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Co-composting of anaerobic sewage sludge and biomass amended with biopreparations

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ABSTRACT

This study presents the results obtained from the experiments of the composting process with the constant percentage of sewage sludge, green waste, organic fraction, municipal waste and structure-forming material in each sample. Modification of the process of composting consisted in adding a commercial biopreparation and inoculation of the mixture with the leachate from the process of composting conditioned with ultrasound field. The process was carried out in five trials, including one control, the other mixtures for composting biopreparations and compost leachates. Additional modification consisted of conditioning with ultrasonic field of 20 kHz leachate and 13 μm amplitude with time of 10 s. The composting mixtures were inoculated on the 7th day of the process. The obtained results indicate that returning of the compost leachate did not impact on intensification of the composting process and caused an insignificant increase in the temperature, which, however, did not have a substantial effect on stabilization. High content of nickel in the compost samples and presence of eggs of intestinal parasites excludes the composts studied from using them as organic fertilizers according to polish law. The permissible value of polycyclic aromatic hydrocarbon (6 mg·kg/DM) was exceeded for one of the mixtures of the composts obtained. The introduced modifications aimed at streamlining the process and improving the quality of the final product in the conducted experiments did not bring the expected results.

Keywords: Co-composting; Sewage sludge; Biomass; Biopreparation

1. Introduction

Nowadays, sewage sludge composting and possible use of the obtained product in agriculture became one of the main strategies for its disposal. Composting is a biological process, which decomposes and stabilizes organic substances under thermophilic conditions generated as a result of biologically produced heat [1,2]. Composting is commonly considered as one of the most-effective ways for recycling of organic wastes, that produces a stable, pathogen-free final product [3,4]. The process has been traditionally used as a treatment method for the organic fraction of municipal solid waste (OFMSW), agricultural and farming residual, sludge from wastewaters treatment plant. In recent years, composting of anaerobic sludge has been widely studied with different types of co-substrates and with a variety of bulking agents [5,6]. The addition of a bulking material in order to increase the porosity of the waste is one of the most useful methods. Another option is co-composting of two or more types of organic wastes that can be beneficial to the composting process, providing higher porosity, better C:N ratio, addition of active biomass, or simultaneous management of interesting wastes [7]. The volume ratio of sewage sludge to bulking agent should be between 1:1

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and 1:4 [8]. The majority of organic material originates from the bulking agent, but significant biodegradation by means of natural aerobic microorganisms occur in the sewage sludge organic material [9]. The main factors that must be considered in the case of composting of biosolids are the moisture, pH, the initial C:N ratio, the air supply and porosity of the waste [10]. Physical and chemical properties of wastes may not always be suitable for composting. In many cases, some preliminary changes need to be induced to the initial waste in order to receive the proper parameters. Another important factor is the presence of nitrogen. Pakou et al. [10] have reported the optimal C/N ratio between 25/1 and 30/1. The processes performed at C/N ratios as low as 10/1 have also been reported [11], but at such low C/N ratios the undesirable emission of ammonia can be significant [12]. In recent years, research focused more on the biodegradable C/N ratio, which was in ranges between 3.9/1 and 12.7/1 [13]. Komilis et al. [13] introduced the biodegradable C/N ratio as a novel indicator that could be used to characterize the composting process. The authors concluded that the initial total C/N ratio did not correlate significantly with the degradability of the mixtures as opposed to the biodegradable C/N ratio. While the total C/N ratio did not change much during the process, the biodegradable C/N increased from average 10 to 20. Other positive aspects of mixing the sludge with the other components are minimization of the moisture content (MC) from 70%–90% to optimal 50%–60% maintaining the optimal oxygen content (15%–20%). If the MC is higher than 70%, anaerobic process begins [14]. The application of biological stimulation through specifically selected and prepared microorganisms and preparation of compost leachate with ultrasound field may have an important impact on intensification and improvement of the effectiveness of the composting process [15]. Quality of composts depends on the content of heavy metals (HMs) [16], pathogens [17] as well as on the presence of permanent organic contaminants [18], including polycyclic aromatic hydrocarbons (PAHs) [19]. The use of compost in field applications is mainly limited by its total HM content and by the bioavailability of these metals or their mobility. It is known that the mobility of HMs, their bioavailability and related eco-toxicity to plants depends strongly on their specific chemical fractions or ways of binding rather than total metal concentration [20–22]. Therefore, it is important not only to analyze total HMs content but also to estimate the metal distribution and ecological risk of HMs in sewage sludge composts [23]. Transitions of PAHs during composting due to the reduction in their concentrations are connected with the two phenomena: adsorption and biodegradation. Thermophilic phase is characterized by a fast decline in the total concentration of PAHs at the level of even 50%–70%. An increase in total concentration occurs during the next stages. Due to the mineralization of the organic matter and limitation of the amount of sorption active sites, initially adsorbed PAHs are desorbed. Eventually, a reduction in total concentrations of the total concentrations of hydrocarbons is observed (even up to 84%). A degree of degradation depends largely on the temperature of the composting process [15]. Due to the presence of permanent organic contaminants, composting of sewage sludge with addition of organic fraction of municipal waste might occur relatively slowly. The application of biological stimulation through specifically selected and prepared microorganisms and preparation of compost liquors with ultrasound field might impact on intensification and effectiveness of the composting process [24].

The main objective of the composting process as organo-recycling is to create a compost that will no longer be waste but fertilizer. Waste used for composting should meet certain requirements in terms of chemical composition and physical properties, if not meet a number of process modifications, streamlining the process and aiming at improving the quality of the final product – compost.

The experiments were aimed at the determination of the effect of addition of biopreparations for the process of co-composting of the organic fraction in municipal waste, sewage sludge from the dairy industry, green waste from urban areas and structure-forming material. Furthermore, the objective of this study was to evaluate the effect of the addition of biopreparation on the process of composting, on physical and chemical parameters during the process. The final product of the process was evaluated under the account of its applicability in the environment. A novelty in the conducted research was the use of conditioned composting debris as biopreparations. Disintegration of leachate was carried out using ultrasound. The aim was also to determine the impact of disintegrated leachates on the quality of the compost obtained.

2. Methods

2.1. Substrates

Raw materials used for this study were collected from a regional municipal landfill and waste water treatment plant (Silesian region, Poland). The sewage sludge used in the study was digested sludge (15-d digestion at the temperature of 37°C). The digested sewage sludge (SS) samples, after dewatering, were composted with co-substrates. The high MC (92.45%–97.37%) of sludge (SS) was caused by sludge dewatering in laboratory conditions. Sawdust (BA – bulking agent) and green wastes (GW) in the form of grass clippings were used as co-substrates for composting experiments. The OFMSW was also used. It is a fraction of the permeate (<80 mm) was established with the sifting of mixed municipal waste from a city of over 200,000 residents. The characteristics of substrates for research were shown in Table 1. Selected samples were subjected to analysis and technological research on the day of collection. All determinations were made using a three-point repetition.

2.2. Microbial inoculum preparation

Radivit (Neudorff, Poland) biopreparation was used in this study. It contains living organisms that accelerate composting mass. It is intended for composting of all types of waste, accelerates the formation of compost hygienically valuable compost. Radivit composter supplies composting mass in natural trace elements, which prevents the growth of undesirable compounds and leads to a faster transformation of hygienically clean wastes and valuable compost. The formulation consists of a dry weight of compost bacteria and fungi cultures, contained in a special nutrient substrate of carbohydrates and proteins. Composition: nitrogen (N) 8% of the entire contents pH approximately 6.5.

Table 1
Physical and chemical parameters of the substrates

Parameter	Unit	SS	GW	BA	OFMSW
Dry matter	%	26.33–27.55	38.00–39.25	45.59–57.01	41.61–61.47
Volatile matter	%	15.49–14.09	24.94–32.84	42.82–53.13	16.75–35.59
Moisture content	%	92.45–97.37	60.75–62.00	42.99–54.41	38.53–58.39
TKN	mg/g	20.70–21.70	10.92–19.04	7.56–10.78	10.92–12.46
TP	mg/g	0.24–0.25	0.21–0.23	0.12–0.22	0.21–0.22
TOC	mg/g	331.9–288.7	303.7–337.6	366.0–371.9	235.65–257.55
C/N	–	13.30–16.03	17.73–21.82	33.96–49.20	20.67–21.56

2.3. Composting procedure

The process of composting was carried out in the bioreactor with a capacity of 45 L. The bioreactor was equipped with a temperature monitoring system, process gases and a suction and pressure pump with a capacity of 60 L/h to maintain an adequate degree of aeration. The upper part of the reactor contains an easy-to-remove cover that allows easy loading of the load and material sampling at any time. The air is supplied from the bottom of the reactor by means of an aeration pump, and its flow is regulated smoothly by means of a flow regulator. Temperature measurement takes place at three points using thermocouples placed inside the bioreactor. The temperature values are recorded by three sensors located at a distance of 10 cm from the double perforated platen. The results from the temperature measurement during the process were given in the form of an average of three sensors [25]. The mixtures for the composting process were prepared by adding constant quantities by weight of raw matter co-substrates and adding suitable doses of biopreparation and inoculation of the mixture with the leachate from the process of composting. The weight of the mixture for composting was 10 kg. The following weight contents of the substrates were adopted for the study:

- Sample I – 35% sludge, 45% green waste, 10% OFMSW, 10% structure forming material (BA)-control.
- Sample II – 35% sludge, 45% green waste, 10% OFMSW, 10% structure forming material (BA) + 50 g of Radivit (Neudorff) biopreparation.
- Sample III – 35% sludge, 45% green waste, 10% OFMSW, 10% structure forming material (BA) + 12.5 g of Radivit (Neudorff) biopreparation.
- Sample IV – 35% sludge, 45% green waste, 10% OFMSW, 10% structure forming material (BA) + 12.5 g of Radivit (Neudorff) biopreparation (leachate returned after 7th day).
- Sample V – 35% sludge, 45% green waste, 10% OFMSW, 10% structure forming material (BA) + 12.5 g of Radivit (Neudorff) biopreparation (sonication of leachate was carried out after 7th day by means of the ultrasound disintegrator).

2.4. Ultrasonic disintegration

Ultrasonic Disintegrator (Sonics VC 750) generating ultrasounds of the oscillation frequency f = 20 kHz was used for the sonication of effluents. The volume of sonicated leachate was 250 mL for 10 s, while the amplitude of vibration was close 13 µm. Each process of composting took 28 d from the day of loading the bioreactor. For the first 7 d, the temperature was monitored twice a day. For the other days, this operation was repeated once a day, until the last day. On a regular basis, every 7 d, the content of the bioreactor was mixed and the samples were taken for analyses.

2.5. Samples preparation

Samples of composted mass were collected in accordance with PN-Z-15011-1 "Compost from municipal waste – Sampling" [26]. Samples for analysis of physical and chemical parameters were taken at different stages of composting 0, 7, 14, 21 and 28 d. Physico-chemical analyses of test substrates, mixtures and obtained composts were carried out for samples dried at 105°C to a constant weight, which were then ground using an A13 basic laboratory mill from IKA. All analysis were performed in triplicates. The results are presented in the tables and figures as the arithmetic means. Modification of the process of composting consisted in adding a commercial biopreparation and inoculation of the mixture with the leachate from the process of composting conditioned with ultrasound field.

2.6. Physico-chemical analyses

Dry matter determined in accordance with PN – EN 12880 [27], volatile solids, MC, total phosphorus (TP) determined in accordance with PN-Z-15011-3:2001. Total N by the Kjeldahl method (PN-Z-15011-3:2001) (TKN). Total organic carbon (TOC) was measured using TOC analyzer (Multi N/C 2100, Analytik Jena, Germany). Total content of HMs was determined with ICP-mass spectrometry (Optima 200 DV). Dried and ground samples were subjected to mineralization with a mixture of acids (65% HNO_3, 70% $HClO_4$ and 30% H_2O_2) using microwave energy (SpeedWave MWS-2 Berghof, Germany). In the samples prepared in this way, the total content of selected metals (Pb, Cd, Hg, Cr, Zn, Ni) was determined by gas chromatography on an atomic emission spectrometer with inductively excited plasma mass spectrometry (Optima 200 DV, USA). The metals were determined in three parallel samples. All the physico-chemical properties of samples were carried out in triplicates and the mean values with standard deviation (SD) are presented.

2.7. PAHs analysis

All methods and techniques used for the analysis of PAHs were based on those recommended by the manufacturer of chromatography products, Restek LC columns, Macherey – Nagel SPE columns, and on the standards and methods available in papers [27,28].

2.8. Microbial analysis

The numbers of *E. coli* and *Salmonella* spp. microorganisms were determined using selective media specific for the test group (Merck KGaA, Germany) and confirmed by molecular analysis EMA-qPCR [29,30]. The number of helminth eggs was determined following Schwartzbrod [31]. Results have been presented as means with SD.

3. Results and discussion

3.1. Temperature profiles during the composting

Waste temperature is a measurable parameter that reflects the rate of decomposition of organic matter which occurs in the mass of the composted waste. The rate of this decomposition increases with the temperature. The process occurs most effectively in the range from 45°C to 55°C. If the temperature decreases below 20°C, the microorganisms do not proliferate and the decomposition rate declines significantly. If the temperature rises over 60°C, some microorganisms are inhibited or die, and consequently the spectrum of the organisms decreases, which manifests itself in lower effectiveness of the decomposition. Changes in the temperature allow for determination of the transition of the material studied into individual phases. Temperature changes during the process of co-composting of all samples are presented in Figs. 1 and 2.

The maximum temperature in the samples II and III was obtained on the fourth day of the process, with 68.5°C in the sample II and 67°C in the sample III. Next, this parameter declined rapidly until it reached 22.3°C. In the sample III, the high temperature of the intensive composting phase was maintained for the longest period. High temperature is conducive to destruction of pathogenic organisms, which might be present in the substrates. Due to comparable results obtained in the sample II and sample III, which differed with the doses of biopreparation, an optimum dose of 12.5 g was determined for the next samples.

On the 7th day of the process, the leachate was returned from the sample IV, whereas the sample V was conditioned with ultrasound field. It has not been observed that leaching sonification significantly changes the dynamics of temperature changes. Samples 4 and 5 were found to be convergent.

Kulikowska and Gusiatin [34] on the basis of their own research state that the intensity of aeration affects both the length of the thermophilic phase and the maximum temperature. Although the relationship between the aeration strategy/aeration rate and the temperature profile during composting of different waste has been the subject of numerous studies, the results are not conclusive [34]. Discrepancies may result from the composition of the mixture for composting. Aeration at lower or higher intensity than that considered optimal may result in overheating or excessive cooling. This means that the optimum amount of introduced air for composting a particular kind of waste should be determined experimentally. For example, temperature distribution and applied aeration in research by Gao et al. [35] were 65°C and 9 d (18 L/h kg OM) and 68°C and 8 d (30 L/h kg OM), respectively. A further increase in aeration rate to 42 L/h kg OM caused cooling; the maximum temperature did not exceed 60°C and the duration of thermophilic phase was only 5 d, at which temperatures exceeded 55°C only for 2 d. On the contrary, research by de Guardia et al. [36] has shown that the maximum temperature during composting rises with increases in aeration rate. At aeration rate of 1.69 L/h kg DM, the maximum temperature did not exceed 50°C. At 3.2 L/h kg DM, it increased to 62°C, while in range of 8.48–16.63 L/h kg DM, it exceeded 67°C. In the research, a high aeration rate of 60 L/h was used, which could affect the short-term high temperature and, consequently, the lack of composting hygienization [36].

3.2. Physico-chemical parameters

The changes in main physical and chemical parameters during the composting are shown in Table 2. The MC affects directly the microbial activity, the temperature of the compost, and hence the rate of decomposition. The optimal MC for composting is at high C/N ratio of around 55%–60% [37].

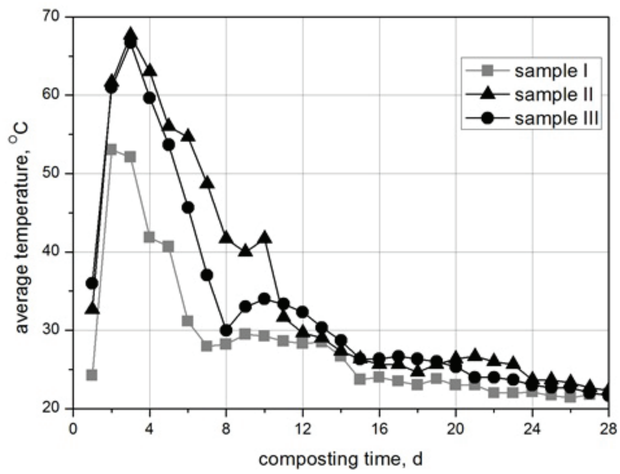

Fig. 1. Temperature during composting, sample no. I, II and III.

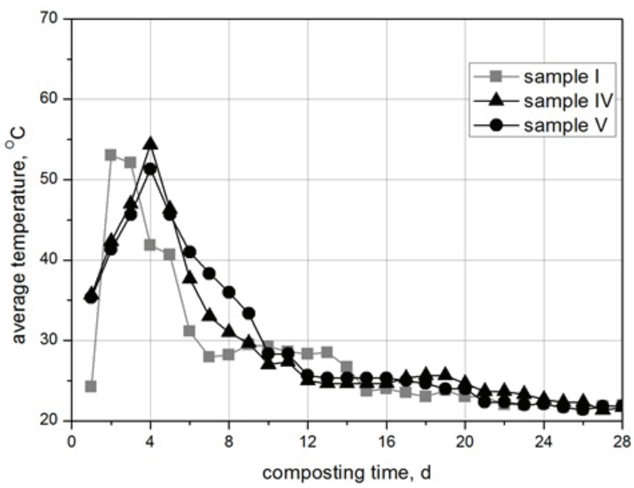

Fig. 2. Temperature during composting, sample no. I, IV and V.

Table 2
Physical and chemical characteristics of substrates/products obtained during the composting process

Parameter		Dry matter	Volatile solids	TKN	TP	TOC	C/N
Sample	day/s	%	%	mg/g DM	mg/g DM	mg/g DM	–
I	0	31.80±1.2	22.26±0.56	14.50±0.23	0.54±0.01	320.25±2.1	22.09
	7	29.75±0.8	20.01±0.60	14.85±0.30	0.45±0.03	300.42±1.5	20.23
	14	27.12±0.95	18.56±0.85	14.32±0.12	0.39±0.02	298.11±5.2	20.82
	21	26.98±1.1	17.11±0.42	14.12±0.10	0.33±0.05	287.14±4.3	20.34
	28	26.80±1.0	17.96±0.50	14.55±0.11	0.25±0.01	272.87±8.2	18.75
II	0	30.2±1.2	19.33±0.89	11.1±0.56	0.19±0.01	317.9±10.1	28.6
	7	28.64±0.7	18.96±0.54	10.92±0.78	0.18±0.01	301.85±8.4	27.64
	14	26.93±1.4	16.93±1.1	6.99±0.85	0.33±0.02	299.01±5.4	42.77
	21	29.02±1.1	17.53±0.88	10.64±1.2	0.28±0.05	297.65±9.4	27.97
	28	29.24±0.9	17.06±0.58	13.72±1.4	0.21±0.04	282.85±8.7	20.62
III	0	32.8±1.5	21.32±1.1	12.1±2.1	0.19±0.05	327.9±7.4	27.1
	7	29.84±1.3	19.2±1.0	11.76±1.7	0.18±0.07	321.05±4.7	27.3
	14	26.57±1.0	18.65±0.85	11.9±1.2	0.2±0.02	309±8.5	25.97
	21	27.64±1.1	18.84±0.78	11.48±0.87	0.23±0.01	307.4±5.8	26.77
	28	26.57±0.84	17.58±0.66	12.32±2.4	0.17±0.01	264.55±6.8	21.47
IV	0	31.9±2.8	20.74±2.1	10.3±1.4	0.19±0.02	270.4±8.4	26.3
	7	28.76±1.7	13.87±1.1	9.5±1.2	0.7±0.03	262.95±7.5	27.67
	14	20.03±2.4	11.27±1.8	6.86±1.0	0.43±0.01	225±9.2	32.8
	21	18.39±1.7	8.52±1.1	7.84±0.8	0.33±0.02	229.85±8.4	29.32
	28	19.32±1.6	7.78±1.0	8.4±0.78	0.22±0.06	237.85±9.7	28.31
V	0	28.3±2.5	18.4±2.0	5.21±1.1	0.19±0.02	250.3±10.1	48
	7	26.04±2.1	17.26±1.8	5.46±1.3	0.45±0.08	222.35±9.5	40.73
	14	24.12±2.2	13.15±1.6	6.44±1.5	0.42±0.05	228.5±8.6	35.48
	21	19.42±1.9	9.97±1.4	8.47±1.3	0.31±0.06	217.05±10.6	25.63
	28	19.16±1.7	13.05±1.5	9.1±2.0	0.22±0.04	237.5±9.5	26.09

With an insufficient level of C/N, the amount of nitrogen decreases, the process slows down and, consequently, the compost is poorly mineralized and provides only insignificant amounts of nutrients for vegetation. Furthermore, excess carbon causes a slowdown in decomposition of the organic matter. The proper C/N ratio is usually found in the mowed grass and in the OFMSW.

The MC in the experiments (I, II, III, IV, V) has been insignificantly higher since it amounted to from 68.10% to 80.84%, which might result from poorly dewatered sewage sludge. The MC increased continuously to the end of the observation period. It can be noted that the initial MC was high in all samples as well as in the final product.

The C/N ratio was used by many authors as one of the most important indicators of compost maturity. However, it cannot be used as an absolute indicator of compost maturity due to its large variation depending on composted materials [38].

The values of the C/N ratio for the substrates studied ranged from 13.30 to 49.20; which was related to significant differences in the contamination of total Kjeldahl nitrogen substrates. In the case of sample V, high C/N ratio was observed in the beginning of the process, which points to low nitrogen content in the composted mass.

Values of the C/N quotient over the 28-d process for most of the mixtures (I, II, III, V) had a downward trend. The largest fluctuations in the C/N ratio during the process were recorded for the mixture IV. The final C/N of the mixture IV and V was the highest of the four ratios, because the initially higher C/N resulted in a final higher C/N during the composting process. The obtained products necessitated continued stabilization. The final value of the C/N ratio for mixture I was 18.75, while for mixture II it was 20.62.

At the 7th day of the process in the sample IV, the leachate was returned, whereas in the sample V, the compost liquors conditioned with ultrasound field were added after the 7th day. This combination caused a minimal increase in the temperature and MC, from 75.88% to 80.84%.

The TKN concentration in the composting mass remained constant during composting or even increased in all composts by the end of the process. The increase measured in all of the samples was due to loss of weight in the mass being composted as a result of organic matter degradation [39,40], emission of carbon dioxide and the loss of water through evaporation.

The concentration of phosphorus was at a similar level, it ranged from 0.17 to 0.7 mg/g DM. For the first sample, a gradual decrease in the phosphor content was observed from the day of the 28th day of the experiment. For samples II and III phosphorus content was varied in the small range of from 0.17 to 0.33 mg/g DM. However, for samples IV and V, after 7 d the observed increase in the content of phosphorus and then a gradual decrease to 28 d.

One of the factors which limit the natural use of this type of materials is total content of HMs. The total content of these elements in composts allows for evaluation of the use of composts. The final metal contents in compost are mainly governed by their concentrations in the composted materials (feedstock composition). However, HM concentration in the final compost is one of the factors determining the possibility of their use as organic amendments [41]. Therefore, evaluation of their concentration is mandatory. In the present study, total HM concentrations in composts were a low content, one exception was nickel (Table 3), which substantially exceeded the permissible values of concentrations contained in the Ordinance of the Minister of Agriculture and Rural Development (OMARD) as of June 18, 2008 on the performance of some provisions of the Act of Fertilizers and Fertilizing [42]. The main source of HMs in the substrates used for composting is sewage sludge, as confirmed by Grigatti et al. [43]. In the tested composts, a large difference between the samples was obtained for zinc, it is not known what caused the divergence. As shown in the research of Singh and Kalamdhad [44], the mobility of metals and their bioavailability depend strongly on their specific chemical forms or ways of binding, rather than total concentration.

3.3. Microbiological analysis

One of the problems posed by the direct use of composted sewage sludge and an organic fraction of MSW in agriculture is the risk of plant and human contamination by pathogens. During the composting process, *Salmonella* spp. and a number of live helminth eggs were determined in samples taken at the initial and final stage of the composting process (Table 4).

Presence of eggs of intestinal parasites was found in all the analyzed products. 35 in sample I, 20 in sample II, 25 in sample III, 40 in sample IV and 30 in sample V. This disqualifies the composts studied from their use as an organic fertilizer. Presence of *Salmonella* sp. was found in sample V. Literature data showed that helminth eggs could survive with such MC as in biosolids stored in the environment [45,46]. Gallizzi [45] composted faecal sludge mixed with sawdust. The results of that research showed that the inactivation of all eggs is possible when the temperature of the compost heaps exceeds 45°C for at least 5 d. Kone et al. [46] observed excellent removal efficiency of *Ascaris* eggs in their study, which can be attributed to the good temperature pattern.

The main requirement for the use of compost in agriculture is its sanitary safety, which means that there must be no pathogenic bacteria of the genus *Salmonella*, live eggs of parasites (*Ascaris* sp., *Trichuris* sp., *Toxocara* sp.) or weed seeds. As the temperature required to destroy the pathogens is at least 55°C, and weed seeds should be above 60°C, in most cases the temperature during the thermophilic phase of composting makes the feedstock completely hygienic [40].

However, it is known that not only high temperature but also the duration of high temperature is important. According to the guidelines of the World Health Organization (WHO) in order to achieve full hygienization of compost, it is enough to temperature above 50°C for a period of about 7 d. Despite the fact that the achievements in individual mixtures of temperatures above 50°C, persisting for several days, did not achieve a satisfactory degree of hygienization, the presence of live parasitic eggs was found, which disqualifies the use of composts [47].

3.4. PAHs

PAHs are an example of toxic organic compounds with the best-analyzed carcinogenic properties, they can be formed during the anaerobic decomposition of organic matter contained in ripening compost [15,48]. Organic pollutants

Table 3
Total HM content after after 28 d of composting

Total content mg/kg DM	Lead (Pb)	Cadmium (Cd)	Hydrargyrum (Hg)	Chromium (Cr)	Zinc (Zn)	Nickel (Ni)
I	0.45	<0.03	0.032	2.85	7.56	184.12
II	0.43	<0.03	0.021	2.63	5.2	170.00
III	0.53	<0.03	0.079	2.17	9.33	193.33
IV	0.7	<0.03	0.0315	1.87	11.33	323.33
V	0.46	<0.03	0.064	15.33	4.0	296.66
OMARD (2004, 2008)[a]	140	5	2	100	1,500	60
EU range[b]	70–1,000	0.7–10	0.7–10	70–200	210–4,000	20–200

[a]Polish standards.
[b]European standards after Brinton (2000).

Table 4
Comparison of the results of helminthological examinations of the composts in terms of eggs of *Ascaris lumbricoides* and *Salmonella* sp.

Parameter	Sample I Compost	Sample II Compost	Sample III Compost	Sample IV Compost	Sample V Compost
Salmonella sp. CFU/kg DM	Not detected	Not detected	Not detected	Not detected	Detected
Living helminths' eggs (eggs/kg DM)	35±1	20±1	25±2	40±3	30±2

Table 5
Values of individual types of PAH

Type of PAH	Unit	Sample I	Sample II	Sample III	Sample IV	Sample V
Naphthalene	mg/kg DM	0.75±0.02	0.83±0.2	0.001±0.0001	0.18±0.05	0.31±0.01
Acenaphthylene		0.12±0.01	0.14±0.07	0.16±0.02	0.001±0.0002	0.36±0.02
Acenaphthene		1.20±0.07	2.60±0.8	0.21±0.03	0.19±0.01	0.22±0.08
Fluorene		0.09±0.01	0.089±0.01	0.01±0.001	0.22±0.02	2.20±0.04
Phenanthrene		0.085±0.01	0.10±0.02	0.024±0.008	0.27±0.01	0.03±0.004
Anthracene		0.08±0.01	0.05±0.01	0.09±0.007	0.07±0.01	0.005±0.0004
Fluoranthene		0.25±0.01	0.50±0.05	0.009±0.001	0.13±0.05	0.012±0.005
Pyrene		0.48±0.02	0.53±0.02	0.01±0.002	0.65±0.02	0.02±0.008
Benz(a)anthracene		0.18±0.03	0.27±0.02	0.03±0.002	0.47±0.1	0.03±0.004
Chrysene		0.36±0.04	0.19±0.01	0.02±0.001	0.48±0.07	0.03±0.008
Benzo(b)fluoranthene		0.24±0.02	0.19±0.01	0.04±0.001	0.55±0.04	0.05±0.002
Benzo(k)fluoranthene		0.13±0.01	0.11±0.06	0.001±0.0002	0.26±0.01	0.009±0.0001
Benzo(a)pyrene		0.21±0.02	0.16±0.07	0.01±0.0004	0.44±0.08	0.03±0.001
Dibenz(a,h)anthracene		0.13±0.03	0.13±0.02	0.004±0.001	0.13±0.01	0.27±0.04
Indeno(1,2,3-cd)pyrene		0.03±0.01	0.05±0.01	0.004±0.0001	0.01±0.001	0.004±0.0001
Benzo(ghi)perylene		0.13±0.01	0.24±0.03	0.03±0.002	0.05±0.01	0.07±0.002
Sum of concentrations of 16 PAHs		4.465	6,179	0.653	4.101	3.65

(including PAHs) contained in produced composts are limited by the regulations in force in Austria (6 mg/kg DM), Denmark (3 mg/kg DM) and Luxembourg (10 mg/kg DM) [49]. They are permanent pollutants occurring in all components of the natural environment. PAHs can be of natural or anthropogenic origin (including organic matter decomposition and processes combustion), and their concentration is of special importance when in the food chain they reach the human body [50,51].

Based on qualitative and quantitative chromatographic analysis, 16 priority PAHs were found in samples of compost (Table 5). It was found after analysis of the composts that value of PAH (6 mg/kg DM) was exceeded for mixture II. In other cases, PAHs concentrations were lower than 6 mg/kg DM. The obtained significant differences in the sum of concentrations for individual mixtures could be related to differences in the intensity of the process transformation of PAHs. According to Lazzari et al. [15] transformation of PAHs, associated with reducing their concentration, they are associated with two at the time of composting phenomena: adsorption and biodegradation. The thermophilic phase is characterized by a large decrease in the sum of PAH steels at the level of even 50%–70% [15]. In the next stages, there is a slight increase in the sum of PAHs. Initially adsorbed PAH in connection with the mineralization of organic matter and limitation number of sorptive active centers, desorption. Finally, a reduction in the sum of hydrocarbon concentrations is observed up to 84%. PAHs exhibit a very high susceptibility to changes in the external factors, such as temperature and pH and presence of many chemical compounds, for example, surface-active agents or pesticides.

4. Conclusions

The obtained composts were characterized by high moisture, high values of C/N ratio, which might suggest the lack of stabilization of the composts and the necessity of its maturing. The content of nickel (Ni) in all the composts studied substantially exceeded the permissible values specified in standards, the composts obtained in the study cannot be used for agricultural purposes. It was found that the primary choice for effective composting is very careful selection of raw materials and their physical–chemical characteristics. Application of treatments based on biopreparations dosing improves the composting process, but it was not a satisfactory solution. The use of indirect technological measures such as leaching recirculation or their sonification did not bring about the expected acceleration of composting Returning the compost leachates to the mixture might increase concentration of contaminants in the stabilized mass, which leads to deteriorated effectiveness of microorganism activity and consequently to inhibition of the decomposition process. In the future, in order to optimize the composting process, the optimal composition of the composting mixture should first be determined. Then test the effect of biopreparations on the course of the process and the final product – compost.

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