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ORIGINAL PAPER

Fertilizer value of composts obtained with addition of coffee grounds and maize

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Abstract

Management of catering waste, including coffee grounds, is becoming an important economic issue. Coffee grounds contain both organic compounds and mineral compounds, including macronutrients and micronutrients. The purpose of the study was to determine the fertilizer value of composts obtained using coffee grounds. The compost was prepared from vegetable raw material and coffee grounds with the addition of biocarbon or effluent obtained during yeast production. The experiment included 4 treatments: M – control - maize straw; M+CG – maize straw + coffee grounds; M+CG+BC – maize straw + coffee grounds + willow biochar; M+CG+E – maize straw + coffee grounds + yeast effluent. The amount of waste materials introduced into the composted maize biomass was limited not only due to their physical parameters, but also because of the humidity of the feedstock. The ratios of feedstocks used in individual treatments by weight of the dry matter were: M+CG – 1:0.89; M+CG+BC – 1:0.89:0.1; M+CG+E – 1:0.89:0.07. After mixing the materials, moisture of the mixture was equilibrated to 60% by weight. Aeration of the biomass was performed in cycles, 6 times a day; the air was flowing through the bioreactor in the amount of 15 dm^3 min^{-1} for 60 min; the biomass was manually shifted every 10 days. The content of macronutrients and trace elements was determined in the product with regard to the admissible values for organic fertilizers. Composts with a very high proportion of coffee grounds meet the criteria regarding the minimum NPK and organic matter content in the fertilizer aspect. Coffee grounds are characterized by a low content of heavy metals, which in practice can cause their dilution in biological processing products. Utilization of the effluent from a yeast factory for irrigation of composted biomass is not possible on an industrial scale. A small addition of this waste leads to significant salinity of the compost.

Keywords: biocarbon, coffee grounds, compost, fertilizer value, macro- and microelements

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INTRODUCTION

In circular economy, an important part of the system is the management of organic waste, including food waste. Sanitary and odour hazards enforce specific handling of these wastes. Correct logistical activities help to eliminate those hazards. Reduced time of transportation of waste from the consumer to the installation as well as appropriate technology allow the use of rational solutions.

Coffee is one of the most popular agricultural products and the second most commonly marketed goods in the world. Imports of coffee are systematically increasing, both in the European Union and in Poland (ICO.org. 2017). In 1996, the import of coffee to Poland amounted to 435,000 bags of 60 kg each, while in 2013 it was already 3,284,000 bags (ICO.org 2017). According to statistics, the import of coffee to Poland increased in 2013 by more than 7 times compared to 1990 (ICO.org 2017). Higher coffee weight imported to Poland (over 200,000 Mg in recent years) is directly proportional to the weight of coffee imported to other UE Member States (ICO.org). In consequence, imports of coffee lead to the generation of similar quantities of food waste (Tsai et al. 2012). On the basis of data of the Polish National Waste Management Plan (KPGO 2016), one can estimate that coffee grounds constitute about 0.6% of kitchen and garden waste. Since this percentage relates to the stimulant such as coffee, it should be treated as an important share in the resulting waste.

Coffee grounds are a specific food waste. Their characteristic features are homogeneity and possibility of selective treatment, especially in the food service industry. Food establishments are able to source this waste selectively, which could greatly facilitate its management. Although in Poland about 75% of coffee is consumed in households (Bartkowicz 2015), the amount of selective sourcing of coffee grounds, especially in places with high numbers of travelling guests or in tourist destinations, can become significant. Particular attention should be paid to coffee service networks. Thermal hygienisation during coffee brewing is conducive to a short-term storage of waste. Despite their humidity, coffee grounds are not prone to rapid microbiological processes and have no odour-generating properties. Compounds remaining in coffee grounds after extraction also limit the microbiological processes, as they inhibit the growth of microorganisms (Kim et al. 2012, Pujola et al. 2013).

Various uses of coffee grounds are sought (Kondamudi et al. 2008, Pujola et al. 2013, Yamane et al. 2014), including the production of biodiesel and antioxidant materials, or as a biosorbent of hydrophobic substances. Some propose (Ciesielczuk et al. 2015, Grard et al. 2015) to use coffee grounds in substrates applied in urban gardens. Based on local organic materials, such substrates are an alternative amendment to the often polluted soils of urban agglomerations. Coffee grounds can be directly applied to the soil (Cruz et al. 2012, Yamane et al. 2014), which can help to achieve many outcomes, for example improved agrotechnical parameters or long-term carbon sequestration.

Organic recycling carried out under aerobic conditions should be a reasonable method of coffee grounds management on a large scale. This can reduce the physiological stress of plants noted by Cruz et al. (2012) when a large share of coffee grounds is introduced directly into the soil. Composting of coffee grounds exclusively is unreasonable due to their structure and chemical composition. This waste requires feedstocks to supplement and improve the parameters of the composted biomass structure (Kopeć et al. 2016). The basic problem here is the degree of fragmentation, which restricts air access to deeper biomass layers in a prism or bioreactor. That is why, studies on the composting of coffee grounds with waste paper and other mineral additions have been conducted in order to optimise the process conditions and produce a high-quality fertiliser (Martin 2015).

Because of the high content of persistent carbon, food waste in the form of coffee grounds can be a substitute of biochar (Yamane et al. 2014). Low-temperature conversion of biomass allows one to obtain a stable market product whose properties will improve the properties of soil or compost (Mierzwa-Hersztek et al. 2016). Biochar, due to its specific surface area, may act as a buffer with regard to the substances present in coffee grounds and, after their application to the soil, it can reduce the physiological stress in plants (Cruz et al. 2012). An important factor is an increase in retention and sorption capacity, e.g. in relation to ammoniacal nitrogen (Głąb et al. 2016). Due to the variety of materials and technologies, sorption, including that of ammoniacal nitrogen, requires even more detailed studies under different environmental conditions and in different soil-plant systems. Proper selection of feedstocks provides opportunities for accelerating the composting process and obtaining a product with desired properties (Holes et. al. 2014). This is due to the form of air-water relationships, which affects the biological activity of the composted biomass. In this study, we added willow biochar to the composted maize biomass with coffee grounds in order to check whether this addition would have an effect on the fertilising parameters of compost.

These feedstocks, coffee grounds and biochar contain persistent carbon, thus the composting process is unusual. The study also involved the use of yeast effluent for the irrigation of compost, as we assumed that this may improve the composting process and the management of this waste with a very high sodium content.

MATERIALS AND METHODS

Conditions and scheme of the experiment

Waste was composted for 140 days, from mid-May to the end of September 2015. The process was carried out in 1.2 x 1.0 x 0.8 m bioreactors with the perforated bottom to allow active aeration. Laboratory bioreactors were sheltered against precipitation but exposed to the outside temperature and sunlight. This ensured heat exchange between the composted material and the surrounding environment. The basic feedstock used in the composting process was shredded maize straw (29.3 kg D.M.). This material was used because of the good C:N ratio (37.2) and high homogeneity of the feedstock. The authors assumed that maize straw could be a substitute for biodegradable municipal waste, such as grass and leaves. Moreover, maize straw is characterized by an optimal C:N ratio in relation to coffee grounds. Biomass prepared in this way was amended with food waste (coffee grounds) obtained from service networks, as well as (industrially obtained) willow biochar or effluent formed during the production of yeast (industrial waste).

The scheme of the experiment included 4 treatments: M – control – maize straw; M+CG – maize straw + coffee grounds; M+CG+BC – maize straw + coffee grounds + willow biochar; M+CG+E – maize straw + coffee grounds + yeast effluent.

The amount of waste materials introduced into the composted maize biomass was limited not only due to their physical parameters, but also because of the humidity of the feedstock. The ratios of feedstocks used in individual treatments were, by weight of the dry matter: M+CG - 1:0.89; M+CG+BC - 1:0.89:0.1; M+CG+E - 1:0.89:0.07. After mixing the materials, moisture of the mixture was equilibrated to 60% by weight. Aeration of the biomass was performed in cycles, 6 times a day; the air was flowing through the bioreactor in the amount of 15 dm^3 min^{-1} for 60 min; the biomass was manually shifted every 10 days. In the course of the composting process, the outside temperature in the shadow and temperature of the composed biomass (at half height of the composted matter) were recorded every 30 min using a DT-171 data logger.

Compost samples collected after 140 days were regarded as the final product, and chemical composition of the compost was determined.

Chemical and physical analyses

In order to identify the properties of matter composted by aeration, dry materials were dried at 105°C for 12 h (Jindo et al. 2012; PN-EN 12880:2004) and analysed. The pH of materials (material : water = 1:2.5) was determined electrochemically using a pH meter (pH – meter CP - 505), electrical conductivity (material : water = 1:2.5) was measured with a conductivity meter (Conductivity/Oxygen meter CCO - 501) Meier et al. (2017), and the contents of total nitrogen, carbon, and sulphur were determined with an Elementar's Vario EL Cube elementary analyser (Elementar Analysensysteme 2013). Once the sample was dry-mineralised in a muffle furnace (at 450°C, for 5 hours) and its residue dissolved in diluted (1:2) nitric acid; the content of ash components was determined in a dried and ground plant material. The content of the studied elements in the prepared solutions was determined by ICP-AES on an Optima 7300 DV. The mercury content in the material was determined using an AMA 254 apparatus, in which it is released from the amalgamator and measured in the sample by atomic absorption, at 254 nm and the detection limit of 0.00001 mg of mercury.

Analysis quality control and statistical analyses

Chemical analyses of the samples were performed in two replicates. The accuracy of chemical methods was verified based on the certified reference materials: CRM IAEA/V – 10 Hay (International Atomic Energy Agence), CRM – CD281 – Rey Grass (Institute for Reference Materials and Measurements). The data were compiled using the STATISTICA 12 software (StatSoft 2006). Variations in the treatments were determined by calculating the standard deviation (± SD).

RESULTS AND DISCUSSION

The selection of feedstocks for the composting process is important because it enables the creation of optimal conditions for the development of microorganisms (Akhter et al. 2015). The chemical composition of feedstocks used in the study is shown in Table 1. The content of most elements in solid materials was typical of plant materials. Differences in the chemical composition result from various regions in which the material was obtained as well as from properties of individual species. It is worth mentioning that willow biochar had a high content of calcium. Coffee grounds used in the study had a significantly lower content of chromium, nickel, lead, and iron compared to other plant feedstocks.

The content of macronutrients in green coffee depends on the species, farming technology as well as the region where it is grown, and varies within the range (IFA 1992): 17–35 g N kg^{-1}, 1–3 g P kg^{-1}, 15–53 g K kg^{-1}, 1.6–2.8 g Mg kg^{-1}, 1.5–7 g Ca kg^{-1}, and 1.3–2.9 g S kg^{-1}. Green coffee beans also contain a number of micronutrients, including: 20–50 mg Mn kg^{-1}, 12–84 mg Zn kg^{-1}, 13–32 mg Cu kg^{-1}, and 61–112 mg Fe kg^{-1}. These amounts of ash components in coffee grounds, i.e. after extraction, will not be significantly modified. Szymanowska and Wołosiak (2014) concluded that the coffee roasting process influences the content of dry matter, reducing sugars and the acidity of coffee. These changes depended on the temperature and time of roasting.

Table 1

Chemical composition of substrates used in the composting process

Element	Maize straw (M)	Coffee grounds (CG)	Biochar (BC)	Yeast effluent (E)
C (g kg^{-1})	393±1[!]	507±12	639±35	no[#]
N (g kg^{-1})	10.57±0.50	23.80±0.46	9.67±0.93	no
S (g kg^{-1})	0.200±0.018	0.144±0.020	0.085±0.009	no
Na (g kg^{-1})	0.019±0.001	0.368±0.002	0.416±0.024	255±103
K (g kg^{-1})	11.81±0.35	9.584±0.150	8.230±0.080	2.025±0.30
Ca (g kg^{-1})	3.262±0.210	1.217±0.030	29.9±0.2	6.595±0.250
Mg (g kg^{-1})	1.646±0.033	1.862±0.068	1.763±0.031	1.818±0.069
P (g kg^{-1})	3.527±0.044	1.443±0.009	2.904±0.128	33.2±0.6
Cd (mg kg^{-1})	0.234±0.018	0.008±0.006	0.577±0.142	0.065±0.018
Cr (mg kg^{-1})	15.00±0.93	0.07±0.050	19.16±3.74	2.21±0.02
Cu (mg kg^{-1})	3.03±0.07	12.80±0.46	8.67±0.29	0.535±0.223
Fe (mg kg^{-1})	648.3±45.6	47.17±22.37	2316±203	20.97±1.47
Mn (mg kg^{-1})	35.15±0.434	28.59±1.032	113.3±6.337	12.06±0.270
Ni (mg kg^{-1})	6.985±0.422	0.343±0.047	11.18±2.507	0.394±0.038
Pb (mg kg^{-1})	6.184±0.224	0.337±0.060	7.497±0.53	0.600±0.035
Zn (mg kg^{-1})	61.75±3.12	6.183±0.32	116.2±5.14	3.199±0.213
Hg (mg kg^{-1})	0.020±0.002	0.025±0.002	0.011±0.002	0.013±0.002

[!] ±SD, [#] was not determined

Changes in the content of ingredients during coffee roasting and extraction primarily concern volatile compounds, of which approx. 1000 have been identified so far. On the other hand, Świetlik and Trojanowska (2014) noted that the average share of the forms of dissolved metals in coffee infusions may be 20%. The influence of the coffee type and methods of its brewing on the distribution of metals between dissolved and suspended phases was demonstrated.

The highest loss of dry matter (64%) was determined in the maize straw (M) composting, where 100% was the mass of substrates before the composting process, such as those shown in Figure 1. Biochar and coffee grounds are stable materials, less prone to biological decomposition and weight loss during the process. The accumulation of effects was observed after introducing yeast effluent into the composted matter: changes in the chemistry of the environment, reduced decomposition through the narrowed diversity of microbiological decomposition, and reduced decomposition of stable carbon from coffee grounds.

The outside temperature reflected the meteorological conditions in the months in which the composting process was conducted. In the first 20 days

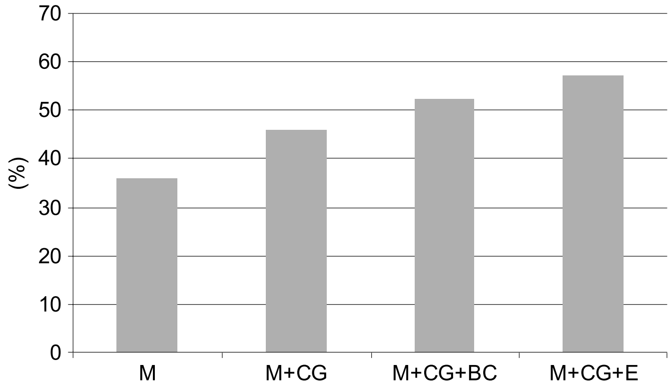

Fig. 1. Percentage share of dry matter residue after the composting process

of composting, the highest temperature was identified in maize straw (M) treatment. In the entire composting period, the temperature in this treatment was clearly different from the one in composts with the addition of coffee grounds. During the composting of maize straw with coffee grounds, temperatures indicating intense microbiological processes were maintained for a long period of time (80-100 days). In the maize straw treatment, the compost temperature equalled the ambient temperature in the period of 40th-60th day, indicating that the microbial activity was stopped. This is confirmed by the studies of respiration activity (Kopeć et al. 2016). Biochar or yeast effluent introduced into the composted mass of maize straw and coffee grounds did not differentiate the standard deviation within the designated 20-day periods.

It is believed that that the temperature should be kept at approximately 70°C for one hour during the composting process for the purposes of compost hygienisation (Commission Regulation 2011, Saveyn, Eder 2014). Other temperature profiles guaranteeing hygienisation are acceptable in industrial composting. It is possible to decrease the temperature, but it needs to be maintained longer (e.g. min. 55°C for at least 14 days). It should be noted that the selected proportions of maize straw and coffee grounds were not conducive to microbiological processes allowing the attainment of high temperature ranges, such as those shown in Figure 2. The conclusion is that the share of coffee grounds must be reduced in practice. The experiment was carried out with relatively small amounts of composted materials and in a bioreactor exposed to dynamic heat exchange with the environment.

In all treatments, the C:N ratio, i.e. an indirect indicator of compost stability, was from 10.5 to 11.8 at the coefficient of variation of 5.8%. Values of this ratio indicate the end of the composting process (Table 2). It is worth noting that the content of C and S in the compost M+CG was lower than in the compost with the addition of yeast (M+CG+E), which resulted from the compaction and losses of elements during the composting process (Table 2).

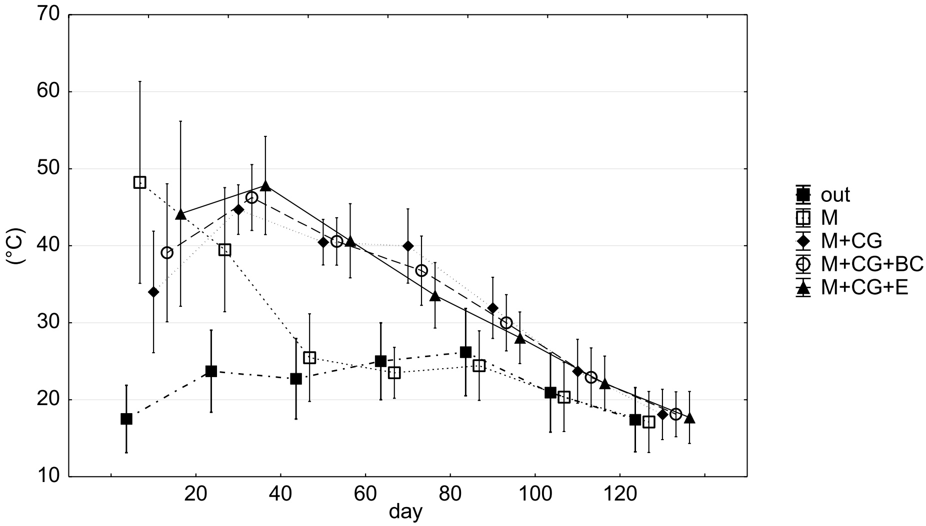

Fig. 2. Changes in ambient temperature and compost weight in 20-day cycles

Table 2

Selected parameters of composts

Parametr	M	M+CG	M+CG+BC	M+CG+E
pH	7.89±0.20[!]	7.01±0.19	7.33±0.12	6.65±0.24
EC (m S^{-1})	6.78±0.20	2.78±0.08	2.70±0.11	7.15±0.22
Ash (g kg^{-1})	188.9±9.4	136.3±5.4	125.1±4.9	161.8±5.7
C (g kg^{-1})	365±3	417±7	442±21	423±8
N (g kg^{-1})	31.6±0.7	39.8±0.5	37.6±0.9	39.8±1.0
S (g kg^{-1})	0.337±0.015	0.290±0.012	0.268±0.027	1.330±0.043
Na (g kg^{-1})	0.126±0.057	0.445±0.032	0.244±0.013	13.740±0.342
K (g kg^{-1})	38.98±0.200	23.226±0.120	21.004±0.130	19.411±0.90
Ca (g kg^{-1})	10.689±0.317	6.238±0.222	7.893±0.157	13.865±0.436
Mg (g kg^{-1})	5.099±0.057	4.297±0.045	3.758±0.102	3.638±0.43
P (g kg^{-1})	10.749±0.013	5.950±0.045	5.157±0.041	7.863±0.180
Cd (mg kg^{-1})	0.499±0.009	0.263±0.010	0.239±0.011	0.202±0.010
Cr (mg kg^{-1})	2.493±0.111	2.119±0.089	4.874±0.140	3.465±0.159
Cu (mg kg^{-1})	8.76±0.23	20.51±0.45	19.49±0.39	16.31±0.57
Fe (mg kg^{-1})	713.6±27.1	589.3±10.4	700.6±30.7	632.8±25.7
Mn (mg kg^{-1})	87.13±3.21	69.88±2.31	73.28±2.94	66.47±1.42
Ni (mg kg^{-1})	1.396±0.011	1.381±0.019	2.981±0.022	2.097±0.020
Pb (mg kg^{-1})	8.05±0.91	5.93±0.72	4.38±0.43	3.06±0.11
Zn (mg kg^{-1})	119.1±2.1	71.3±2.9	65.4±0.9	54.3±0.4
Hg (mg kg^{-1})	0.02±0.001	0.011±0.001	0.012±0.001	0.011±0.001

[!] ±SD

The resulting composts had different values of electrical conductivity and pH (Table 2). These differences are due to the fact that coffee grounds are a feedstock which was submitted to aggressive extraction with hot water. Intensively leached, poorly bonded ions made the composts amended with coffee grounds have low EC values. The high content of sodium in yeast effluent (M+CG+E) resulted in the highest electrical conductivity of composts. The addition of stable materials such as biochar and coffee grounds is of practical significance, since in industrial composting of food waste, it may reduce the salinisation of composts.

There may be different approaches to the fertilising value of converted waste (Saveyn, Eder 2014). Some EU countries use lists of raw materials and others refer to the quality of products. Pursuant to the Polish law, a fertiliser can be marketed once it meets a number of requirements, such as the declared minimum content of macronutrients and the maximum content of heavy metals (Journal of Laws 2008). However, the authorities are working on amendments to the existing legislation, which will clarify the requirements for the use of these products (waste) in the environment, including agriculture.

Currently, the permissible content of impurities in organic fertilisers must not exceed 100 mg Cr kg^{-1}, 5 mg Cd kg^{-1}, 60 mg Ni kg^{-1}, 140 mg Pb kg^{-1}, and 2 mg Hg kg^{-1} (Journal of Laws 2008). In these fertilisers, no live eggs of *Ascaris* sp., *Trichuris* sp., and *Toxacara* sp., as well as *Salmonella* and, in special cases relating to raw materials, *Enerobacteriacae* bacteria are permissible. For macronutrients, their declared minimum content should be as follows: N (0.3%), P (0.2% P_2O_5), and K (0.2% K_2O). Organic fertiliser should contain at least 30% of an organic matter (Journal of Laws 2008).

The content of organic matter and NPK in composts was several times higher than the declared minimum value. In the analysed composts, the addition of coffee grounds increased the nitrogen content compared to the treatment with only maize straw applied. This may be due to its greater nitrogen weight resulting from the process or higher sorption of the element. Phosphorus and potassium contents were diluted in composts with coffee grounds, which contained less of these elements that maize straw. When it comes to fertilising, the higher content of phosphorus in yeast effluent compost does not compensate for the manifold increase in the sodium content, which salinates the product.

Apart from physical and sanitary impurities, heavy metal contaminants are important from the point of view of food chains. In the case of the composts obtained in this experiment, the cadmium content was many times lower than the permissible value, especially as a result of dilution with coffee grounds, which contained far less cadmium than maize straw or willow biochar. The same applies to chrome. The content of mercury in composts did not exceed 3% of the permissible value, 5% in the case of chromium and nickel, and 6% for lead. The cadmium content in maize straw compost was

10% of the permissible value; however, as in the case of other metals, coffee grounds diluted the content of this element significantly.

The content of elements in biochar compost was shaped by the dilution effect resulting from the introduction of biochar or smaller losses of dry matter during the composting process.

It is assumed that low-temperature production of biochar is an environmentally friendly technology for reducing biodegradable waste stream and its further recycling (Holes et al. 2014). Currently, there are three known methods of producing and using biochar compost. The first method involves direct mixing of biochar with compost and application of the resulting mixture into the soil without additional incubation (Blackwell et al. 2009); other methods involve co-composting of biochar with other raw feedstock inputs before they are applied into the soil, as well as the incubation of biochar with fresh compost for a certain period, directly before its introduction into the soil (Khan et al. 2016). Given the diversity of the analysed mixtures and multidirectionality of microbiological changes during composting, the study was conducted with the aim to assess the effect of the composting process and the addition of substrates in it, on the fertilising indicators of composts. Co-composting of various feedstocks, including biochar, seems to be the most optimal solution when it comes to technology. Oliveira et al. (2014) reported on the effectiveness of composting of Poly(lactic acid) (PLA) with various additions; however, they underlined the slowdown of the process when coffee grounds were added. Despite agronomic problems related to the direct application of coffee grounds, Yamane et al. (2014) see a great potential in this waste for improved soil fertility.

The management of yeast effluent did not meet expectations, since the use of process heat to evaporate the hydrated waste that is generated in large quantities salinates the compost, thus excluding its application in the soil. The addition of biochar as a feedstock in the composting process is of no fertilising significance. The high share of biochar in compost is impractical and economically unjustified. The feedstock improves the retention and absorption properties of composts, so this solution is meaningful. The issues discussed in this study need to be improved, as the optimal proportions of feedstocks in the composting process require determination, taking into account different aspects of the environmental impact, (Gondek et al. 2017).

CONCLUSIONS

Temperature changes during the composting process indicate that persistent carbon in the form of coffee grounds or biochar slows down the microbial activity and prolongs the composting process. Composts with a very high share of coffee grounds meet the criteria of minimum NPK and organic matter contents for fertilising. Coffee grounds have a low content of heavy metals, which, in practice, can lead to their dilution in the products of biological treatment. The use of yeast effluent for the irrigation of composted biomass is not possible on an industrial scale. A small addition of this waste results in significant salinisation of compost.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, software, validation, formal analysis investigation resources, data curation, visualization, supervision, project administration, funding acquisition M.K and J.A; writing – original draft preparation, M.K; writing – review and editing, J.A. and BK. All authors have read and agreed to the published version of the manuscript.

Declaration of conflicting interests

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