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Indoor Pretreatment of Biowaste Using the Bokashi Method

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Abstract

Approximately one-third of municipal solid waste is biodegradable waste, necessitating its urgent processing into compost or biogas. Indoor composting of biowaste has recently received increased attention due to its economic, environmental, and social benefits, offering a significant contribution to sustainable waste management and circular economy. Instead of disposing of biowaste in landfills, compost is produced as a useful organic soil improver, fertiliser or bio-based product. This study analyses the physicochemical parameters of biowaste and the obtained pre-compost during the Bokashi treatment, considering the effects of different inoculants, occasional mixing of biowaste, and exposure to air. The pretreatment of biowaste was compared based on pH, electrical conductivity, temperature and height of the compost mass, moisture, dry matter, volatile matter, carbon and nitrogen content, and C/N ratio. Collected leakages were analysed for volume, pH, electrical conductivity, and turbidity. In addition, the obtained pre-composts underwent further maturation in two soil types, and the same physicochemical parameters were monitored. Finally, FTIR spectroscopy was employed to analyse the initial biowaste, final pre-compost masses, and the collected leakages. There is no significant difference between the pre-composts and also between the leakages. The results indicate that Bokashi treatment of biowaste with *Inoculant 1* efficiently yielded a higher carbon and nitrogen content in the final pre-compost, and produced a lower volume of compost leakage. This paper highlights the Bokashi method's efficiency in facilitating indoor biowaste treatment.

Keywords

Indoor composting, inoculant, fermentation, biowaste, pre-compost maturation

1 Introduction

We are all faced with the escalating generation of municipal solid waste, primarily driven by population growth and increased living standards. One-third of this waste comprises biodegradable compounds, and improper disposal can lead to environmental pollution, affecting water sources and soil. It can also contribute to the depletion of natural resources, as the gases and leachate release a variety of pollutants into the environment. Methane from landfilled biowaste is a very potent greenhouse gas (GHG), and a major contributor to GHG emissions. The existence of illegal landfills is a growing global problem. Addressing proper disposal of biodegradable waste is therefore paramount for effective solid waste management.[1,2] Converting biodegradable waste into value-added products, such as compost or biogas offers a potential solution.[3] While centralised composting facilities are common, they are often insufficient in certain areas to meet the demand. Such communities are increasingly interested in decentralised approaches, such as household composters due to the economic, environmental, and social benefits that these facilities offer.[4] Typical examples of such an approach include the Bokashi method, composting in the garden, devices for drying and grinding of biowaste, *etc.* Special attention should be given to indoor composting, as backyard composting of garden and food waste is not always accessible to everyone.[5] Indoor composting can significantly contribute to sustainability and the circular economy. Instead of landfilling biowaste, it is converted into compost, becoming a resource for organic soil improvers, fertilisers, and bio-based products.[6]

The Bokashi method also known as Bokashi pickling has recently gained attention as a practical solution for household composting. Compared to aerobic composting, the Bokashi method is based on the fermentation of organic waste using effective microorganisms in the form of an inoculant. The resulting product is rich in nutrients and can be used to enrich the soil. Fermentation occurs within a shorter timeframe of 10 to 20 days, as compared to aerobic composting, resulting in two fractions:[7] pre-compost and leachate. The leachate can also serve as a liquid organic fertiliser.[8] The Bokashi method is conducted in closed containers, reducing the risk of nuisances, such as flies, unpleasant odours, and the risk of gas pollution.[9] The process is innovative as it offers the possibility to recycle and reuse organic waste in less time and on a smaller area, while reducing the environmental impact compared to other methods of organic waste disposal.[7,8] Bokashi composting requires no addition of bulking agents (carbon-rich material from parks, gardens, and households), necessary for aerobic composting and not always available in urban households or buildings. The resulting Bokashi pre-compost is actually pickled food waste that is less attractive to pests and can safely be buried directly in the garden or compost heap or passed on to local providers for reuse.

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This way, home composting can be carried out not only in houses with gardens and planted balconies but also in urban buildings.[9]

Lew et al.[10] applied the Bokashi composting method to banana peels with three types of Bokashi bran using 12, 22, and 32 ml of effective microorganisms EM-1 mother culture. They found that 12 ml of EM-1 was the most effective ratio for Bokashi composting, resulting in a faster decomposition rate and an optimal C/N ratio. *Formowitz et al.*[11] investigated the effects of adding microorganisms on the decomposition of banana residues during Bokashi production. They found that Bokashi with molasses and Bokashi effective microorganisms (EM) reduced the number of root nematodes under greenhouse conditions compared to the control. *Ghanem et al.*[12] investigated the effects of using Bokashi compost from recycled kitchen waste on lettuce (*Lactuca sativa* L. var. *capitata* L.) grown organically at home. They found that both Salmonella and Shigella were absent from both the head of lettuce and the outer leaves. *Xiaohou et al.*[13] applied Bokashi to rice crops in combination with subdrainage to improve saline-alkaline soils, and demonstrated that this method controlled secondary soil salinity more effectively, and increased grain yield and quality compared to other treatments.

From the above literature review, it is clear that the biological treatment of indoor biowaste using the Bokashi method is still a major challenge for domestic use. Our intention here is to further analyse the physicochemical parameters during Bokashi treatment of biowaste with the addition of an inoculant, and to investigate how the addition of a different type of inoculant as well as the occasional mixing of biowaste and exposure to air, affect the change in physicochemical parameters of Bokashi treatment and the final pre-compost. The parameters include measurement of pH, electrical conductivity, temperature, and height of the compost mass, moisture, dry matter, volatile matter, carbon and nitrogen content, and C/N ratio. Leakages were collected and analysed for volume, pH, electrical conductivity, and turbidity. In addition, the obtained pre-composts were further processed for maturation into two soil types, and the main physicochemical parameters were also measured. Finally, the initial biowaste, final pre-compost masses, and the collected leakages were analysed using FTIR spectroscopy.

2 Experimental

2.1 Biowaste composting process

The biowaste utilised in this study was sourced from the nearby campus restaurant of the University of Split. The substrate (biowaste) comprised lettuce (3.60 kg), cabbage (7.10 kg), leek (0.5 kg), onion peels (5 kg), potato peels (1.35 kg), and orange peels (4.55 kg). A Hurricane HMH-E 2440 shredder (iSC GmbH, Landau an der Isar, Germany) was employed to shred the biowaste. The shredded biowaste (cca 22 kg) was evenly distributed among three commercial composters ("Organko") with rectangular dimensions of 38 × 27 × 32 cm). After shredding, the initial properties of the biowaste (Table 1) were used to determine additional physicochemical parameters.

The first Organko was filled with the commercial inoculant Compost Help (designated as *Inoculant 1*) containing lactic acid bacteria, photosynthetic bacteria, yeast, wheat feed flour, molasses, and water. The Organko composter was alternately filled with one layer of biowaste and one layer of Inoculate 1, approximately 800 g *per* total volume, as specified in the declaration. Water was sprayed during the addition of the inoculant to moisten and activate the microorganisms. Each layer was pressed to eliminate air. Throughout the process, the Organko was closed with a lid, not subjected to mixing, and only briefly exposed to air during sampling. The second Organko composter was filled with Substral Naturen Compost Maker (designated as *Inoculant 2*), consisting of unspecified bacteria and fungi, to initiate or accelerate the decomposition process. As indicated in the declaration, approximately 5 g of *Inoculant 2* was added per total volume. During composting, the compost mass was mixed manually once a day for 2–3 min and then pressed to remove air. The third Organko was filled with biowaste only, and the mixing procedure was carried out in the same way. The addition of different inoculants and the occasional exposure to air of the second and third Organko were aimed to investigate their effects on the process and the resulting pre-compost. An overview of the initial conditions in all three Organko composters is presented in Table 1.

The total height of the compost mass in the Organko composters was 20 cm. The composting process unfolded in the faculty laboratory over a 19-day period to yield pre-compost. Manual sampling of the compost mass and leakage was performed during composting. Compost mass sampling was performed manually at six points (zig-zag pattern) in approx. 250-g quantities after 5, 8, 12, and 18 days. The compost mass was then mixed for homogenisation, and subsequently used for further determination of physicochemical parameters. The leakage was drained daily from the container at the bottom of each basket, and stored in the refrigerator.

2.1.1 Compost mass analysis

The following parameters were analysed for each compost sample: pH an electrical conductivity (determined in filtrate obtained by mixing 5 g of the sample with 100 cm^3 of deionized water and measured using a pH/conductivity combimeter Orion Star Series Meter Thermo Fischer Scientific Inc., Beverly, MA, USA), temperature (using digital thermometer Testo 925), height of compost mass (with manual meter), moisture, and dry matter (by drying the sample at 105 °C for 24 h), volatile matter (by annealing in a muffle furnace at 550 °C for 4 h), carbon content (calculated from the volatile matter content), nitrogen content (by Kjeldahl method), and C/N ratio (dividing the carbon content by the nitrogen content). All analyses adhered to standard methods, and the obtained parameters are presented in Tables 2 and 3.[14]

2.1.2 Leakage analysis

The collected leakage was analysed for the following parameters: volume, pH, electrical conductivity, and tur-

Table 1 – Overview of initial conditions in Organko composters
Tablica 1 – Pregled početnih uvjeta u Organko komposterima

	Inoculant type Tip inokulanta	Inoculant dose Doza inokulanta	Biowaste mixing Miješanje biootpada	Initial biowaste characteristics Karakteristike polaznog biootpada
Inoculant 1 *Inokulant 1*	commercial inoculant Compost Help	approximately 800 g *per* total volume približno 800 g po ukupnom volumenu	no	pH = 5.01 σ = 426 μS cm^{-1} $w(H_2O)$ = 89.52 % w(DM) = 10.48 % w(VM) = 90.59 % w(C) = 50.33 w(N) = 2.74 % C/N = 19.09 h = 20 cm t = 24 °C
Inoculant 2 *Inokulant 2*	Substral Naturen Compost Maker	approximately 5 g *per* total volume približno 5 g po ukupnom volumenu	yes	
Without inoculant Bez inokulanta	–	–	yes	

σ – electrical conductivity, $w(H_2O)$ – moisture content, w(DM) – dry matter content, w(VM) – volatile matter content, w(C) – carbon content, C/N ratio – ratio of carbon and nitrogen, h – height of biowaste in composter, t – temperature of initial biowaste
σ – električna vodljivost, $w(H_2O)$ – udio vlage, w(DM) – udio suhe tvari, w(VM) – udio hlapljive tvari, w(C) – udio ugljika, C/N ratio – omjer ugljika i dušika, h – visina biootpada u komposteru, t – temperature polaznog biootpada

Table 2 – Changes in the height of biowaste mass and temperature during Bokashi treatment
Tablica 2 – Promjena visine biootpadne mase i temperature tijekom Bokashi obrade

Time /days Vrijeme /dani	Reduction in height of biowaste mass Smanjenje visine biootpadne mase / %			Temperature Temperatura / °C		
	Inoculant 1 *Inokulant 1*	*Inoculant 2* *Inokulant 2*	Without inoculant Bez inokulanta	*Inoculant 1* *Inokulant 1*	*Inoculant 2* *Inokulant 2*	Without inoculant Bez inokulanta
0	0	0	0	24	24	24
5	14.3	22.5	17.5	26	26	26
8	24.3	30.0	25.0	25	24	24
12	25.7	35.0	32.5	21	19	24
18	37.1	37.5	35.0	25	25	27

bidity. Ultimately, the leakages collected over time were mixed, and the COD values in the mixed samples were also determined (using the dichromate method). The results are summarised in Table 4.

2.2 Maturation of pre-compost

Fifty grams of pre-compost were mixed with 300 g of soil in open containers for further maturation. Two types of soil were used: Soil 1 – used in agriculture and treated with agricultural products, and Soil 2 – not used in agriculture. Both soils were characterised by pH, electrical conductivity, moisture, dry matter, volatile matter, carbon and nitrogen content, and C/N ratio. The results are summarised in Table 5. The mixtures were stirred at regular intervals. After 15 days, the same parameters as above were determined.

2.3 Fourier transform infrared spectroscopy

Fourier transform infrared (FTIR) spectra of solid dry samples (initial biowaste, Pre-compost with *Inoculant 1*, Pre-compost with *Inoculant 2,* and Pre-compost without inoculant) and the corresponding final leakages obtained from the pre-composts were recorded using Spectrum Two spectrometer (Perkin-Elmer, USA) with the Universal Attenuated Total Reflectance (UATR) technique in the range from 4000 to 400 cm^{-1}, at a resolution of 4 cm^{-1} in 10 scans at 25 °C. The reflection crystal was diamond. The aim was to investigate the presence of characteristic bonds belonging to functional groups. Due to the complex nature of all the samples, the investigation was mainly focused on the difference between the samples' spectra and their main absorption bands, as it may not always be possible to assign the observed bands to specific functional groups. The obtained spectrum of each sample represents the sum of IR absorptions of all present compounds, and therefore, the vibration band maximum may move to lower or higher wavenumbers compared to pure compounds.

3 Results and discussion

3.1 Analysis of biowaste composting process

The changes in the height of the biowaste mass and temperature during the Bokashi treatment are presented in Table 2.

Table 3 – Comparison of physicochemical parameters of the initial biowaste and obtained pre-composts
Tablica 3 – Usporedba fizikalno-kemijskih parametara početnog biootpada i dobivenih pretkomposta

Samples	pH	σ / µS cm^{-1}	$w(H_2O)$ / %	w(DM) / %	w(VM) / %	w(C) / %	w(N) / %	C/N ratio
Initial biowaste Početni biootpad	5.01	426	89.52	10.48	90.59	50.33	2.74	19.09
Pre-compost with *Inoculant 1* Pretkompost s *Inokulantom 1*	3.75	792	81.67	18.33	93.17	51.76	3.35	15.45
Pre-compost with *Inoculant 2* Pretkompost s *Inokulantom 2*	3.61	616	85.81	14.19	92.40	51.30	2.61	19.62
Pre-compost without inoculant Pretkompost bez inokulanta	4.01	485	86.67	13.33	91.22	50.67	2.97	17.04

σ – electrical conductivity, $w(H_2O)$ – moisture content, w(DM) – dry matter content, w(VM) – volatile matter content, w(C) – carbon content, C/N ratio – ratio of carbon and nitrogen
σ – električna vodljivost, $w(H_2O)$ – udio vlage, w(DM) – udio suhe tvari, w(VM) – udio hlapljive tvari, w(C) – udio ugljika, C/N ratio – omjer ugljika i dušika

A notable reduction in the height of the biowaste mass is evident across all three performances, reaching a value of 35–37.5 % after 18 days. The biowaste mass with *Inoculant 2* experienced a slightly more rapid reduction in height, followed by the biowaste mass without addition of an inoculant, while the slowest reduction was observed in the biowaste mass with *Inoculant 1*. A slight deviation in the reduction of the biowaste mass with *Inoculant 1* was observed in the sample collected on Day 12 of the process, potentially attributable to sudden external cooling. Merfield[9] also found that fermentation is influenced by external temperature variations.

A marginal increase in temperature is evident, ranging from an initial 24 °C to 25–27 °C. On Day 12, a sudden temperature drop was observes, as previously mentioned, but the final temperature values are almost identical to the initial values. Compared to the temperature fluctuations in classical composting (up to 50–80 °C),[15] the temperature fluctuations in our experiments are much less pronounced. This was expected in the compost mass with *Inoculant 1*, where fermentation/food pickling occurs. No temperature increase was observed in the other two biowaste masses, despite the use of a different type of inoculant, occasional mixing, and exposure to air. The comparison of physicochemical parameters (pH values, electrical conductivity, moisture, dry matter, volatile matter, carbon and nitrogen content, and C/N ratio) of the original biowaste and the obtained pre-compost is summarised in Table 3.

The pH of the original biowaste was 5.01, likely attributable to the higher proportion of orange peel in the biowaste, known for its acidic properties. Following composting, the pH of all three pre-composts (see Table 3) is even lower compared the initial pH. When *Inoculant 1* is added under anaerobic conditions, the low pH is an indicator of the progress of fermentation and the presence of organic acid. Typically, the pH of fermentation compost is 4, a value achieved here.

With the addition of *Inoculant 2* and occasional mixing, the pH also decreases, indicating that conditions in this composter are becoming anaerobic. The low oxygen content promotes the decomposition of carbohydrates to acetic acids, rather than their complete decomposition to carbon dioxide and water. According to *Sundberg et al.*,[16] low pH is an inhibiting factor in the transition from the mesophilic to the thermophilic phase during composting. This implies that the acidity of household waste has a negative effect on the temperature rise in the initial composting phase, slowing down the decomposition rate.

A slight increase in electrical conductivity was observed in all three pre-composts, although slightly more pronounced in the pre-compost with *Inoculant 1* compared to the other two variants. Nevertheless, the electrical conductivity values remain significantly below the upper limit for the substrate used in seed germination in container plant production.[17]

The moisture content of the original biowaste was 89.52 %, indicating the presence of fresh food waste. According to *Jain et al.*,[18] high moisture content can promote leakage development, discussed in more detail further herein. A slight decrease in moisture content was observed in all three final pre-composts, primarily related to the decrease in the water-binding capacity of the compost mass. According to *Jedrczak*,[19] higher moisture is more suitable for the fermentation process. Under aerobic composting conditions, a higher moisture content increases the risk of colonisation and the formation of anaerobic zones.

The results of the pre-compost produced with *Inoculant 1* show slightly higher nitrogen, carbon, and volatile matter, with a slightly lower C/N ratio. Based on all parameter values given in Table 3, the indoor Bokashi method performed efficiently with the addition of *Inoculant 1* (Organko 1), while the addition of another type of inoculant (*Inoculant 2*) and occasional mixing of biowaste and exposure to air (Organko 2 and 3) had no significant effect on changes in physicochemical parameters during the Bokashi treatment, and the final pre-compost.

3.2 Analysis of compost leakages

Leakage was collected throughout the composting process. The comparison of the physicochemical parameters of the compost leakage in the initial and final phases is summarised in Table 4.

Table 4 – Comparison of physicochemical parameters of compost leakage
Tablica 4 – Usporedba fizikalno-kemijskih parametara kompostnih procjednih voda

Sample Uzorak		Volume of collected leakage / ml Volumen prikupljene procjedne vode / ml	pH	σ / mS cm^{-1}	Turbidity / NTU Mutnoća / NTU	COD / g O_2 l^{-1} KPK / g O_2 l^{-1}
Leakage with *Inoculant 1* Procjedna voda s *Inokulantom 1*	initial, početno	754	4.03	12.96	652.5	–
Leakage with *Inoculant 2* Procjedna voda s *Inokulantom 2*		710	4.78	5.34	886.0	
Leakage without inoculant Procjedna voda bez inokulanta		770	4.92	5.51	867.0	
Leakage with *Inoculant 1* Procjedna voda s *Inokulantom 1*	final, konačno	1845	4.21	15.48	346.5	52.14
Leakage with *Inoculant 2* Procjedna voda s *Inokulantom 2*		2469	3.29	10.27	192.0	35.02
Leakage without inoculant Procjedna voda bez inokulanta		2449	3.36	10.54	562.0	39.00

Table 4 shows that a considerable amount of leakage (ranging from 710 to 770 ml) was collected during the initial phase of shredding the biowaste and preparing the composter. As mentioned earlier, according to *Kumari et al.*,[20] electrolyte leakage is a good indicator of cell death due to stress in plants, resulting in a higher amount of electrolyte leakage. In total, 2469 and 2449 ml of leakage were collected during composting of biowaste with *Inoculant 2* and without inoculant, respectively, while the lowest values were obtained with *Inoculant 1* (1845 ml). The electrical conductivity values in the leakage were 1000 times higher than the values in the compost mass (see Table 3), as expected, considering that the amount of dissolved salts is concentrated in the leakage. The turbidity was also very high in the initial phase, while the values in the final leakage samples were lower. The very high COD values in the mixed leakages indicate the presence of both biodegradable and inorganic substances susceptible to oxidation with dichromate. These values significantly exceed the limit prescribed by Croatian regulations for discharge into the sewerage system (125 mg O_2 l^{-1}).

3.3 Analysis of the results of the maturation process

Each of the previously obtained pre-composts was used for further maturation in Soil 1, which was used in agriculture, and Soil 2, which was not used in agriculture. After 15 days, the following parameters were determined: pH, electrical conductivity, moisture, dry matter, volatile matter, carbon and nitrogen content, and C/N ratio. The comparison is presented in Table 5.

The initial pH of Soils 1 and 2 was 8.13 and 8.95, respectively. Although the pH of the pre-composts was acidic (Table 3), the pH values remained in the range of 8.12–9.02 after adding pre-composts to Soils 1 and 2. The electrical conductivity also increased slightly after adding pre-composts to Soils 1 and 2. Despite the higher moisture content in the pre-compost (in the range of 81.67–86.67 %, Table 3) compared to the soils (24.28 % for Soil 1, and 7.41 % for Soil 2), the moisture content showed a decreasing tendency after mixing in the ratio pre-compost : Soil = 1 : 6 and 15 days of maturation without additional adjustment of moisture. Consequently, the dry matter content increased slightly. However, the values of volatile matter and carbon content in the mixture after 15 days of maturation differed slightly compared to the initial values in the original soils (volatile matter values for Soil 1 and Soil 2 were 14.33 % and 8.78 %, respectively). After mixing with soils with lower nitrogen and carbon content compared to pre-composts, the final values of C/N ratio in Soil 1 remained almost unchanged, while in Soil 2, a slight decrease in C/N ratio was observed.

Each time the Organko containers were opened, an intense smell of pickled food (or sweet-sour smell) could be detected. The drained leakage also had a very intense and unpleasant smell of pickled food. However, the intensity of the sweet-sour odour decreased significantly as the mixed mass of pre-compost and soil matured.

3.4 FTIR analysis

FTIR analysis provided a very complex spectrum for each solid sample (initial biowaste and pre-composts), Fig. 1. This was expected due to the large number of organic molecules such as more or less complex carbohydrates (starch, cellulose, hemicellulose, lignin *etc.*), proteins, fats, and other smaller organic or inorganic molecules present in the used fruits and vegetables in the initial biowaste.[21–26] The obtained spectra of all samples were interpreted based on data found in the literature.[27–29] The spectrum of leakage is mainly dominated by water content, Fig. 2. The presence of water in all samples is evident from the absorption band maximums (absorption peaks) at around 3280 and 3314 cm^{-1} for pre-composts and leakage, respectively, while the additional band from fee water is around 1635 cm^{-1} for all samples. The difference in the wavenumber of O−H stretching of non-bonded hydroxyl group in water at higher wavenumber is influenced by a large num-

Table 5 – Comparison of physicochemical parameters of the used soils before and after pre-compost addition
Tablica 5 – Usporedba fizikalno-kemijskih parametara upotrijebljenih tala prije i poslije dodavanja pretkomposta

Sample Uzorak	pH	σ / µS cm^{-1}	w(H_2O) / %	w(DM) / %	w(VM) / %	w(C) / %	w(N) / %	C/N ratio
Soil 1 Tlo 1	8.13	143.50	24.28	75.72	14.33	7.96	0.51	15.67
Soil 2 Tlo 2	8.95	74.90	7.41	92.59	8.78	4.88	0.23	31.63
Soil 1 + Pre-compost with *Inoculant 1* Tlo 1+ Pretkompost s *Inokulantom 1*	8.50	177.25	20.43	79.57	12.85	7.14	0.50	14.41
Soil 2 + Pre-compost with *Inoculant 1* Tlo 2 + Pretkompost s *Inokulantom 1*	8.94	111.40	5.46	94.54	8.87	4.92	0.23	21.66
Soil 1 + Pre-compost with *Inoculant 2* Tlo 1+ Pretkompost s *Inokulantom 2*	8.53	156.06	13.62	86.38	13.52	7.52	0.46	16.30
Soil 2 + Pre-compost with *Inoculant 2* Tlo 2 + Pretkompost s *Inokulantom 2*	9.02	99.05	5.60	94.40	7.78	4.32	0.25	17.01
Soil 1 + Pre-compost without inoculant Tlo 1+ Pretkompost bez inokulanta	8.12	227.00	10.02	89.98	15.16	8.43	0.53	16.05
Soil 2 + Pre-compost without inoculant Tlo 2 + Pretkompost bez inokulanta	8.63	109.90	2.89	97.11	7.69	4.27	0.26	16.16

σ – electrical conductivity, w(H_2O) – moisture content, w(DM) – dry matter content, w(VM) – volatile matter content, w(C) – carbon content, C/N ratio – ratio of carbon and nitrogen
σ – električna vodljivost, w(H_2O) – udio vlage, w(DM) – udio suhe tvari, w(VM) – udio hlapljive tvari, w(C) – udio ugljika, C/N ratio – omjer ugljika i dušika

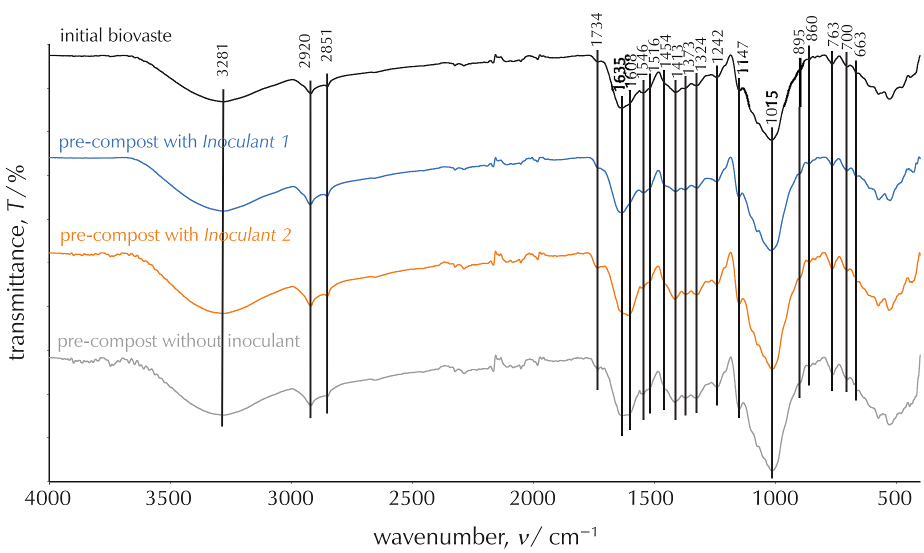

Fig. 1 – FTIR spectra of initial biowaste, pre-compost with *Inoculant 1*, pre-compost with *Inoculant 2* and pre-compost without inoculant
Slika 1 – FTIR spektri početne biomase, pretkomposta s *Inokulantom 1*, pretkomposta s *Inokulantom 2* i pretkomposta bez inokulanta

ber of other organic molecules that have bonded hydroxyl groups and interfere with absorption of water. Considering the complexity of the solid samples, a comparison of FTIR spectra is the only way to obtain information leading to conclusions about how different conditions during composting of initial biowaste influence the composition of the pre-compost.

The initial biowaste, apart from OH group vibrations, exhibited absorption peaks at 2920 and 2852 cm^{-1}, which can be correlated with the presence of methylene (CH_2) groups derived from polysaccharides like cellulose. The absorption at 1734 cm^{-1} belongs to C=O stretching and can indicate the presence of pectin in plants, Fig. 1. Free water absorption is around 1633 cm^{-1}. In the same absorption region, from 1720 to 1560 cm^{-1}, COO^- stretching of hemicellulose, aromatic skeleton vibration of lignin,

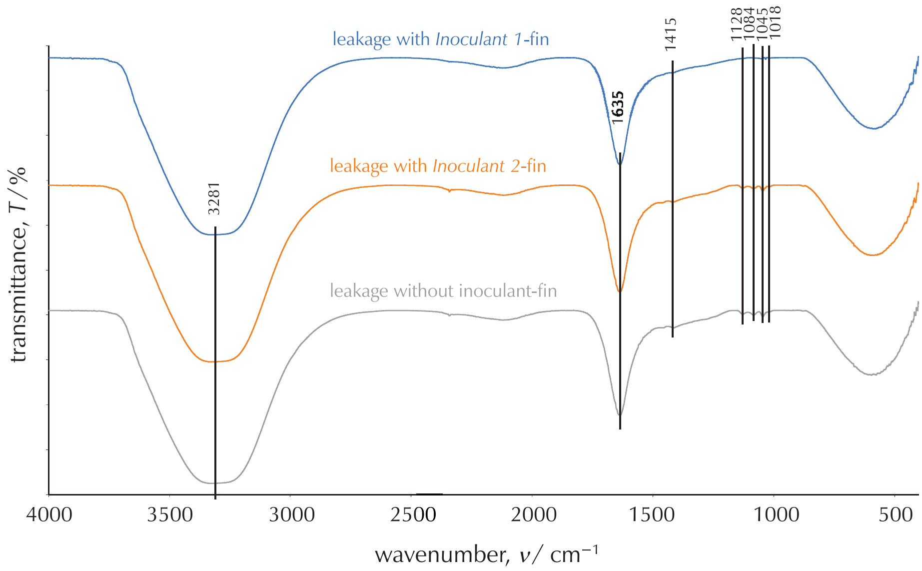

Fig. 2 – FTIR spectra of leakage with *Inoculant 1*-fin, leakage with *Inoculant 2*-fin, and leakage without inoculant-fin (note: fin – refers to mixed final samples)

Slika 2 – FTIR spektri procjedne vode s *Inokulantom 1*-fin, procjedne vode s *Inokulantom 2*-fin i procjedne vode bez inokulanta-fin (napomena: fin – odnosi se na miješane konačne uzorake)

and N–H in plane vibration of amines (1608 cm^{-1}) were observed. The vibration of N−H in-plane from amides II has absorption around 1546 cm^{-1}, while the vibration at 1516 cm^{-1} is attributed to the lignin phenolic backbone. Wavenumbers of 1454 and 1413 cm^{-1} can be attributed to O−H in-plane bending in cellulose and hemicellulose and C−H bending in CH_3 group in lignin. C−H bending of cellulose and hemicellulose and N−O stretching of nitrate can be assigned to the absorption at around 1373 cm^{-1}. Absorption at 1324 and 1242 cm^{-1} can be attributed to C−N stretching of secondary amines and C−N stretching of amide III or C−O stretching of carboxyl group of hemicellulose, respectively. C−H of aromatic in-plane bending and C=O stretching of lignin are dominant vibrations at 1147 cm^{-1}, but at the same position S–O stretching in inorganic sulphate also appears. The wavenumber of 1015 cm^{-1} is associated with the C−O stretching vibrations of pectin, while 895 and 860 cm^{-1} belongs to the anometric vibration at b-glycosidic linkage of cellulose or hemicellulose and C−H out-of-plane bending of lignin, respectively. Absorption peaks at 763, 700, and 663 cm^{-1} are associated with NH_2 out-of-plane vibration of primary amine group, N−H wag of secondary amine group and S−O bends of inorganic sulphate, respectively.

Analysis of initial biowaste gave insight into the complex nature of mixed organic material, but comparison of the FTIR spectra of the solid samples obtained in different conditions showed almost the same spectrum, Fig. 1. It is evident that the spectra of solid samples had almost the same absorption bands with almost the same intensities. Therefore, the occasional mixing of biowaste and exposure to air had no significant effect on the composition of the pre-compost. If differences exist, they are not detectable with this technique, primarily because of the complex composition of the analysed material. The same analysis was performed with leakages taken after preparation of the pre-composts (final leakages), Fig. 2.

As mentioned previously, in the leakages of the pre-composts, water is the dominating component with its intense absorption bands in FTIR spectra of all liquid samples, as expected given the conditions during preparation of pre-compost. The interpretation of these spectra was also based on literature data.[41] The FTIR spectra of leakage with *Inoculant 2* and without inoculant showed similar spectra with adsorption peaks at 1415, 1128, 1084, 1045, and 1018 cm^{-1}. The wavenumber of 1415 cm^{-1} can be associated with the N−O stretching of nitrate; however, the wavenumber is somewhat higher that in the solid samples. The domination of water adsorption and its influence on other molecules in the leakage has to be taken into account. The vibration at 1128 cm^{-1} can be assigned to S−O stretching of inorganic sulphate. Other peaks are also visible in the spectra found in the literature but their interpretation was not provided.[29] In future investigations, separation of leakage components should be performed with chromatographic techniques, making their interpretation feasible. The leakage with *Inoculant 1* had barely visible peaks at 1415, 1045, and 1018 cm^{-1}. Their intensity was very low and in the noise level, indicating the very low concentration of other molecules present in the leakage except water, emphasising the necessity of chromatographic techniques.

4 Conclusion

The initial biowaste contained cabbage (32 %), onion peels (23 %), orange peels (21 %), lettuce (16 %), potato peels (6 %), and a small amount of leeks (2 %). It was characterised by a low initial pH of 5.01, attributed to the acidic properties of the orange peels. The moisture content was very high (89.52 %) and originated from fresh food waste. The electrical conductivity was 426 $\mu S\,cm^{-1}$, volatile matter content 90.69 %, carbon content 50.33 %, nitrogen content 2.74 %, and the initial C/N ratio was 19.09.

Composting of biowaste in three commercial Organko composters – one without inoculant, one with the addition of Compost Help – designated as *Inoculant 1*, and one with the addition of Substral Naturen Compost Maker, designated as *Inoculant 2*, yielded pre-composts of very similar values of physicochemical parameters. The study demonstrates that the indoor Bokashi method can be carried out efficiently with the addition of *Inoculant 1* (in Organko 1), while the addition of another type of inoculant (*Inoculant 2*) and the occasional mixing of biowaste and exposure to air (in Organko 2 and 3) have no significant effect on the physicochemical parameters during the Bokashi treatment and final pre-compost. After mixing with soils having lower nitrogen and carbon content than the obtained pre-composts, the final C/N ratio values for Soil 1 remained almost unchanged, while Soil 2, showed a slight decrease, still within the acceptable value. FTIR spectroscopy confirmed these conclusions, indicating that occasional mixing of biowaste and exposure to air did not produce significantly different pre-composts or leakages.

The results of this study confirm that the Bokashi method in a commercial biowaste Organko composter can be a suitable tool for successful indoor biowaste treatment. Compared to conventional composting, it offers shorter decomposition time, requires no energy consumption or mixing, and yields a final product with higher nutritional value for plants. This method can be a practical way to accept and store biowaste without unpleasant odours to prepare biomass for composting or anaerobic digestion. The results of this study facilitate the implementation of indoor composting and can be helpful in the management of biowaste in both densely populated urban areas and remote rural areas. Such composters could serve as a useful tool for the implementation of a circular economy for biodegradable waste, which is part of our society's low-carbon transition.

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SAŽETAK

Kućna predobrada biootpada primjenom Bokashi metode

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Gotovo trećina proizvedenog krutog komunalnog otpada pripada biorazgradivom otpadu, te je njegova daljnja prerada u kompost ili bioplin prijeko potrebna. U posljednje vrijeme kućno kompostiranje biootpada dobiva sve veću pozornost zbog ekonomskih, ekoloških i društvenih koristi. Kućno kompostiranje može dati značajan doprinos u postizanju održivog gospodarenja otpadom i kružnog gospodarstva. Umjesto odlaganja biootpada na odlagalištima, proizvodi se kompost kao koristan organski dodatak tlu, gnojivo ili bioproizvod. U ovom radu ispitani su fizikalno-kemijski parametri biootpada i dobivenog pretkomposta tijekom Bokashi metode obrade, kao i učinak dodavanja druge vrste inokulanta, povremenog miješanja biootpada i izloženosti zraku na sam proces. Procesi predobrade biootpada uspoređeni su preko pH, električne vodljivosti, temperature i visine kompostne mase, sadržaja vlage, suhe tvari, hlapljive tvari, sadržaja ugljika i dušika te C/N omjera. Procjedne vode su prikupljene i analizirane na volumen procjedne vode, pH, električnu vodljivost i mutnoću. Osim toga, dobiveni pretkomposti proslijeđeni su na daljnje sazrijevanje u dva tipa tla, a praćeni su isti fizikalno-kemijski parametri. Početni biootpad, konačna pretkompostna masa i sakupljena procjedna voda analizirani su i FTIR spektroskopijom. Uočeno je da nema značajne razlike između analiziranih pretkomposta kao ni između procjednih voda. Rezultati pokazuju da Bokashi obrada biootpada s *Inokulantom 1* osigurava veći sadržaj ugljika i dušika u konačnom pretkompostu te proizvodi manji volumen procjedne vode. Ovaj rad naglašava da Bokashi metoda može učinkovito olakšati provedbu kućne predobrade biootpada.

Ključne riječi
Kućno kompostiranje, inokulant, fermentacija, biootpad, sazrijevanje pretkomposta

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