Decomposition of Single-use Products Made of Bioplastic under Real Conditions of Urban Composting Facility

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ABSTRACT

According to Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019, single-use plastic cutlery, cotton buds, straws and stirrers will be banned in the member states of EU from summer 2021 onwards. Many of them are being replaced by compostable products. The aim of the research was to assess the biological disintegration of selected single-use products under real conditions of urban composting facility. All tested products are established for the Slovak market as 100% compostable by a composting facility. The eight selected products from five different producers were placed into a composting pile of the urban composting facility for 12 weeks. The samples were visually inspected on a regular basis. Temperature and humidity of the pile were continuously measured at the same time. Three samples from each kind of tested product were analyzed, 3 pieces of filter paper were used as the reference samples. The research showed that all tested products were completely or partially disintegrated during the considered period. The average degree of the disintegration of 90% was not reached for one producer only.

Keywords: bioplastics, disintegration, compost, composting facility, single-use products.

INTRODUCTION

Plastics have become an indispensable commodity in today's life due to their wide range of applications, particularly in packaging [Groh et al., 2019]. The threat of plastic pollution has mobilized global governments, business corporations, and local communities to combat against its proliferation in the environment [Schnurr et al., 2018]. Social, technological, and institutional amendments like nationwide phasing out of single-use plastics, resolutions by businesses and corporations to reduce their plastic footprint, initiatives by non-profit organizations to clean up beaches and ocean, behavioural changes in public to reduce the consumption and littering of single-use plastics have raised hope of positive changes in the recent past [Heidbreder et al., 2019; Moore, 2015; Xanthos and Walker, 2017].

The announcement of plastic pollution as a worldwide crisis by the United Nations in 2017 [UNEP, 2017] has made several businesses establishments to adjust their corporate strategies, preparing for an accelerated transition to a circular economy. Bioplastics are promoted as an alternative to the conventional petroleum-based non-biodegradable plastics. With a production volume of 2.11 million tons in 2019, their market share is very low (1% of all plastics) but expected to increase in the future [European Bioplastics, 2019]. The term "bioplastics" is still ill-defined. It includes the materials made from renewable feedstocks, the materials supposed to degrade naturally (biodegradable), or both. It is currently unclear whether the plant-based materials which are often blended with synthetic materials (e.g., cellulose, and bamboo-based materials) fall under

that category. Either way, they are produced to fulfil the same function as plastic materials and appear as such to the consumer [Zimmermann et al., 2020]. The new circular economy action plan adopted in March 2020 [EC, 2020], commits the European Commission to develop a policy framework on the sourcing, labelling and use of biobased plastics and on the use of biodegradable or compostable plastics, including their labelling.

Although biodegradable polymers have been commercialized for over 30 years, this niche market is beset with a variety of roadblocks led by high prices and lack of an industrial infrastructure to deal with these materials [Vaverkova and Adamcova, 2015, Czech et al. 2013]. Industrial composting appears to be an expected and preferred way of the disposal/recovery of such materials [Sedničková et al., 2018]. Compostable materials certified for industrial composting (EN13432) achieve min. 90% disintegration under laboratory conditions at 58°C in 90 days. That means 10% of dry weight allowed to be retained by 2 mm sieve [Song et al., 2009].

Our research was focused on evaluating the degradability of bioplastic packaging under real conditions of the urban composting facility. The tested products are commonly available on the market and labelled as compostable. Scientific publications routinely observe the behaviour of biodegradable polymers under laboratory conditions simulating the composting process. On the other hand, the research of biodegradable municipal waste (BMW) which is conducted under the real conditions of a local processor, is still very rare, not only in Slovakia. The laboratory conditions cannot simulate all the factors affecting the process of the disintegration. For this reason, this kind of research is necessary and irreplaceable for municipal waste management.

MATERIAL AND METHODS

The research was conducted in the urban composting facility in Krškany (Nitra District, Southwest Slovakia). In this place, the BMW produced by family house gardens and public greenery located in the territory of the city of Nitra are processed. Our procedure was based on the certified methodology "Methodology for evaluation of degradation of degradable polymer materials in real composting environment" [Vaverková et al., 2014]. According to specific conditions, it was necessary to partially modify the methodology. At the beginning, the examined product samples were photographically documented, and the initial weight of each sample was recorded. A cellulose unreinforced filter paper with a diameter 15 mm was used as the reference sample. Each product was tested in three identical samples; the disintegration of 8 products made by 5 producers was monitored. The detailed overview is listed in Table 1.

Table 1. Characteristic of samples

Producer	Sample	Use	Type	EAN cod / specification	Biodegradation	Certification
Na:Pac	Al A2 A3	bowl	sugar-cane / PLA	CRL050	Industrial composting	Patent ZL200480010476.8
Na:Pac	B1 B2 B3	lid	cellulose / sugar-cane	CR1002	Industrial composting	Patent ZL200480010476.8
Eco-Product	C1 C2 C3	lid	PLA	644632902600	Industrial / home composting	ASTMD6400, D6868, BPI
Biotrem	D1 D2 D3	plate	wheat bran	5905279376007	Industrial Home composting	EN 13432
Biotrem	E1 E2 E3	fork	PLA / wheat bran (10%)	5905279376366	Industrial composting	EN 13432
Naturesse	F1 F2 F3	fork	CPLA	CPLA14162	Industrial conposńng	EN 13432
Vegware	G1 G2 G3	plate	sugar-cane	5060271922314	Industrial composting	TUV AUSTRIA, BPI
Yegware	H1 H2 H3	soup bowl	cellulose board / PLA	5060271920280	Industrial composting	TUV AUSTRIA, BPI
Papirna Perstejn s.r.o.	I1 I2 I3	filter paper	cellulose	624880104150	–	ISO 9001

The samples marked with number 3 (i.e., A3, B3, C3 …) were encapsulated in a plastic net with a 2×2 mm mesh diameter. The remnant samples (numbered 1 and 2) were packed in a fiberglass net case/pack with a 4×4 mm mesh diameter. The prepared samples were then inserted and fixed between two layers of a test plastic-covered net. The net with samples had a size of 1×2 m and the 10×10 mm mesh diameter (Figures 1 and 2).

The composting pile with a volume of approx. 11 m^3 placed in a box with a lid was formed by a homogeneous mixture of the following three types of fresh BMW:
- wood chips (10%$_{vol}$),
- waste from the gardens of family houses collected in bio-containers (50%$_{vol}$),
- grass from public greenery (40%$_{vol}$).

On 6 July 2019, the net with the samples was inserted into the composting pile. Approx. 60%$_{vol}$ of the prepared substrate was situated under the net and the rest of the composting stack was used to cover the tested samples (Figure 3).

Throughout the whole research, the 3 measuring probes (no. 1, 2, and 3) were placed directly under the tested net for the measurement of temperature and humidity of the substrate. Simultaneously, the probe no. 4 measured the outside air temperature. The measured values were recorded by the datalogger at hourly intervals. The average values of temperature and humidity for each week of the experiment were calculated from the data obtained by measuring probes 1, 2 and 3. The diagram in the Figure 4 shows the development of the substrate humidity. The average value of humidity for the entire monitored period was 35%$_{vol}$.

The diagram in the Figure 5 shows the temperature development of the substrate and exterior. The average value of temperature for the entire monitored period was 62.6°C. The outside air temperature (measured using probe no. 4) amounted to 22°C, on average.

After the set period (12 weeks), the tested material was removed from the test net. Afterwards, it was cleaned from the compost and dried before the final measurement of the weight. The resulting values of the sample remnants weight were recorded and compared with the initial weight values. The disintegration degree of the individual samples was quantified by the following formula:

Figure 1. Preparation of samples for packaging

Figure 3. Placement of samples in the compost pile
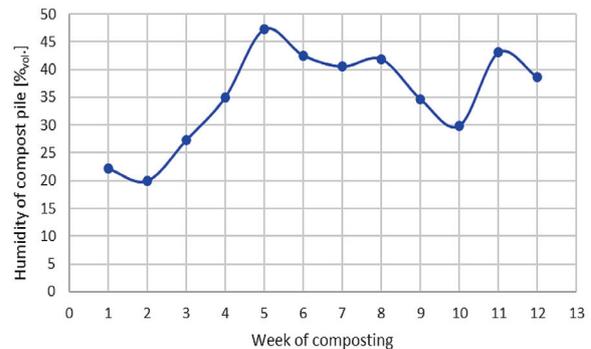

Figure 2. Prepared net with samples

Figure 4. Average weekly humidity of compost pile for the experimental period
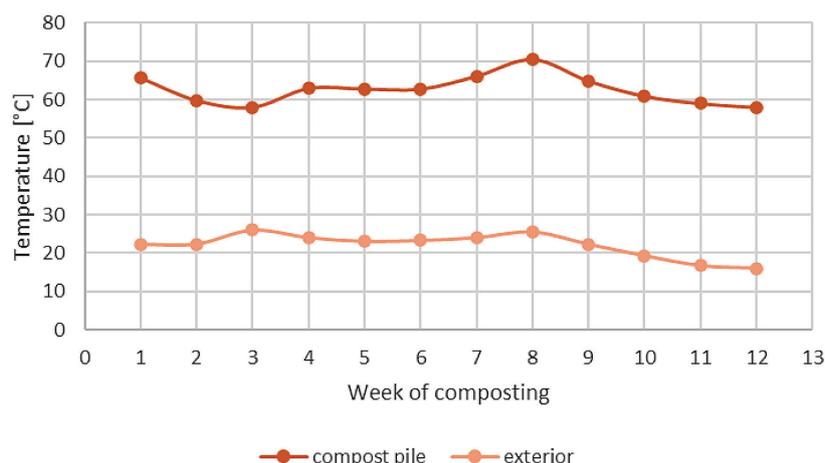
Figure 5. Average weekly temperature in compost pile and exterior for the experimental period

$$D(\%) = \frac{Mi - Mr}{Mi} \times 100 \qquad (1)$$

where: D – degree of disintegration (%),
Mi – sample weight at the beginning of the experiment (g),
Mr – sample weight at the end of the experiment (g).

RESULTS AND DISCUSSION

During the 84 days of the study, 8 inspections were performed, including the start and the end of the experiment. The detailed itemization of the entire experiment development is listed in the Table 2. The table shows the average values of temperature and humidity on the controlled day including the days of the composting substrate digging.

Disintegration of the samples packed into the net with the 4×4 mm mesh diameter

Total number of the samples A to I numbered 1–2 (see Table 1) was 18 (including filter papers).

The resulting values of the weights before and after the experiment are listed in the Table 3. The degree of disintegration was calculated using the Eq. (1).

The Na:Pac caps (i.e. samples B1 and B2) are the only ones which did not achieve the required degree of the 90% disintegration throughout the monitored period (see Figure 6). The weight loss of the caps was only 0.63% which is less than the required limit. The remaining test samples exceeded the value of 90% disintegration. The disintegration degree of these samples in the nets with the 4×4 mm mesh diameter in 12 weeks was sufficient. Both reference filter paper samples (I1 and I2) were disintegrated in 100%.

Disintegration of the samples packed into the net with the 2×2 mm mesh diameter

All tested samples A to I marked with the number 3 had a 2×2 mm mesh package (see Table 1). The Table 4 shows the resulting values of the measured weights before and after the experiment. The results demonstrate that the remnants from the three brands have stayed on the 2×2 mm

Table 2. Experiment schedule of works

Date	Time from start (day)	Sample checking	Digging compost pile	Average temperature of compost pile (°C)	Average humidity of compost pile (%$_{vol}$)	Average exterior temperature (°C)
6 July	0	Start-up of the test		50.8	11.1	26.5
12 July	7	✓	✓	64.2	19.9	20.1
20 July	15	✓		42.2	15.4	26.1
2 August	28	✓		56.3	40.4	22.2
16 August	42	✓	✓	56.5	35.5	20.5
30 August	56	✓		62.2	36.0	27.3
13 September	70	✓		52.5	31.4	21.1
27 September	84	End of test		49.7	24.3	15.4

Table 3. Weight of samples before and after composting and the disintegration degree of these samples in the nets with the 4×4 mm mesh diameter

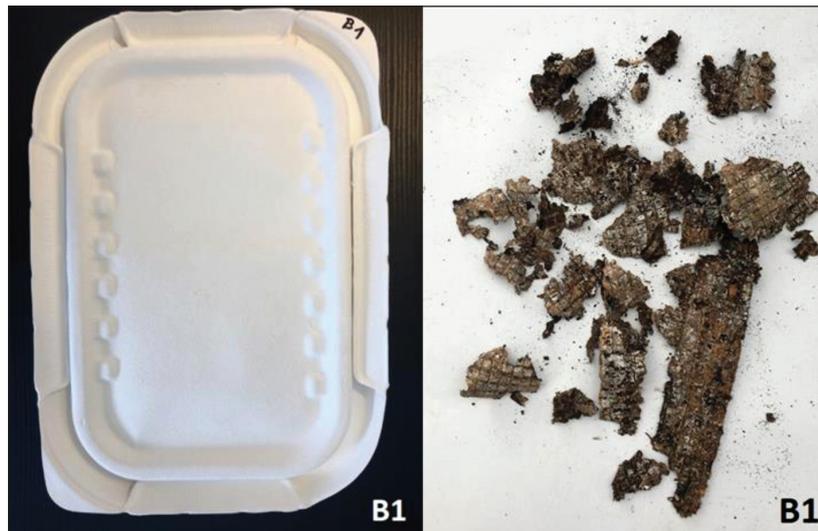| Producer	Na:Pac		Eco-product	Biotrem		Naturesse	Vegware	
Samples	A1+A2	B1+B2	C1+C2	D1+D2	E1+E2	F1+F2	G1+G2	H1+H2
Weight at the beginning of the experiment (g)	13.65	40.55	10.08	139.28	15.66	10.21	21.38	8.59
Weight at the end of the experiment (g)	0.99	4.31	0	3.78	0	0	0	0
Degree of disintegration (%)	92.73	89.37	100	97.29	100	100	100	100

Figure 6. Sample B1 (Na:Pac) before and after degradation in the compost pile

mesh. The lid and the bowl from the Na:Pac (samples A3 and B3) represented the smallest weight loss from all tested products. The lid made of cellulose and sugar cane (sample B3) had the worst resulting disintegration degree, only 34.28%. The products of Vegware brand (samples G3 and H3) have not achieved the required 90% disintegration limit in this type of the net, but the degree of disintegration still achieved a greater value than in the case of Na:Pac products. The Biotrem plate (sample D3) made of wheat bran had the degree of disintegration lower than the 90% limit only by 1.76%. The reference sample of the filter paper (I3) disintegrated to 100%. The figures 7 to 11 show the sample pictures of the products which have not achieved the required disintegration degree.

Overall evaluation of the research results

The results show that the certificated compostable substitutes for disposable plastics available on the market do not always demonstrate the compostability required for composting under real conditions of the urban composting facility. On the other hand, it is likely that the bioplastics would be exposed to mechanical influences during a conventional compost

Table 4. Weight of samples before and after composting and the disintegration degree of these samples in the nets with the 2×2 mm mesh diameter

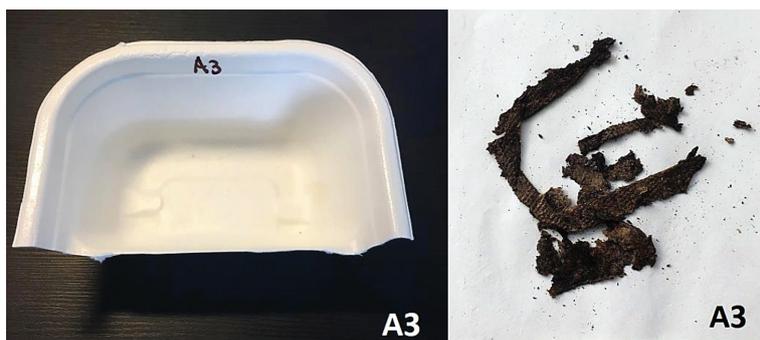| Producer	Na:Pac		Eco-product	Biotrem		Naturesse	Vegware	
Samples	A3	B3	C3	D3	E3	F3	G3	H3
Weight at the beginning of the experiment (g)	10.99	22.43	5.02	73.1	7.95	5	11.19	5.22
Weight at the end of the experiment (g)	2.86	14.74	0	8.6	0	0	8.82	1.02
Degree of disintegration (%)	73.99	34.28	100	88.24	100	100	74.77	80.56

Figure 7. Sample A3 (Na: Pac) before and after degradation in the compost pile

Figure 8. Sample B3 (Na: Pac) before and after degradation in the compost pile

Figure 9. Sample D3 (Biotrem) before and after degradation in the compost pile
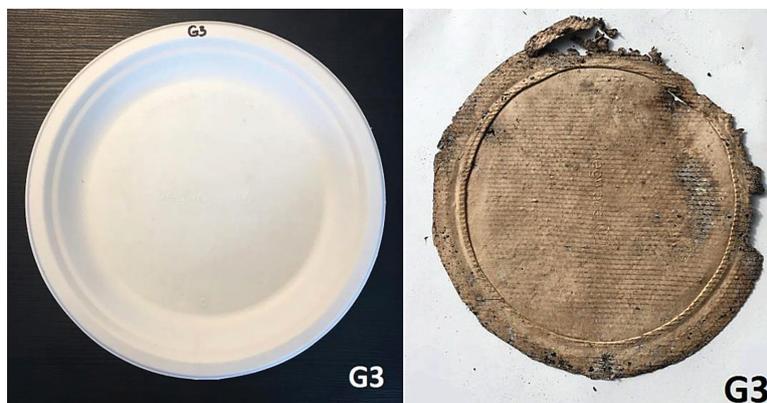

Figure 10. Sample G3 (Vegware) before and after degradation in the compost pile

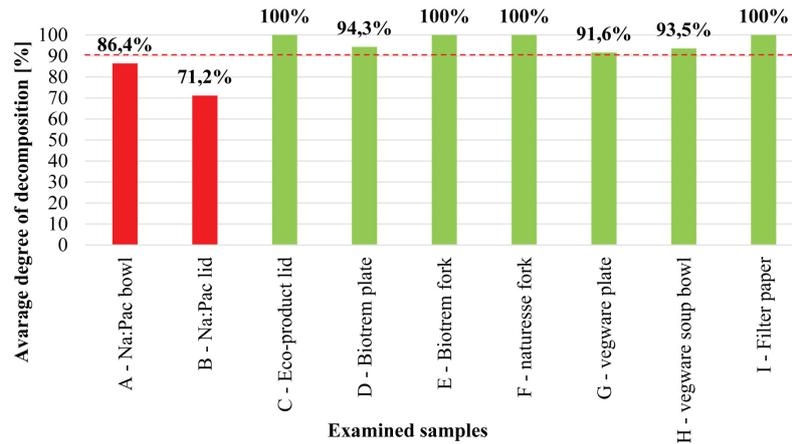**Figure 11.** Sample H3 (Vegware) before and after degradation in the compost pile

Figure 12. Average degree of decomposition of the examined samples (%)

digging that would support the biodegradation and simultaneously the increase of the resulting disintegration degree. The diagram in Figure 12 shows the ultimate comparison of all tested products. The final percentage calculation of the average weigh losses includes all 3 samples of each product packed in the 2×2 mm mesh, and in the 4×4 mm mesh. The diagram shows that the minimum disintegration limit of 90% is reached by all examined products except the lids and the bowls of the Na:Pac brand. After the 12 weeks of the bioplastic's degradation by composting, each product has been partially or completely disintegrated. Although the Na:Pac brand products did not reach the required value, it is highly likely that in a longer period of time and under similar conditions in the substrate, the selected bioplastics would eventually disintegrate completely.

CONCLUSIONS

As many as 11 out of 18 samples (including the reference samples) completely disintegrated in the industrial composting pile in the composting facility in 12 weeks. The rate of the disintegration of individual compostable product types is different under real composting facility conditions and does not only depend on material composition of a specific product, but also on a composition of the composting pile and the used composting technology.

The Nitra city composting facility can process all tested products safely as all of the undisintegrated pieces are being separated during the sowing of the final compost and returned into the composting process. The application of a compost made from compostable bioplastics in soil is suitable only if it concerns the biobased biodegradable bioplastics.

In order to be able to control the processing of the products is necessary to implement the closed-loop system. The provider of single-use compostable products (dishes) is obligated to collect them after the using and hand them over for recovery to a determined composting facility. The replacement of single-use plastics by biodegradable bioplastics is conditioned by the introduction of uniform product labelling in the EU and a gigantic campaign to inform citizens about the impending changes and their significance.

Acknowledgments

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