Małgorzata WORWĄG • Adrianna GROJEC

BIODEGRADATION OF FOOD WASTE USING MICROORGANISMS ISOLATED FROM THE ENVIRONMENT

Małgorzata WORWĄG (ORCID: 0000-0001-9029-8944) – *Czestochowa University of Technology*
Adrianna GROJEC (ORCID: 0009-0002-1066-3054) – *Czestochowa University of Technology*

Correspondence address:
Generała Jana Henryka Dąbrowskiego Street 73
42-202 Częstochowa, Poland
e-mail: malgorzata.worwag@pcz.pl

ABSTRACT: Biodegradation of food waste is a key component of sustainable waste management that can bring significant environmental and economic benefits. The use of biological methods for waste disposal represents environmentally friendly technologies with high efficiency. The purpose of this study was to determine the rate of biodegradation of food waste using microorganisms from the environment in an aerobic process in an ECHO respirometer in accordance with ISO 14855-1:2012. The biodegradation process was carried out at 58 °C ± 2 °C and adequate humidity. During the experiment, CO2 production and O2 consumption were monitored, and the degree of biodegradation was determined. In the study, combinations based on variable organic waste content and the dose of microorganisms in suspension were used. In addition, a commercial biopreparation designed to promote composting was used. A significant improvement in the degree of waste biodegradation was observed with the addition of microorganisms isolated from the environment. Increasing the dose of microorganisms did not significantly improve the efficiency of the process. The commercial biopreparation used was characterised by low efficiency, and no increase in the degree of biodegradation of waste was observed after its use.

KEYWORDS: biopreparations, microorganisms, composting

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Introduction

Food waste (FW) is a significant environmental issue worldwide (Chan et al., 2016). It often ends up in landfills without adequate treatment, leading to environmental degradation through soil, water, and air pollution (Kwon & Lee, 2004; Li et al., 2013; Wang et al., 2016). Proper handling and management of FW enable its conversion into valuable products such as fertilisers and nutrient sources (Chong et al., 2004; Lee et al., 2010).

However, food waste may lack sufficient native microorganisms compared to other organic materials, particularly those of animal origin, such as manure (Acevedo et al., 2005). Therefore, effective and environmentally friendly treatment of FW often requires microbial support in the form of inoculation. The term "inoculation" originates from the Latin *inoculare*, meaning to introduce an organism or substance artificially. While historically used in the context of infectious diseases, it is now widely understood as the introduction of a selected microbial population into a medium to achieve a desired outcome beyond what occurs naturally (Rynk et al., 1992; Goldstein, 1994; Madigan et al., 1999).

Various inoculation strategies have been developed. One method involves using pre-isolated or selected microorganisms in concentrated liquid or solid forms. Another approach reuses material in the intermediate stages of biotransformation as an inoculum for new material. A third method uses organic residues rich in saprophytic microorganisms, such as manure. However, practical implementation of inoculation can be challenging, as microbial populations are not always the limiting factor in degradation processes.

The meaning of "inoculation" may vary by discipline. In microbiology, it often refers to the addition of a small number of microorganisms, while in engineering, it may involve a significant biomass of microbes. In environmental sciences, inoculation may refer to the use of compost as an inoculum in bioremediation or composting processes (Acevedo et al., 2019).

High biotransformation efficiency can be achieved by inoculating with native microflora, which are well adapted to the specific raw materials used. These raw materials act as "natural selectors" for microbial populations. Research has shown that enzymes isolated from microorganisms can perform similarly to whole microbial cultures. However, producing enzyme preparations requires more complex procedures, and the yields are often comparable to those achieved with living microorganisms (Golueke, 1991; Gouin, 1992).

The progress and rate of biodegradation depend on various factors, including environmental conditions (temperature, moisture, pH), microbial availability and diversity, and the chemical composition and structure of the waste material. Biodegradability testing methods have advanced in response to increasing concern over the environmental persistence of post-consumer waste. Since biodegradation is highly influenced by environmental conditions, it is essential to test it under conditions that realistically simulate natural environments.

Several analytical techniques are used to monitor the biodegradation of waste during composting, such as mass loss, changes in mechanical properties, and molecular weight reduction. However, while these indicators may reflect substrate degradation, they do not always confirm true biodegradation (Gutowska et al., 2013).

Respirometric methods, which measure oxygen consumption and/or carbon dioxide (CO_2) release, are considered the most reliable for assessing biodegradation. Automated respirometric systems allow simultaneous monitoring of multiple samples, reduce labour, and provide real-time data. These features are beneficial for developing new materials and obtaining biodegradability certifications.

The objective of this study was to isolate native microorganisms from food waste and assess their effectiveness in biodegrading different quantities of waste, compared to inoculation with a commercial biopreparation.

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Research methods

Substrate

The substrate of the study was food waste, consisting of: pomace from apples, beets, carrots; compost; and microcrystalline cellulose. Table 1 shows the characteristics of the substrates for the study. The waste was characterised by a high hydration of 84.08% and a high Kjeldahl nitrogen content of 16.24 mg/g. Commercial compost was characterised by a hydration of 69.33% and a low Kjeldahl nitrogen content (8.54 mg/g). The organic carbon content for the waste and compost was estimated at a high level of 417.7 and 422.7 mg/g d.m. The TOC content of microcrystalline cellulose was 0.3 mg/g d.m., and the hydration was 44%.

Table 1. Substrate characteristics

Substrate	Waste	Commercial Compost	Microcrystalline
TOC [mg/g s.m.]	417.7	422.7	0.3
Hydration	84.08%	69.33%	44%
Dry matter	15.92%	30.67%	-
Kjeldahl nitrogen [mg/g]	16.24	8.54	-

*TOC (ang. Total Organic Carbon).

Biopreparations

Proprietary biopreparation

To prepare a proprietary biopreparation, isolation of microorganisms from the leachate of composted vegetable food waste was carried out. Composting was carried out at ambient temperature (20°C÷25°C) for 2 months. The detailed composition of the compost mixture from which the biopreparation was prepared is shown in Table 2. The obtained leachate formed the basis for the preparation of the biopreparation. 40 ml of Sabouraud medium and 5 ml of compost leachate were poured into sterile laboratory bottles. In order to multiply the microorganisms contained in the leachate, the mixture was placed in a shaking incubator for a period of 5 days at 55°C using shaking at 100 rpm. The resulting culture of microorganisms was used as a proprietary biopreparation in the next stage of the study.

Table 2. Waste composition

Apple peelings and cores	93 g
Banana peel	132 g
Lemon pulp and zest	251 g
Pomelo peels	318 g
Khaki peelings	215 g
Mandarin peels	105 g
Potato peels	576 g
Onion peels	27 g
Eggshells	43 g

Commercial biopreparation

The commercial biopreparation *BioAzoBacter* is a microbial concentrate composed of beneficial microorganisms, including *Azotobacter vinelandii*, *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Trichoderma viride*. The formulation is designed to enhance the mineralisation and decomposition of organic matter and waste by approximately 30%. Additionally, it contributes to mass enrichment and odour neutralisation, while simultaneously inhibiting the growth of pathogens and pests.

The biopreparation was applied in accordance with the manufacturer's recommendations, at a dose of 1 L per 50–100 kg of organic waste. Based on this guideline, two dosage levels were used in the study: the recommended dose (7 ml) and a double dose (14 ml), adjusted proportionally to the quantity of treated organic material.

Methods

Experimental procedure – biodegradation testing methodology

This study employed the international standard ISO 17556 method (Determination of the ultimate aerobic biodegradability in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved). While compliant with ISO guidelines, biodegradation testing without the aid of advanced analytical techniques can be time-consuming. A total of 12 bioreactors were used in the experiment (Figure 1), each containing a specific combination of organic waste, cellulose, and/or the biopreparation (as detailed in Table 3). Biodegradation was monitored over a 4-week period using an ECHO respirometer, in accordance with ISO 14855-1:2012, by measuring CO_2 evolution(expressed in ppm) and O_2 consumption (expressed in g). The process was conducted under controlled conditions at a temperature of 58 ± 2 °C and maintained humidity (Figure 2). During the biodegradation process, the organic material underwent decomposition, resulting in a measurable reduction in waste volume. Upon completion, the samples were subjected to physicochemical analyses, including determination of dry matter content, pH, total phosphorus, Kjeldahl nitrogen, and concentrations of heavy metals. In addition, microbiological analyses were performed to detect the presence of *Salmonella* spp. and *Escherichia coli*. The research methodology included both qualitative and quantitative analyses to detect the presence of *Escherichia coli* and *Salmonella* spp. The microorganisms were identified using selective media specific to the target groups (Merck KGaA, Germany), and their presence was confirmed by molecular analysis using EMA-qPCR (Kacprzak et al., 2015). The results are presented as means ± standard deviation.

Table 3. Biodegradation mixtures used in the ECHO respirometer

1	300 g compost			200 ml water
2	300 g compost	25 g cellulose		200 ml water
3	300 g compost	50 g cellulose		200 ml water
4	300 g compost	25 g of waste		200 ml water
5	300 g compost	50 g of waste		200 ml water
6	300 g compost	25 g of waste	7 ml of commercial biopreparation	200 ml water
7	300 g compost	50 g of waste	15 ml of commercial biopreparation	200 ml water
8	300 g compost	25 g of waste	40 ml of own biopreparation	150 ml water
9	300 g compost	50 g of waste	80 ml of own biopreparation	100 ml water
10	300 g compost	7 ml of commercial biopreparation		200 ml water
11	300 g compost	40 ml of own biopreparation		150 ml water
12	300 g compost	75 g waste		200 ml water

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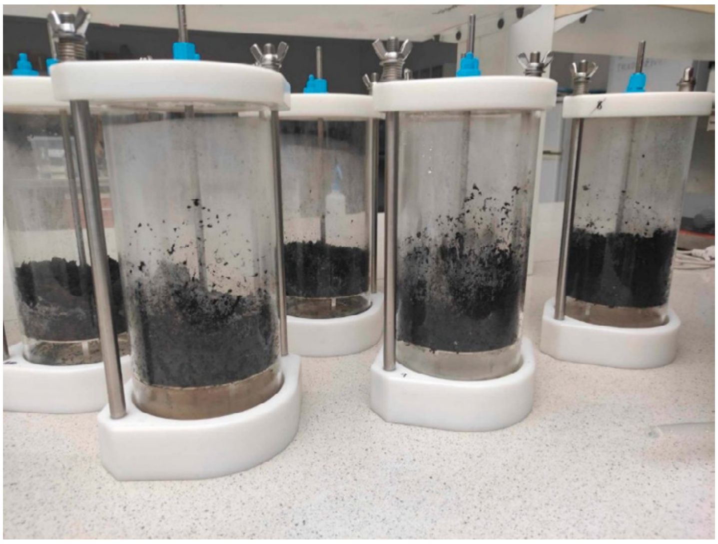

Figure 1. Analysis of prepared samples in the ECHO respirometer

Results of the research

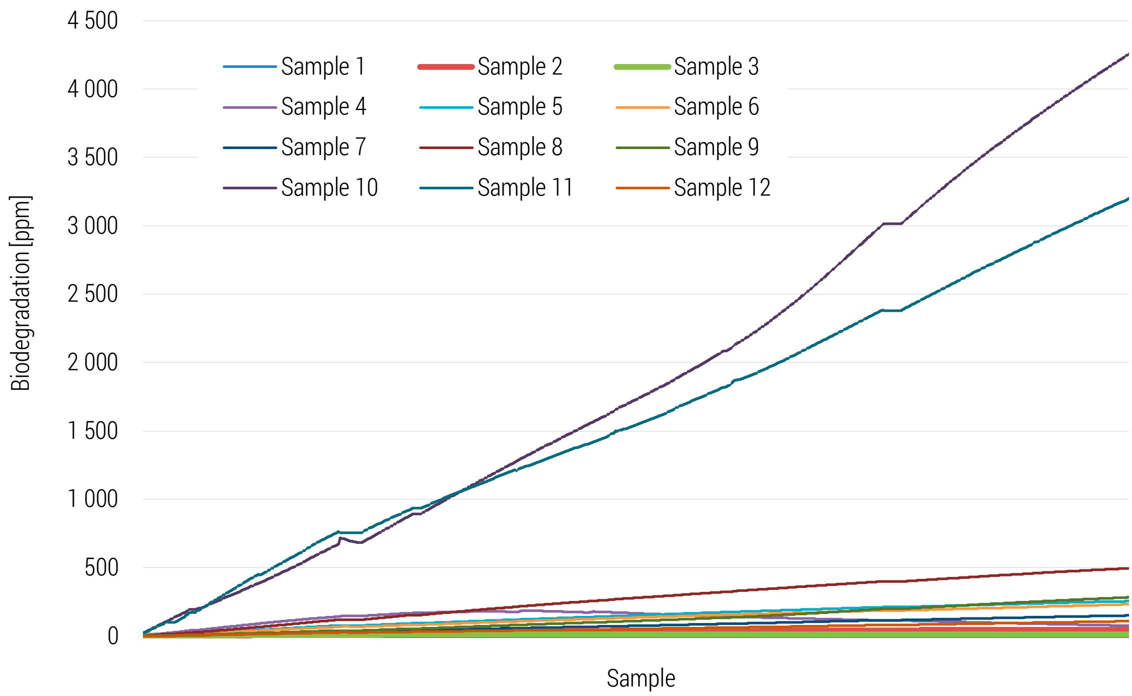

Figure 2. Comparison of biodegradation values for the tested mixtures

Figure 2 shows the biodegradation for the combinations studied. The highest level of biodegradation was recorded for sample 10, a value of 4300 ppm. This suggests that the commercial biopreparation accelerates the biodegradation process, but is not effective enough for waste (Samples 6 and 7). In sample 5, which contained a larger amount of waste (50 g), the biodegradation process was slightly more efficient than in sample 4, where a smaller amount of waste (25 g) was used. Sample 12, containing 75 g of waste, showed the lowest level of biodegradation of all waste samples. These results indicate that increasing the amount of waste to 75 g significantly reduces the level of biodegradation. Sample 6, containing a lower amount of commercial biopreparation (7 ml) and a smaller amount of waste (25 g), showed 1.5 times higher biodegradation efficiency compared to a sample with twice the amount of commercial biopreparation and waste. A similar phenomenon was observed

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for samples 8 and 9 that contained their own biopreparation, where a smaller amount of biopreparation (40 ml) achieved the best biodegradation results in samples containing both waste and biopreparation. Sample 11 was highly biodegradable, comparable to sample 10. The addition of 40 ml of the own biopreparation significantly improves biodegradation, approaching the values achieved by sample 10.

Figures 3 and 4 show the sum and mean of the biodegradation values for each sample. Sample 1, consisting only of compost and water, showed no biodegradation activity, suggesting no spontaneous decomposition process under controlled conditions without additives. Samples 10 and 11, which achieved the highest biodegradation values, contained a commercial and proprietary biopreparation with no added waste, respectively. High values indicate the significant effectiveness of biopreparations in catalysing the biodegradation process. Sample 8, also containing its own biopreparation, but in a different proportion (40 ml of the biopreparation), shows higher values than other samples with waste, which may indicate the potential of the own biopreparation in optimising the biodegradation process. The low biodegradation value in sample 1 highlights the importance of the addition of the biopreparation to the composting process.

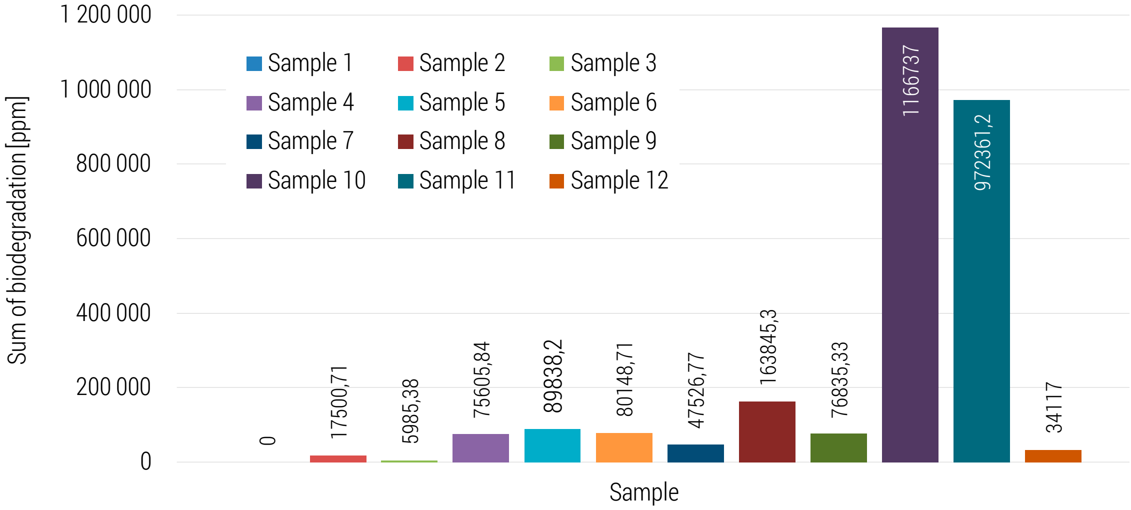

Figure 3. The sum of the biodegradation values for each sample. Results from the ECHO respirometer

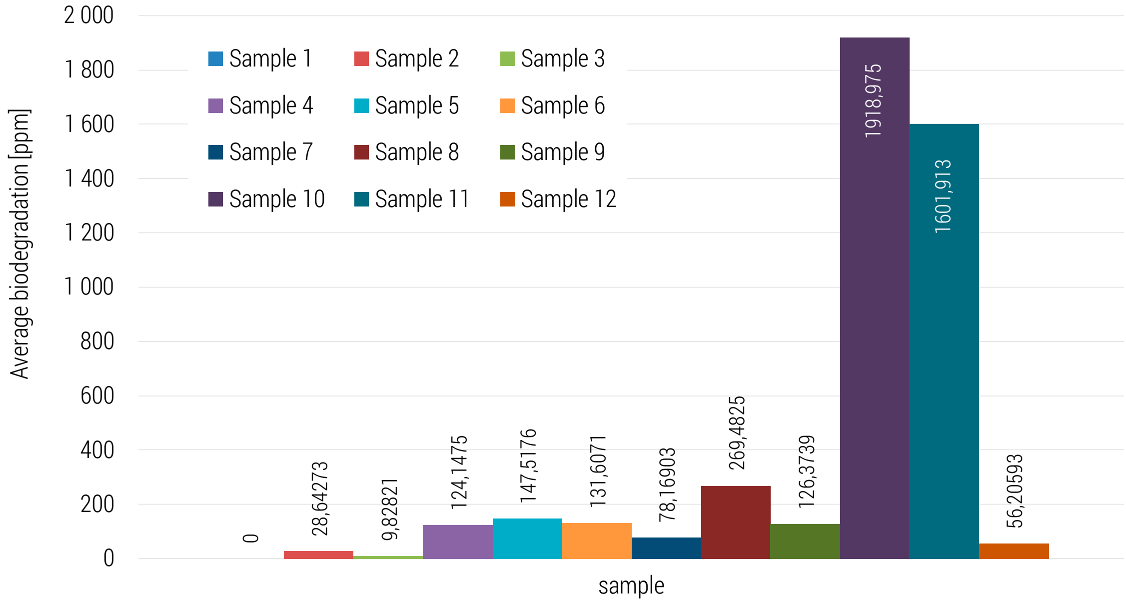

Figure 4. Average biodegradation values for individual samples. Results from the ECHO respirometer

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Analysing the consumption of O_2 (Figure 5), it can be seen that all samples show different rates of oxygen consumption. Sample 2 consumed the most oxygen of all samples, at 15.36 g O2. This is probably due to the intense activity of cellulose-decomposing microorganisms, resulting in high oxygen demand. Sample 10 used 9.54 g O_2. Despite the lower amount of oxygen consumed compared to sample 2, the rate of oxygen consumption was faster, which may suggest active degradation of organics aided by a commercial biopreparation. Sample 3 used 9.38 g O_2. High oxygen consumption may be due to a high proportion of cellulose. Sample 9 drew 8.20 g O_2. Higher oxygen consumption compared to other samples may indicate intensive biodegradation of both the compost and the added waste, supported by the own biopreparation. Sample 7 used 8.11 g O_2. Despite the smaller amount of commercial biopreparation, the sample showed similar oxygen consumption as samples with larger amounts of biopreparation, which may indicate its effective activity in the biodegradation process. Sample 8 used 7.67 g O_2. The lower oxygen consumption than in sample 7 may be due to less added waste and self-biopreparation. Sample 6 used 6.91 g O_2. Despite the small amount of commercial biopreparation, the sample showed moderate oxygen consumption, which may indicate its effectiveness in the biodegradation process with less waste. Sample 5 drew 6.76 g O_2. Despite the lack of biopreparation, the sample showed moderate oxygen consumption, which may suggest the natural ability of microorganisms from the compost to decompose organic waste. Sample 12 consumed 6.39 g O_2. Despite the higher amount of waste, oxygen consumption was lower than in samples with smaller amounts of waste, which may indicate lower microbial activity in the presence of larger amounts of organic materials. Sample 11 used 4.85 g O_2. Despite the relatively low oxygen consumption, the proprietary biopreparation has shown effectiveness in the biodegradation process. Sample 1 took 2.91 g O_2. The low oxygen consumption in this sample may be due to the lack of additional organic materials to decompose, which limits the activity of microorganisms. This sample was a control. Sample 4 absorbed 1.93 g O_2. The lowest oxygen consumption in this sample may indicate less microbial activity with relatively little waste added.

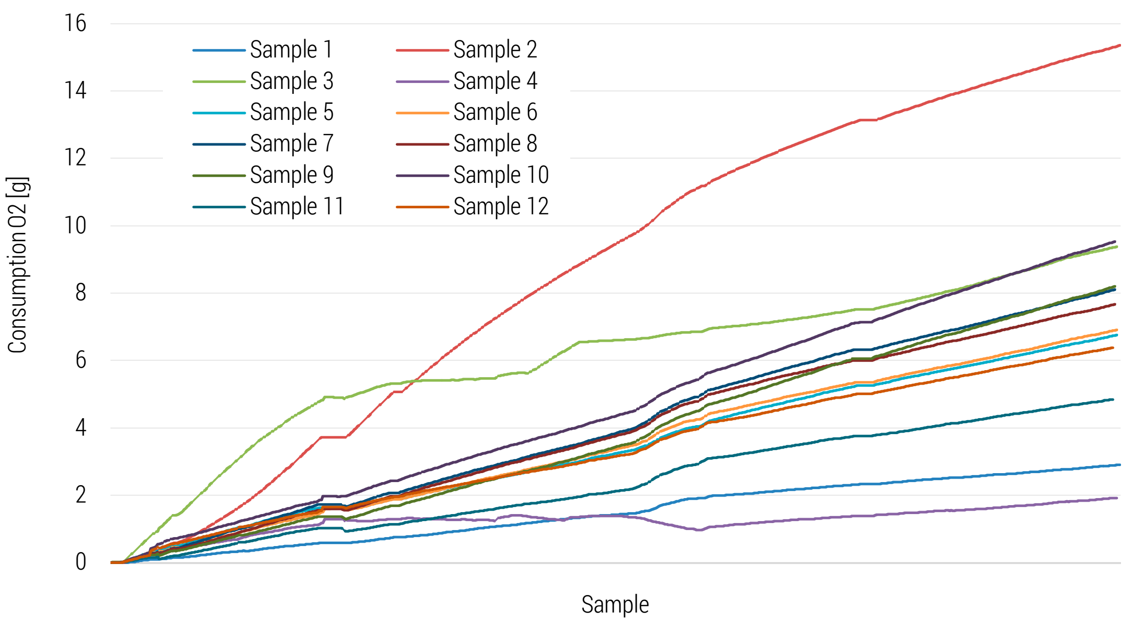

Figure 5. Comparison of oxygen consumption for all samples

Sample 2 showed the highest CO_2 production at 22138 ppm. It contained compost and cellulose, which may have promoted the intensification of the biodegradation process, leading to greater carbon dioxide production. Sample 3 came in second place in terms of CO_2 production, at 13538 ppm. It contained a higher amount of cellulose compared to sample 2, suggesting that a smaller amount of cellulose generates more carbon dioxide. Samples 7, 10, and 9 showed similar CO_2 production results, with 8528 ppm, 8515 ppm, and 8390 ppm, respectively. Different combinations of compost, organic waste and biopreparations were used in these samples, which affected the intensity of the biodegra-

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dation process and the production of CO_2. Sample 5 produced 7789 ppm CO_2, which also indicates an efficient decomposition process of the organic materials contained in the sample composition. Sample 8 produced 7623 ppm CO2, containing compost, waste and own biopreparation. This proves the effectiveness of the biopreparation used in supporting the biodegradation process. Sample 6 showed a production of 7176 ppm CO_2, which is a moderate result compared to the other samples. Sample 12 produced 6002 ppm CO_2, which places it in the middle of the result range, which may be due to the lower amount of organic waste used in this sample. Samples 11 and sample 4 showed a production of 5819 ppm and 3545 ppm CO_2, respectively. Sample 11 contained a biopreparation of its own, which may have affected the biodegradation process, while sample 4 was a more basic composition with less waste. Sample 1 – control containing only compost, showed the lowest CO_2 production, amounting to 2732 ppm. This confirms that the amount and type of additional organic materials have a significant impact on the intensity of the biodegradation process and the production of CO_2 (Figure 6).

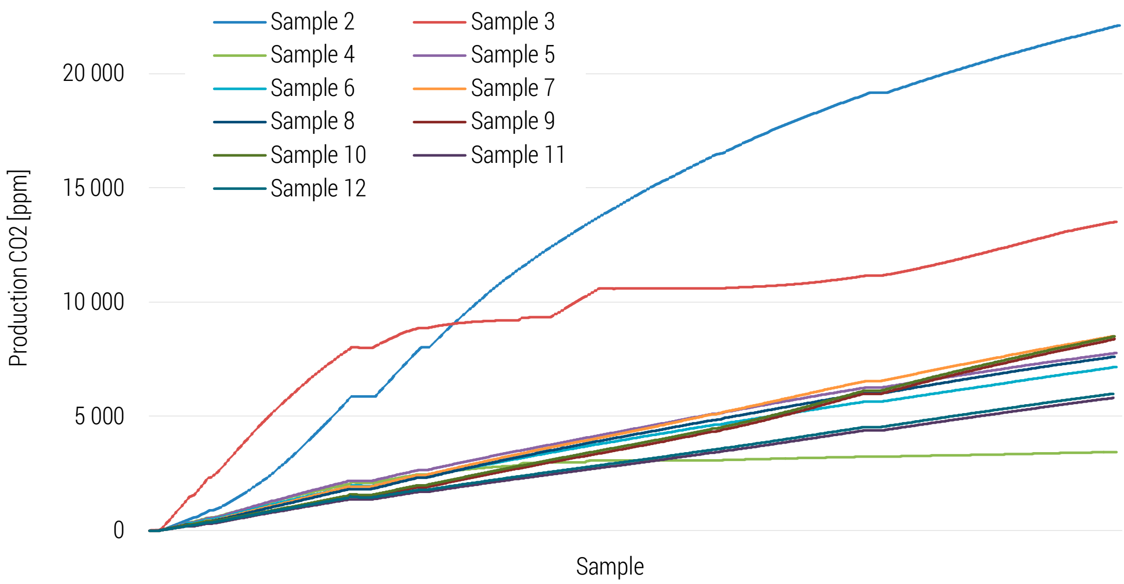

Figure 6. Comparison of carbon dioxide production for all samples

Dry matter and water content

Table 4 shows the average values of organo, mineral and water compounds in 12 samples after the biodegradation process, along with the standard deviation. The content of organic compounds ranged from 0.480 g for the combination with 50 g of waste (sample 5) to 0.610 g for the combination with 50 g of cellulose (sample 3). The content of mineral compounds ranged from 0.328 g for the combination with 50 g of cellulose (sample 3) to 0.467 g for the combination with 50 g of waste and 15 ml of commercial biopreparation (sample 7). The water content ranged from 0.120 g for the combination with compost alone and 7 ml of own biopreparation (sample 10) to 5.028 g for the combination with 50 g of waste and 80 ml of own biopreparation (sample 9).

Table 4. Mean and Standard Deviation after Process

Sample	Average and SD of organic compounds content [g]	Average and SD mineral content [g]	Water content [g]
1.	0.508 ± 0.005	0.423 ± 0.005	3.204
2.	0.548 ± 0.018	0.381 ± 0.020	2.686
3.	0.610 ± 0.005	0.328 ± 0.007	1.710
4.	0.512 ± 0.009	0.417 ± 0.012	0.760

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Sample	Average and SD of organic compounds content [g]	Average and SD mineral content [g]	Water content [g]
5.	0.480 ± 0.007	0.453 ± 0.009	3.299
6.	0.483 ± 0.002	0.448 ± 0.003	3.218
7.	0.471 ± 0.004	0.467 ± 0.006	3.754
8.	0.492 ± 0.005	0.438 ± 0.006	2.965
9.	0.495 ± 0.002	0.437 ± 0.001	5.028
10.	0.509 ± 0.004	0.435 ± 0.006	0.120
11.	0.482 ± 0.003	0.448 ± 0.004	3.553
12.	0.508 ± 0.005	0.440 ± 0.009	0.167

Nitrogen, phosphorus, pH

Table 5 shows the results of Kjeldahl nitrogen, phosphorus and pH in 12 compost samples. The Kjeldahl nitrogen content of the samples ranges from 10.08 to 18.82 mg N-NH_4/g. The highest contents were recorded in samples 12 (18.82 mg N-NH_4/g), 9 (17.01 mg N-NH_4/g) and 8 (16.8 mg N-NH_4/g), while the lowest content was recorded in sample 3 (10.08 mg N-NH_4/g).

Phosphorus content in the samples ranges from 0.138 to 0.261 mg/g. The highest value was observed in samples 9 (0.261 mg/g), 5 (0.256 mg/g) and 4 (0.256 mg/g), and the lowest in sample 6 (0.138 mg/g).

The pH values in the samples range from 6.74 to 7.52, with the highest pH values observed in samples 9 (7.52), 12 (7.46) and 10 (7.41), and the lowest in samples 3 (6.69) and 1 (6.74).

Table 5. Results of nitrogen, phosphorus and pH content obtained after the process

Sample	Kjeldahl nitrogen (mg N-NH_4/g)	Available phosphorus (mg/g)	pH KCl	pH H_2O
1.	14.91	0.226	6.76	6.74
2.	14.56	0.231	7.17	6.74
3.	10.08	0.174	7.05	6.69
4.	15.26	0.256	7.36	7.23
5.	15.47	0.195	7.18	7.14
6.	15.26	0.138	7.04	7.15
7.	16.17	0.252	7.18	7.19
8.	16.80	0.164	7.10	7.08
9.	17.01	0.261	7.52	7.36
10.	16.38	0.187	7.41	7.17
11.	15.75	0.179	7.30	7.20
12.	18.82	0.258	7.38	7.46

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Heavy metals

Table 6 shows the results obtained from the analysis of heavy metals (Cd, Cr, Cu, Ni, Pb, Zn) in the tested mixtures after the biodegradation process. The concentrations of heavy metals in the analysed samples did not exceed the permissible standards set both for fertilisers by Regulation of the Minister of Agriculture and Rural Development of June 18, 2008, on the implementation of certain provisions of the Law on Fertilisers and Fertilisation (Regulation, 2008). In all samples, the cadmium content is below 0.58 mg/g, which means that it does not exceed either fertiliser standards or soil quality standards, regardless of the runoff fraction. The introduction of cellulose into the compost has no significant effect on the heavy metal content compared to the control sample (sample 1). Chromium content in the samples ranges from 5.65 mg/g (sample 7) to 15.55 mg/g (sample 5). Copper concentrations in the samples range from 11.53 mg/g (sample 7) to 17.67 mg/g (sample 1). Nickel values range from 4.63 mg/g (sample 3) to 9.87 mg/g (sample 5). Lead content in the samples ranges from 1.64 mg/g (sample 9) to 2.48 mg/g (sample 4). Zinc content ranges from 47.7 mg/g (sample 3) to 76.0 mg/g (sample 1). Samples 4 and 5, which contain waste, show different heavy metal values. Sample 4 has lower Cr and Cu content compared to sample 5, which may be due to the larger amount of waste in sample 5. Sample 12, which also contains waste, shows similar heavy metal values to other samples with waste. Larger amounts of waste may increase the content of some metals.

Table 6. Heavy metal content in the samples after the process

Heavy metals [mg/kg]						
Sample	Cd	Cr	Cu	Ni	Pb	Zn
1	<0.58	10.52	17.67	7.54	2.27	76.0
2	<0.58	10.52	15.23	7.08	1.96	63.3
3	<0.58	5.65	11.53	4.63	1.79	47.7
4	<0.58	11.05	17.14	7.86	2.48	70.1
5	<0.58	15.55	17.21	9.67	2.17	71.7
6	<0.58	12.22	17.13	8.11	1.95	71.8
7	<0.58	5.65	11.53	4.63	1.79	47.7
8	<0.58	11.92	16.06	8.29	2.08	69.0
9	<0.58	12.15	16.41	8.47	6.14	71.9
10	<0.58	15.27	15.27	8.43	1.79	78.4
11	<0.58	12.19	15.55	8.59	1.86	66.4
12	<0.58	10.15	15.58	6.76	1.67	64.8

Microbiological Analysis

Table 7 presents the results of microbiological analysis conducted on 12 samples collected after the biodegradation process. The samples varied in composition, including different proportions of food waste, compost, and the use of either a commercial or proprietary biopreparation. The presence of pathogenic microorganisms, specifically *Salmonella spp.* and *Escherichia coli*, was assessed in each sample using selective media and molecular confirmation methods (qPCR).

None of the samples tested positive for *Salmonella spp.* or *E. coli*, indicating that the applied biodegradation process – regardless of the type or quantity of biopreparation used – was effective in eliminating these common pathogens. This confirms the microbiological safety of the resulting material and suggests the suitability of both proprietary and commercial microbial preparations for use in composting and organic waste treatment.

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Table 7. Microbiological Analysis Results of Biodegradation Samples

Sample	Sample Composition	Salmonella spp.	E. coli
1	Compost (control)	Not detected	Not detected
2	Compost + 7 ml commercial biopreparation	Not detected	Not detected
3	Compost + 14 ml commercial biopreparation	Not detected	Not detected
4	Compost + 40 ml proprietary biopreparation	Not detected	Not detected
5	25 g waste + 7 ml commercial biopreparation	Not detected	Not detected
6	50 g waste + 15 ml commercial biopreparation	Not detected	Not detected
7	75 g waste + 25 ml commercial biopreparation	Not detected	Not detected
8	25 g waste + 20 ml proprietary biopreparation	Not detected	Not detected
9	50 g waste + 30 ml proprietary biopreparation	Not detected	Not detected
10	75 g waste + 40 ml proprietary biopreparation	Not detected	Not detected
11	25 g waste without biopreparation	Not detected	Not detected
12	50 g waste without biopreparation	Not detected	Not detected

Discusion

Biodegradation, a natural process of organic matter decomposition by microorganisms, plays a crucial role in reducing organic waste. The aim of this study was to evaluate the effect of inoculation with native microflora on the biodegradation of food waste at varying quantities in the mixture, in comparison to a commercial biopreparation. Additionally, the study aimed to identify the optimal conditions for biodegradation.

In the first stage, microorganisms were isolated from composted vegetable food waste. Using the obtained microflora, a proprietary biopreparation was developed in the form of a liquid suspension containing fungi and a culture medium. The biodegradation process was carried out using an ECHO respirometer. Variable amounts of food waste (25, 50, and 75 g) were tested, supported by the addition of either the proprietary or a commercial biopreparation.

The results confirmed the beneficial effects of the applied biopreparations. The proprietary biopreparation showed particularly high efficiency, especially in samples containing waste, surpassing the performance of the commercial product. The lowest biodegradation level was observed in the sample with 75 g of waste, while mixtures with 25 g and 50 g of waste achieved similar biodegradation rates. Both biopreparations, and especially the proprietary one, enhanced the process efficiency, as evidenced by a higher degree of biodegradation and a greater reduction in organic matter content after the process.

These findings are in line with previous studies emphasising the role of microbial inoculants in accelerating organic matter degradation. For example, Li et al. (2024) demonstrated that microbial inoculation not only accelerates composting but also enhances the quality of the final product. Similarly, Bernal et al. (2009) reported that the addition of selected microbial consortia can improve nutrient retention and compost maturity during organic waste treatment.

The lower biodegradation efficiency observed in samples with 75 g of waste may be explained by oxygen limitation or microbial inhibition due to substrate overload. Jurado et al. (2014) described similar effects during composting of food waste with high moisture content, where excess substrate led to suboptimal aeration and inhibited microbial activity.

Furthermore, the study showed that waste contributes to the enrichment of samples with biogenic elements such as phosphorus and nitrogen, which are beneficial for microbial activity during biodegradation. This observation supports the findings of Greff et al. (2022), who noted that organic wastes serve as a valuable nutrient source, improving microbial growth and enzymatic degradation. Elevated nutrient levels can stimulate microbial metabolism, thereby enhancing the rate of biodegradation.

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Heavy metal content in all samples remained within safe limits, confirming the environmental safety of the applied methods. Similar findings were reported by Liang et al. (2003), who demonstrated that aerobic composting not only stabilises organic waste but also contributes to the safe removal of pathogens and control of heavy metal mobility.

The pH values observed in this study further support the microbial activity during composting. Samples inoculated with biopreparations showed pH values slightly above 7, indicating an alkaline environment that favours the growth of many composting microorganisms. Gajalakshmi and Abbasi (2008) also found that the pH of compost increases with microbial activity due to the degradation of organic acids and production of ammonia.

The use of effective microorganisms in the biodegradation of plant-based waste can significantly contribute to environmental protection and the efficient recycling of organic matter. These findings are valuable for the further development of organic waste management strategies and have potential applications in both industrial and agricultural settings. The inoculation strategy appears to be a key factor in improving process efficiency. The use of mixed microbial cultures is particularly advantageous for metabolising complex substrates, as demonstrated by Ai et al. (2013), who emphasised the synergistic metabolic capabilities of bacterial and fungal consortia in composting systems.

Conclusions

1. The results demonstrated high biodegradation efficiency of the applied biopreparations, particularly in samples containing only compost. The combination of compost and 7 ml of commercial biopreparation achieved the highest total biodegradation (1,166,737 ppm), followed by the sample with 40 ml of proprietary biopreparation (972,361 ppm). This confirms the effectiveness of the in-house product, although the commercial preparation was slightly more efficient under these conditions.
2. In mixtures containing waste, the effectiveness of the biopreparations varied. The sample with 25 g of waste and 7 ml of commercial biopreparation outperformed the one with 50 g of waste and 15 ml. Notably, the combination of 25 g of waste and 40 ml of the proprietary biopreparation yielded significantly higher biodegradation, indicating greater. The analysis of results shows that increasing the amount of waste in the samples negatively affected the biodegradation process. Samples containing 25 g of waste achieved higher biodegradation values than those with 50 g or 75 g of waste.
3. The results indicate that increasing the amount of biopreparation in samples with more waste does not improve the rate of biodegradation. A sample with 50 g of waste and 15 ml of commercial biopreparation exhibited lower biodegradation than a sample with 25 g of waste and 7 ml of the same preparation.
4. Elevated levels of biogenic elements such as phosphorus and Kjeldahl nitrogen were observed in samples with increased waste content. The added waste was the source of these nutrients, confirming its role in enriching the medium for microorganisms involved in biodegradation.
5. Analysis of heavy metal content revealed that concentrations were well below the permissible limits for soils and fertilisers. This indicates that the applied waste and biosolids did not introduce harmful levels of heavy metals, supporting environmental safety.
6. In samples containing both biopreparations and waste, pH values ranged from 7.08 to 7.46, indicating an alkaline reaction. In contrast, samples without biopreparations showed a slightly acidic reaction, with pH values between 6.69 and 6.74. pH measurements in KCl yielded slightly higher values, as expected due to the ionic strength of the solution.
7. Samples with higher doses of biopreparations showed reduced organic content, indicating a more advanced decomposition process. This supports the effectiveness of biopreparations in enhancing biodegradation.
8. Microbiological analysis of the mixtures after biodegradation showed no presence of pathogenic microorganisms such as *Salmonella* spp. or *Escherichia coli*, confirming the microbiological safety of the process.

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The contribution of the authors

Conceptualization, M.W.; literature review, M.W.; methodology, M.W. and A.G.; formal analysis, A.G.; writing, M.W. and A.G.; conclusions and discussion, M.W. and A.G.

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Małgorzata WORWĄG • Adrianna GROJEC

BIODEGRADACJA ODPADÓW SPOŻYWCZYCH PRZY UŻYCIU MIKROORGANIZMÓW WYIZOLOWANYCH ZE ŚRODOWISKA NATURALNEGO

STRESZCZENIE: Biodegradacja odpadów spożywczych jest kluczowym elementem zrównoważonej gospodarki odpadami, który może przynieść znaczące korzyści środowiskowe i ekonomiczne. Wykorzystanie metod biologicznych do unieszkodliwiania odpadów reprezentuje przyjazne dla środowiska technologie o wysokiej wydajności. Celem niniejszego badania było określenie szybkości biodegradacji odpadów spożywczych przy użyciu mikroorganizmów pochodzących ze środowiska w procesie tlenowym w respirometrze ECHO zgodnie z normą ISO 14855-1:2012. Proces biodegradacji przeprowadzono w temperaturze 58 °C ± 2 °C i odpowiedniej wilgotności. Podczas eksperymentu monitorowano produkcję CO2 i zużycie O2 oraz określano stopień biodegradacji. W badaniu zastosowano kombinacje oparte na zmiennej zawartości odpadów organicznych i dawce mikroorganizmów w zawiesinie. Ponadto zastosowano komercyjny biopreparat przeznaczony do promowania kompostowania.
Zaobserwowano znaczną poprawę stopnia biodegradacji odpadów po dodaniu mikroorganizmów wyizolowanych ze środowiska. Zwiększenie dawki mikroorganizmów nie poprawiło znacząco wydajności procesu. Zastosowany komercyjny biopreparat charakteryzował się niską wydajnością, a po jego zastosowaniu nie zaobserwowano wzrostu stopnia biodegradacji odpadów.

SŁOWA KLUCZOWE: biopreparaty, mikroorganizmy, kompostowanie