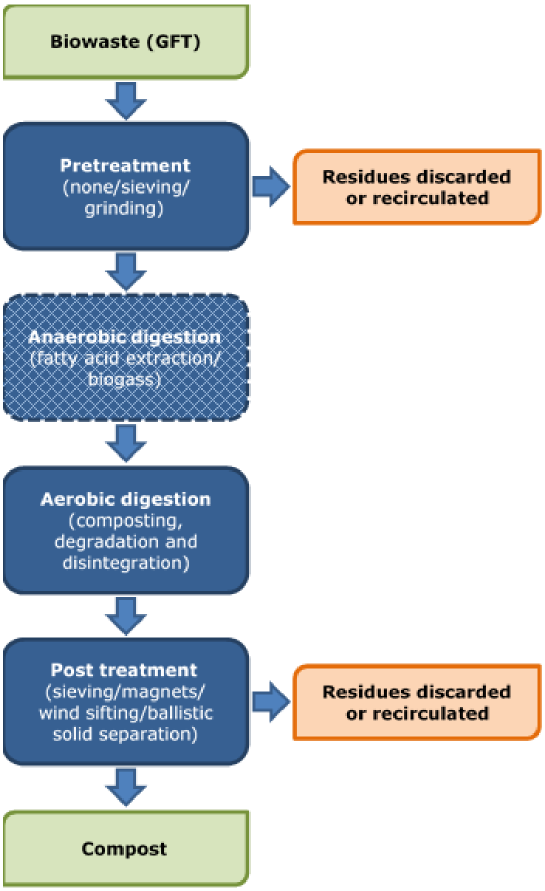


Figure 10 ***Simplified scheme of a municipal organic waste treatment process. Anaerobic digestion is performed only in part of the facilities (approx. 30% of the GFT going to the facilities)***

Approximately 1.5 Mton of source separated municipal organic waste (i.e. household kitchen/vegetable/fruit and garden waste, in the Netherlands so called 'GFT') is collected and processed annually in the Netherlands in 21 installations resulting in 675 kton of compost [1]. 11 of these GFT treatment facilities (in total processing approx. 500 kton of the 1.5 Mton waste) have an anaerobic digestion process as pre-treatment before the aerobic composting process. In the Netherlands, there are roughly 4 different types of composting; tunnels, halls, open air, and pacom (table composting under roof). Each facility has its own unique processing scheme. An overview of the 21 organic waste treatment facilities in the Netherlands and their specific operational differences is shown in Table 6 [10].

- The average residence time is 18 days (and varies between facilities from 5 to 70 days).
- The average turning frequency is 1.9 times (and varies between facilities from 0 to 8 times).
- The average hygienation phase lasts 3.5 days (and varies between facilities from 0.5 to 7 days).
- The average hygienation temperature is 58°C (and varies between facilities from 52 to 60°C).
- 14 out of 21 facilities have a shredder as pre-treatment of the incoming waste.
- 12 out of 21 facilities have a sieving step upfront and remove part of the waste before the actual composting phase.
- 18 out of 21 facilities recirculate the course sieving fraction.
- 14 out of 21 facilities remove (plastic) film after the composting phase by wind sifting.
- 12 out of 21 facilities occasionally dispose of the residual fractions.

Table 6 Overview of the 21 organic waste treatment facilities in the Netherlands and their specific operational differences. The shaded row (#6) indicates the facility of Valor, Van Kaathoven in Sint-Oedenrode [10].

Treatment facility (ID #)	Processed waste in 2017 (kton)	Shredder as pre-treatment	Sieving of input (in mm)	Recirculation of pre-treatment residue	Minimum residence time (days)	Intermediate turning	Wind sifting on fractions	Recirculation of post-treatment residue (coarse)	Recirculation of post-treatment residue (fine)
1	58	Yes	60	No	13	No	Yes	>60	10-60
2	58	Yes	60	No	7	No	Yes	>60	10-60
3	59	Yes	80	Yes	21	7x	Yes	>40	10-40
4	78	Yes	None	Yes	7	No	Yes	>120	10-120
5	74	Yes	60	Yes	32	1x	Yes	>120	10-120
6	57	Yes	None	Yes	12	No	No	>40	10-40
7	150	Yes	150	Yes	7	No	Yes	No	10-?
8	38	No	None	Yes	35	1x	No	>40*	10-40
9	49	No	None	Yes	12	1x	No	>80	10-80
10	71	Yes	150	No	21	5x	Yes	>40*	15-40
11	71	No	None	Yes	12	No	Yes	>50	15-50
12	88	Yes	60	No	14	No	Yes	>60*	15-60
13	144	Yes	60	Yes	18	3x	Yes	>60*	15-60
14	85	No	None	Yes	21	1x	Yes	>50*	15-50
15	229	Yes	60	Yes	35	1x	Yes	>80*	10-60
16	116	Yes	60	Yes	30	9x	Yes	>60*	10-60
17	55	Yes	150	No	15	8x	Yes	>40 >150*	10-40
18	55	Yes	60	No		4x			
19	74	No	None	Yes	5	1x	No	>80*	10-80
20	46	No	None	Yes	6	1x	No	n.a.	>12*
21	80	No	None	Yes	14	4x	No	n.a.	>15*

* Occasional removal due to rising pollution (in Dutch: spuien)

1,5 Mton organic waste was processed in 2017 (which means an average of approx. 71 kton per facility) and 675 kton of compost was produced (= 45 %). The amount of compost produced has remained more or less the same for the last 10 years. The average amount of total 'residu', i.e. residual waste that could not be sold as compost, is about 10%. A substantial amount of organic material is attached to this residue, and cannot be easily separated from it [10].

In consultation with representatives of Vereniging Afvalbedrijven (VA) and Holland Bioplastics (HB) it was decided to execute the trial at the organic waste treatment facility operated by Van Kaathoven (Valor), location Sint-Oedenrode (Eversestraat 1, 5491 SR Sint-Oedenrode, Netherlands). The process for waste treatment and compost production is schematically presented in Figure 11.

This organic waste treatment facility was chosen because:

- the facility processes annually approx. 45.000 tons of GFT. The organic waste input is therefore representative for that of other GFT treatment facilities in the Netherlands.
- the facility runs a batch process (in well controlled "tunnels" of 650 m^3, net processing volume about 450 m^3), which is large enough to be representative of commercial organic waste treatment, and at the same time practical for placing and recovering test samples.
- the duration of a single organic waste treatment cycle is 10-12 days, which is on the short side, but in accordance with common practice in the Netherlands.
- the regular process does not have a separation step before the organic waste enters the composting unit, which means that all (plastic) products present in the organic waste will undergo the composting process.
- after each sieving step of a composting cycle, the residual fractions (i.e. 10-40 mm, and >40 mm) are usually recirculated and composted again in the next cycle. If not completely disintegrated in the first cycle, products will have a longer residence time in the process.
- the staff of the facility has previous experience with composting trials with compostable materials.
- the facility could make one composting tunnel (and staff) available dedicated to the trial in the desired testing period.

3.2.2 Materials

A number of (semi-) commercial compostable plastic test products were selected to investigate the fate of compostable products during organic waste treatment in a commercial industrial facility. Important criteria for the selection include:

- Diversity in type of plastic, i.e. flexible film, rigid products, non-wovens, labels, etc.
- Diversity in base material, i.e. starch-based, PLA-based, etc.
- Commercially available (or at least close to market)
- Demonstrated compostability, i.e. certified according to EN 13432 (or equivalent)
- Expected co-benefit of the product or application for the organic waste treatment process, i.e. products that could:
  - increase the separate collection of GFT and divert typical compostable waste from landfill or incineration
  - reduce contamination of GFT with plastics (e.g. compostable versions of products typically disposed of in the GFT-bin)

Based on these criteria, a set of 9 different compostable plastic products from various producers were selected, consisting of GFT collection bags, plant pots, tea bags, coffee pads, coffee capsules, and fruit labels. The products were made available by Holland Bioplastics (HB) and arrived at WFBR beginning of February 2019. An overview of these products is given in Table 7.

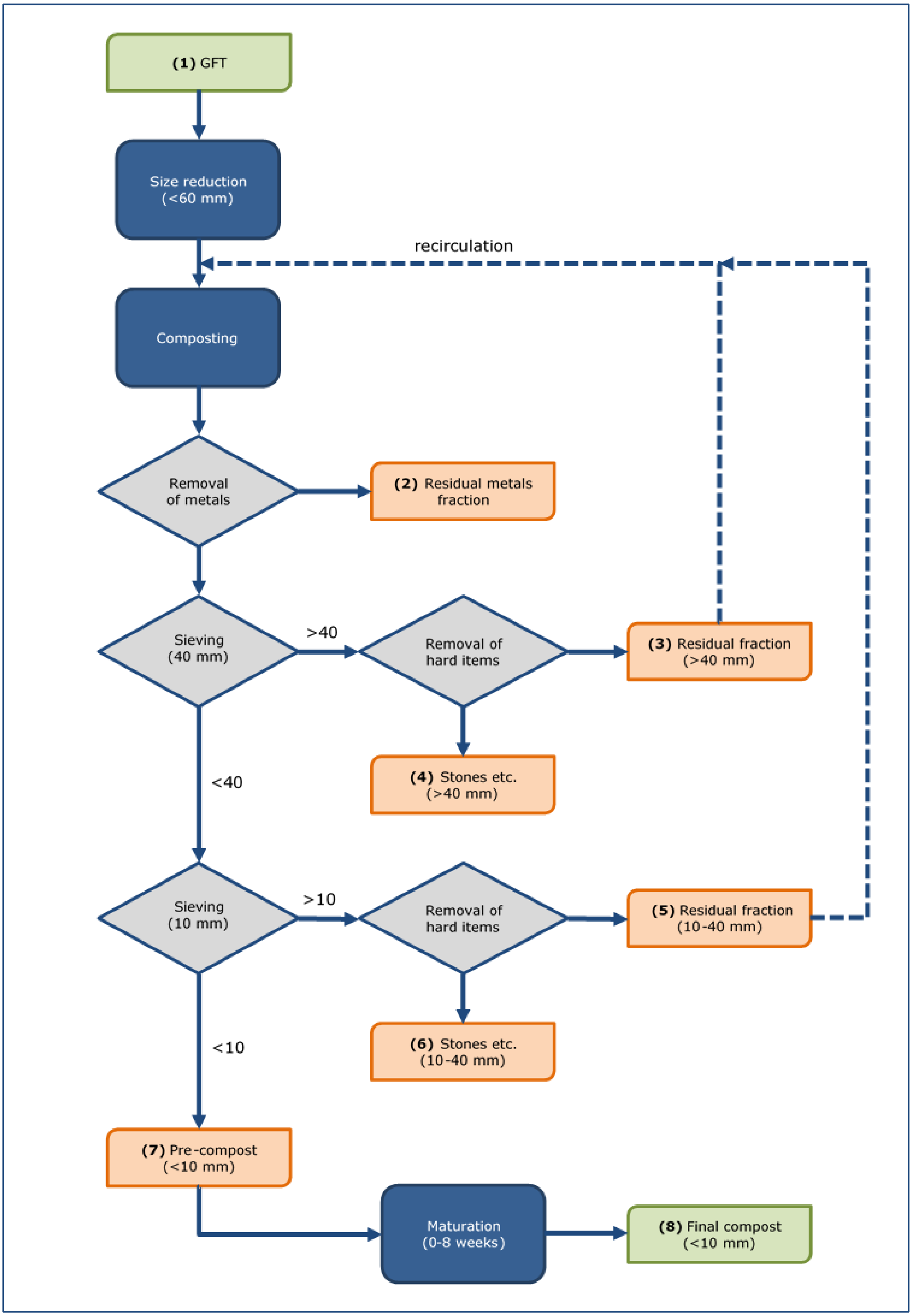
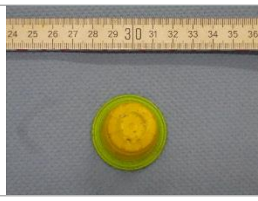


Figure 11 ***Schematic presentation of the organic waste treatment process at the Van Kaathoven (Valor) facility, location Sint-Oedenrode. Dashed arrows indicate that the residual fractions (3) and (5) are occasionally (but not always) recirculated***

Table 7 Overview of materials introduced in the organic waste treatment trial

Code	Product	Composition	Pictures	
A	**GFT collection bag** *Compostability certificates:* *OK compost IND: TA8011300630* *OK compost HOME: O16-1859-A* *Compostable (Seedling): 7P2018*	Thermoplastic starch with biodegradable polyester		
B	**GFT collection bag** *Compostability certificates:* *OK compost IND: TA8011601461* *OK compost HOME: TA8021601496*	Thermoplastic starch with biodegradable polyester		
C	**Plant pot** *Compostability certificates:* *Compostable (Seedling):*	Thermoplastic starch with biodegradable polyester		
D	**Plant pot (cuttings)** *Compostability certificates:* *OK compost IND: TA8011500968*	PLA		
E	**Teabag (used)** *Compostability certificates:* *Compostable (Seedling):*	Paper and PLA fibres		
F	**Fruitlabel** *Compostability certificates:* *OK compost IND: TA8011903519* *Compostable (Seedling): 7H2020*	Biodegradable polyester coated paper		
G	**Coffee capsule (used)** *Compostability certificates:* *OK compost IND: O17-2386-B*	PLA with biodegradable polyesters		
H	**Coffee pad (used)** *Compostability certificates:* *Compostable (Seedling): 7P2096*	Paper and PLA fibres		
J	**Teabag (used)** *Compostability certificates:* *Compostable (Seedling): 7P2174*	PLA filter and thread, PLA coated tag		

3.2.3 Organic waste treatment trials

The organic waste treatment trial consisted of two separate parts:

(A) Following selected compostable products during the organic waste treatment process and identifying in which (residual) fractions the products would likely end up.

(B) Evaluating the disintegration of selected compostable products under the regular operation conditions and timeframe (in relation to the results obtained with laboratory testing required for certification according to EN13432)

3.2.3.1 Part A: Identification of the fate of selected products (full scale)

Substantial amounts of compostable products were introduced into incoming GFT, which was subsequently processed according to regular operation procedures. All main fractions of the process (see Figure 11) were analysed to follow the route (and fate) of these products and identify in which (residual) fractions the products would likely end up.

A load of GFT (approx. 8 m^3) which had freshly arrived at the treatment facility on 7 February 2019, was used without pre-treatment and mixed with the test products. The amount of test product added, is given in Table 8. Figure 12 and Figure 13 show some pictures of the various stages of the experimental set-up.

Table 8 Amount of test product added to freshly arrived GFT for the full scale organic waste treatment trial.

Code	Test product	Approximate number added to organic waste	Approximate mass (excl. content) *(kg)*
A	GFT collection bag, 50 filled with organic waste	1000	5.3
B	GFT collection bag, 50 filled with organic waste	1000	3.7
C	Plant pot, 50 with potting soil	300	18.6
D	Cutting pot, 50 filled with potting soil	500	1.0
E	Teabag, incl. content, used (hot water treatment)	590	0.1
F	Fruit label, half attached to fruit, half still on the roll	1000	0.03
G	Coffee capsule, incl. content, used (hot water/pressure treatment)	1000	2.6
H	Coffee-pad, incl. content, used (hot water treatment)	1000	0.6
J	Teabag, incl. content, used (hot water treatment)	1000	0.3
			Total: 33 kg

Most of the organic waste collection bags were added as empty bags separated from the roll, but 5% was prefilled with GFT and closed with a knot to simulate its use in practice (see Figure 12a).
Most of the plant pots were added as empty pots (as received), but 10-15% was prefilled with commercial potting soil to simulate the way they would likely end up in GFT.
Tea bags, coffee capsules and coffee pads were received in a used state, i.e they had undergone the hot water and/or pressure treatment in their usual application device.
About half of the number of fruit labels were applied on the outside of orange and banana peels. The other half was added as a string of labels still on the roll (see Figure 12b).

The mixture of test products with GFT was left in a pile overnight, and processed the following day. According to normal operation procedures, the GFT mixture was pre-treated with a Komptech Crambo 5000 low speed waste shredder for additional mixing and size reduction (<60 mm). This shredded mixture was blended furthermore with so called structure material (i.e. the >40 mm residual stream from an earlier composting cycle) in order to obtain the right density etc. during introduction in the composting tunnel. As this was insufficient mass to fill the whole composting tunnel, it was placed in a specific and marked section of the tunnel, in between sections filled with regular GFT (not supplemented with test products). The tunnel was run according to normal operation and at the end of the usual residence time, the content of the tunnel was processed further as usual. The section of the tunnel containing the test products was processed the same way, but separately, with thorough cleaning of the sieving line beforehand. The separate fractions were collected, weighed and samples were taken for further evaluation. The residual fractions of sorted out metals (in Figure 11, Fraction 2), hard items >40 mm (Fraction 4) and hard items 10-40 mm (Fraction 6) were discarded, as would be during normal operation. Fraction 7, the pre-compost (<10 mm) was sampled for compost quality analysis. To simulate the recirculation of the fractions >10 mm during normal operation, fractions 3 and 5 were mixed with incoming GFT and introduced the same day in a composting tunnel for a second composting cycle. Also after this second cycle, the separated fractions were collected, weighed and sampled for further evaluation.

Figure 12 Pictures of various stages of the full scale organic waste treatment trial
(a) Filled GFT collection bags, products A and B; (b) Fruit labels on orange peel, product F; (c) GFT batch with test products; (d) Close up of GFT with test products; (e) mixing of GFT with test products; (f) additional mixing and size reduction (<60 mm) with the Crambo 5000 slow speed shredder.

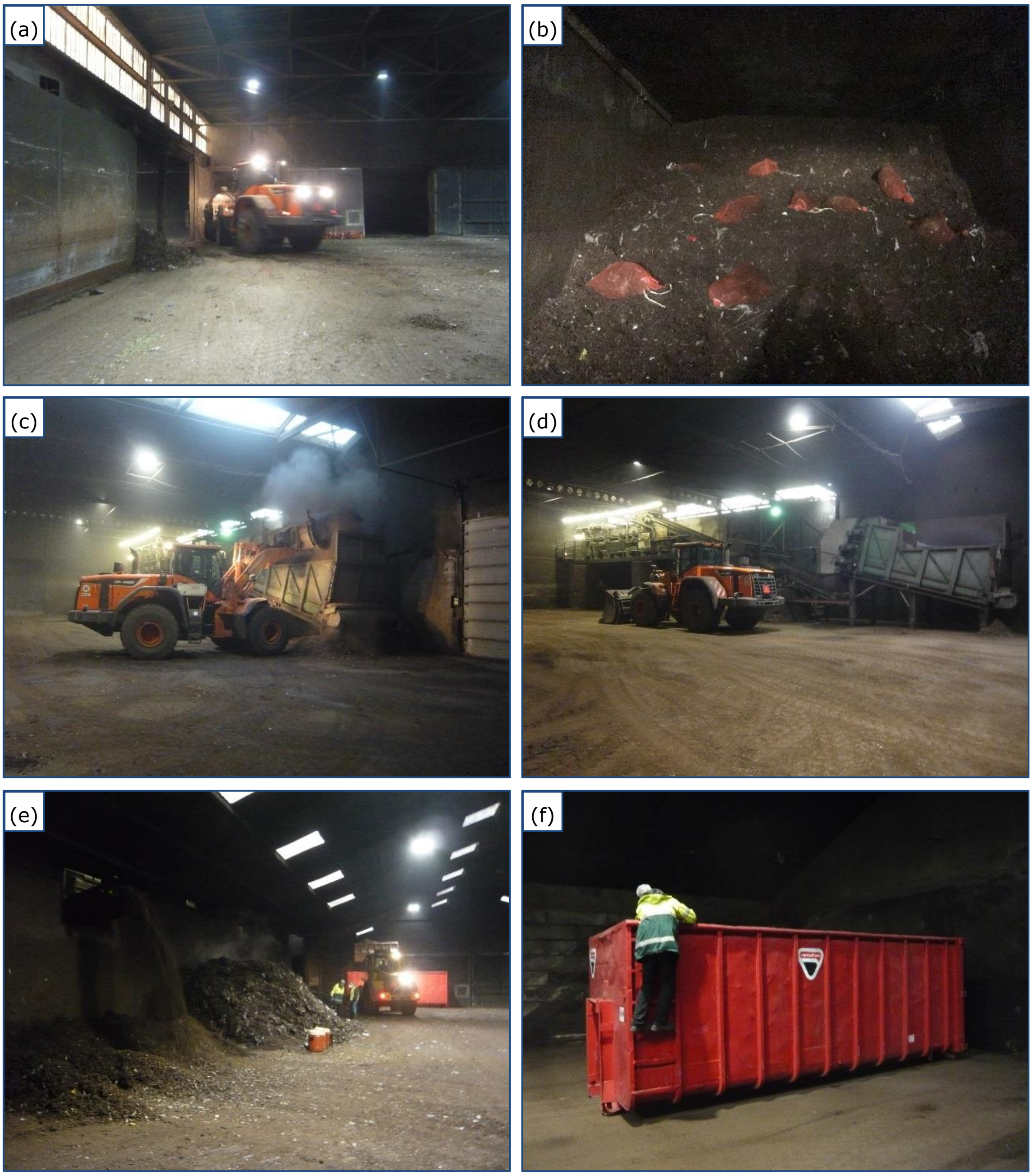


Figure 13 Pictures of various stages of the full scale organic waste treatment trial
(a) Filling of the composting tunnel; (b) Composting tunnel filled with GFT (including the nets for the second part of the trial); (c) Transporting processed waste to the sieving set-up; (d) Overview of the sieving facilities; (e) Output of the sieving step, resp. the 10-40mm fraction and the >40 mm fraction; (f) collection of the various fractions in containers for weighing.

3.2.3.2 Part B: Disintegration of test products in mesh bags

The test products were mixed with recently collected source separated municipal solid organic waste (from which large plastic impurities were removed manually) and put in mesh bags (approx. 50 l, mesh 2 mm) [11]. The amount of test product that was mixed with approx. 25-35 litre of organic waste is given in Table 9. Two pieces of orange peel and a banana skin were added to the content of each mesh bag for reference purposes.

Table 9 Amount of test product per mesh bag, mixed with 25-35 litre organic waste

Code	Test product	Number added per mesh bag	Total mass (excl content) (g)
A	GFT collection bag, partially filled with organic waste	10	53.3
B	GFT collection bag, partially filled with organic waste	10	36.9
C	Plant pot, filled with potting soil	5	310
D	Cutting pot, filled with potting soil	10	21.7
E	Teabag, incl content, used (hot water treatment))	50	11.3
F	Fruit label, half attached to fruit, half still on the roll	75	2.2
G	Coffee capsule, incl. content, used (hot water/pressure treatment)	50	131
H	Coffee-pad, incl. content, used (hot water treatment)	50	30.0
J	Teabag, incl. content, used (hot water treatment)	50	14.0

The next day, the filled mesh bags were placed in duplicate at different representative positions amongst the regular organic waste during the customary loading of the composting tunnel. This was the same tunnel used for part A of the trial. One set of mesh bags was used to mark the beginning of the section with test products, the other set of mesh bags were deposited at the end of the section. The tunnels were operated according to the usual practice. The mesh bags were recovered when the tunnels were unloaded at the end of the customary processing time.

After the first organic waste treatment cycle (approx. 11 days), the mesh bags were opened for visual inspection of the products and photographed. The content of each mesh bag was subsequently mixed with some fresh organic waste (and additional water to bring the moisture content to normal levels) and the mesh bags were refilled with the mixture. These bags were placed again at different representative positions during the customary loading of the tunnel for the next composting run, marking the beginning and the end of the section with test products of Part A of the trial.

After recovery of the mesh bags when the tunnels were unloaded at the end of the second waste treatment cycle (approx. 11 days), the content was analysed with regard to the disintegration of the test product. To enable evaluation of the disintegration, the content of the mesh bags was sieved [10 mm mesh] and all visible fragments of the test products were retrieved manually. The fraction <10 mm was further fractionated with a set of sieves [8 mm square, 4 mm square and 2 mm round] and the visible fragments of the test products were retrieved manually from each fraction, weighed, and photographed.

3.3 Results

3.3.1 Composting runs

The organic waste treatment tunnel was operated according to the usual practice, i.e. composting for 11 days with active aeration from below and spraying moisture from above. Within 12 hours, the temperature rose to above 60°C, was maintained at that level for at least 48 hours for hygienation. The requirements for Keurcompost is minimal 3 days above 50°C [12]. Both runs in the trial fulfilled that requirement. The tunnel was subsequently allowed to dry and cool gradually to about 35°C at the end of the run. The temperature profile of the process and other technical parameters of the two runs are presented in Annex 9. No irregularities were observed.

3.3.2 Part A: Identification of the fate of selected products (full scale)

Figure 14, Figure 15 and Figure 16 show the separate fractions collected after the first composting and sieving cycle. Substantial amounts of plastics were visibly in the residual fractions, and some of the intentionally added test products could be recognised amongst the other plastics already present in GFT. In particular the brightly coloured coffee capsules stood out from the otherwise brown mass of processed GFT.

Figure 14 Fractions collected after the first composting and sieving cycle
Left: Fraction 3 (>40 mm); (a) sampling under the conveyer belt, (b) close up, (c) further close up.
Right: Fraction 5 (10-40 mm); (d) sampling under the conveyer belt, (e) close up, (f) further close up.

Figure 15 Fractions collected after the first composting and sieving cycle
Left: Fraction 3 (>40 mm); (a) collected for recirculation, (b) close up, (c) further close up.
Right: Fraction 5 (10-40 mm); (d) collected for recirculation, (e) close up, (f) further close up

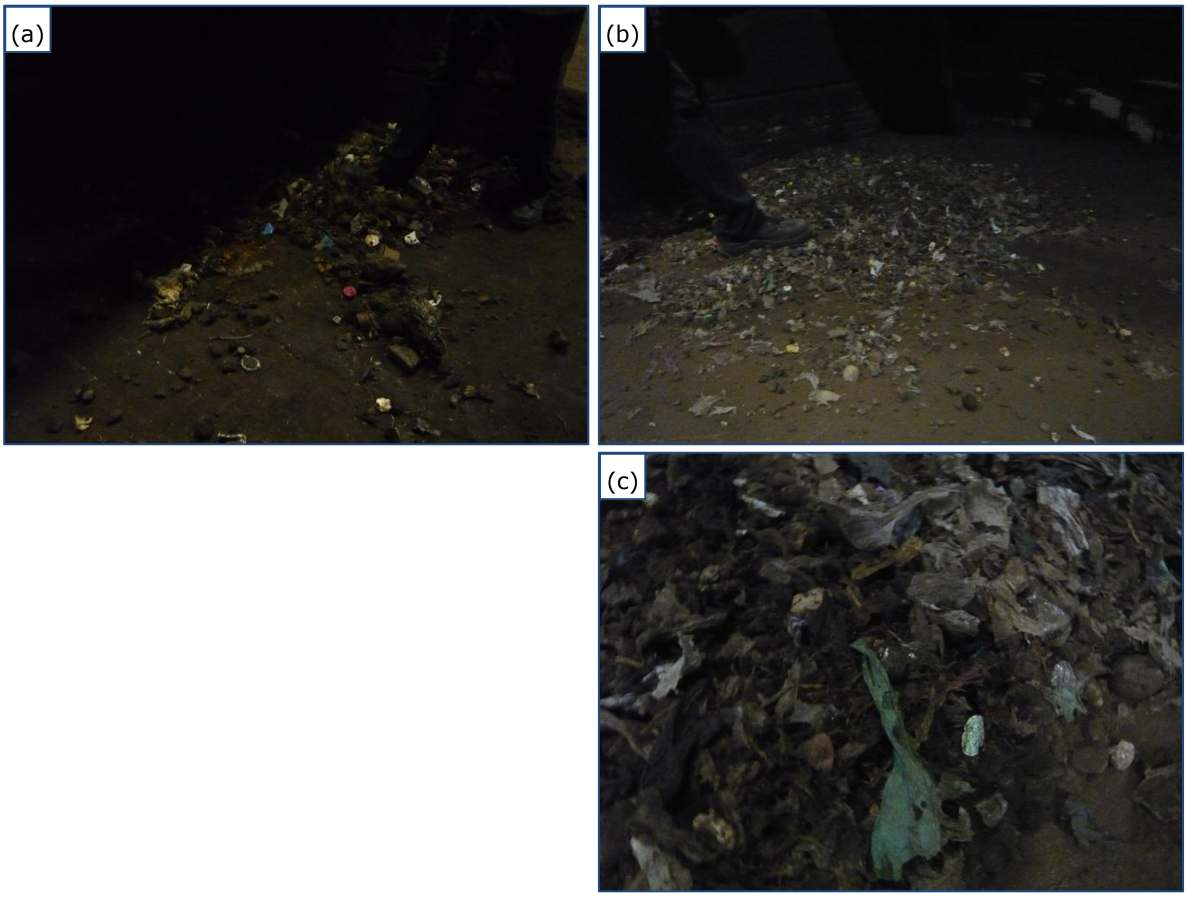


Figure 16 Fractions collected after the first composting and sieving cycle
Left: Fraction 4 (>40 mm); (a) after sieving was completed
Right: Fraction 6 (10-40 mm); (b) after sieving was completed, (c) idem, close up.

The separate fractions collected after each composting and sieving cycle were weighed. The results are shown in Table 10. In both cycles, the fractions 2, 4 and 6 were small compared to the other sieving fractions and were not weighed for that reason. It is estimated that in total they account for less than 1% of the recovered mass. A flow chart of the various fractions of the first waste treatment cycle is presented in Figure 17 in which the width of the arrows represent the relative mass of the fractions.

Table 10 Weight of the various fractions obtained after the two waste treatment cycles

No.	Fraction	First cycle (9 Feb - 19 Feb 2019) (kg)	(%)	Second cycle (19 Feb - 2 Mar 2019) (kg)	(%)
2	Metals	100*	0.3	100*	0.3
3	Residue >40 mm	2,640	8.9	2,980	7.3
4	Hard items >40 mm	100*	0.3	100*	0.3
5	Residue 10-40 mm	20,660	69.0	29,300	72.0
6	Hard items 10-40 mm	100*	0.3	100*	0.3
7	(Pre)compost (<10 mm)	6,420	21.5	8,420	20.7
	Total	29,920	100	40,700	100

* Estimated (not weighed)

In both composting cycles, the largest part of the GFT ended up in fraction 5, the 10-40 mm residual fraction. In the first cycle, this was 69% of the recovered mass, and in the second cycle 72% of the recovered mass. About 21% of the mass ended up in the fraction <10 mm, i.e. the (immature) compost. To put this in perspective, in 2018 the Valor organic waste treatment facility processed 44,434 tons of GFT, and produced 22,999 tons of compost (= 52%). In 2018 the residue that could not be sold as compost (and was incinerated) was 2,544 tons (= 6%), implying that the mass loss due to evaporation and conversion to CO_2 amounted to 18,891 tons (= 43%). For the trial, no true mass balance could be constructed because the total amount of GFT in the section used for the trial was not determined. However, from these figures it is clear that the ratio between residue and compost observed in the trial is much higher that the annual average (3.7 versus 0.1, i.e. a factor 34). From this we can deduce that during normal operation, with recirculation of the 10-40 and >40 residual fractions, a substantial part is further decomposed into the <10 mm fraction and is sold as compost. At the Valor facility, the 10-40 mm fraction is almost infinitely recirculated, as it is only discarded (in Dutch: "gespuid") a few times per year when the amount of plastics or glass has accumulated above a critical level. The >40 mm residual fraction is removed more often, approx. 2-4 times a month. As both residual fractions consist mainly of organic matter, they are subsequently incinerated as 'biomass'.

Samples of the separately collected fractions were further analysed with regard to whether they contained (remains of) the test products deliberately introduced into the GFT. For this, all plastics were recovered from the samples by handpicking. The recovered plastics were subsequently assessed visually/manually whether they originated from the added test products. The results are presented in Figure 18 (for the first cycle) and Figure 19 (second cycle). In addition, Fraction 7 was further characterised with regard to some compost quality parameters in the framework of BRL Keurcompost [12], see Table 11. Pictures of recovered plastics in the various fractions, including (fragments of) test products are presented in Annex 10.

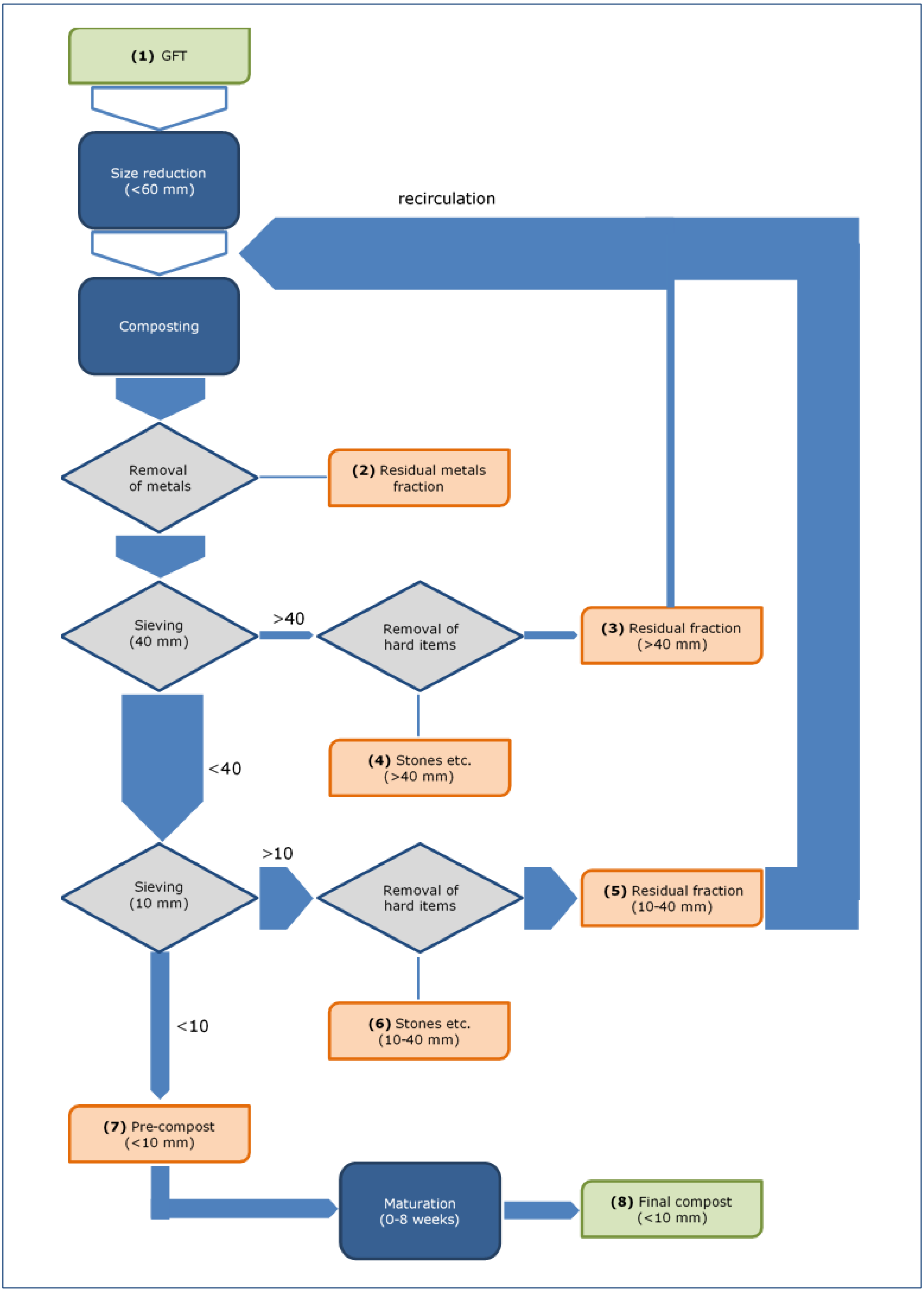


Figure 17 ***Flow diagram of the various fractions of the first waste treatment cycle.*** *The width of the arrows represent the relative mass of the fractions*

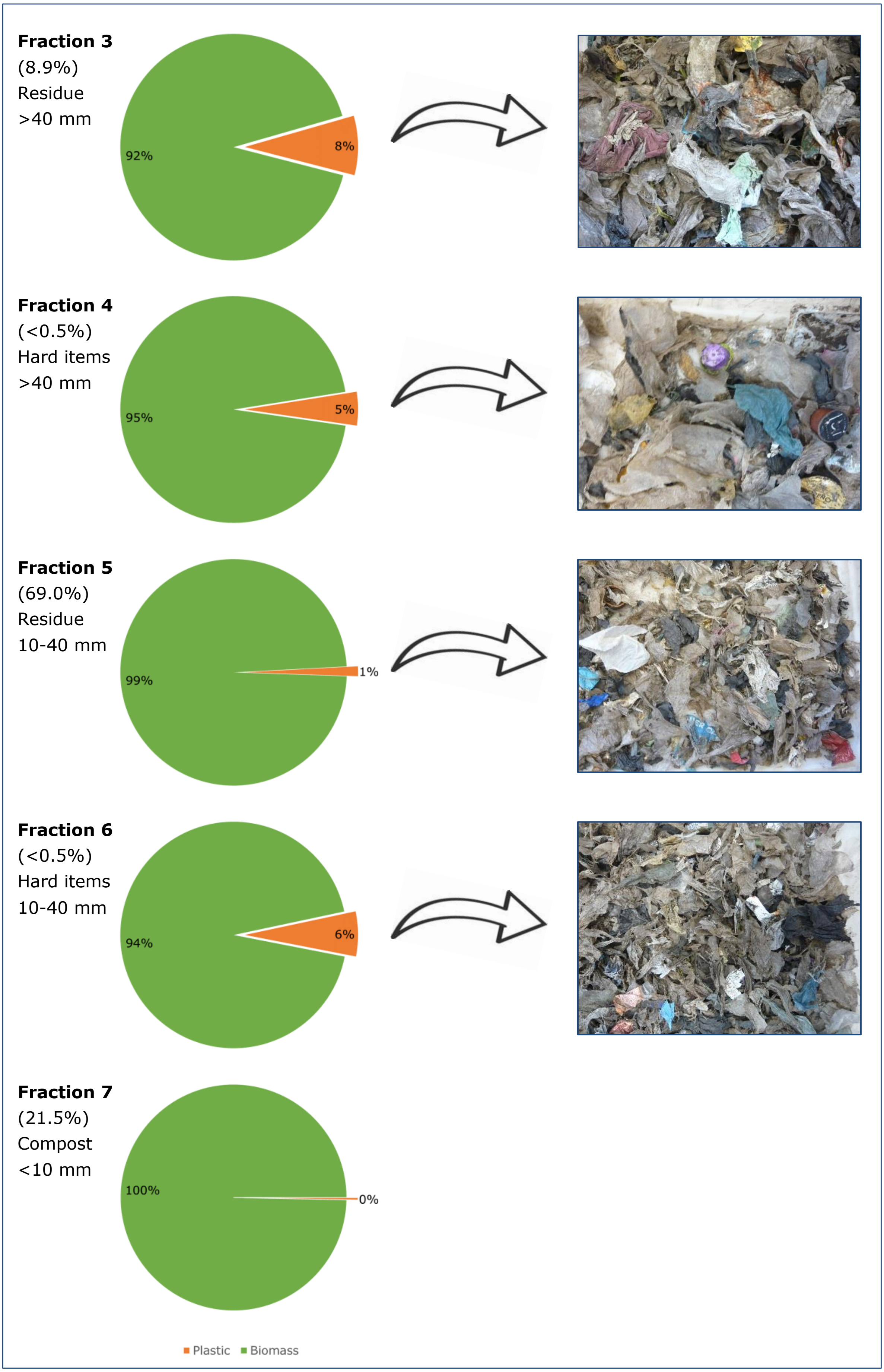


Figure 18 ***Composition of the various fractions obtained after the first waste treatment cycle.*** *Left side: Amount of plastics and biomass present in the fraction; Right side: Pictures of the plastic fraction (more detailed pictures, including any isolated test products in Annex 10)*

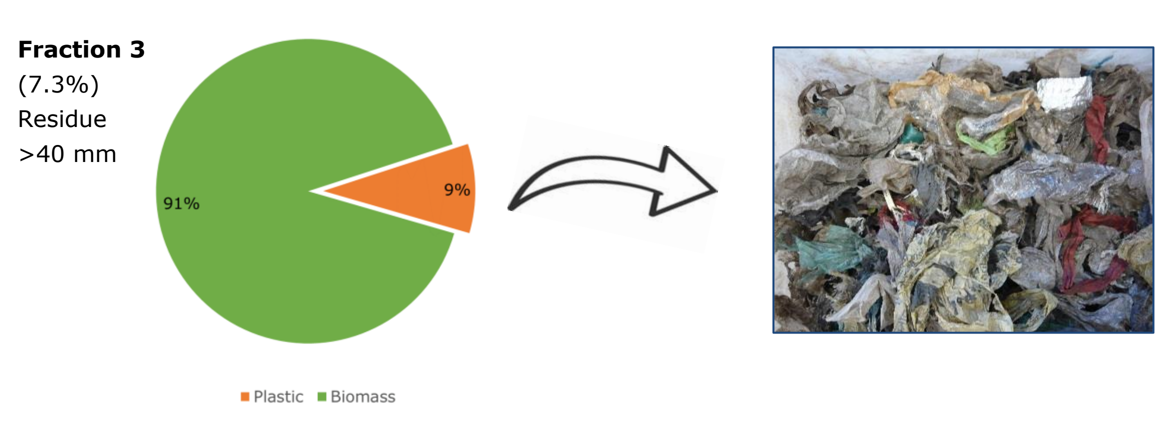


Figure 19 ***Composition of >40 mm residue fraction obtained after the 2nd waste treatment cycle.*** *Left side: Amount of plastics and biomass present in the fraction; Right side: Pictures of the plastic fraction (more detailed pictures, including any isolated test products in Annex 10).*

The residue fractions contain visibly a substantial amount of plastics. Due to the difference in density and the conspicuous colours, it looks more than the actual weight fraction. In Figure 17 and Figure 18 it is shown that the amount of biomass in Fraction 3 (>40mm) is more than 90% and in Fraction 5 (10-40 mm) even 99% on dry weight basis. Surprisingly, the fractions generated by the "ontharder" designed to remove stones and other hard items, still consisted for approx. 5% of plastics, mostly flexible film. However, as these fractions compose less than 1% of the total recovered mass, they do not significantly contribute to the mass balance.

The plastic fraction recovered from the samples of the various residues consisted mainly of conventional plastics (flexible film), in accordance with the regular plastic contamination in GFT (see Section 2). Only a few of the test-products intentionally introduced in the trial could be recovered. In this respect, it should be noted that the analysed samples were small. The sample of fraction 3 was 20 kg out of a total 2,640 kg. The sample of fraction 5 was approx. 10 kg out of a total 20.660 kg. Furthermore, the total amount of test products (33 kg) was diluted in at least 33,000 kg of GFT, so we cannot draw conclusions with regard to the level of disintegration of individual product categories.

Nevertheless, some of the intentionally added test-products could be identified in the various fractions. In Fraction 3, these were predominantly fragments of the GFT collection bags (products A and B). It should be noted however, that an attempt to calculate the recovery is meaningless, not only because of the error margin in the sample size, but also because the incoming GFT already contained substantial amounts of (recognisably certified) compostable GFT collection bags which add up to the recovered amounts. And the amount of bags already present in the incoming GFT was not quantified in this trial beforehand.

From Fraction 4 (the hard items >40 mm), we could recover the coffee capsules (Product G), some intact (but with reduced mechanical strength), and some fragments. Also some fragments of GFT collection bags (product A) could be identified.

Sorting out the plastic fragments from the samples of fraction 5 (10-40 mm) was a tedious job, let alone identifying intentionally added products. Nevertheless some fragments of Product B, G and J were identified. No reliable conclusion can be drawn with regard to recovery rates.

No test-products were identified in the plastics recovered from Fraction 6 (hard items 10-40 mm) and Fraction 7 (Compost, <10 mm). The compost contained 0.3% plastic fragments larger than 2 mm, but none could be attributed to the test products.

The results of the compost evaluation (Table 11) are in accordance with the fact that the trial is performed with GFT collected in the winter period (low amounts of garden waste). Garden waste usually contains a lot of soil, which results in a lower organic matter content and a higher stability (lower respiration). It is clear that storing the compost for 11 days results in substantial further degradation of organic matter (decrease in organic matter from 44.3 to 39.5%, and respiration from 35.4 to 29.6).

Table 11 ***Evaluation of the compost of the two full scale organic waste treatment runs***

	Dry matter (%)	Organic matter (% of DM)	Contaminations Glass (%)	Stones (%)	Plastic (%)	Rest (%)	Respiration (mmol O2/ kg DM*hr)	Rottegrad (°C / Category)
Compost from 1st run (sampled after sieving)	70.3	44.3	0.04	1.37	0.34	0.06	35.4	n.d.
Compost from 1st run (after 11 days of maturation)	77.8	39.5	n.d.	n.d.	n.d.	n.d.	29.6	54.9°C II
Compost from 2nd run (sampled after sieving)	72.1	43.5	n.d.	n.d.	n.d.	n.d.	32.8	48.9°C III

n.d. not determined

3.3.3 Part B: Disintegration of selected products in mesh bags

For this part of the trial, the mesh bags containing the selected products were inserted in the same composting tunnel/cycles as used for part A, so they were exposed to the same conditions. When the content of the tunnel was ready to be sieved, it was carefully unloaded and the mesh bags were recovered. After the first cycle, all bags but one were recovered. Observations regarding the recovery of mesh bags, and the test products are presented in Table 12. Pictures of the recovered mesh bags and their content are shown in Annex 11.

Table 12 ***Observations regarding the disintegration of test products in mesh bags after the first organic waste treatment cycle of 11 days.*** *Codes refer to the materials in Table 7.*

Code	Recovery of mesh bag	Observations
GFT collect bag (A)	Recovered	Bags clearly visible (cling together), reduced mechanical strength
(duplicate)	Recovered (small hole)	Bags clearly visible, reduced mechanical strength
GFT collect bag (B)	Recovered	Bags clearly visible (cling together), reduced mechanical strength
(duplicate)	Recovered (small hole)	Bags clearly visible, reduced mechanical strength (lower than A)
Plant pot (C)	Mesh bag partially damaged	3 pots observed, but brittle
(duplicate)	Mesh bag partially damaged	Lost part of content, no pots recovered, only pieces
Plant pot (D)	Recovered	No pots visible, only reference orange peel
(duplicate)	Mesh bag partially damaged	No pots visible, only reference orange peel
Teabag (E)	Recovered, but rather empty	Few teabags visible, difficult to distinguish from paper (brown)
(duplicate)	Recovered	No teabags found, difficult to distinguish from paper (brown)
Fruit label (F)	**NOT recovered**	
(duplicate)	Recovered	Labels visible, both on fruit as well as on the roll (no loose ones)
Coffee capsule (G)	Recovered	Capsules visible, some broken, softened and brittle, break with little pressure
(duplicate)	Recovered	Capsules visible, mostly fragmented, ring, foil, cup, break with little pressure
Coffee pad (H)	Mesh bag partially damaged	Lost part of content, packed together
(duplicate)	Recovered	Few pads visible, difficult to distinguish from paper
Teabag (J)	Mesh bag damaged a little	Most content recovered, teabags hardly visible (resemble leaves), the seam is easily torn, but fabric strength reasonably maintained
(duplicate)	Recovered	Found just 1 teabag, rest of the waste was well composted (due to better mixture and moisture content?)

Most products could be identified in the waste after the first cycle (11 days in the tunnel), except for product D (the full PLA plant pots) which could not be found in both duplicate mesh bags. The mechanical strength of the other products appeared to have decreased during the waste treatment process – this was not measured, but assessed manually. The GFT in the mesh bags had undergone some degradation, but the origin of a substantial part was still recognisable. The orange peel and banana skin added as reference materials could also be identified in all recovered mesh bags. It was noted that the organic matter in the mesh bags appeared dry and not optimal for composting. This is not surprising, as the waste treatment process is steered in the final phase towards drying the mass in the tunnel to facilitate easy sieving of the processed waste.

After the visual inspection, the content of each mesh bag was subsequently mixed with some fresh incoming organic waste and additional water to bring the moisture content to normal levels, and subsequently exposed to a second waste treatment cycle of 11 days. After this second run, all mesh bags were recovered, but like in the first run, some of the bags were damaged. The content of each bag was dried and fractionated in order to facilitate the recovery of all test products (fragments) by handpicking. The recovered amounts of test products after two consecutive waste treatment cycles are presented in Table 13. It should be noted that the recovered products were not extensively cleaned before weighing. Furthermore, part of the contents was lost in some cases due to the damaged nets. Therefore, the mass balance and corresponding disintegration levels are inaccurate and indicative only. Photographs of the recovered products in the various fractions are shown in Annex 12.

Table 13 ***Recovery and calculated degree of disintegration of test products in mesh bags after the second organic waste treatment cycle of 11 days.*** *Codes refer to the materials in Table 7.*

Product (code)	Mass of product **@ start (excl. content)** (grams)	Recovery* (weight-% of start)	Disintegration* **[100% – recovery]** (weight-% of start)	Recovery in fraction 0-10 mm (grams)	Recovery in fraction >10 mm (grams)
GFT collect bag (A)	53	94	6	5	45
(duplicate)	53	8#	92#	n.d.	4
GFT collect bag (B)	37	100	0	2	35
(duplicate)	37	94#	6#	n.d.	35
Plant pot (C)	310	25#	75#	n.d.	79
(duplicate)	310	38#	62#	15	103
Plant pot (D)	22	1	99	0.3	0
(duplicate)	22	0	100	0	0
Teabag (E)	11	0	100	0	0
(duplicate)	11	0	100	0	0
Fruit label (F)	2.2	0	100	0	0
(duplicate)	2.2	X	*(mesh bag not recovered after 1st waste treatment cycle)*		
Coffee capsule (G)	131	91	9	70	49
(duplicate)	131	59	41	68	9
Coffee pad (H)	30	58#	42#	n.d.	17
(duplicate)	30	86	14	11	14
Tea bag (J)	14	0	100	0	0
(duplicate)	14	0	100	0	0

* Samples were not thoroughly cleaned before weighing, thus percentages are indicative only.

\# possibly some loss of product due to damaged mesh bags

n.d. not determined

3.4 Discussion

3.4.1 Combining results of Part A (full scale) and Part B (mesh bags)

Product A - GFT collection bag
Substantial amounts of this type of GFT collection bag were recovered from the mesh bags after 2 cycles of composting. It was noted that one of the duplicate mesh bags was damaged and much less product could be recovered from it, which at least partly can account for the variance between duplicates. Most of the product was found in the >10 mm fraction. The mechanical properties, however, had deteriorated and the recovered fragments could be torn easily by hand. In this part of the trial, the content of the mesh bags bypassed the regular processing and sieving procedure and was thus not exposed to the usual shear. It is expected that in processes in which shear is applied, fragmentation of product A will be more pronounced. Nevertheless, also in the full scale trial (Part A) the product could be identified in fraction 3 (residue >40 mm) after two waste treatment cycles of 11 days. This means that product A needs a longer residence time, and/or more optimal composting conditions to be fully disintegrated.
Because the Valor facility recirculates the 10-40 mm residue fraction in most cases, and also recirculates the >40 mm fraction a number of times, it is concluded that product A will be sufficiently disintegrated within the process, and will not significantly contribute to an increase in the residue to be discarded.

Extrapolation to other facilities in the Netherlands
In the 6 facilities that have a sieving step up front with no recirculation of the pre-treatment residue, it is expected that product A may be partly removed from the GFT before the actual composting takes place. In the 14 facilities which remove plastic film after the composting phase by wind sifting, it can be expected that to some extent product A will end up in the plastic film fraction, depending on the residence time in the composting phase and the turning frequency and/or shear it encounters before the wind sifting.

Product B - GFT collection bag
The results obtained with product B are very similar to those of the product A. Although mechanical properties of the starting products were slightly different, in the waste treatment process they behaved more or less the same. Substantial amounts of this type of GFT collection bag were recovered from the mesh bags after 2 cycles of composting. Most of the product was found in the >10 mm fraction. The mechanical properties of the plastic had deteriorated as was the case with product A and the recovered fragments could be torn easily by hand. It is expected that in processes in which shear is applied, fragmentation of product B will be more pronounced. Nevertheless, also in the full scale trial (Part A) the product could be identified in fraction 3 (residue >40 mm), fraction 4 (hard items >40 mm) and fraction 5 (residue 10-40 mm) after the first cycle, and also in fraction 3 after the second cycle of 11 days. This means that product B needs a longer residence time, and/or more optimal composting conditions to be fully disintegrated.
Because the Valor facility recirculates the 10-40 mm residue fraction in most cases, and also recirculates the >40 mm fraction a number of times, it is concluded that product B will be sufficiently disintegrated within the process, and will not significantly contribute to an increase in the residue to be discarded. Contamination of the compost with small particles is not expected.

Extrapolation to other facilities in the Netherlands
In the 6 facilities that have a sieving step up front with no recirculation of the pre-treatment residue, it is expected that product B may be partly removed from the GFT before the actual composting takes place. In the 14 facilities which remove plastic film after the composting phase by wind sifting, it can be expected that to some extent product B will end up in the plastic film fraction, depending on the residence time in the composting phase and the turning frequency and/or shear it encounters before the wind sifting.

Product C - Plant pot
With careful scrutiny, substantial amounts of fragments of the plant pots could be recovered from the mesh bags after 2 cycles of composting. None of the pots were intact, already after the first cycle, and the fragments were rather brittle, in particular after they were dried. It is expected that during normal

waste treatment operation in which more shear is applied, product C will be even further fragmented and disintegrated. In weight, the largest amount was found in the fraction >10 mm. However, it should be noted that it required close and thorough inspection to recover the plant pot fragments as they were dark coloured and roughly shaped, and therefore very difficult to discriminate from the rest of the processed organic waste. During normal operation and quality control of produced compost, any fragments of these plant pots would probably not be detected as contaminants.
In the full scale trial, product C was not found at all in the fractions 4-8, and only in one of the duplicate samples of fraction 3 (residue >40 mm) after the first cycle. Because the Valor facility recirculates the 10-40 mm residue fraction in most cases, and also recirculates the >40 mm fraction a number of times, it is concluded that product C will be sufficiently disintegrated within the process, and will not contribute to an increase in the residue to be discarded.

Extrapolation to other facilities in the Netherlands
In the 6 facilities that have a sieving step up front, it is possible that product C will be removed from the GFT before the actual composting takes place as the product is rather bulky, in particular when filled with potting soil.
Any wind sifting in the waste treatment process is not likely yield product C because of its weight, shape and density.
Not fully disintegrated fragments accidentally ending up in the compost, will probably not be recognised as contaminants as their shape and colour are indistinguishable from normal compost.

Product D - Plant (cutting) pots
The full PLA plant cutting pots were completely disintegrated within two organic waste treatment cycles. In fact, even after the first cycle of 11 days, no products or obvious particles could be found during the visual inspection of the content of the mesh bag.

Extrapolation to other facilities in the Netherlands
Product D is expected to be composted to complete disintegration in all facilities, provided that the product is not sorted out beforehand by a pre-treatment process. That is unlikely because due to their size and shape they would normally pass the sieves of currently used pre-screening of input GFT. Also wind sifting in the waste treatment process is not likely to yield product D because as incoming waste they will be filled with potting soil.

Product E - Tea bag
None of this type of tea bag was recovered from the mesh bags after 2 cycles of composting. After the first cycle, some teabags could still be found, but due to their size and colour they could barely be distinguished from the rest of the processed waste – in particular from the remains of the paper which was also significantly present in the GFT. The mechanical properties of the tea bags had deteriorated and the bags found after the first cycle could be torn easily by hand. Since the content of the mesh bags bypassed the regular processing and sieving procedure it was not exposed to the usual shear. It is expected that in processes in which shear is applied, fragmentation of product E will be more pronounced.
In the full scale trial (Part A) the product was not identified in any of the residual fractions. In one of the samples of fraction 3 (>40 mm) of the first waste treatment cycle one tea bag was recovered. But it is uncertain whether this was product E or a conventional product containing PP fibres. NIR analysis could not indicate the presence of PLA nor PP, probably because the remains were too dark.
Based on these results, it is concluded that product E will be sufficiently disintegrated within the process, and will not significantly contribute to an increase in residue to be discarded, nor in visual contamination of the compost.

Extrapolation to other facilities in the Netherlands
Pre-treatment processes on incoming GFT, such as sieving, grinding, and/or wind sifting, are not likely to yield more tea bags in residual streams.

Product F - Fruit label
No fruit labels (product F) were retrieved from the samples of the various residual fractions in the full scale test. This is not surprising because due to their small size, the test products were diluted in the residual fractions by more than 10^6 times (based on the weight of added fruit labels).

In the GFT protected by mesh bags, the fruit labels were still clearly visible after the first waste treatment cycle. Also after the second cycle fruit labels could be observed, but they had completely lost their integrity and could not be separated from the fruit peel on which they were positioned. It should be noted that the disintegration of product F was further advanced than that of the carrier fruit peel itself. This in contrast to some conventional fruit labels that were found in the GFT that had retained their physical integrity, even without support of the carrier fruit or peel (a picture is shown in Annex 12).

Extrapolation to other facilities in the Netherlands
It is expected that in waste treatment processes in which some shear is normal, fragmentation of product F will be even more pronounced.
Based on these results, it is concluded that product F will be sufficiently disintegrated within the process, and will not significantly contribute to an increase in the residue to be discarded, nor in visual contamination of the compost. Pre-treatment processes on incoming GFT, such as sieving, grinding, and/or wind sifting, will not yield more fruit labels in residual streams.

Product G - Coffee capsule
Substantial amounts of the added coffee capsules (product G) were recovered from the mesh bags after 2 cycles of composting. Recovery of fragments proved relatively easy due to the bright colours of the product which clearly stand out from the rest of the GFT in the mesh bag. Some variation between the duplicate mesh bags was observed, already after one cycle. In G1 the majority of the capsules was still intact, although substantially softened and weakened compared to when they were added at the start. The capsules could be broken up between fingers applying a little pressure. In G2, most of the capsules were already fragmented after the first cycle. Like in G1, the material of the fragments was substantially softened and weakened and could be broken up easily with a little pressure. The differences between the duplicates is attributed to variations in the environmental conditions because the rest of the GFT in G2 appeared also in a more advanced state of decomposition than that in G1. Also after the second cycle, the product in G2 appeared further disintegrated than in G1. Approx. 90% of the plastic mass in the coffee capsules in G1 was recovered whereas for G2 this was approx. 60% of the plastic mass.
It was noted that the coffee capsules consisted of different constituents; (i) the brightly coloured body, (ii) a perforated clear lid that separated from the body within the first cycle, and proved more difficult to recover because it took on the colour of the processed waste, and (iii) a ring which maintained its physical integrity somewhat longer than the body of the capsules.
In the full scale trial (Part A) the product was found in fraction 3 (residue >40 mm), in fraction 4 (hard items > 40 mm) and fraction 5 (residue 10-40 mm) of the first cycle. Their appearance was consistent with the fragments recovered from the mesh bags. No capsule (fragments) were found in the samples analysed after the second cycle, but this can be due to the low concentration of approx. 2.5 kg of product in 40,000 kg of GFT mass remaining (i.e. 16,000 times diluted).
Since the content of the mesh bags bypassed the regular processing and sieving procedure it was not exposed to the usual shear. It is expected that in processes in which shear is applied, fragmentation of product G will be more pronounced. However, due to the bright colours used for the body, even tiny fragments (including those smaller than 2 mm) are conspicuous and recognisable in the generally dark brown compost. If the particles would be dark brown as well, it would be impossible to distinguish them from the compost, and recovery rates would be much lower.

Extrapolation to other facilities in the Netherlands
Pre-treatment processes on incoming GFT, such as sieving, grinding, and/or wind sifting, are not likely to yield more coffee capsules in residual streams.

Product H - Coffee pad
Substantial amounts of coffee pads (product H) were recovered from the mesh bags after 2 cycles of composting. After the first cycle, and in lesser extent also after the second cycle, the pads were still recognisable, mainly due to their notable round shape. If it was only for texture and colour, the pads would be barely distinguishable from the paper remains which were also significantly present in the GFT. The physical properties of the pads had deteriorated and could be torn easily by hand. Since the content of the mesh bags bypassed the regular processing and sieving procedure it was not exposed to the usual shear. It is expected that in processes in which shear is applied, fragmentation of product

H will be more pronounced. This is supported by the observation that no coffee pads were identified in any of the residual fractions of the full scale trial (Part A).
Because the Valor facility recirculates the 10-40 mm residue fraction in most cases, and also recirculates the >40 mm fraction a number of times, it is concluded that product H will be sufficiently disintegrated within the process, and will not significantly contribute to an increase in residue to be discarded. Visual contamination of the compost with small fragments is not expected, because these particles look much like the other matter of which compost is composed.

Extrapolation to other facilities in the Netherlands
Pre-treatment processes on incoming GFT, such as sieving, grinding, and/or wind sifting, are not likely to yield more coffee pads in residual streams.

Product J - Tea bag
Only 1 out of 100 added tea bags (Product J) could be recovered from the mesh bags after 2 cycles of composting. After the first cycle, some teabags could still be found, but their mechanical properties had deteriorated and they could be torn easily by hand. Because the mesh bags bypassed the regular processing and sieving procedure, their content was not exposed to the usual shear. It is expected that fragmentation of product J will be facilitated during normal operations that include shear due to turning, unloading and sieving of the processed waste.
In the full scale trial (Part A) one tea bag was identified in Fraction 3 (>40 mm) and one in fraction 5 (10-40 mm). More detailed analysis using NIR was indecisive regarding whether they were made of PLA, probably because the remains were too dark. However, their tensile strength was low, which is consistent with degraded PLA.
Based on the observations, it is concluded that product J will be sufficiently disintegrated within the waste treatment process, and will not significantly contribute to an increase in residue to be discarded, nor in visual contamination of the compost.

Extrapolation to other facilities in the Netherlands
Pre-treatment processes on incoming GFT, such as sieving, grinding, and/or wind sifting, are not likely to yield more tea bags in residual streams.

3.4.2 Reflection with regard to the co-benefit factor

In the current common practice of GFT waste processing in the Netherlands, some of the selected compostable plastic products are likely to end up in one or more of the residual streams. As discussed in section 3.4.1 this will depend on applied pre- and post-treatment processes, and on residence time, turning frequency and/or shear applied in the composting phase. Contamination of the compost by residues of the selected compostable plastic products (which may lead to rejection of the produced compost) is not likely to occur according to the observations in this trial.

The fact that compostable plastic products may end up in one or more residual streams is considered undesirable by the GFT processing facilities because it leads to additional costs for disposal of residues. In this respect the co-benefit effects of the product that compensate for these additional costs should also be regarded. One of the selection criteria for the products evaluated in this trial is the expected co-benefit of the product or application for the organic waste treatment process. For instance by increasing the separate collection of GFT and diverting typical compostable waste from landfill or incineration. Or alternatively by reducing contamination of GFT with conventional plastics (e.g. compostable versions of products that are currently typically disposed of in the GFT bin).

For some products, the (co-)benefit is evident or has already been demonstrated and/or accepted by the waste management community. For example, GFT collection bags (products A and B) have been developed to make the separate collection of GFT easier and more attractive for households, with the objective to increase the amount and quality of collected GFT, and reduce the amount of wet organic waste going to landfill or incineration. Several studies have demonstrated that the availability of biowaste collection bags indeed contributes to these objectives [13-15].

Fruit labels are used by retailers to reduce the amount of packaging while maintaining the identification and traceability in the logistic chain. It is a typical product that is destined to end up together with food waste in the GFT. The benefit of a compostable fruit label (Product F) is prevention of the contamination of compost with plastic particles by replacing a persistent plastic by one that degrades during waste treatment (and the maturation and application phase of the compost).

The other selected products (C, D, E, G, H and J) are compostable alternatives for packaging products that contain conventional plastics, and are often disposed of together with their wet organic content in the GFT bin, i.e. plant pots, tea bags, coffee pads and coffee capsules. The (co-)benefit of these products is threefold:

- avoid having to educate households not to dispose these products in the GFT bin, against what they have gotten accustomed to (because it was accepted previously).
- prevent contamination of compost with plastic particles by replacing a persistent plastic by one that degrades during waste treatment.
- Increase the total amount of biowaste in GFT.

With regard to the latter, we introduce the *co-benefit factor*, which is the ratio between the wet organic content and the plastic packaging. When this ratio is high, every kilo of accepted packaging product brings along a multiple amount of wet organic waste into the GFT. Table 14 shows the co-benefit factor for the plant pots (products C and D), the tea bags (products E and J), the coffee capsules (product G) and the coffee pads (product H). They were determined by separately weighing the packaging product and its (wet or dry) content.

Table 14 Co-benefit factor of selected products

Product	C	D	E	G	H	J
Co-benefit factor (kg dry content/kg packaging)	4.4	7.8	7.2	1.6	8.8	3.3
Co-benefit factor (kg wet content/kg packaging)	*19*	*29*	*44*	*5*	*28*	*23*

The co-benefit factor calculated from the dry content is in fact the minimum ratio between the weight of content and packaging. In reality, the content will not be completely dry and will contain more moisture than the plastic can take up. The business model for waste treatment facilities, however, uses disposal rates for incoming waste based on wet weight, which makes it more relevant to take the wet weight of the content into account. Of course this may vary somewhat as the moisture content of, for example a used coffee pad, when it arrives at the waste treatment facility depends on how it is treated before disposal and the conditions during transportation. But an estimation is given in Table 14 based on measurements of the moisture content in a typical disposal state after use.
A co-benefit factor of 23 for product J means that every kg of PLA tea bags comes with 23 kg of wet tea leaves as compostable waste.

The co-benefit factor of the organic waste collection bags (products A and B) is more complicated to estimate, and therefore not given in Table 14. Assuming that a GFT collection bag of 5 grams is used to collect 1 kg of wet weight GFT would result in a co-benefit factor of 190 (kg wet content/kg plastic). This is much higher than for the other products in this trial, but only valid if this amount of GFT would not be collected at all if no GFT collection bag was used. However, it is likely that at least part of this amount of GFT also would have been collected without the use of compostable bags, either by direct disposal in the GFT-bin or by using alternative carriers such as paper or conventional non-compostable bags. Although there is evidence that the availability of compostable biowaste collection bags increases the separate collection of GFT and diverting typical compostable waste from landfill or incineration [13-15], it is unrealistic to assume that no GFT is collected without these products.

3.4.3 Summary of the discussion

The discussions in sections 3.4.1 and 3.4.2 lead to a qualification of the disintegration rate and fate of the selected compostable products in the process currently in practice for the treatment of GFT at Valor in Sint Oedenrode. These are summarized in Table 15. It should be noted that this is a schematic representation of the expert opinion of the authors, based on all observations during a single full scale trial (including the experiences with the mesh bags) performed in February-October 2019.

Table 15 ***Qualification of the disintegration rate of tested compostable products, their risk of ending up in discarded residue fractions or contaminating the final compost.*** *(NB. expert opinion of the authors based on all observations in the organic waste treatment trial performed at the facilities of Valor, Sint Oedenrode).*

Product (code)	Co-benefit factor (kg extra GFT / kg product)	Disintegration rate	Risk of ending up in discarded residue fractions	Risk of visual contamination of compost
GFT collect. bag (A)		+	Low	Low
GFT collect. bag (B)		+	Low	Low
Plant pot (C)	+++	++	Low	Low
Plant pot (D)	+++	+++	Low	Low
Tea bag (E)	+++	++	Low	Low
Fruit label (F)		++	Low	Low
Coffee capsule (G)	++	+	Low	Possibly
Coffee pad (H)	+++	++	Low	Low
Tea bag (J)	+++	+++	Low	Low

Disintegration rate:
All selected test products score positive with regard to their disintegration rate because they all showed substantial fragmentation and loss of mechanical strength within the two composting cycles. The full PLA products (product D and product J) score the highest (+++) as they could not be found in the waste anymore after just one composting cycle of 11 days. Products C, E, F and H score a little lower (++), because some fragments, although difficult to distinguish from the compost, could still be identified upon close examination of the content of the mesh bags after two cycles of composting. Products A, B and G score the lowest (+) of selected test objects. With these products, substantial fragmentation and loss of mechanical strength was observed within two composting cycles of 11 days, but fragments were still recognisable as (deteriorated) plastics.

Risk of ending up in discarded residue fractions:
Even though the scores of the disintegration rate vary between products, the risk of ending up in discarded residue fractions is considered low for all tested compostable products. Because the Valor facility recirculates the 10-40 mm residue fraction in most cases, and also recirculates the >40 mm fraction a number of times, it is concluded that the true residence time will be sufficient for complete disintegration so the tested products will not significantly contribute to an increase in residue to be discarded.

Risk of visual contamination of compost:
Due to the bright colours used in the coffee capsules (Product G), even tiny fragments are conspicuous and recognisable in the generally dark brown compost. Fragments of partially disintegrated coffee capsules are likely to pass the 10 mm sieve in the Valor process and thus end up in the compost fraction. Based on the fact that the product is certified according to EN 13432, it is likely that degradation of the material will continue during maturation and use of the compost to complete biodegradation. But if the compost is used shortly after its production, which is regularly the case at Valor, the brightly coloured particles of product G will contribute to the (visible) contamination of the compost. For all other tested products, the risk of visual contamination of the compost is considered low because in case disintegrated fragments should pass the 10 mm sieve, they will not be easily recognised as plastic contaminants. In the trial it needed dedicated attention and a trained eye to distinguish them from the other organic matter in the compost due to their similar shape and colour.

3.5 Conclusions

After a waste treatment cycle of 11 days approx. 21% of the processed waste ended up in the compost fraction (i.e. <10 mm). The largest part was the 10-40 mm fraction (approx. 70%) which during normal operation at the selected facility is recirculated in the waste treatment process. The main residue fractions consisted predominantly of organic matter (justifying their recirculation at Valor) and contain only low amounts of plastics: the largest residue fraction (10-40 mm) contained approx. 1% of plastics by weight.

One waste treatment cycle of 11 days is for most selected products not sufficient to completely disintegrate them. Orange peel and banana skin, introduced as reference materials, were also not disintegrated within one cycle of 11 days.

For some products (in this trial the full PLA plant pot, product D), one waste treatment cycle of 11 days is sufficient for complete disintegration, which is significantly faster than the reference products orange peel and banana skin. This is attributed to the type of material the product is made of (i.e. PLA) rather than its thickness.

According to the observations in this trial, the selected compostable plastic products are not likely to cause visual contamination of the final compost with plastic residues.

All selected compostable plastic products in this trial are not expected to contribute significantly to the residue to be discarded in the waste treatment process operated at Valor because of their recirculation procedure.

Extrapolating the findings to other processes operated in the Netherlands, it is expected that in some waste treatment facilities, some of the selected compostable products will end up in fractions that are discarded, but this will depend on the pre-treatment processes installed, the residence time in the composting phase, the turning frequency and the shear it encounters before and during post-treatment.

Due to the bright colours used in the coffee capsules (Product G), even tiny fragments are conspicuous and recognisable in the generally dark brown compost. If the particles would be dark coloured as well, they are indistinguishable from the compost, and recovery rates (contamination) would be much lower.

4 Conventional plastic contamination in compost

4.1 Introduction

Compost has to meet strict quality requirements. Since it is used in agriculture it is highly undesirable that compost would be a carrier for (plastic) pollution. Although at present contamination of compost with glass is the biggest issue for the compost market, in the public opinion the visual contamination with plastic receives the most attention.

The average visual contamination of compost produced from organic waste (GFT) in the Netherlands is shown in Table 16 [10]. Plastic contamination is measured in the fraction of particles larger than 2mm that predominantly consist of plastics. From Table 16 it can be observed that the contamination level is around 0.1%.

Table 16 Visual contamination of compost produced from GFT as measured in 2016, 2017 and 2018 [10]

Amount based on dry matter	2016	2017	2018
Contaminants > 2mm (mainly plastic) [wt-%]	0.04	0.03	0.04
Stone > 5mm [wt-%]	0.43	0.34	0.51
Glass, 2-20 mm [wt-%]	0.06	0.05	0.07
Total contamination excl. stone [wt-%]	0.11	0.09	0.11

The implementation decision of the Manure and Fertilizers Act [16] state that compost cannot contain more than 0.5% by weight of foreign non-biodegradable parts. To allow certification according to the "Keurcompost" certification scheme, compost has to fulfil additional requirements [12]. Maximum allowed contamination levels are a part of the certification scheme and requirements on visual pollution are listed in Table 17.

Table 17 Maximum allowed visual contamination of compost according to the "Keurcompost" certification scheme [12]

Amount based on dry matter	Keurcompost Class A	Keurcompost Class B	Keurcompost Class C
Other Contaminants > 2mm (mainly plastic) [wt-%]	≤0.05	≤0.10	≤0.20
Stone > 5mm [wt-%]	≤1.00	≤2.00	≤2.00
Glass, 2-20 mm wt-[%]	≤0.05	≤0.10	≤0.20

The average visual plastic contamination would qualify for Keurcompost Class A, but the contamination levels are close to the maximum allowed levels. The average visual pollution with glass is too high to allow certification according to Keurcompost Class A. It is expected that regulations will become more strict in the future whereas it will be more difficult (and costly) to maintain current contamination levels.

In order to get a better understanding of the origin of the plastic contamination in compost, samples of the contaminants isolated during regular quality measurements were further analysed with regard to polymer type.

4.2 Analysis

Plastic particles originating from compost quality measurements were provided by the Dutch Waste management Association. These plastic particles have been extracted from compost over the past years. A random set of samples was selected for NIR identification. Piece by piece plastic particles were analysed by NIR. The NIR scanner identifies PE, PP, PET, PS, PVC, PLA, PC, PMMA, PA, PUR and cellulose. In total 85 grams of particles were analysed and about 62 grams of these particles were identified as plastics. After sorting, pictures were taken and the film fraction and the fraction rigid plastics were weighed separately.

4.3 Results and discussion

The material composition of the plastic particles found in compost is shown in Figure 20Figure 20 Composition of plastic particles (contamination) found in compost. All identified plastics were non-biodegradable, conventional plastics. Analysis shows that the main material found is PP. The amount of PP is significantly larger than the amount of PE. This was surprising because as shown in Section 2 the plastic material most commonly found in GFT was PE.

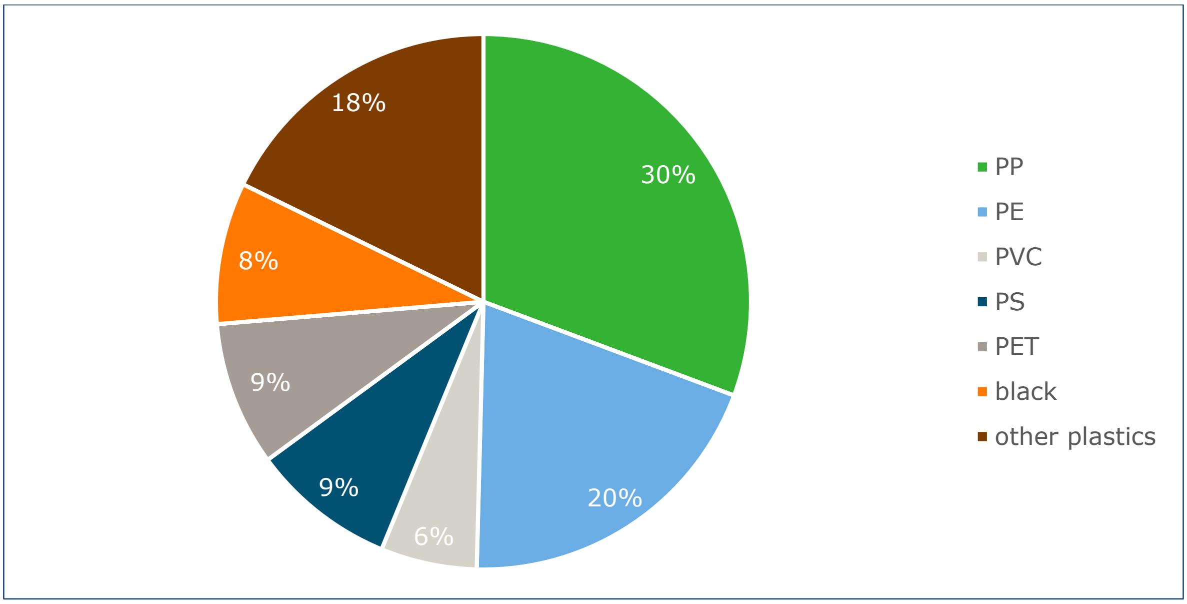


Figure 20 Composition of plastic particles (contamination) found in compost

Table 18 gives an overview and comparison of the presence of PP, PE, PET, PS and PVC found in respectively compost, GFT, and the plastic packaging present at households (i.e. the plastic packaging potential [6]). The fractions of PP, PS and PVC found in compost are rather high compared to those found in GFT. As compared to the plastics packaging potential, the fraction of PET found in compost is low and the fractions of PP, PVC and PS found in compost are high.

Table 18 Composition in the 5 main polymer types found in compost, GFT and according to the plastic packaging potential, including data from [6]

Polymer type	Found in Compost (%)	Found in GFT (%)	Packaging potential (%)
PP	41	36	24
PE	27	45	41
PET	8	15	26
PS	12	3	6
PVC	12	1	3

Based on Table 18 it is difficult to directly relate the plastic fragments found in compost to plastics found in GFT or plastic packaging present at households. For some polymer types (PP and PE) pictures give some insight (see Annex 13) as some fragments can be recognized as parts of caps and closures. Separating flexible (film) fragments from rigid fragments and objects could help to understand plastic contamination in compost (see Table 19, Figure 21 and Figure 22).

Table 19 ***Plastics found in compost separated by polymer type and packaging type (rigid or flexible film)***

Polymer type	Total (g)	Film (%)	Rigid (%)
PP	19	34	66
PE	12.2	76	24
PVC	3.6	36	64
PS	5.4	6	94
PET	5.4	22	78
Nor NIR	5.3	2	98
Other plastics	11	53	47
Total	61.9	40	60

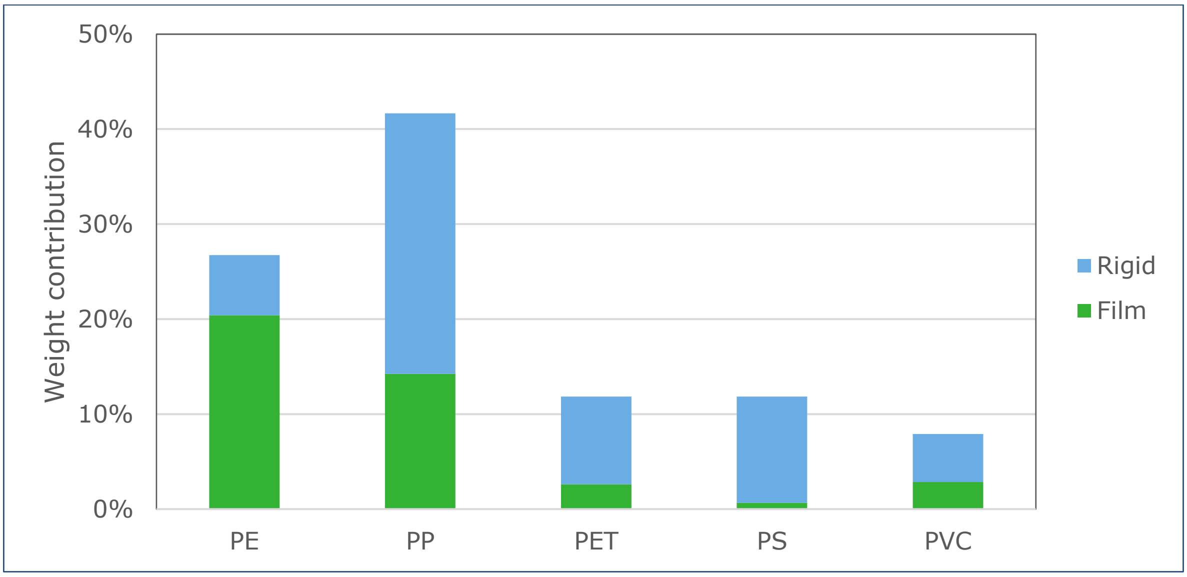


Figure 21 ***Relative amount of main plastics types found in compost; film versus rigids***

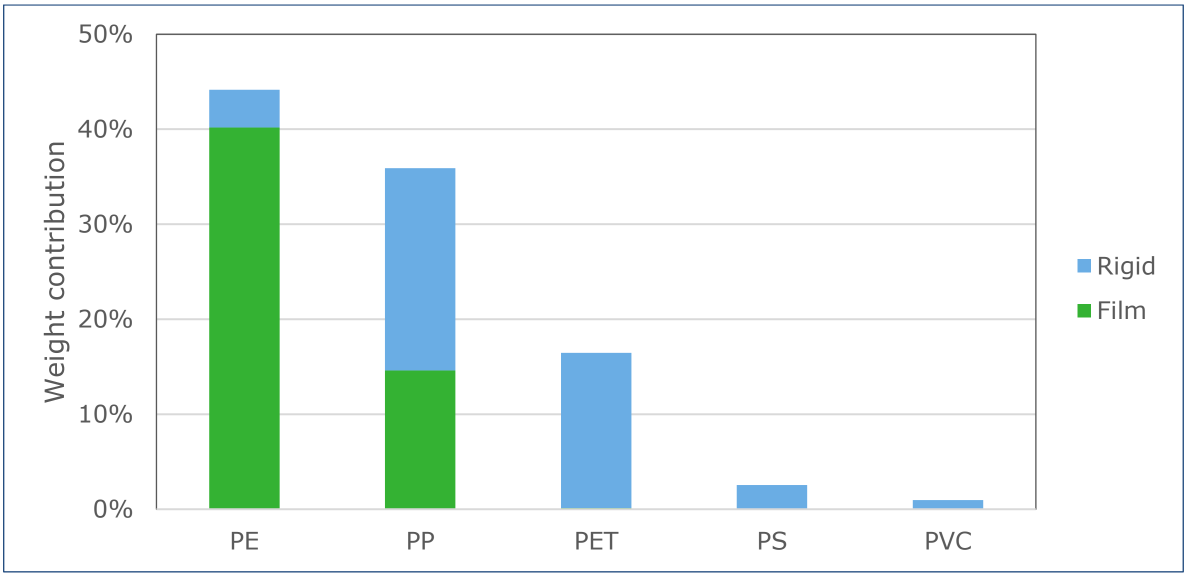


Figure 22 Relative amount of main plastics types found in GFT; film versus rigids

For most polymer types found in compost, the rigids form the largest fraction (based on weight) compost, although the flexible film fragments are more visible (see the pictures in Annex 13). Only for PE, the main contaminants in compost were in the form of flexible film. The largest category of fragments found in compost is derived from rigid PP products, and in this category caps and closures could be identified (see Annex 13). Also small PE based closures are found as a contaminant in GFT.

Comparing Figure 21 and Figure 22 suggests that some plastic articles are more easily removed than others in the process from GFT to compost, such as PE film of a sufficient size and PET bottles. As opposed to (parts of) caps and closures which appear more difficult to remove during the treatment process. Moreover, some smaller plastic parts may be overlooked during sampling of GFT. Additionally it must be stated that data is based on 1 measuring point for the plastic composition in GFT and seasonal influences may substantially affect the outcome.

4.4 Conclusions

No compostable plastics were identified amongst the plastic fragments found in compost. No clear relation was observed between the plastic fragments found in compost and the composition of plastic materials found in GFT or the composition of the packaging materials used by households. PP is the main polymer found in compost. More rigid plastics than flexible films were found in compost which does not match with the results for the plastics found in GFT described in section 2. Various pieces of caps an closures could be recognised in compost but other packaging objects could not be identified because the particles are small and dirty.

There is no clear relationship between the plastic fragments found in compost and food packaging. The cause for the relative high amounts of PS and PVC based particles found in compost is unknown.

5 Overall conclusions

The composition of the current contamination of conventional plastics in GFT was analysed with regard to polymer type and packaging type. The analysis showed that the amount of non-degradable plastic was higher than the amount of compostable waste bags used to collect GFT. Relatively high amounts of flexible packaging (films) and flower pots indicate that a part of the contamination can be explained by the association of the packed product with organic waste. Nevertheless, a substantial part of the plastic products is either accidentally or intentionally disposed of with GFT.

The composition of the current visual contamination of conventional plastics in compost was also analysed with regard to polymer type (and packaging type where possible). No compostable plastics were identified amongst the plastic fragments found in compost. No clear relation was observed between the plastic fragments found in compost and the composition of plastic materials found in GFT or the composition of the packaging materials used by households. The main material found in compost is PP. In compost more rigid plastics were found than flexible films, whereas in GFT it was the other way around. Various pieces of caps and closures were found in compost but the majority of the recovered fragments were too small or dirty to be able to attribute them to specific packaging products. No clear relationship was observed between the plastic fragments found in compost and food packaging. The causes for the relative high amounts of PS and PVC based particles found in compost remain unexplained.

A full scale commercial organic waste treatment trial representing the current practice in the Netherlands was performed to study the fate of (compostable) packaging products when processing GFT.

In this trial, roughly 20% of the processed GFT that was unloaded from the tunnel after a waste treatment cycle of 11 days passed the sieves <10 mm and is the compost fraction. The rest mainly ended up in two residual fractions, the largest part (roughly 70%) in the 10-40 mm fraction which during normal operation at the selected facility are recirculated in the waste treatment process. The other 10% ended up in the >40 mm fraction which usually is also recirculated, but discarded when too much pollution accumulates, in practice a few times per month. The fractions that are always discarded (i.e. metals and hard items) are relatively small and have a marginal effect in the total mass balance.

The main residue fractions (10-40 mm and >40 mm) consisted predominantly of organic matter (which is consistent with the short composting time, i.e. a total cycle of 11 days with only a few days above 50°C) and contain only low amounts of plastics. The largest residue fraction (10-40 mm) contained approx. 1% of plastics by weight.

One waste treatment cycle of 11 days was for most selected products not sufficient to completely disintegrate. Orange peel and banana skin, introduced as reference materials, were also not disintegrated within one cycle of 11 days. For some products (in this trial for example the full PLA plant pot, product D), one waste treatment cycle of 11 days was sufficient for complete disintegration, which is significantly faster than paper and most organic matter, including the reference products orange peel and banana skin. This is more attributed to the type of material the product is made of than its thickness because thin compostable waste bags were not completely disintegrated within one cycle of 11 days.

Due to the bright colours used in the coffee capsules (Product G), even tiny fragments are conspicuous and recognisable in the generally dark brown compost. If the particles would be dark coloured as well, they are indistinguishable from the compost, and recovery rates (visual contamination) would be much lower.

According to the observations in this trial, none of the selected compostable plastic products are likely to cause visual contamination of the final compost with plastic residues. They are also not expected to contribute significantly to the residue to be discarded in the waste treatment process operated at Valor because they will further decompose when the residue fractions are recirculated and composted in the next cycle.

When these findings are extrapolated to the other waste treatment facilities operating in the Netherlands, it is expected that in some processes, some of the selected compostable products will end up in fractions that are discarded, but this will depend on the pre-treatment processes installed, residence time in the composting phase, the turning frequency and the shear it encounters before or during post treatment. The additional costs associated with disposal of this increase in residue will need to be compensated with the co-benefit of these products for the waste treatment process.

Literature

1. Rijkswaterstaat (2018) Afvalverwerking in Nederland: Gegevens 2017. Werkgroep Afval registratie, Rijkswaterstaat, Utrecht: ISBN 978-94-91750-21-2. (*www.afvalcirculair.nl/publish/pages/156829/afvalverwerking_in_nederland_gegevens_2017_def.pdf*).
2. Rijkswaterstaat (2019) Samenstelling van het huishoudelijk restafval, sorteeranalyses 2018; Gemiddelde driejaarlijkse samenstelling 2017. Rijkswaterstaat, Utrecht. (*www.afvalcirculair.nl/publish/pages/162286/samenstelling_huishoudelijk_restafval_2018.pdf*).
3. VANG Uitvoeringsprogramma VANG - Huishoudelijk Afval, Herijking 2018 – 2020 (*www.vang-hha.nl/publish/pages/106281/uitvoeringsprogramma_vang-hha_2018-2020.pdf*).
4. A. Oerlemans (2019) Inwoners van de Drechtsteden gooien veel te veel plastic en glas in hun groente-, tuin- en fruitafval. AD 02-05-2019 (*www.ad.nl/dordrecht/inwoners-van-de-drechtsteden-gooien-veel-te-veel-plastic-en-glas-in-hun-groente-tuin-en-fruitafval~ac935644/*)
5. EN 13432 (2000) Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging. European standard EN 13432, CEN, Brussels, Belgium. ICS 13.030.99; 55.020.
6. Brouwer, M.T., et al. (2018), Predictive model for the Dutch post-consumer plastic packaging recycling system and implications for the circular economy. Waste Management, **71**: p. 62-85.
7. Rijkswaterstaat (2018) Verkenning kwaliteit deelstromen gft-afval, papier, glas en textiel uit huishoudens. VANG-HHA. (*www.vang-hha.nl/kennisbibliotheek/@204935/verkenning-kwaliteit/*).
8. Vereniging Afvalbedrijven (2019) Kwaliteit gft-afval verslechtert en leidt tot zorgen bij de compostsector (*www.verenigingafvalbedrijven.nl/userfiles/files/190219_Notitie%20kwaliteit%20gft.pdf*).
9. Thoden van Velzen, E.U., Brouwer, M.T. and Huremovic, D. (2018) Sorting protocol for packaging wastes, Wageningen Food & Biobased Research. (*www.research.wur.nl/en/publications/sorting-protocol-for-packaging-wastes*)
10. Tim Brethouwer (2019) Personal communication: Information from Vereniging afvalbedrijven.
11. ISO 16929 (2013) Plastics - Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test. International Standard ISO 16929:2013. ISO, Geneva, Switserland.
12. Beoordelingsrichtlijn Keurcompost, versie 6.1, geldend vanaf 15 mei 2018 (*www.keurcompost.nl/wp-content/uploads/images/BRL-Keurcompost-6-1_geldend-vanaf-15052018_DEF.pdf*).
13. Sarah Edwards (2018) Informing Organic Waste Collections, Eunomia, 23 April 2018. (*www.eunomia.co.uk/case_study/informing-organic-waste-collections/*).
14. Sjoerd le Noble (2017) Houten verbetert scheiding etensresten met aanrechtbakje. (*www.vang-hha.nl/nieuws-achtergronden/2017/aanrechtbakje/?utm_source=nieuwsbrief&utm_medium=e-mail&utm_term=20170221&utm_content=link_ID0ATXBG0UXBG&utm_campaign=Nieuwsbrief%20VANG-HHA%20februari%202017*).
15. Michael Kern, Hans-Jörg Siepenkothen, Thomas Turk (2018) Collection and quality of kitchen-based biowaste - Evaluation of sorting analyses., Müll und Abfall 10/2018, pp. 526-531.
16. Uitvoeringsbesluit Meststoffenwet. Geldend 01-01-2019 – 31-12-2019. (*www.wetten.overheid.nl/BWBR0019031/2019-01-01*).

Annex 1 Packaging list used for sorting

PET bottle clear ≤ 0.5 litre
PET bottle coloured ≤ 0.5 litre
PET bottle clear > 0.5 litre
PET bottle coloured > 0.5 litre
PE beverage bottles
PP beverage bottles
PS beverage bottles
Misc. beverage bottles
PET non-beverage bottles
PE non-beverage bottles
PP non-beverage bottles
Misc. non-beverage bottles
PET thermoforms & rigids
PE thermoforms & rigids
PP thermoforms & rigids
PVC thermoforms & rigids
PS thermoforms & rigids
Carriage bags (PE) > A4
Carriage bags (PE) < A4
PET flexible packages > A4
PET flexible packages < A4
PE flexible packages > A4
PE flexible packages < A4
PP flexible packages > A4
PP flexible packages < A4
PVC flexible packages > A4
PVC flexible packages < A4
PS flexible packages > A4
PS flexible packages < A4
Rigid packages made from non-NIR identifiable plastics
Flexible packages made from non-NIR identifiable plastics > A4
Flexible packages made from non-NIR identifiable plastics < A4
Misc. plastics (PC, PLA, etc.)
Laminated flexible packages and blisters
EPS trays
EPS blocks
Silicone tubes
PET non-packages
PE rigid non-packages
PE film non-packages
PP non-packages
PVC non-packages
PS non-packges
non-NIR identifiable non-packages
Beverage cartons
Metals
Organics & undefined
Textiles
Paper & cardboard
Glass
MAD
Total weight

Annex 2 Analysis on packaging type of plastics found in GFT

Plastics found in GFT	Gross weight (g)	Gross contribution (%)	Remarks
PET beverage bottles (all)	581	1,7	Independent of size and colour
PE beverage bottles	106	0.3	
PP beverage bottles	0	0.0	
PS beverage bottles	0	0.0	
Misc. beverage bottles	0	0.0	
PET non-beverage bottles	400	1.2	
PE non-beverage bottles	261	0.8	
PP non-beverage bottles	260	0.8	
Misc. beverage bottles	0	0	
PET thermoforms & rigids	2638	7.9	
PE thermoforms & rigids	508	1.5	
PP thermoforms & rigids	2967	8.9	
PVC thermoforms & rigids	214	0.6	
PS thermoforms & rigids	562	1.7	
Carrier bags PE (all)	1522	4.6	Independent of size
PET flexible packages (all)	24	0.1	Independent of size
PE flexible packages (all)	6444	19.3	Independent of size
PP flexible packages (all)	3238	9.7	Independent of size
PVC flexible packages (all)	0	0.0	
PS flexible packages (all)	0	0.0	
Rigid packages not-NIR identified	1230	3.7	Black or dark coloured
Flexible packages not-NIR identified	4296	12.8	Black or dark coloured, all sizes
Misc. plastics (PC, PLA, etc)	139	0.4	
Laminated flexible packages	572	1.7	
PVC blisters	40	0.1	
EPS trays	0	0.0	
EPS blocks	0	0.0	
Silicone tubes	0	0.0	
PET non-packages	0	0.0	
PE rigid non-packages	0	0.0	
PE film non-packages	134	0.4	
PE film non-packaging bags	734	2.2	Additional category
PP non-packages	840	2.5	
PVC non-packages	6	0.0	
PS non-packages	65	0.2	
Not-NIR identified non-packages	973	2.9	Black or dark coloured
PE waste collection bags	275	0.8	Additional category
PE film with content	936	2.8	Additional category
PP flower pots	1139	3.4	Additional category
PP rigids with content	348	1.0	Additional category
Other flower pots (not NIR)	1986	5.9	Additional category, black or dark coloured
Total plastics sorted	**33,438**	**100%**	
Plastics that could not be sorted	9260		
Compostable waste bags	11669		Additional category

Annex 3 Bottles and flasks found in GFT

PE beverage bottles

PE non-beverage bottles

PP non-beverage bottles

PET bottles

PET flasks

Annex 4 Rigid packaging found in GFT

PE rigids

PP thermoforms and rigids

Rigid PET objects

PS thermoforms and rigids

PP flower pots

Flower pots, not NIR identified

Rigid packaging, not NIR identified

Annex 5 Flexible packaging found in GFT

PE carrier bags

PE based flexible packaging

PE film, non-packaging bags

PE waste collection bags

PP flexible packages

PET film

Flexible film not NIR identified

Annex 6 Non-packaging plastics in GFT

PE film, non-packaging

PP non-packaging

PS non-packaging

PVC non-packaging

Non-packaging, not NIR identified

Annex 7 Biodegradable products in GFT

PLA

Biodegradable waste bags

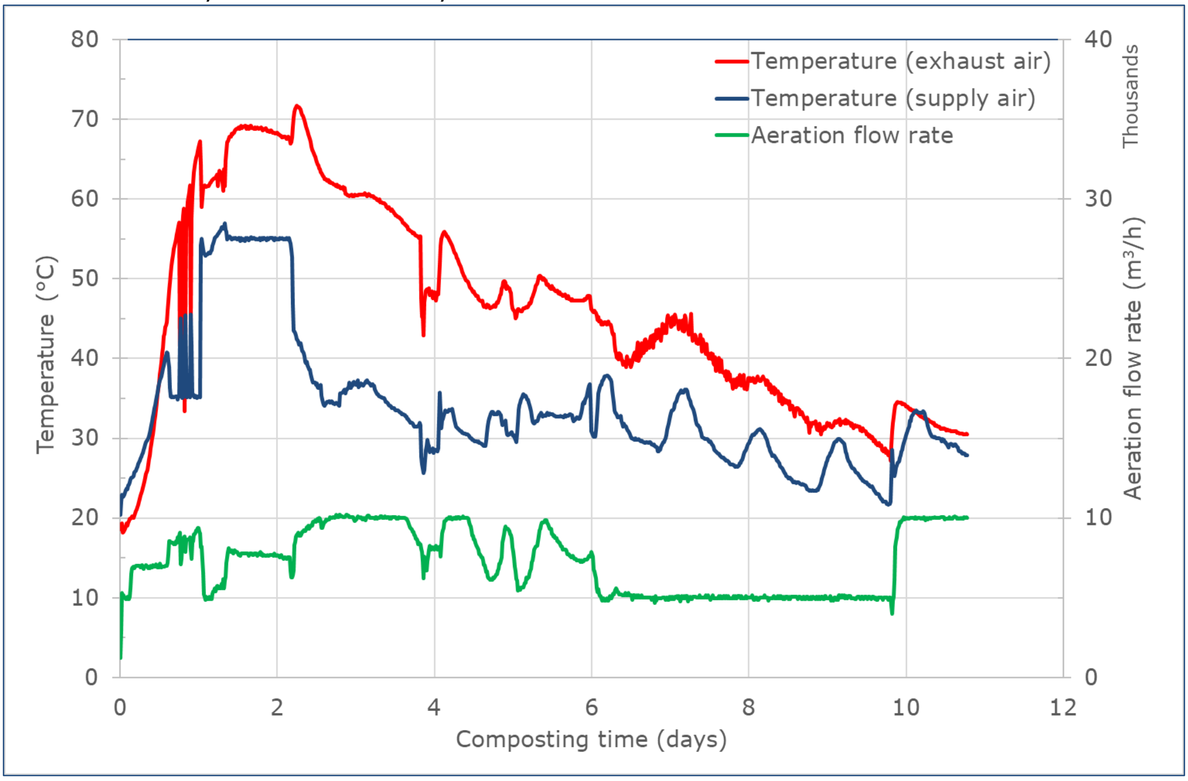
Annex 8 Other packaging found in GFT

PVC blisters

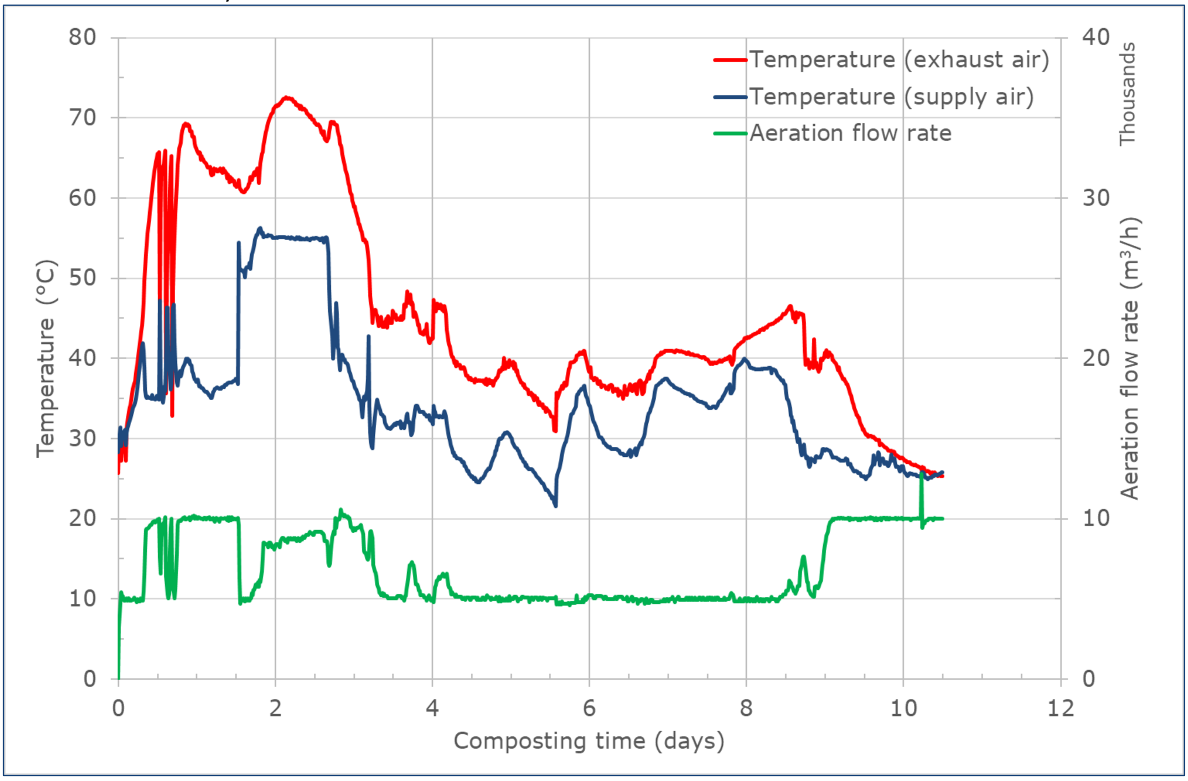
Laminates

Annex 9 Technical parameters of organic waste treatment trials

1st run: 9 February 2019 – 19 February 2019



2nd run: 19 February 2019 – 2 March 2019



Annex 10 Pictures of recovered plastics in the residual fractions 3-6

First cycle, Fraction 3 (>40 mm)

Recovered plastics

Recovered plastics (close-up)

Recovered plastics (close-up)

Recovered Product A

Recovered Product B

Recovered Product C

First cycle, Fraction 3 (>40 mm) **Duplicate sample**

Recovered plastics

Recovered plastics (close-up)

Recovered plastics (close-up)

Recovered Product A

Recovered Product B

Recovered Products E, G and J

Recovered Product E

Recovered Product G

Recovered Product J

First cycle, Fraction 4 (Hard items, >40 mm)

Recovered plastics

Recovered plastics (close-up)

Recovered plastics (close-up)

Recovered products

Recovered Product B

Recovered Product G

First cycle, Fraction 5 (10-40 mm)

Recovered plastics

Recovered plastics (close-up)

Recovered plastics (close-up)

Recovered products

Recovered Product B

Recovered Product G

Recovered Product J

First cycle, Fraction 6 (Hard items 10-40 mm)

Recovered plastics	Recovered plastics (close-up)	Recovered plastics (close-up)
		
Recovered Products		
(none)		

Second cycle, Fraction 3 (>40 mm)

Recovered plastics	Recovered plastics (close-up)	Recovered plastics (close-up)
		
Recovered Products	Recovered Product A	Recovered Product B
		
Recovered other compostable film		
		

Annex 11 Pictures of the content of the mesh bags recovered after the first organic waste treatment cycle of 11 days

Product A

A1 (mesh bag as recovered)

A1 (content of mesh bag)

A1 (close-up of content)

A1 (close-up of content)

A2 (mesh bag as recovered)

A2 (content of mesh bag)

A2 (close-up of content)

A2 (close-up of content)

Product B

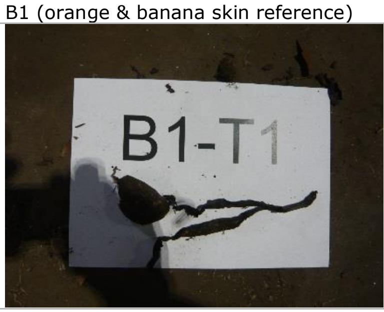
B1 (mesh bag as recovered)

B1 (content of mesh bag)

B1 (close-up of content)

B1 (close-up of content)

B1 (orange & banana skin reference)



B2 (mesh bag as recovered)

B2 (content of mesh bag)

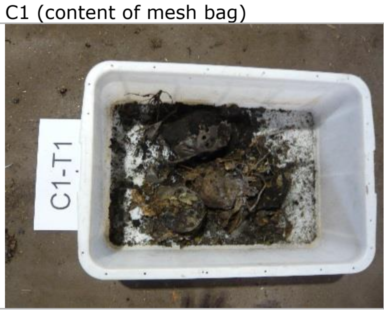
B2 (close-up of content)

B2 (close-up of content)

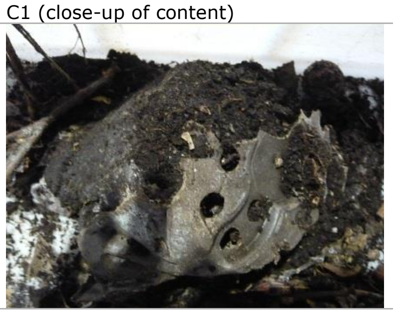
Product C

C1 (mesh bag as recovered)

C1 (content of mesh bag)



C1 (close-up of content)



C1 (close-up of content)

C2 (mesh bag as recovered)

C2 (content of mesh bag)

C2 (close-up of content)

C2 (close-up of content)

C2 (orange skin reference)

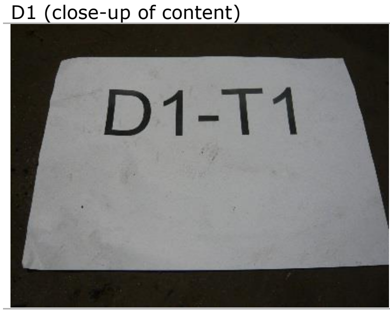
Product D

D1 (mesh bag as recovered)

D1 (content of mesh bag)

D1 (close-up of content)

D1 (close-up of content)

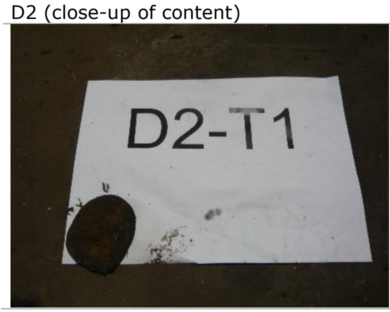


D2 (mesh bag as recovered)

D2 (content of mesh bag)

D2 (close-up of content)

D2 (close-up of content)



Product E

E1 (mesh bag as recovered)

E1 (content of mesh bag)

E1 (close-up of content)

E1 (close-up of content)

E2 (mesh bag as recovered)

E2 (content of mesh bag)

E2 (close-up of content)

E2 (close-up of content)

Product F		
F1 (mesh bag NOT recovered)		
F2 (mesh bag as recovered)	F2 (content of mesh bag)	F2 (close-up of content)
		
F2 (close-up of content)		
		

Product G

G1 (mesh bag as recovered)

G1 (content of mesh bag)

G1 (close-up of content)

G1 (close-up of content)

G2 (mesh bag as recovered)

G2 (content of mesh bag)

G2 (close-up of content)

G2 (close-up of content)

Product H

H1 (mesh bag as recovered)

H1 (content of mesh bag)

H1 (close-up of content)

H1 (close-up of content)

H1 (close-up of content)

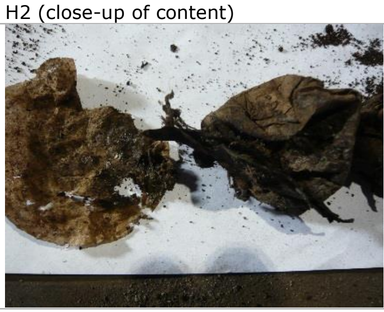
H2 (mesh bag as recovered)

H2 (content of mesh bag)

H2 (close-up of content)

H2 (close-up of content)

H2 (close-up of content)



H2 (close-up of content)

Product J

J1 (mesh bag as recovered)

J1 (content of mesh bag)

J1 (close-up of content)

J1 (close-up of content)

J2 (mesh bag as recovered)

J2 (content of mesh bag)

J2 (close-up of content)

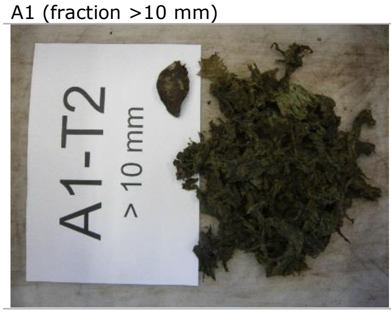
J2 (close-up of content)

J2 (close-up of content)

Annex 12 Pictures of products recovered from the mesh bags after two consecutive organic waste treatment cycles

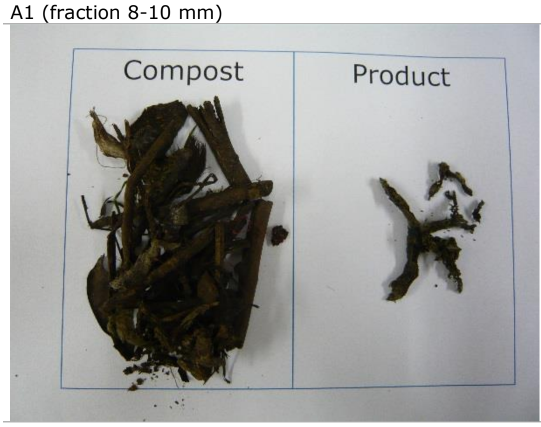
Product A

A1 (fraction >10 mm)



A2 (fraction >10 mm)

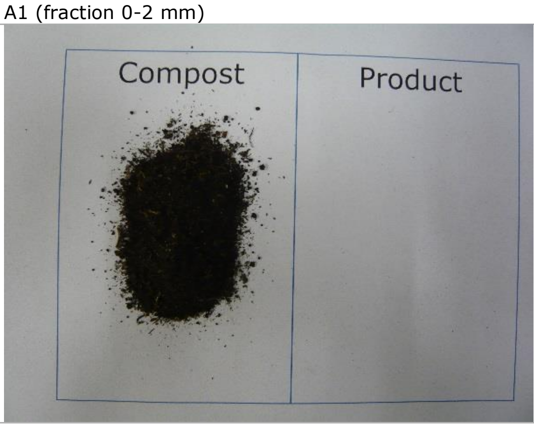
A1 (fraction 8-10 mm)



A1 (fraction 4-8 mm)

A1 (fraction 2-4 mm)

A1 (fraction 0-2 mm)

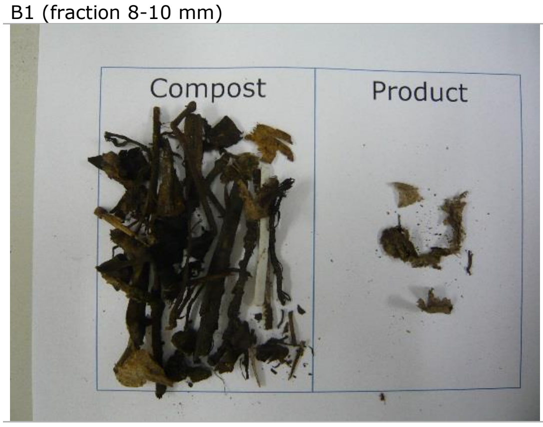


Product B

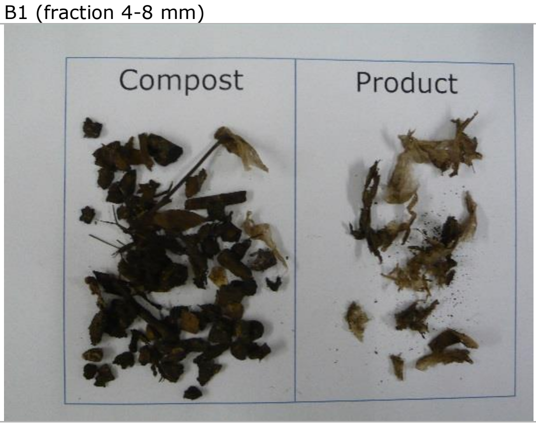
B1 (fraction >10 mm)

B2 (fraction >10 mm)

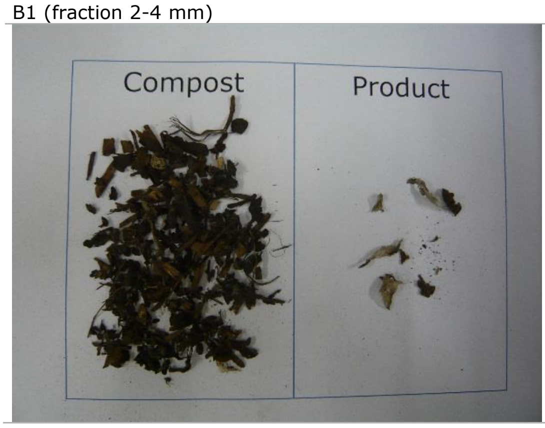
B1 (fraction 8-10 mm)



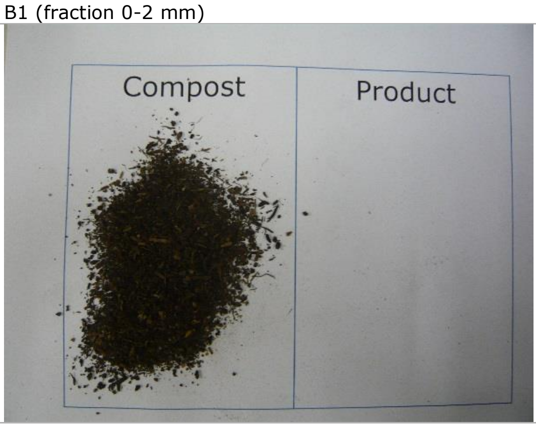
B1 (fraction 4-8 mm)



B1 (fraction 2-4 mm)



B1 (fraction 0-2 mm)

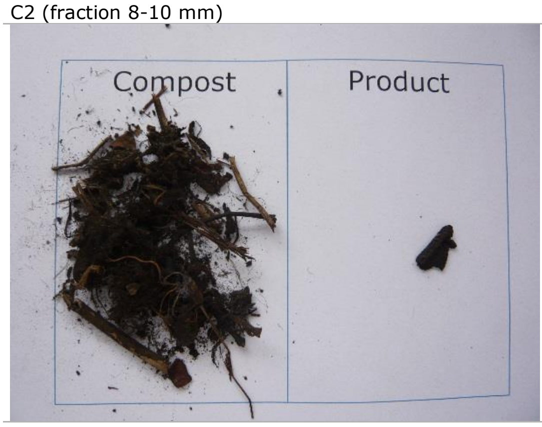


Product C

C1 (fraction >10 mm)

C2 (fraction >10 mm)

C2 (fraction 8-10 mm)



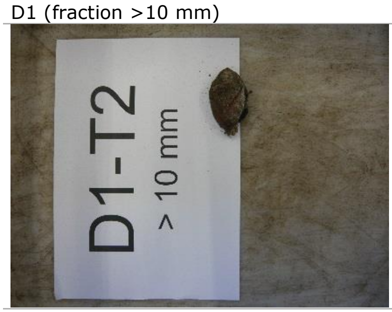
C2 (fraction 4-8 mm)

C2 (fraction 2-4 mm)

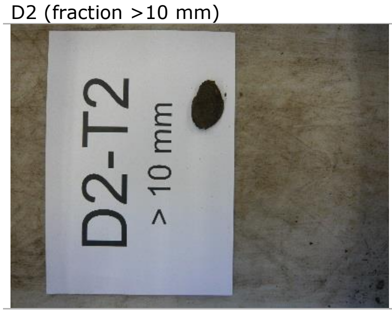
C2 (fraction 0-2 mm)

Product D

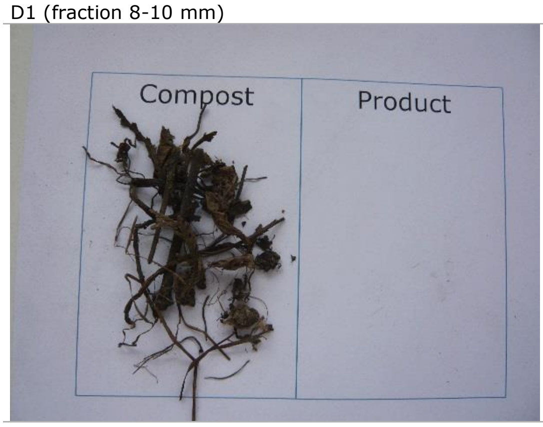
D1 (fraction >10 mm)



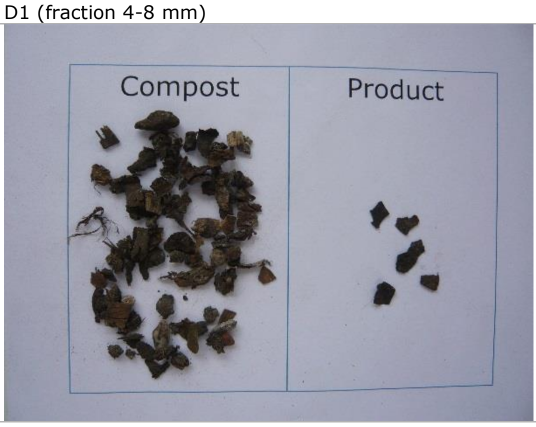
D2 (fraction >10 mm)



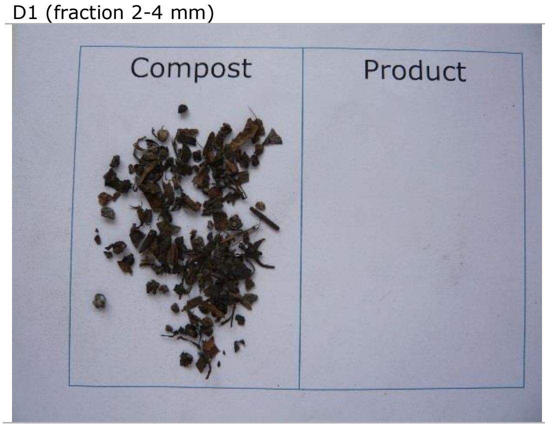
D1 (fraction 8-10 mm)



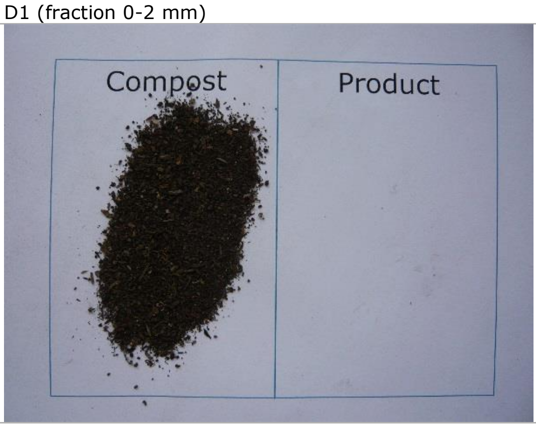
D1 (fraction 4-8 mm)



D1 (fraction 2-4 mm)

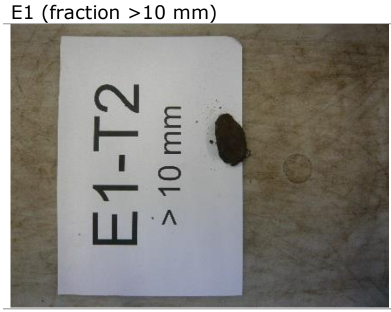


D1 (fraction 0-2 mm)

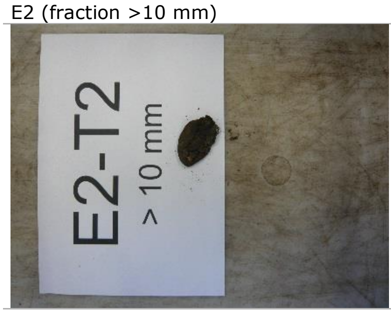


Product E

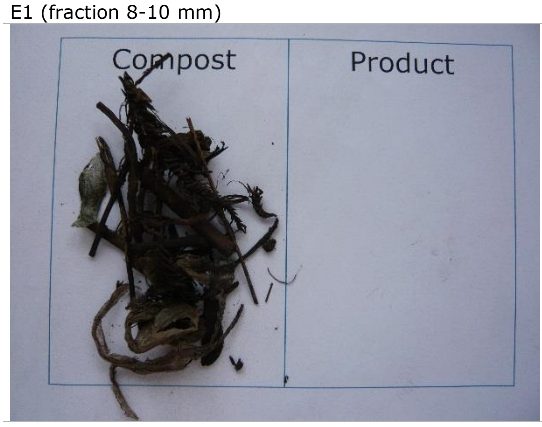
E1 (fraction >10 mm)



E2 (fraction >10 mm)

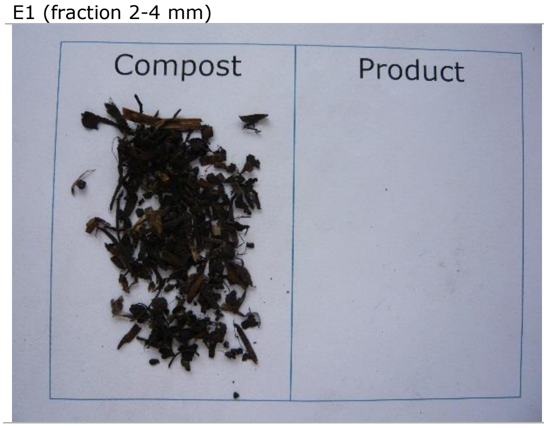


E1 (fraction 8-10 mm)

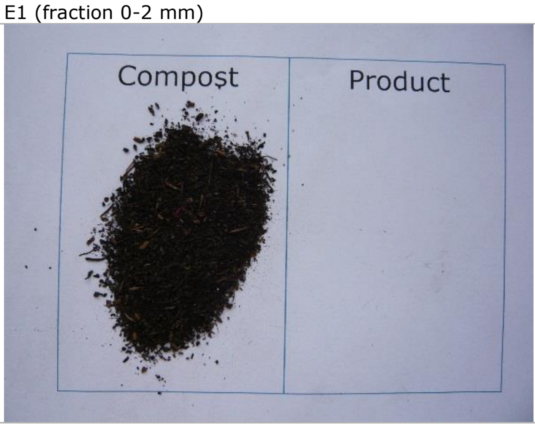


E1 (fraction 4-8 mm)

E1 (fraction 2-4 mm)



E1 (fraction 0-2 mm)



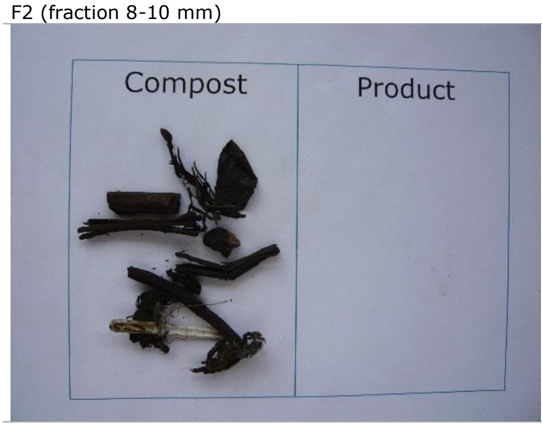
Product F

F1 (fraction >10 mm)

Mesh bag not recovered

F2 (fraction >10 mm)

F2 (fraction 8-10 mm)



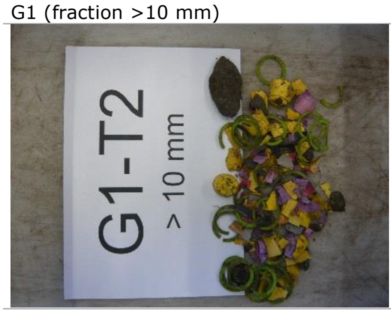
F2 (fraction 4-8 mm)

F2 (fraction 2-4 mm)

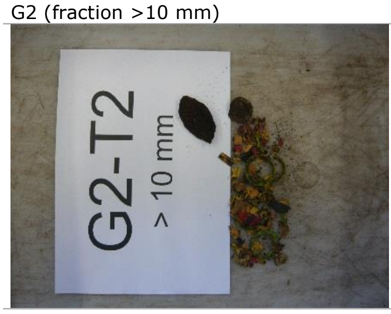
F2 (fraction 0-2 mm)

Product G

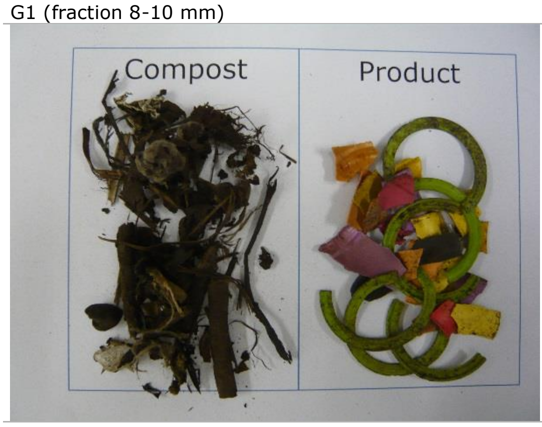
G1 (fraction >10 mm)



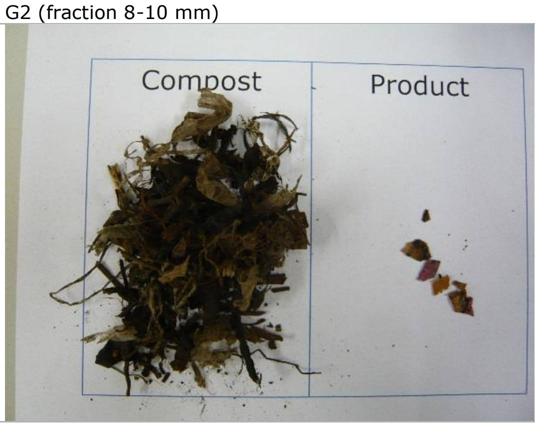
G2 (fraction >10 mm)



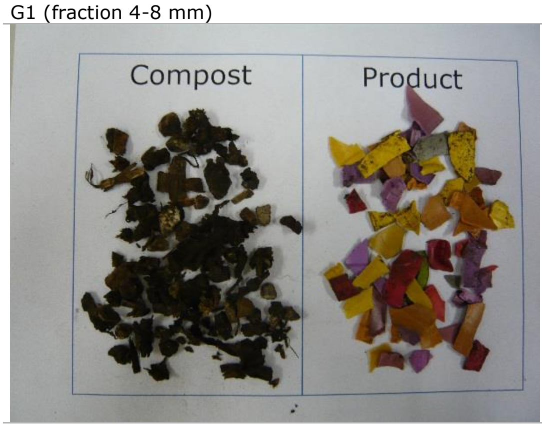
G1 (fraction 8-10 mm)



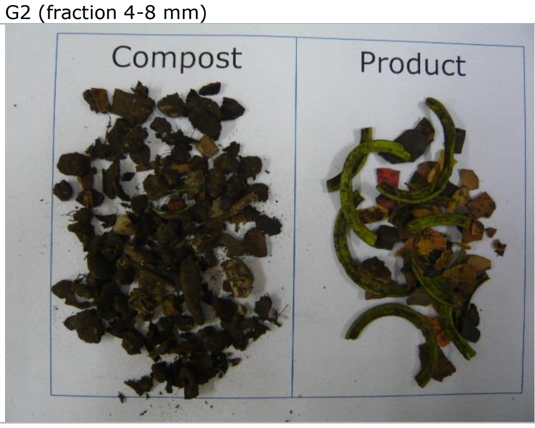
G2 (fraction 8-10 mm)

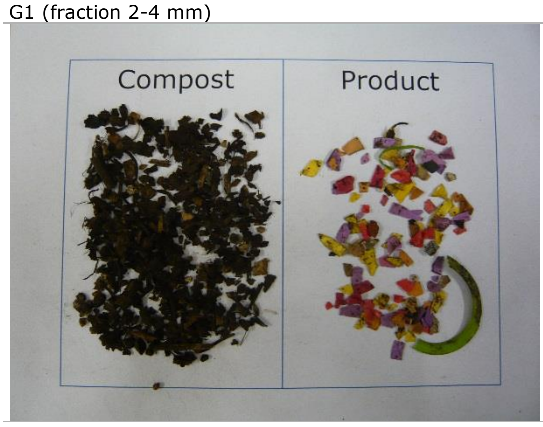
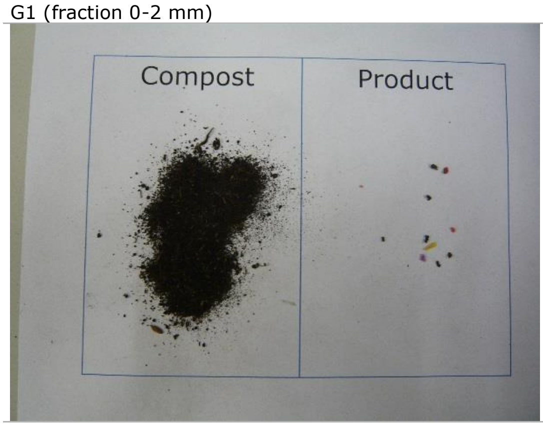
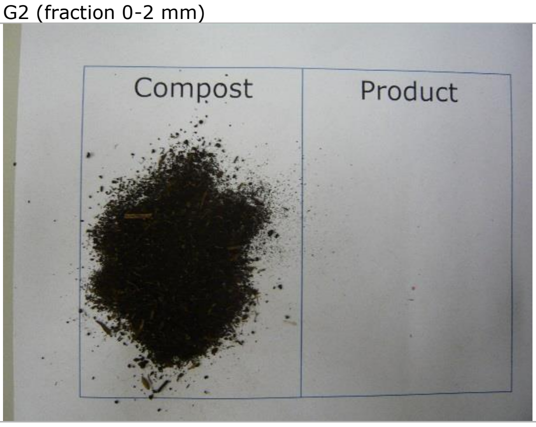


G1 (fraction 4-8 mm)



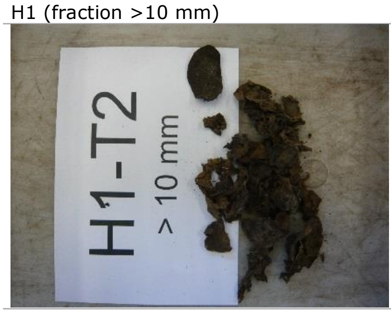
G2 (fraction 4-8 mm)



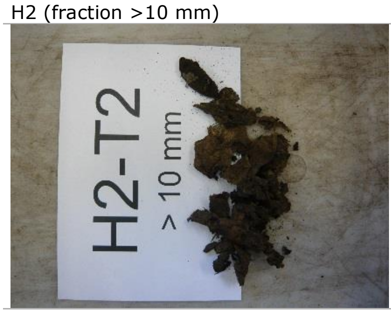
G1 (fraction 2-4 mm)	G2 (fraction 2-4 mm)
	
G1 (fraction 0-2 mm)	G2 (fraction 0-2 mm)
	

Product H

H1 (fraction >10 mm)

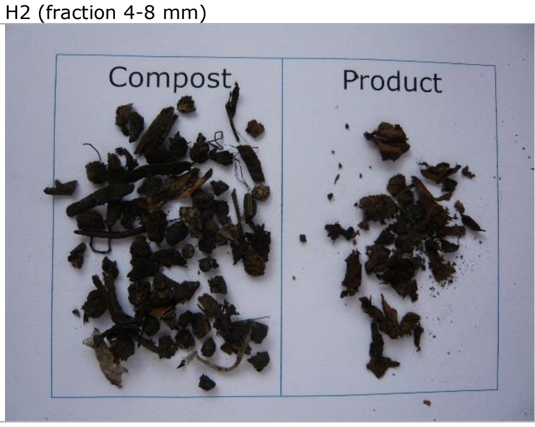


H2 (fraction >10 mm)

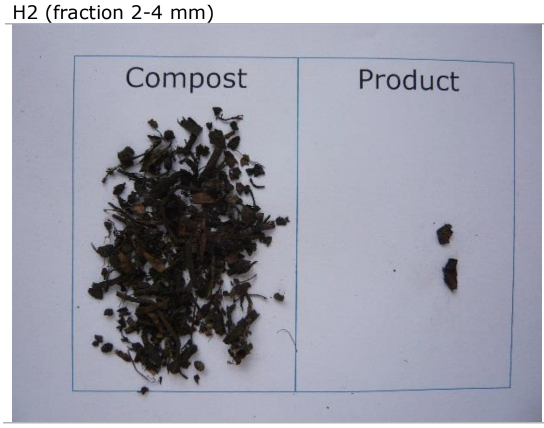


H2 (fraction 8-10 mm)

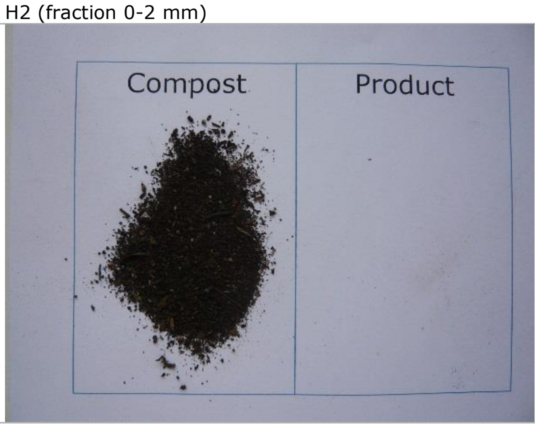
H2 (fraction 4-8 mm)



H2 (fraction 2-4 mm)

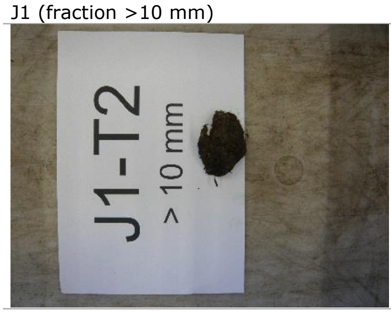


H2 (fraction 0-2 mm)



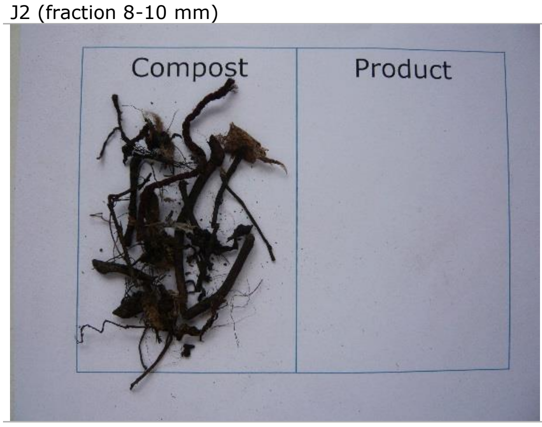
Product J

J1 (fraction >10 mm)

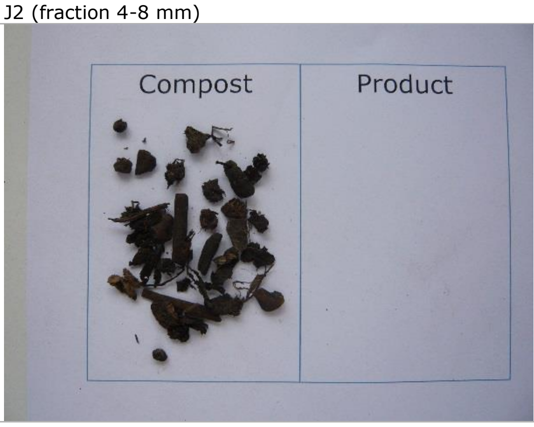


J2 (fraction >10 mm)

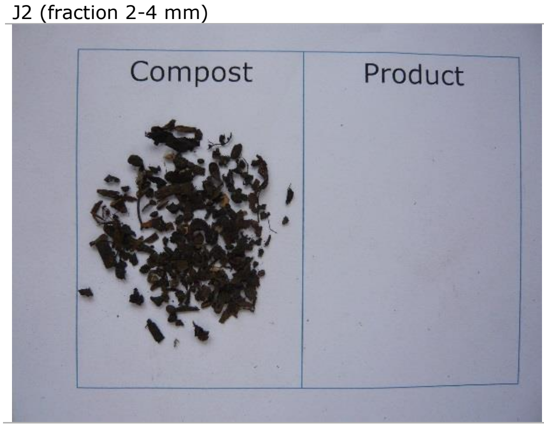
J2 (fraction 8-10 mm)



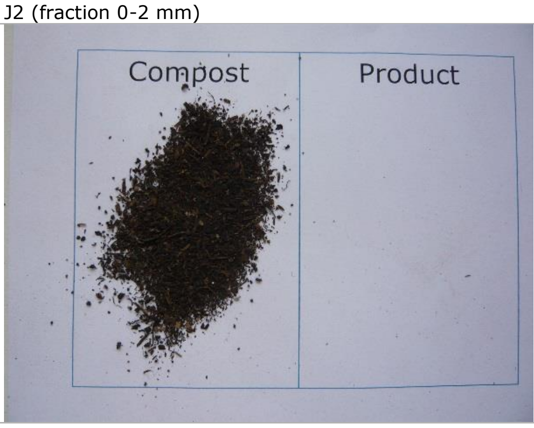
J2 (fraction 4-8 mm)



J2 (fraction 2-4 mm)



J2 (fraction 0-2 mm)



Annex 13 Plastics found in compost

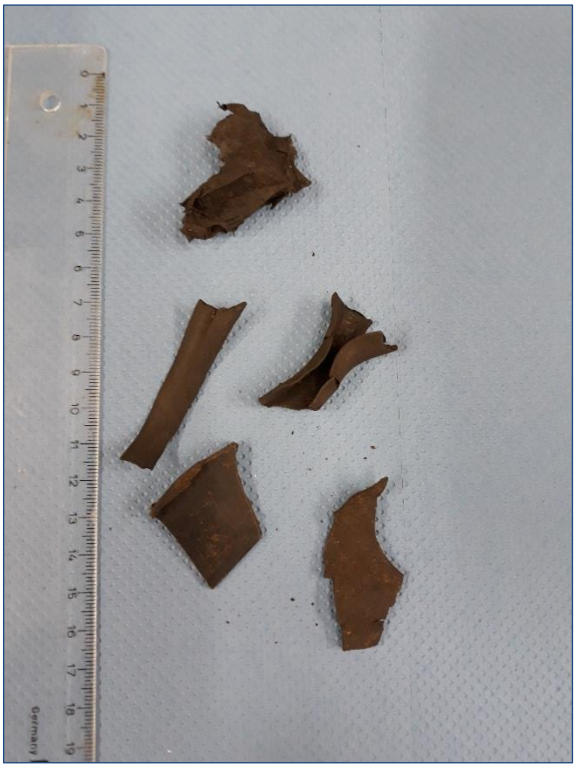
PE

PP

PET

PS

PVC



Not NIR identified

Other plastics

Not plastic

To explore the potential of nature to improve the quality of life

Wageningen Food & Biobased Research
Bornse Weilanden 9
6708 WG Wageningen
The Netherlands
www.wur.eu/wfbr
E info.wfbr@wur.nl

Report 2020

The mission of Wageningen University and Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 12,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.