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THE ANALYSIS OF BIODEGRADATION PROCESS OF SELECTED PAPER PACKAGING WASTE

Anna Nowińska, Joanna Baranowska, Mateusz Malinowski
University of Agriculture in Krakow

Abstract

In recent years, a significant surge in the mass of generated waste with varying morphological composition has been observed. Packaging made of both plastic and paper has an increasing share in the municipal solid waste stream. The multiplicity of packaging means that proper methods and installations are needed to appropriately manage the waste generated from it. A special type of packaging waste is made of paper and cardboard and it is considered as biodegradable waste. It can be processed in both mechanical (material) and biological treatment processes. Thanks to the microorganisms involved in biological treatment processes, the organic matter present in waste should be decomposed (biodegradable).

The main aim of the study was to analyze the dynamics of the biodegradation process of selected packaging waste made of paper and cardboard in various research environments. The waste used for the analysis differed primarily in grammage. The dynamics of the decomposition rate of the examined waste was analyzed for materials placed in 4 different research environments. The analysis showed significant differences in the rate of biodegradation of the tested waste. Differences were also found in the rate of material decomposition in individual research environments. Materials with low grammage such as paper towels and sandwich paper wrapper were the fastest to biodegrade.

Key Words: waste, packaging waste, paper and cardboard, biodegradation

INTRODUCTION

Alternatives to packaging made of plastics are sought all over the world because they constitute a growing environmental problem. One of the most popular alternatives currently are packaging made of paper and cardboard. Paper and cardboard are biodegradable. Their main ingredient is cellulose $(C_6H_{10}O_5)_n$. The time and dynamics of the biological decomposition of paper and cardboard depend primarily on the paper products themselves, i.e. such parameters as their grammage and moisture content, but also on the environmental conditions in which they are – the temperature and moisture content of the medium, the presence of living organisms that can significantly accelerate biodegradation process (Saraswathi and Saseetharan 2010, Jabir and Jabir 2016). Biodegradable waste, including paper and cardboard is mostly subjected to biological treatment processes, e.g. in composting plants. As a result of these processes, stabilized residues are obtained with a changed waste code or a product, which is e.g. compost. After the biological process, the residues can be used in agriculture (as a fertilizer) or in cement plants as an alternative fuel (Malinowski *et al.* 2019). Paper and cardboard are also suitable for material (mechanical) recycling as part of which new cellulose products for common use are produced.

Processes in which biodegradable waste is treated are divided into aerobic and anaerobic. Aerobic processes include composting, aerobic biostabilization and biological drying, while anaerobic ones include methane fermentation (Jędrczak 2007). Jędrczak (2007) states that raw material suitability for biological treatment using an aerobic or anaerobic method is determined by its structure (size, shape and mutual arrangement of grains). Currently, the most popular processes in the field of biological waste treatment include composting and aerobic biostabilization (conducted in mechanical and biological treatment plants for municipal solid waste). Biodegradable waste should not be stored in landfills. That is why new methods of its rational management are constantly being sought.

The main purpose of the research was to analyze the time and rate of biodegradation of selected packaging waste made of paper and cardboard. Due to the very wide variety of packaging that is widely available on the market, the materials that the average person comes into contact with on a daily basis (cardboard packaging, sheet of paper, paper packaging, baking paper and paper towel) were used for the analysis. The packaging was placed in 4 different research environments. Individual research environments generated waste in a decomposed state or were the result of an aerobic decomposition process (including compost).

This research is an attempt to answer the question about the impact of various research environments and the type of biodegradable material on its property which is biodegradability.

MATERIAL AND METHODS

There are numerous types of packaging made of paper and cardboard on the market. Each of them has different durability and mechanical strength. Packaging differs in grammage and other additions introduced (refining e.g. dyes) during production. Out of many materials available on the market, 5 were selected, which were considered the most common or very easily available. The grammage (Table 1) was determined for each of the materials applying the following formula:

$$G = \frac{weight\ of\ the\ packaging}{surface\ \ area}\ [\mathrm{g \cdot m^{-2}}] \qquad (1)$$

Table 1. Grammage of packaging waste analyzed

Type of material	Grammage [$g \cdot m^{-2}$]
Cardboard (cardboard packaging)	410.63
Paper packaging	143.14
Sheet of paper	77.49
Baking paper	39.88
Paper towel	32.47

Source: Own elaboration

The methodology of the undertaken analyzes was developed, among others, on the basis of research conducted by a team of scientists under the supervision of M. Vaverková, which conducts similar experiments at the Mendel University in Brno (Czech Republic). Based on their analyses, three most commonly used research methods of decomposition of biodegradable materials or waste can be distinguished (Vaverková *et al.* 2014, Vaverková and Adamcová 2015, Adamcová *et al.* 2018):

- mass measurement,
- surface are measurement,
- the thermogravimetric and spectral analysis,
- measurement of fiber distribution using an electron microscope.

Vaverková *et al.* (2017) used several research environments (e.g. compost and soil). Several research environments were also employed in the research that was conducted in the Laboratory at the University of Agriculture in Krakow. This was to compare the impact of various environments on the course and final effect of the decomposition process of the analyzed bags. The investigation was carried out in four research environments:

- in compost,
- in the undersize fraction separated from municipal solid waste (called: organic fraction of municipal solid waste),
- in stabilized waste with addition of 10% biochar (produced from wood chips),
- in the universal soil substrate.

Parameters that may affect the rate of biodegradation are primarily pH, moisture content and repiration activity – AT4 (Table 2). The reaction of the environment, i.e. pH, indicates the alkalinity or acidity of the material being tested. Moisture content indicates how much water is in the material. Its presence can contribute to an increase in the rate of numerous biological processes, because water consists in natural environment for abundant microorganisms living in waste. AT4 is a parameter expressing the oxygen demand of a waste sample over 4 days, expressed in $mgO_2 \cdot g^{-1}$ d.m. It is determined in a short-term microbiological test to reveal respiration activity – carbon dioxide emission or oxygen uptake rates (Siemiątkowski *et al.* 2012). The high AT4 value indicates a very high content of organic matter and microorganisms in the material and its high biological activity, including susceptibility to decomposition.

Table 2 Parameters of materials used as research environments

Research environment	pH	Moisture content [% w/w]	AT4 [$mgO_2 \cdot g^{-1}$ d.m.]
Stabilized waste with 5% biochar addition	8.8	46	27
Undersize fraction (organic fraction form MSW)	6.8	36	21
Universal substrate (soil)	6.3	22	<1
Compost	6.5	19	<1

Source: Own elaboration

The packaging waste obtained for the analysis was cut to uniform sizes (shape of a circle with an area of 415 cm^2). The waste prepared in this way was placed into previously prepared containers with a volume of 20 dm^3. The containers were filled in such a way that a minimum 5 cm layer of a specific research environment was placed in them (Table 2) at the bottom, and then a layer of the analyzed packaging was laid on it, alternating with a minimum 5 cm layer of the research environment. Each container was filled with only one type of research environment. Each packaging was analyzed in 3 replications in each of

4 research environments (compost, horticultural substrate, undersize fraction of waste and stabilized waste with the addition of biochar).

Every 3 days packaging waste was removed from the containers and a photograph was taken. Then the packaging waste was again placed in containers. This method of documenting changes was carried out regularly for a period of 30 days. Photographs were taken from a height of 60 cm at the right angle to the photographed surface.

The photographs taken were subjected to the image analysis using AutoCAD software. After scaling the photo, all areas marking the tested material and loss in its surface area were carefully outlined. After marking all the contours created, the software calculated their surface area of non-degraded waste. In this way, data on the surface area of all materials that had not been biodegraded after a given period of time were obtained. The results obtained from the conducted image analysis were visualized using graphs.

In addition, an analysis of the rate and dynamics of changes in the decomposition of tested materials was carried out in the study. The average chain index of dynamics of changes was used to determine the dynamics of changes (Zeliaś 2000):

$$\bar{\imath} = \sqrt[n-1]{\frac{y_1}{y_0} \cdot \frac{y_2}{y_1} \cdot \frac{y_3}{y_2} \cdots \frac{y_n}{y_{n-1}}} = \sqrt[n-1]{\frac{y_n}{y_0}} \qquad (2)$$

where:

y_0 – value of the studied phenomenon in the period taken as the basis for comparison;

y_1, y_2, y_3, ..., yn – value of the accumulation index.

And then, based on the above calculated index, the average rate of change was determined [%]:

$$\bar{T} = (\bar{\imath} - 1) \cdot 100 \qquad (3)$$

RESULTS AND DISCUSSION

The obtained research results are presented in graphs (Figure 1A-E). In the case of cardboard, no defect in the surface of the material was observed in any of the containers after 3 replications of the test. The only changes that could be observed were the delamination of cardboard. In the case of paper packaging, the largest surface area loss was noted when the material was in the compost and the smallest in the undersize fraction.

In the case of a sheet of paper and baking paper, the most significant changes in surface area were observed when packaging waste was placed in containers with compost and stabilized waste with the addition of biochar. In containers with the universal substrate and the undersize fraction, after 30 days, a substantial part of the material remained that had not decomposed.

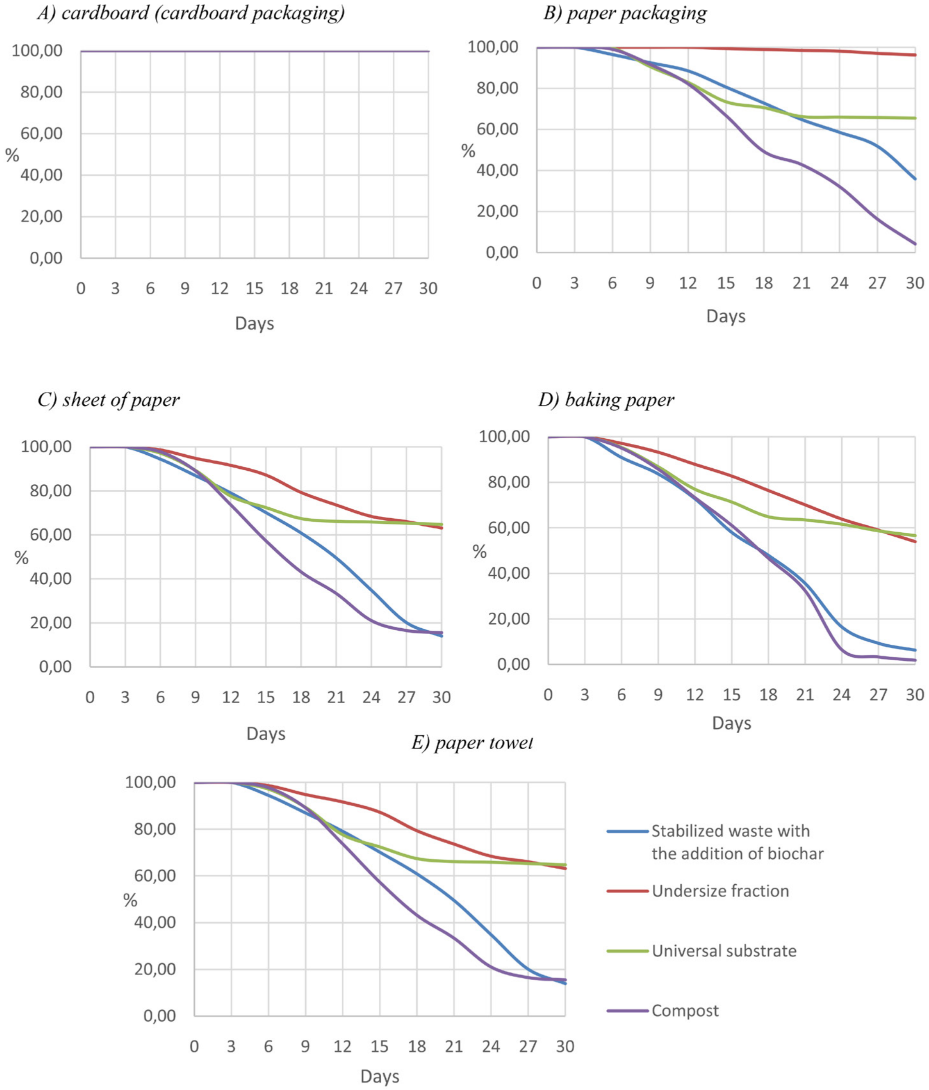

Figure 1 Changes in the surface area of materials during the research
Source: Own study

In the case of paper towel, the biodegradation process developed the fastest in a container with compost. After 30 days, the only research environment in which the paper towel was not completely biodegraded was the undersize fraction.

Based on the results obtained during the image analysis, the average chain index of dynamics of changes and the average change rate were calculated (Table 3). The average change rate depicts the percentage of surface loss that occurred between subsequent measurements (every 3 days). Cardboard was the only material in case of which no changes were seen in the surface area, even after 30 days of the process. The change rate for this material was therefore 0%. In the case of other materials, a surface loss could be observed, which translated into negative values of the change rate. The total decomposition of the material subjected to analysis occurred in 3 cases – when the paper towel was placed in a container with a stabilized waste with the addition of biochar, in a container with a universal soil substrate and compost.

Table 3. The average chain index of changes and the average change rate that occurred during the biodegradation process for the tested materials in research environments

Material	Stabilized waaste + biochar		Undersize fraction		Universal soil substrate		Compost	
	$\bar{i}$	$\bar{T}$ [%]	$\bar{i}$	$\bar{T}$ [%]	$\bar{i}$	$\bar{T}$ [%]	$\bar{i}$	$\bar{T}$ [%]
Cardboard (cardboard packaging)	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Paper packaging	0.90	-9.74	0.99	-0.39	0.96	-4.14	0.73	-27.10
Sheet of paper	0.82	-17.87	0.96	-4.49	0.96	-4.25	0.83	-16.99
Baking paper	0.76	-24.16	0.94	-5.99	0.94	-5.54	0.67	-32.76
Paper towel	t.d.*	t.d.	0.72	-28.32	t.d	t.d.	t.d	t.d.

** t.d. – total decomposition of the material*
Source: Own elaboration

The highest rate of change in the surface area of the examined waste was characterized by samples placed in compost and stabilized waste with the addition of biochar. However, the rate of paper and cardboard decomposition placed in the undersize fraction and universal soil substrate was more than 4 times lower.

CONCLUSION

As a result of the conducted research, it can be stated that the majority of the analyzed packaging waste (except cardboard) made of paper decomposed at least partially within 30 days. Materials of lower grammage such as paper towel decomposed the fastest. The greater the grammage of packaging waste made of paper, the more time was needed to observe changes in the surface of the material. The materials subjected to the test differed in dynamics and decomposition rates. The analysis proved that the grammage of these materials as well as the environment in which they were placed influenced the biodegradation process of paper and cardboard. The short decomposition time of packaging made of paper means that they do not pose a threat to the environment associated with their long-term decomposition whether in the natural environment or in landfills as is the case with plastics, glass or metals.

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Corresponding author: Eng. Anna Nowińska
Eng. Joanna Baranowska
Eng. Mateusz Malinowski, PhD
University of Agriculture in Krakow
Department of Bioprocesses Engineering, Energetics and Automatization
Ul. Balicka 116b/417
30-149 Krakow
Phone: +48 (12) 662 46 60
E-mail: nowinska.ann@gmail.com
jobaranov@gmail.com
mateusz.malinowski@urk.edu.pl

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