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Assessment of Disintegration of Compostable Bioplastic Bags by Management of Electromechanical and Static Home Composters

Lorenzo Maria Cafiero [1,*], Margherita Canditelli [1], Fabio Musmeci [1], Giulia Sagnotti [2] and Riccardo Tuffi [1]

[1] Department for Sustainability, ENEA—Casaccia Research Center, 00123 Rome, Italy; margherita.canditelli@enea.it (M.C.); fabio.musmeci@enea.it (F.M.); riccardo.tuffi@enea.it (R.T.)

[2] Technical Assistance Unit, Sogesid c/o Ministry of the Environment, Land and Sea, 00147 Rome, Italy; Sagnotti.Giulia@minambiente.it

* Correspondence: lorenzo.cafiero@enea.it; Tel.: +39-06-3048-3332

Abstract: Interest in small scale composting systems is currently growing, and this in turn raises the question of whether the compostable bags are as suitable as in industrial composting facilities. In this work the physical degradation percentage of compostable lightweight bioplastic bags in two types of composter was examined. The main goal was to understand whether the mild biodegrading conditions that occur in electromechanical or static home composters are sufficient to cause effective bag degradation in times consistent with the householders' or operators' expectations. Bags, which complied with standard EN 13432, were composted in a number of 600 L static home composters, which were run in different ways (e.g., fed only with vegetables and yard waste, optimizing the humid/bulking agent fraction, poorly managed) and a 1 m^3 electromechanical composter. Six months of residence time in static home composters resulted in 90–96 wt% degradation depending on the management approach adopted, and two months in the electromechanical composter achieved 90 wt%. In the latter case, three additional months of curing treatment of the turned heaps ensured complete physical degradation. In conclusion, in terms of the level and times of physical degradation, the use of compostable bioplastic bags appeared promising and consistent with home composting practices.

Keywords: composting; electromechanical composter; static home composter; compostable bioplastic bags; physical degradation

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1. Introduction

With over 6 million tons of organic waste collected and treated using recycling operation (composting and anaerobic digestion) in 2017 [1], Italy achieved a satisfactory performance level among European countries in terms of organic waste management [2]. One important contribution to this achievement was compostable bioplastic bags for the separate collection of organic waste. In fact, compostable bioplastic bags decrease the contamination of the final product (i.e., compost) with macro or micro fossil plastics resulting from the use of conventional, not biodegradable, plastic shopping bags and save a not negligible portion of the organic waste with fossil plastics, which is removed by sorting systems [3].

Bioplastics represent an emerging sector: 2.11 Mt of bioplastics were produced throughout the world in 2019 and the global production capacities are predicted to reach approximately 2.42 Mt by 2024 [4]. Flexible packaging remains the largest application field for bioplastics, accounting for 43 wt% of the total bioplastics market in 2019 [4].

In Italy, the separate collection of organic waste must be done with reusable containers or with industrially compostable bags that are certified in accordance with UNI EN 13432-2002 [5] and national legislation [6]. Furthermore, in 2011, single-use plastic bags at cash registers, followed by single-use fruit and vegetable plastic bags (whose thickness is below 50 microns) in 2018, were banned in Italy and replaced with compostable bioplastic bags [6–8].

Recently, the possibility of treating organic waste in small-scale composting facilities has raised quite a lot of interest [9], especially in order to serve those geographical areas where remote and small communities (islands, mountain villages, etc.) lie away from the main logistic routes. In these cases, the municipal waste management companies have to employ costly waste collection and transportation systems; however, community and home composting of organic waste could be a cheaper and more sustainable alternative. Then, the use of compostable bioplastic bags could be a hygienic alternative that replaces standard waste bags in home and community composting too.

It must be said that, in spite of the shared name, industrial, community, and home composting involve different process intensities. Therefore, although the biodegradability of compostable bioplastic bags in industrial facilities is well ascertained, this is not the case in small scale composting installations [10]. The different conditions in home and industrial composting may lead to a significant difference in biodegradation of bioplastics. For example, Rudnik and Briassoulis [11] studied the degradation behavior of polylactic acid (PLA) plastic under home composting conditions in an 11 month period: PLA showed a very slow degradation, which was attributable to the process temperature, which was lower than that of the industrial-scale trial, which could be carried out with a higher temperature range. Needless to say, the low effectiveness of home composting is accepted by householders when the undigested residues come from garden or kitchen waste, but it could cause complaints when packaging is still found not to have completely degraded in the static home composter, especially when that packaging is expected to be "compostable".

Community composting comes between home and industrial composting [9]. In Italy, this practice is encouraged and legally defined [12,13] as "composting of the organic fraction of municipal waste collectively carried out by numerous domestic and non-domestic users to produce compost for use by the contributing users". The process is carried out using electromechanical composters (ECs) provided with forced air circulation, periodic turning of the organic mass, and temperature monitoring, which ensure that the bio-oxidation stage is accomplished. Generally, ECs are classified on the basis of the number of chambers and turning system [9]. In any case, ECs should be provided with an open space in which the curing phase be completed. Partial, stabilized, organic matter put out by the EC is arranged in a heap under a roof cover and periodically turned. The review paper of Bruni C. et al. [14] concerning the spread of community composting confirmed that this practice is at its beginning and mentions just some experiences out of Italy, two in Spain, two in Ireland, and one in Lithuania. The ECs used in that case had an input capacity from 10 to 26 t y^{-1} and a reactor volume from 0.5 m^3 to 2 m^3.

The use of compost as a microbial community and an aggressive ambient for the biodegradation or disintegration of different bioplastics has been extensively studied during the past decade, and biodegradability of bioplastics can be strongly attributed to the environment conditions (such as temperature, pH, and moisture content) and to the chemical structure of the polymer [15]. However, the large majority of these studies were carried out in a controlled composting environment using a laboratory-scale test [16–18] and to the best of our knowledge, there is a shortage of specific studies on the degradation of compostable bioplastic bags under home and community composting conditions that simulated a real process (without controlling the organic waste feed, loading the composters gradually, etc.). Furthermore, although most municipalities or composting associations provide guidelines for home and community composting, the establishment of a standardized process remains very challenging because these kinds of composting are not professional waste management activities, but practices carried out on private premises, or they are not organized and therefore very difficult to monitor.

This study was undertaken to get a better understanding of the feasibility of composting single-use, lightweight, compostable, bioplastic bags (the single-use bags for fruit and vegetables) in home and community composting facilities (static home composters and

EC, respectively) in the real management of the food waste produced by a canteen. This feasibility was expressed as the total physical degradation of compostable bioplastic bags at the end of the composting process.

2. Materials and Methods

2.1. Experimental Setup

2.1.1. Community Composting

In this work, two types of ECs were used. The Joraform JK5100 EC (see Figure 1) is equipped with a shredder at the feed hopper, a double chamber with a total volume of 2 m^3, and a turning system consisting of an internal rotating shaft coupled with peripheral blades. Fresh organic waste mixed with bulking agent was continuously fed into the first chamber for the first 15 days; after that, the material was transferred into the adjacent chamber, which allowed it to be transformed for a further 15 days without coming into contact with fresh material. The aeration and turning were electronically controlled, but the temperature inside the chamber was not. After a few days the test was stopped for reasons that will be explained in the Section 3.1.

Figure 1. The Joraform JK5100 electromechanical composter (EC).

The SustEco, model BigHanna T60, which is shown in Figure 2, is an EC that has no internal mechanical components in motion and is continuously fed. It consists of a single 1 m^3 rotating cylindrical chamber. A fan ensures air ventilation through the organic matter inside the composter and the exhaust air is sent to a biofilter for odor removal. The composter has three thermocouples installed at three points along the axis of the cylinder, which monitor the temperature of the composting organic matter. On the opposite side of the feeding system, an exit hole allows the partially stabilized organic waste to come out and not accumulate in the chamber. Semi stabilized compost continuously comes out of the EC as a result of overflow and is moved to a heap, where it undergoes a curing stage for a number of weeks.

The input capacity of the two ECs is 25–30 kg day^{-1} (up to 10 households of 4 people each) and the filling grade is 60–70%, which corresponds to a holdup of 350–450 kg.

2.1.2. Home Composting

The EuroSintex (Eurosintex srl, Bergamo, Italy), “Angolo Verde 800” model of static home composters, which has an octagonal basis, and a volume capacity of 1200 L was used (Figure 3). Air oxygen passed through holes drilled in the side walls and through a pallet, on which the composters were mounted.

Figure 2. The BigHanna T60 EC.

Figure 3. The Eurosyntex Angolo Verde static home composters.

2.1.3. Compostable Bioplastic Bags

The compostable bioplastic bags used in the experimental work are made of a patented biodegradable and compostable starch and polyester-based plastic, sold under the trademark Mater-bi (Figure 4). These bags are manufactured by Industria Plastica Toscana

(Florence, Italy). They comply with UNI EN 13432:2002, are marked with license No. 16 issued by Novamont, and bear the following labels: “ok compost”, “Vinçotte for foods”, “CSI High performance”. A single bag has handles, weighs about 5 g, is 21 cm wide and 37 cm long, and has a thickness of less than 50 microns.

Figure 4. Compostable bioplastic bag used in the experiments.

2.1.4. Measuring Instrumentation

The main parameters (temperature and moisture) of the composting process were periodically monitored, in order to check whether any undesired anaerobic phenomenon had occurred.

In the case of the EC, the temperature measurement was made using thermocouples embedded in three different zones of the cylindrical chamber: the inlet, middle, and outlet zones. The system made 12 measurements per day (one every two hours) for each thermocouple.

The temperature of the organic matter in the heaps and static home composters was measured using TC Direct T-type thermocouples, recording the mean value taken from the three different points (one at the center, two at the edge of the organic matter), 1 m below the surface, on a daily basis.

The moisture of the organic waste was monitored by taking three 200–300 g samples every two–four weeks from the middle of the chamber—the samples were placed inside an oven at 105 °C until their weight remained constant. The pH measurements were made using a Hanna Instrument pH-meter, model 8424, on samples at the end of the composting processes. Samples of 10 g, which had been homogenized and milled using a laboratory cutting mill (IKA, model M20) were added to 100 mL of distilled water, stirred for 15 min and left to rest for 30 min. The pH of the suspension was then measured.

The aerobic stabilization of the compost was determined by means of a respiration test in compliance with the UNI/TS 11184-2016 standard methodology [19]. The test was performed by a Costech 3024 respirometer. An extensive description of the scientific apparatus was reported by Adani [20]. The compost was considered stable when its dynamic respiration index (DRI) was less than 500 mg O_2 kg SV^{-1} h^{-1}.

2.2. Methods

The experiments were carried out at ENEA Casaccia Research Center, which has a daily catering service that generates about 150 kg of kitchen waste from meal leftovers and from the operations of cleaning vegetables and preparing the food. A breakdown of the work is illustrated in the diagram in Figure 5.

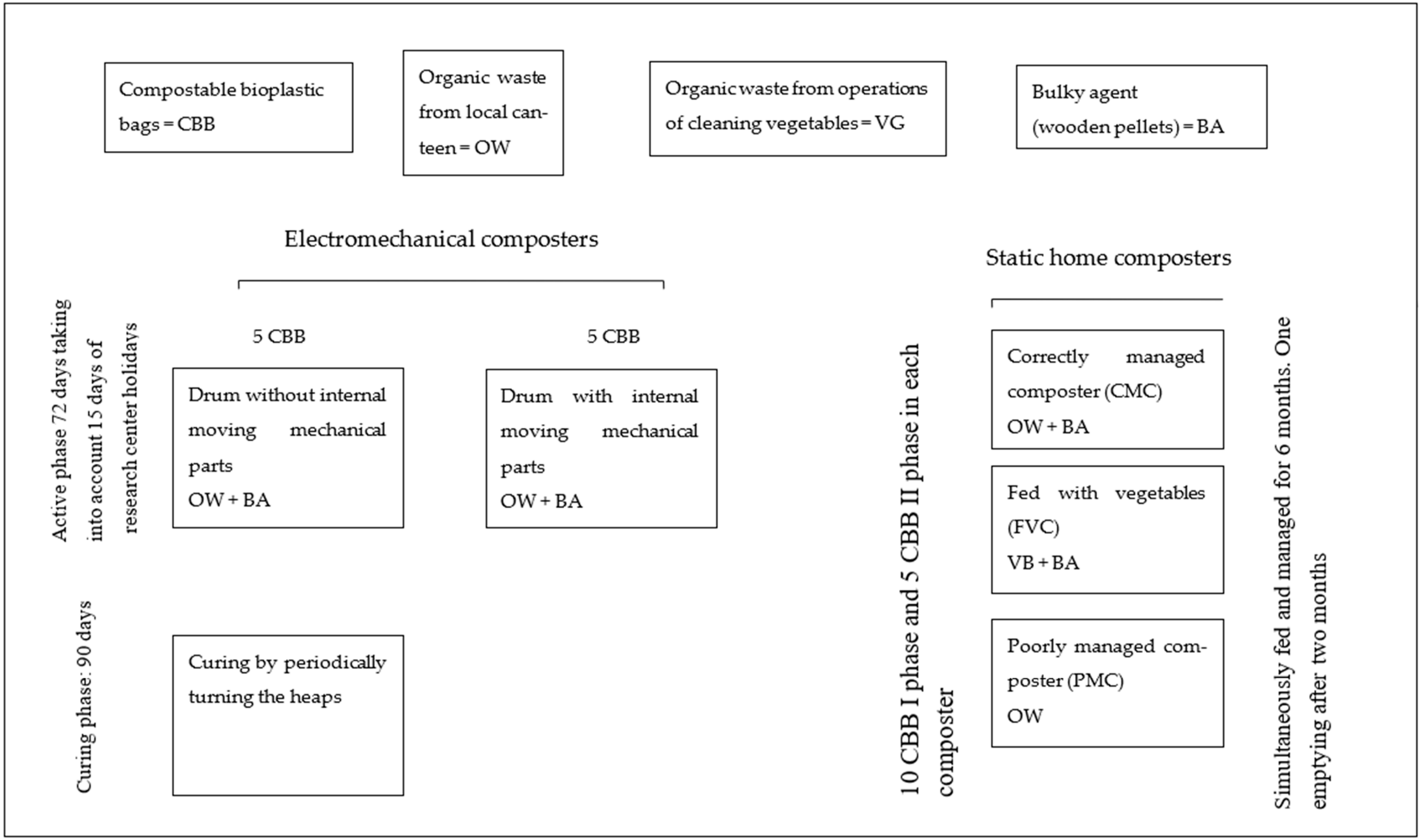


Figure 5. Breakdown of the work.

2.2.1. Community Composting and Curing

The ECs were started during the first few days of June, and fed daily with 20–30 kg of kitchen waste and 2 kg of bulking material. The start-up alone entailed feeding in 30 kg of wooden pellets. After one month, when the temperature was about 40–50 °C, six bags, containing 1 kg of food waste each, were loaded. After a few days, the test with the Joraform JK5100 was interrupted for reasons that will be explained in Section 3.1. Food waste and bulking material continued to be loaded for 72 days. At regular time intervals (every day in the first week, then twice a week until the end), bags inside the chamber were inspected visually in order to monitor the state of degradation. These observations were documented with photographic pictures. During this period the semi-stabilized compost coming out from the composter was put onto the heap.

Some considerations about residence time are needed. Preliminary tests ascertained that the organic matter did not always spend the same time inside the composter. It was observed that not less than twenty days were needed before withdrawal at the output. On the other hand, the upper end of this time range was uncertain and could last tens of days. For example, the supplier declared a treatment time of four to seven weeks was needed to obtain an "environmentally friendly peat compost" [21]. However, previous experiments [22] ascertained that a cured compost can only be obtained following a subsequent curing stage of a number of months in a turned heap. The only operating time that can be mentioned with respect to the EC is the time it takes to reach the "overflow" level, which was estimated to be not less than twenty days. In the case described here, the loading time was chosen for reasons of expediency, as it was necessary to come to a compromise between the minimum time necessary to reach the "overflow" level and the reduction in the daily load as a result of the canteen closing during the summer holidays. On this basis, it was decided that the composter should be emptied after 60 days of loading (overall 72 days, including 12 days of stoppage in the middle of August due to summer holidays). Therefore, the processing time of a single piece of bag inside the composter cannot be more than 72 days. Overall, the EC was loaded with 590 kg of organic matter and 76 kg of bulking agent.

After 72 days, the EC was completely emptied and the semi-stabilized compost from the EC and from the partially formed heap and the residual bioplastic fragments were mixed together and put on to a new heap in order to complete the curing process. Once a week, the heap was turned to allow an exchange of air and watered to adjust the moisture content if this fell below 40 wt%. As described in Section 2.1.4, the temperature was monitored daily. The curing lasted three months, until the temperature inside the heap reached a steady value, close to room temperature. The stabilized condition was confirmed by means of a respiration test (Section 2.1.4).

2.2.2. Static Home Composting

Static home composting was carried out between June and December, with three composters operating in order to reproduce the variability of operating conditions under which home composting might be carried out by a private householder. The first composter, which was identified with the name "Correctly Managed Composter" labelled as CMC was fed every day with 2 kg of kitchen waste and 0.2 kg of bulking agent. The second composter, which was named "Fed with Vegetables Composter" (FVC), again maintaining the weight ratio between the organic fraction and the bulking agent to 10:1, was fed every day only with vegetable scraps, with an average quantity of 1 to 4 kg per day, in order to stimulate an increase in temperature as much as possible. The third composter, which was identified with the name "Poorly Managed Composter" (PMC), was fed every day with just 2 kg of kitchen waste, which did not undergo any preparation, to which dry leaves or plant cutting were added, as necessary. The organic matter in the CMC was periodically turned and watered. Moreover, in the FVC, from time to time, if necessary, freshly chopped grass was added in order to bring about a rapid increase in temperature and sustain the biodegradation process. A bottom layer made up of dried branches and leaves (about 25 kg weight) was prepared for all the three composters, and cured compost was added as the inoculum (about 11 kg weight) to the CMC and FVC. Bags were added in accordance with what is reported in Table 1.

Table 1. Timetable of the insertions and withdrawals of compostable bioplastic bags during home composting campaign.

Date (Elapsed Time)	Introduction of Compostable Bioplastic Bags
1st day	5 empty compostable bioplastic bags added to each static composter.
15th day	3 empty compostable bioplastic bags added and 2 compostable bioplastic bags filled with 1 kg of kitchen waste added to each static home composter.
45th day	Compostable bioplastic bag fragments examined after completely emptying the static home composters
85th day	2 empty compostable bioplastic bags and 2 compostable bioplastic bags filled with 1 kg of kitchen waste added to each static home composter.
175th day	End of the test: the static home composters were completely emptied and the compostable bioplastic bags fragments examined

2.2.3. Recovery of Compostable Bioplastic Bag Fragments

On emptying any of the composters (after 72 and 45 days for the EC and the static home composters, respectively) and at the end of the composting process, all the organic matter was screened using a sieve of 5 cm and subsequently using a sieve of 2 mm in accordance with the criteria established by the ISO 16929 test method pass level [22,23]. Any bioplastic bag fragments larger than 2 mm were taken apart, cleaned of any organic particles stuck to them by means of sonication in an ultrasonic bath, dried at 40 °C, and weighed.

3. Results and Discussion

3.1. Experiments with the ECs

As revealed in Section 2.1.1, the experiment with the Joraform JK5100 was interrupted after a few days because of clogging of the internal moving components caused by the bags wrapping around them. As a result, it was decided to stop the experiment and this EC model was judged inappropriate for the treatment of bioplastic bags. The experimental work was therefore accomplished by the BigHanna model T60 EC and Figure 6 shows the trend of the temperatures in three different zones of the chamber and the moisture content during the bio-oxidation phase.

During the first 30 days, the moisture content of the feed was always more than 40 wt% with a maximum of 55 wt% on the 25th day. These high values went back to fresh fruit and vegetables, which contain a lot of water, typically consumed in the Mediterranean diet during the warm season. As observed in previous experiments, in case of management the EC, this moisture level appeared to negatively affect the evolution of the temperatures in the three chamber zones, especially in the case of the outlet zone, where the temperature fell from 63 to 45 °C in 18 days. In the following days, the introduction of extra pellets made it possible to reduce the excessive moisture to 30 wt%, and, consequently, to increase the temperatures.

In the middle days of August (corresponding to the range of the 40th–49th days of the experiment), the research center was closed for the holidays. In this period, the temperatures fell again, reaching a minimum of less than 30 °C. When the research center re-opened, the organic mass looked dryer and, indeed, the moisture content had decreased to 30 wt%. When the loading of kitchen waste was regularly resumed, the temperatures in the inlet and in the middle zones rapidly increased again, but the temperature in the outlet zone remained almost constant. Generally speaking, despite the research center's closure, the trend was good with temperatures always above 40–45 °C, with peaks close to 70 °C.

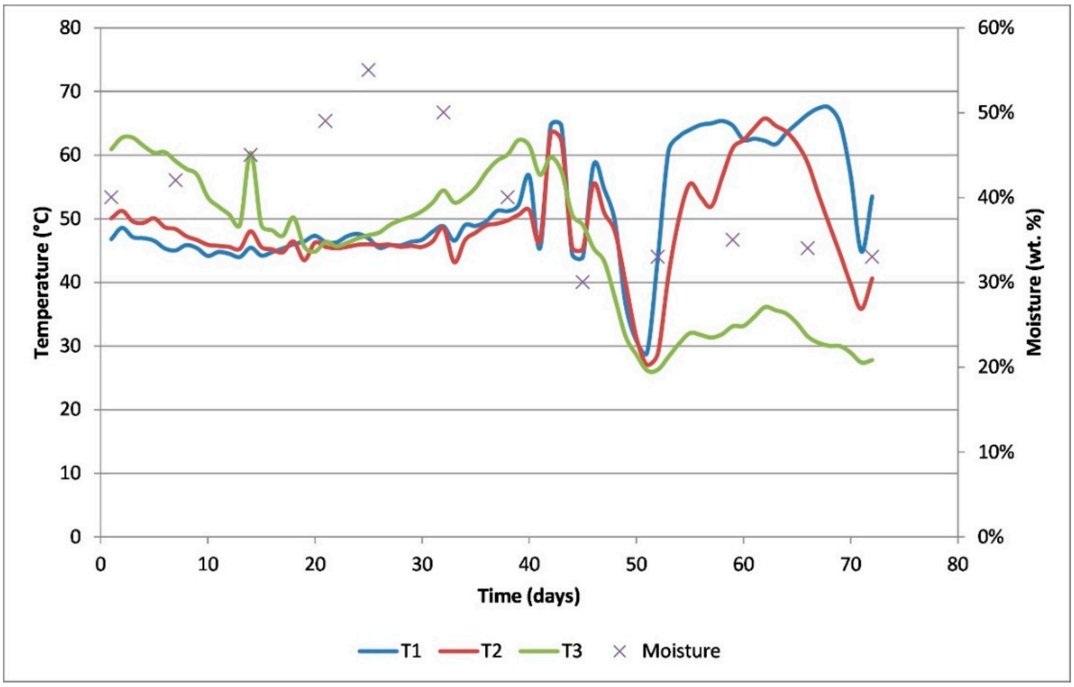


Figure 6. Temperatures and moisture content of the organic waste during the experiment time in the BigHanna model T60 EC (T1, inlet zone; T2, middle zone; T3, outlet zone).

Figure 7 shows some pictures taken at various times during the bio-oxidation phase, which help to clarify the general trend of the process.

As can be seen in the sequence of pictures in Figure 7, the compostable bioplastic bags appeared in and disappeared from the organic mass, and were subjected to the movement of the rotating cylinder. Then, a mechanical stress contributed to the bioplastic disintegration as well as the aggressive environment established inside the EC. The compostable bioplastic bags appeared intact until the 14th day and the first large compostable bioplastic bag fragment appeared on the 18th day. On the 23rd day the first compostable bioplastic bag fragment was found in the output material coming out of the EC. From this day onwards, compostable bioplastic bags that were open or partially broken were seen in the chamber and more or less big fragments were found in the output material.

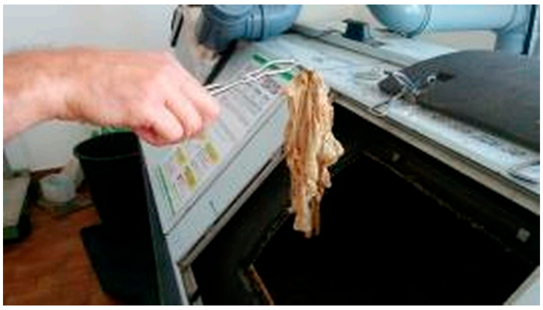
(**A**) The 1st day: a compostable bioplastic bag immersed in the organic waste.

(**B**) The 4th day: a compostable bioplastic bag immersed in the organic waste.

Figure 7. *Cont.*

(**C**) The 9th day: a compostable bioplastic bag filled with food waste.

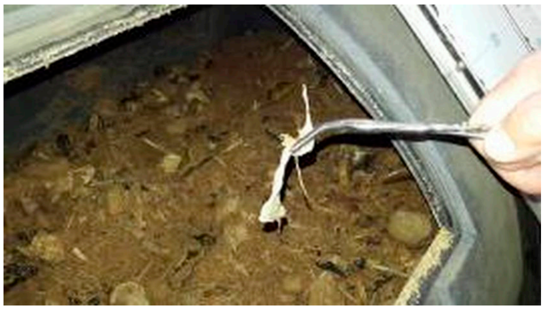
(**D**) The 14th day: a compostable bioplastic bag emerges near the composter outlet.



(**E**) The 18th day: a large compostable bioplastic bag fragment, which was temporarily removed.

(**F**) The 23rd day: the first compostable bioplastic bag fragment found in the output material from the composter.

(**G**) The 24th day: a compostable bioplastic bag containing food waste appears broken, having lost its content of humid fraction near the input section of the composter.



(**H**) The 26th day: a fragment of compostable bioplastic bag film found in the middle section of the composter.

(**I**) The 30th day: a compostable bioplastic bag containing food waste appears open.

(**J**) The 35th day: a compostable bioplastic bag film found in the output material from the composter.

Figure 7. *Cont.*

(**K**) The 40th day: a compostable bioplastic bag film found in the output material from the composter.

(**L**) The 72nd day: fragments of compostable bioplastic bags mixed with organic material during the screening.

Figure 7. Sequence of pictures illustrating the evolution of the degradation of compostable bioplastic bags in the EC.

In the middle of September, 72 days after the beginning of the test, the EC was emptied as shown in Figure 8, and all the organic mass (the organic mass still in the chamber plus the organic mass forming the heap) was screened using a 2 mm sieve. Forty-three sample fragments were found with a total weight of 3.22 g, which was equivalent to slightly more than 10% of the initial 30 g introduced. A difference was noticed in the shape of the fragments collected little by little in the first 72 days of daily loading in comparison to those fragments collected on the last day when the EC was emptied. The former had rounded edges while the latter were "fibrous" and elongated in shape.

Figure 8. Emptying of the composter and screening of the output material in search of compostable bioplastic bag fragments.

Table 2 summarizes the mass balance between the overall ingoing and outgoing organic material during the 72 days.

Table 2. Mass balance of the compostable bioplastic bags introduced into the EC after 72 days.

Compostable Bioplastic Bags	Amount	Weight Loss
Compostable bioplastic bags initial weight (g)	30	-
Residual compostable bioplastic bags weight after 72 days (g)	3.22	89
Residual compostable bioplastic bags weight after 148 days (g)	n.d.	100

n.d.: not detected.

The trend of the temperatures with reference to the curing process is reported in Figure 9 from the middle of September to the first days of December (the 72nd and the 148th day respectively) in comparison to the ambient temperature. For 20 days, the temperatures were between 50 and 60 °C, where the periodic turning and watering of the heap was essential in order to reactivate the heap and maintain high temperatures.

Indeed, as the cold season approached and the aerobic potential ran out, the effect of these operations became less effective, until, on the 148th day, the temperature fell below 30 °C.

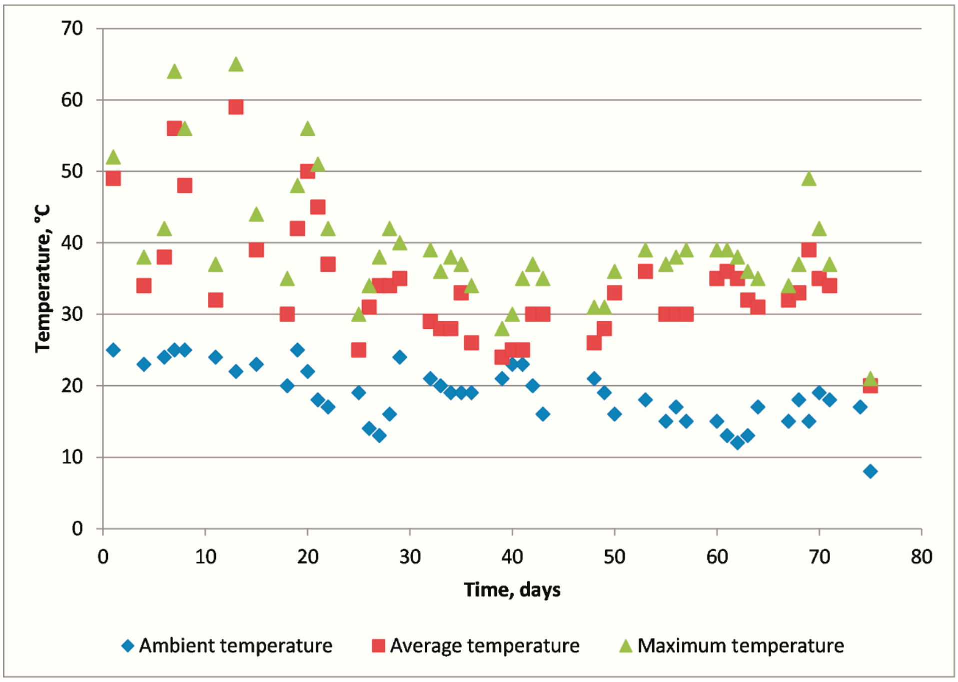


Figure 9. Temperatures of the heap measured during the curing stage.

All the organic material again underwent 2 mm screening and no larger residual compostable film fragments were found (Table 2). In conclusion, the physical degradation of the bags was complete.

Figures relating to the characteristics of the final product are reported in Table 3 and show complete aerobic stabilization.

Table 3. General figures relating to the cured mass after treatment in the EC.

Parameters	Cured Heap
pH	7.8
Moisture (wt%)	45 ± 0.2
Final appearance	Granular, earthlike,
Odour	Agreeable
DRI (mg O_2 kg SV^{-1} h^{-1})	461

3.2. Home Composting

Table 4 shows the mass balance and all the parameters measured for each composter after six months. Following the different management approaches, 358 kg was loaded into the CMC, 448 kg into the FVC, and 265 into the PMC. The yield in "compost" considered as the residual mass minus the bulking agent and the inoculum, divided by the overall quantity of food loaded was 8 wt% for the CMC, 20 wt% for the PMC, and 24 wt% for the FVC. These results demonstrate that, when supported by a sufficiently high room temperature, the process was effective. The lower yield of the FVC was due to a remarkable moisture content bound to the vegetable input, which in some way greatly reduced the biodegradation process. This was confirmed both by the temperature trend, which we comment on further, below, and by pH and moisture analysis on the last day of the experiments. Considering the pH, all the examined composts showed values above 8 and it was observed that the treatment needed additional curing times. The moisture of the CMC, of 50 wt% fell to within the range recommended by Italian Environmental Protection

Agency [24], and for the remaining two composters the values exceeded 75 wt%. In the case of PMC, this was an indication of a weak activation of the aerobic process, which did not increase the temperature, allowing the water content to evaporate. The appearance of the organic material removed from the three composters at the end of the experiments was the most significant indication of which composter had been used: in the CMC, the product appeared grainy and powdery, mulchlike, and gave off an agreeable odor of mold and earth; the material removed from the FVC was dark, very humid and lumpy, and had an odor like that of rotten fruit; finally, the PMC looked heterogeneous with large lumps of sludge-like material mixed with granular mulch, while the smell was pungent and similar to rotten fruit.

Table 4. General figures relating to the management of the three static home composters.

Parameters	CMC	FVC	PMC
Total loaded food fraction (kg)	292	377	258
Total loaded bulking agent (kg)	55	60	7
Inoculum, i.e., cured compost (kg)	11	11	0
Watering (kg)	55	16	0
Total loaded amount (kg)	358	448	265
Total withdrawn amount (kg)	89	162	58
pH	8.4	9.2	8.7
Moisture (wt%)	50 ± 20	75 ± 3	73 ± 3
Appearance	Mixed mulch and cuttings	Dark, very humid	Mixed sludge
Odor	Agreeable	Rotten fruit	Pungent smell/rotten fruit

Figures 10–12 below show the temperature trend for the three composters. The experimental work, which started at the end of the spring season, benefitted from the warm environmental temperatures of June–September, which were well above 25 °C.

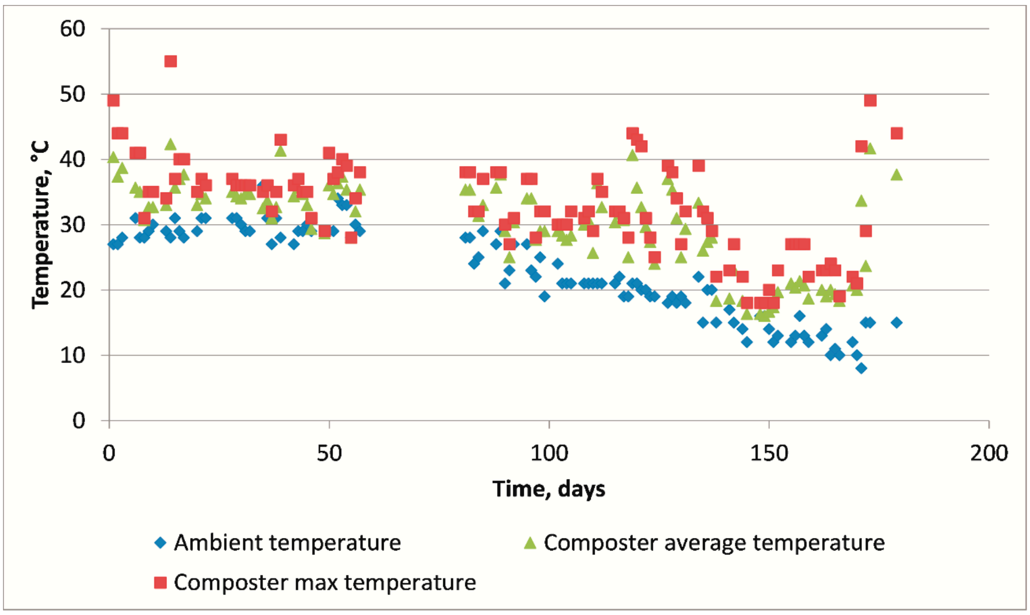


Figure 10. Trend of temperatures in the correctly managed composter (CMC).

For the CMC, the difference between the average and ambient temperature remained around 5–10 °C, and maximum temperature managed to achieve very high values, even 20 °C, well above the ambient temperature. It is interesting to note maximum temperature peaks of 50 °C, with ambient temperatures near to 10 °C. This indicates that there was a well-established composting process in the CMC.

In the FVC (Figure 11), the average temperatures during the June–August period were well above those of the CMC in the same period. Around the end of August, a temperature decreases due to the high moisture content of the vegetable-rich feed, followed by a rapid increase when 10 kg of finely chopped grass was added, was seen.

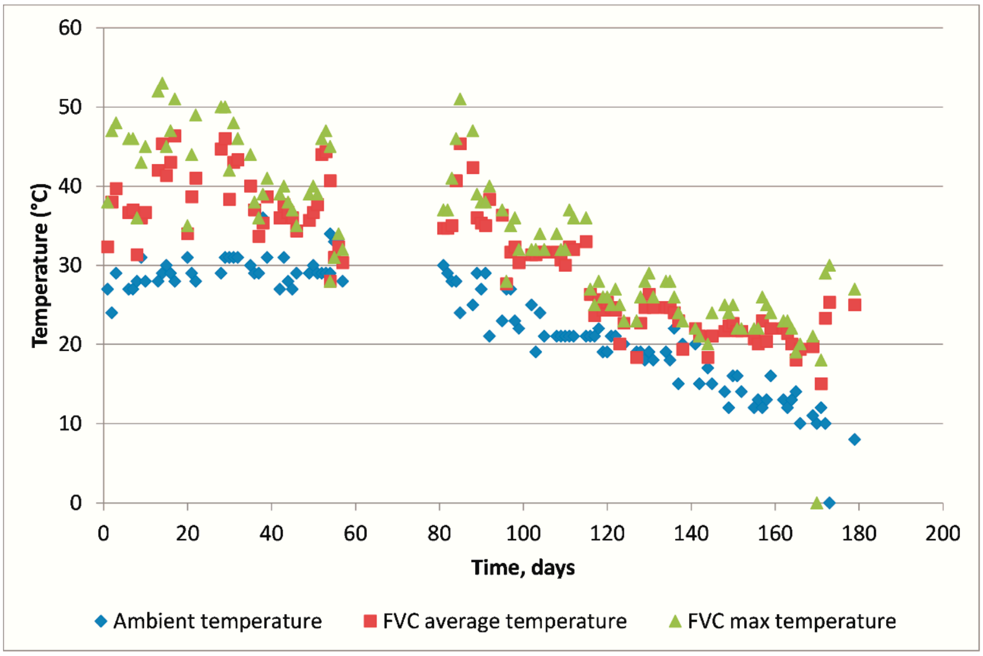


Figure 11. Trend of temperatures in the fed with vegetables composter (FVC).

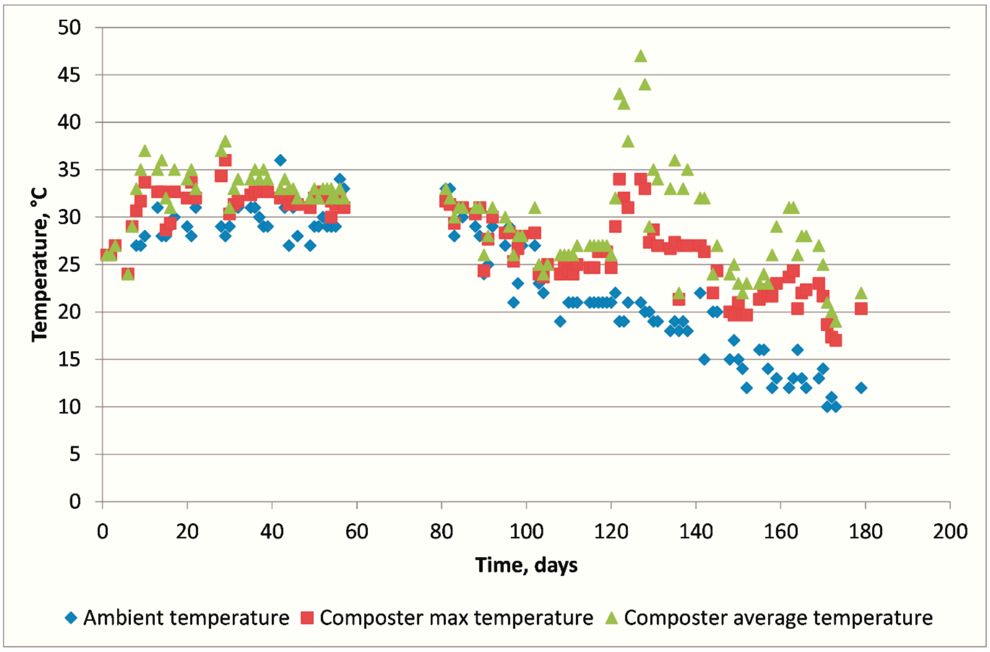


Figure 12. Trend of the temperatures in the poorly managed composter (PMC).

In the autumn period, unlike the CMC, we noted a progressive decrease following the ambient temperature trend with no upturn. The temperatures stabilized at around 20 °C in the October–November period.

In addition to the warm season, the better ratio of kitchen waste to bulking agent also probably contributed to the high temperature reached by these two composters in comparison to those reached by the PMC. Figure 12 shows the trend for the PMC. During the June–August period, the composter temperature remained equal to the ambient temperature, in the October–November period, the process reached a high level of activity, achieving maximum peaks even higher than 45 °C.

In none of the composters, did the interruption due to the research center closing for the summer holiday influence the evolution of the temperatures.

Table 5 shows the results relating to the residue amounts of the bags in the course of the initial removal after two months of experiments, and at the conclusion of all of the experiments after six months of treatment.

Table 5. Physical degradation of bags during the two removals of bag residues (after 2 months and 6 months, respectively, from the beginning of the test).

Composters Type	Time Period of Experiments	Compostable Bioplastic Bags Introduced		Compostable BioPlastic Bag Residues Removed (g)	Degradation Rate (wt%)
		Bag Number	Weight (g)		
PMC	First emptying (1st–45th day)	10	50	24.0	52
	Whole set of experiments (1st–180th day)	14	70	3.7	95
FVC	First emptying (1st–45th day)	10	50	7.6	85
	Whole set of experiments (1st–180th day)	14	70	7.2	90
CMC	First emptying (1st–45th day)	10	50	11.3	77
	Whole set of experiments (1st–180th day)	14	70	2.9	96

During the first two months, the best performance was achieved by the FVC with a 85 wt% degradation rate, whereas the PMC achieved 52 wt% and the CMC 77 wt%. If we consider the whole process, which lasted six months, where a total of 14 bags, corresponding to 70 g, was added to each composter, the best performances were achieved by the CMC (96 wt%) and the PMC (95 wt%), whereas the FVC stopped at 90 wt%. This disappointing performance of the FVC may have been due to an excessive moisture content (and subsequent fall in temperatures) of the organic mass, which was not evaporated because of the insufficiently high ambient temperatures from September onwards. Conversely, the high temperature reached in the PMC in the second part of the test, achieved a degradation activity on the bags which resembled that of the CMC. In any case, it seems from these results that four months in the warm season is enough to complete the degradation of the compostable bioplastic bags. Unlike the test with the EC, domestic composting degraded the bags into a few rather large fragments, without clear fraying phenomena.

Finally, it is important to point out that although the complete maturation of the produced composts was not confirmed, the mass balance showed a mass reduction of organic waste of 92, 76, and 80 wt% for the CMC, FVC, and PMC respectively.

4. Conclusions

This study looked at the suitability of single-use lightweight compostable bioplastic bags for collecting organic waste intended for treatment in static home composters and ECs. To this end, the physical degradation of compostable bioplastic bags was evaluated under mild composting processes with the following results:

- The EC provided with inside moving parts was unfit, as the bags caused clogging and the risk of jamming.

- Thanks to the good aerobic conditions reached during the process, the EC degraded the bags up to 90 wt% of the initial amount introduced in 72 days, and the subsequent curing process completed the physical degradation of the residual fragments.
- Composting carried out by static home composters is greatly dependent on the external ambient temperature and operating conditions. In any case, a degradation of 90% to 96% was achieved, regardless of whether or not the composter was managed carefully.

To conclude, these compostable bioplastic bags can be used to collect organic waste and can be treated by home and community composting, even when the composters are poorly managed.

However, it is important to stress that in this study a few bags were added to a large mass of organic waste. In order to replicate a more realistic situation, we set up new experiments where all organic waste will be collected in compostable bioplastic bags and sent to composters. Finally, the compost that will be produced will undergo agronomical and ecotoxicological tests. Experiments are in progress.

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