detritus Multidisciplinary Journal for Waste Resources & Residues

COMPOSTING OF VEGAN KITCHEN WASTE: APPLICABILITY ASSESSMENT

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Article Info:
Received:
28 November 2021
Revised:
19 May 2022
Accepted:
6 June 2022
Available online:
30 June 2022

Keywords:
Composting
Vegan
Food waste
Kitchen waste
Phytotoxicity
Applicability

ABSTRACT
Kitchen waste from vegan households can be a raw material for home or backyard composting. However, the use of waste without components like eggshells or meat can constitute several problems, including the decrease of the process temperature and the content of Ca, N, K, Mg, Mn, Na, and S. The scientific aim of the study was to investigate possibility of production and applicability of vegan compost (VC) produced from kitchen waste during 12-weeks backyard composting. The VC properties have been compared to the traditional compost (TC), made from plant- and animal-origin waste materials. Analyses showed that VC and TC have similar properties, reaching a pH close to 7.5, respiratory activity AT_4 <2 $mgO_2 \cdot (g\ dry\ mass)^{-1}$ and dry matter content of ~79%. VC didn't show any phytotoxic effect on garden cress; it was characterized by the highest seed germination (100%) and it stimulated the growth of plants' roots. It was characterized by a higher content of phosphates, P and K, and achieved a lower BOD/COD ratio, demonstrating its maturity and low rotting potential. VC also contained less chloride, Ni, and Pb and showed a lower potential for nitrates leaching. The values of contaminants contained in VC samples didn't exceed the limit values for organic fertilizers. Therefore, studies indicated that plant-based kitchen waste can be a valuable substrate to produce compost and proved that vegan households, restaurants, and cafes are not disqualified from implementing a circular economy by using them assecondary material.

1. INTRODUCTION

Among the factors influencing the choice of a vegan diet, in addition to religious or ethical beliefs regarding animal welfare, environmental aspects are increasingly mentioned (Christopher et al., 2018). They pertain to the reduction of the negative impact of the livestock industry, consisting largely in greenhouse gas emissions and deforestation (Ruby, 2012). Growing awareness is leading to the increase in the number of vegans in the world, especially among the younger generations (Aavik, 2019). A vegan diet, defined as the complete relinquishment of animal products such as meat, dairy, eggs, and honey (Norman & Klaus, 2020), has become common in most Western countries (Dolan, 2016). For example, in the UK the number of people who declare to follow a plant-based diet increased in 2006-2016 by 350% (Marsh, 2016). The Vegan Society, a charity promoting veganism, saw a 20% increase in membership over the 3 years from 2011 to 2014 (The Vegan Society, 2014). This trend is also visible in the media, which defined 2014 as "the year of the vegan" (Rami, 2014). The elimination of animal products in the diet also has the backing of institutions such as The United Nations, who argue that plant-based diets benefit the environment (Carus, 2010).

Growing popularity of veganism is reflected in increasing production of vegan food, the supply of meat alternatives, and the number of restaurants serving plant-based dishes (Norman & Klaus, 2020). Therefore, these products have become a potential composting material, whereas vegan restaurants or cafes – become sources of feedstock for producing vegan compost. At the same time, kitchen waste from vegan households can be used as a raw material for home or backyard composting, a procedure that has become more important in residential waste management in recent years (Faverial & Sierra, 2014).

The main idea of composting is to produce a valuable product – a material that has a high potential for use in

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https://doi.org/10.31025/2611-4135/2022.15194

agriculture as a soil amendment and may replace or reduce use of synthetic fertilizers (Radziemska et al., 2019). For this purpose, a final product which is made of a wide range of substrates, such as green waste from gardens and parks, urban solid wastes, or agricultural waste such as manure, is used (Pellejero et al., 2017). The benefits of applying compost as an organic fertilizer are due to many related effects of this material on the soil. By the direct impact on its macrostructure, it changes the pore volume, leading to a more favorable moisture distribution, and consequently gas exchange (Pellejero et al., 2017). The use of compost also reduces the apparent density, increases the stability and permeability of soil aggregates, as well as water retention capacity, thus contributing to the inhibition of land erosion (Zebarth et al., 2011). In addition, compost, as a source of humic substances, promotes favorable conditions for plants' growth, resulting from the increase of the buffer capacity of the soil and cation exchange capacity (Pellejero et al., 2017). It is related to fertilization through the increased carbon and other nutrient supply (like N, P, K, Ca, Fe) (Kowaljow & Mazzarino, 2007). This increases the activity of microorganisms (Pellejero et al., 2017) and may increase the yield, quantity, and quality of the desired plants, incl. fruit (Giannakis et al., 2014). Additionally, the use of compost has an environmental justification; it reduces greenhouse gas emissions by increasing soil's carbon storage (Cerda et al., 2018) and what is more, composting might offer the opportunity for energy recovery (de Souza Lima & Mahler, 2020).

However, composting vegan waste that doesn't contain elements such as eggshells or meat may lead to several problems. The lack of the first component may reduce the content of calcium necessary for plant growth (Quina et al., 2017), while the lack of meat – lowering the process temperature and the content of N, K, Mg, Mn, Na, Sr and S (Storino et al., 2016). Moreover, home and backyard composting of vegan waste may lead to the formation of excessive leachate, which is associated with the high proportion of fruit and their potential to fast degradation and thus the production of organic acids (Chanakya et al., 2007). An important aspect related to the use of compost as a crop additive is also its phytotoxicity. In order to secure its functions as a material supporting seed germination and plants' growth, the material stabilization during the composting process is necessary to remove possible phytotoxic substances (Illera-Vives et al., 2015). Thus, it is necessary to use the effective process technologies that enable the production of a good quality product, to keep a sustainable household level circular economy.

Therefore, the following question arises: Is the vegan backyard compost applicable for home-garden purposes like a traditional compost? The scientific aim of the study was to investigate the possibility of production and applicability of high-quality vegan compost from kitchen waste during backyard composting. The properties have been compared to traditional compost, made from plant- and animal-origin waste materials.

2. MATERIALS AND METHODS

2.1 Composted waste

Kitchen waste of plant origin (fruit and vegetable remains, peelings, coffee grounds, tea bags – vegan compost) and their mixture with animal-origin waste (eggshells, cheese, skins, yoghurts – traditional compost) were obtained from a 3-person household from May to July 2020 (spring and summer period, Poland). Substrates were collected twice a week throughout the composting process, stored in a freezer at T=-18°C, separately for vegan and traditional samples. After completion of the field tests of backyard composting, they were transported in a portable freezer to the Biomass and Waste Laboratory, Wrocław University of Environmental and Life Sciences, Poland. Properties of raw materials are presented in Figure A.1 (Supplementary content).

2.2 Experimental set-up

Vegan and traditional waste samples were backyard composted in two designed composters, built of plastic crates (26 dm^3 each). To increase the volume of each composter to 122 dm^3, a garden net based on a wooden bracket was attached. The air flow into the waste mass was provided through the perforation of crates walls. Additionally, to facilitate aeration, the bottom of each box was covered with three layers: 20 cm high layer made from small branches and sticks, then a layer of garden soil, and finally a layer made of mowed grass with mass ratio 3:1 for the last two (Figure 1). The composters were placed in a shaded, wind-protected place without water accumulation. On each day of the process, air temperature (°C), its humidity (%), and the amount of precipitation (mm) were measured at five-hour intervals (9 am, 2 pm, and 7 pm).

The backyard composting process was carried out outdoor in May-July 2020 for 12 weeks with mixing the material after 8 weeks in order to homogenize the sample and equalize the moisture content. The substrates were dosed twice a week, resulting in the accumulation of ~9 and 12 kg of vegan and traditional material, respectively (Figure 2).

2.3 Composts Characteristics

2.3.1 Sieve analysis

The vegan and traditional composts produced during the 12-week process were sifted separately without layers of branches and sticks, soil and mowed grass by laboratory shaker with electromagnetic drive MULTISERW-Morek LPzE-4e, Marcyporębie, Poland, using sieves with a mesh size of 16, 8, and 3.15 mm after shaking for 15 minutes. The fractions >16 mm, 16-8 mm, 8-3.15 mm, <3.15 mm were then weighed with the laboratory scale RadWag WPT/R 15 C2, Radom, Poland, with an accuracy of 0.01 g.

2.3.2 Dry Matter and Organic Matter Content

Plant- and animal-origin waste added each week to the composting process, as well as the samples of obtained vegan and traditional composts, were analyzed for dry matter content at 105°C for 24 hours in three replications using the laboratory dryer WAMED, model KBC-65W, Warsaw, Poland, by PN-EN 14346:2011 (Polish Committee

FIGURE 1: Backyard composters bottom preparation: a) branches and sticks layer; b) mowed grass layer; c) covering garden soil; blue crate - vegan compost, black - traditional compost.

for Standardization, 2011a). After that, all these samples were analyzed for organic matter content at 550°C using the muffle furnace Snol 8.1/1100, Utena, Lithuania, in accordance with PN-EN 15169:2011 (Polish Committee for Standardization, 2011b).

2.3.3 Physicochemical Composition and Heavy Metals Content

For vegan and traditional compost, in accordance with the PN-Z-15009:1997 standard (Polish Committee for Standardization, 1997), water extracts were made in three repetitions. Briefly, dry matter content was determined in the collected materials' samples in accordance with the procedure described in section 2.3.2. Then the samples were prepared in a 1:10 ratio of compost to water (m/m). Three conical flasks with a volume of 0.5 dm^3 were prepared, 41.66 g of vegan and traditional compost were placed in each, and 333.33 ml of water of purity grade 3 was added. After 1 h, the flasks were closed and shaken for 4 hours using digital orbital shaker ELMI DOS-20L, Calabasas, USA. Then the flasks were uncovered and placed for 16 h under static conditions. After this time, they were closed again, and shaking was repeated for another 4 hours. After that, the samples were left for another 2 h for solids sedimentation. The obtained water extracts were filtered using 0.45 μm filter paper and then subjected to the physicochemical analyzes listed in Table A.1 (Supplementary content).

2.3.4 Respiratory Activity

AT_4 respiratory activity was determined in triplicates for vegan and traditional compost using the OxiTop®Control measuring system, Weilheim, Germany, in accordance with Binner et al. (2012); Kilian & Macedowska-Capiga (2011). Briefly, ~50-55 g material samples in 2.5 L glass vessels were placed for 7 days in a WAMED KBC-65W, Warsaw, Poland, climatic chamber at 20°C. Each day the vessels were opened for 15 min to aerate the samples.

Based on the Equation 1, the total oxygen consumption was calculated for the samples of vegan and traditional compost:

$$OD = \Delta p \cdot \frac{M_{O2}}{R \cdot T} \cdot \frac{V_{ges} - V_{abs} - V_{sample}}{m_{d.m}} \quad (1)$$

where:

OD: oxygen consumption, $mgO_2 \cdot g\ d.m.^{-1}$,

Δp: pressure difference, mm hPa,

M_{O2}: molecular weight of oxygen, M_{O2}=31988 mg mol^{-1},
R: general gas constant, R=83,14 dm^3 hPa (K mol^{-1}),
T: temperature, K,
V_{ges}: total volume of the measuring vessel, dm^3,
V_{abs}: volume of the absorber and internal auxiliary equipment, dm^3,
V_{sample}: sample volume, dm^3,
$m_{d.m}$: mass of dry matter, g.

According to Kilian & Macedowska-Capiga (2011), the so-called lag-phase, which ends when the mean of the 3-hour measuring interval reaches 25% of the mean of the 3-hour interval with the greatest oxygen demand, was substracted.

2.3.5 Composts Phytotoxicity

The experiment was carried out using water extracts of vegan and traditional composts prepared according to the procedure described in section 2.3.3 with seed germination and early growth microbiotest with higher plants – Phytotoxkit (MicroBioTest Inc., 2004).

First, a test of water holding capacity of the reference soil was performed by filling a 100 cm^3 cylinder with 90 cm^3 of soil sifted through a sieve with a mesh size of 2 mm and 50 cm^3 of distilled water. It was mixed until the soil was completely saturated with water. After reaching the equilibrium state (complete saturation of the soil and formation of a water layer above the soil surface), the supernatant was poured into a 50 ml measuring cylinder. The operation was repeated after a few minutes. The volume of water required to completely saturate the reference soil was calculated as the difference in the volume of water added to the soil and the volume of the supernatant recovered in the measuring cylinder. Then for each treatment, the 90 cm^3 of reference soil was placed on a transparent PVC test plate composed of a bottom part separated by a middle ridge into two compartments and a flat cover (Figure 3). Subsequently, 30 cm^3 of water extract was introduced into the soil with a syringe. The material was evenly leveled to obtain a uniform layer thickness. A paper filter was placed on the surface of the soil, and at its top edge 10 seeds of *Lepidium sativum* were placed in one row at the same intervals from each other. The plate was closed and placed in a holder for 3-days vertical incubation in the dark at 25°C in a climate chamber ST 3 BASIC, POL-EKO-APARATURA, Wodzisław Śląski, Poland. The experiment was performed in 3 variants: vegan compost, traditional compost, and control (reference soil with distilled water) in triplicates. The image of the seed germination capacity in each plate was recorded with a camera after 3 days, and the root length was measured with the ImageJ software, Wayne Rasband.

Based on the Equation 2, the percentage of seed germination was calculated:

$$A = 100 \cdot \frac{(a-b)}{a} \qquad (2)$$

where:
A: seed germination, %,
a: total amount of seeds,
b: number of non-sprouted grains.

The inhibition of root elongation was calculated according to:

$$I = 100 \cdot \frac{(C-T)}{C} \qquad (3)$$

where:
I: inhibition of root elongation, %,
C: root length value measured for samples with reference soil, mm,
T: value of the root length measured for samples with the tested material, mm.

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Properties of Composts

Physical and chemical properties are not the only important elements determining compost quality; they also influence its utilization and handling (Agnew & Leonard, 2003). One of them is the particle size distribution of the product of the process. Vegan and traditional compost differed in particle size distribution, the former being distinguished by a higher share of the largest and the smallest fraction (45.90 and 27.88% for groups >16 mm and <3.15 mm, respectively), while in the case of animal-based material, the largest share was recorded for the first two com-

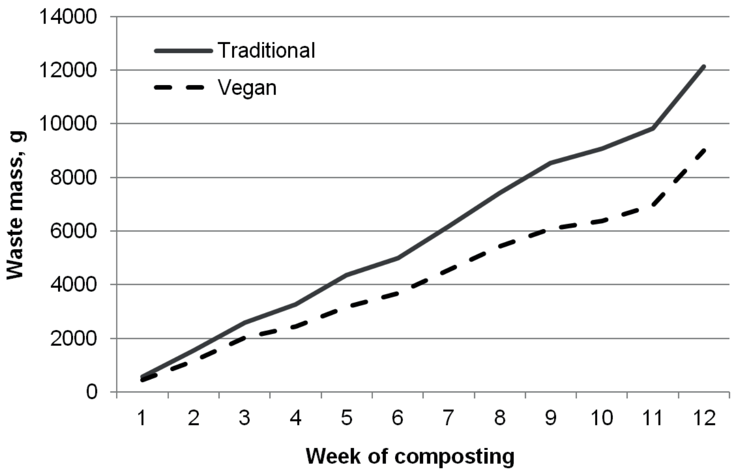

FIGURE 2: Cumulative mass of traditional and vegan waste added to backyard composting.

partments with the largest particle diameter (35.34 and 26.49% for fractions >16 mm and 16-8 mm, respectively, Figure 4). The greatest percentage of the >16 mm group in vegan compost was related to the type of its main building components, including large-sized peelings derived from vegetables such as zucchini, potatoes, celery, but also from turnip, radishes, and lettuce leaves; the high proportion of the fine fraction can be associated not only with greater susceptibility to decomposition of waste of plant origin, but also with their form, e.g. coffee or tea grounds. Although these kinds of wastes were also subjected to traditional compost, a smaller differentiation between the groups was observed here, which may result from the presence of eggshells, which were initially combined into coherent conglomerates, separated during the sieve analysis, and passed to each of the granulometric fractions.

The initial water content in the substrates changes during the composting process due to the decomposition of organic compounds available in the waste and related heat generation and vaporization (Liao et al., 1997). The final dry matter content in the conducted studies was similar for both types of compost, averaging 80.00 and 79.08% for traditional and vegan samples, respectively (Table 1). A similar level was reported for composts made from cattle manure and its mixtures with herbal plants residues (Khater, 2015). The obtained result could have been influenced by the location of the composters in a place where no water accumulated, but also by the duration of the process. The lower moisture level of vegan and traditional samples compared to the reported by (A. Kalamdhad & Kazmi, 2008) in the case of compost made of cattle manure, sawdust and vegatable waste in the rotary drum composter (~20 and ~50% respectively), may be due to the fact that the processes carried out differed significantly in duration. In our experiment, during the 12 weeks of backyard composting, moisture could have been lost as a result of a number of processes such as convective air movement, water vapor diffusion in high temperatures areas or during material turning after 8 weeks (Agnew & Leonard, 2003), which may not have happened or occured to a lesser extent during the 20 days of the composting of (A. Kalamdhad & Kazmi, 2008).

Vegan and traditional compost were characterized by similar pH (7.5 and 7.8, respectively, Table 1). Values not exceeding pH=8 were also recorded for the compost pro-

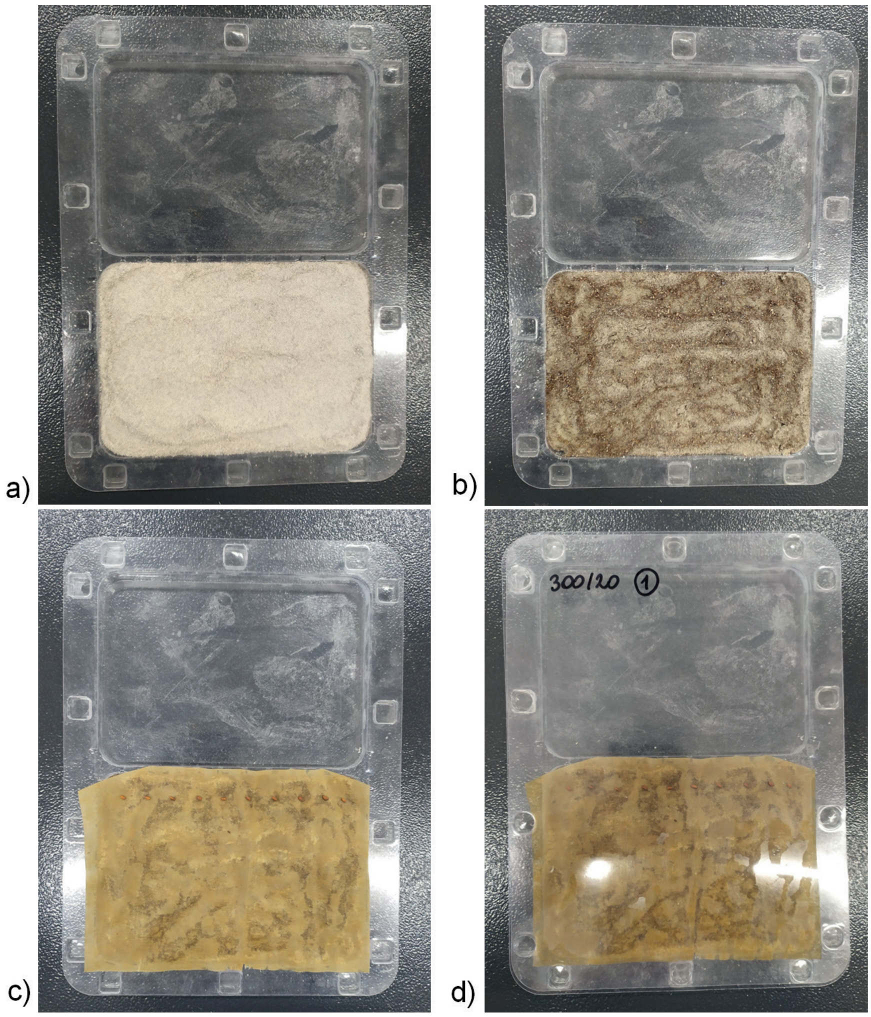

FIGURE 3: Procedure of using the Phytotoxkit test: a) reference soil on a test plate; b) soil saturation with distilled water, c) Lepidium sativum seeds on a paper filter; d) closed test plate prepared to incubation.

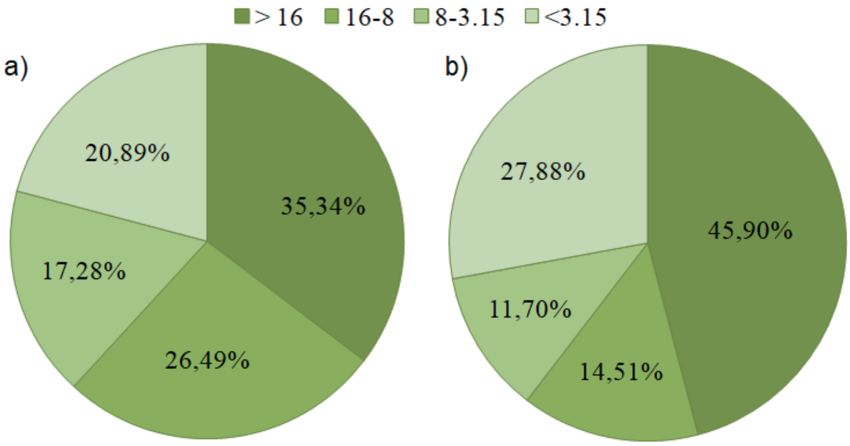

FIGURE 4: Particle size distribution (weight, %): a) vegan compost; b) traditional compost.

duced by (Kalamdhad & Kazmi, 2009b) from cattle manure, mixed green vegetable waste, food waste, grass cuttings, paper waste and sawdust, where the pH at the second and the third run of composting was equal to 7.92 and 7.72 respectively, and for composts tested by (Khater, 2015) (pH ranging from 7.2 to 7.8 for cattle manure and sugar cane plants residues, as well as for herbal plants residues, respectively). The similarity between samples obtained as a result of backyard composting conducted in this research was also seen in case of turbidity of water extracts. A lower index was recorded for vegan compost (16.2 compared to 17.6 NTU – Nephelometric Turbidity Units – for traditional compost, Table 1). These values are significantly lower than obtained by other researchers; turbidity of raw compost leachate tested by (Tawakkoly et al., 2019) reached 670 NTU; after processing it significantly decreased, but still exceeded approx. 14x the values noted in this experiment (252 NTU). Even higher value was obtained by (Brown et al., 2013), where the initial compost leachate was characterized by turbidity at the level of 1370 NTU. Such low results for vegan and traditional composts compared to those available in the literature indicate the advantage of their safe use. Compost leachate, due to the content of excessive nutrients and other substances, can become dangerous and harmful to the earth's surface and groundwater. Therefore, it is particularly important to manage properly the composted mass of waste and the final product.

TABLE 1: Physical and chemical properties of final composts; d.m. – dry matter.

	Vegan compost	Traditional compost
Dry matter content, %	79.08 ± 1.84	80.00 ± 0.05
pH	7.50	7.80
BOD_5, mg $O_2 \cdot dm^{-3}$	19.20	20.00
COD (Cr), mg $O_2 \cdot dm^{-3}$	109.60	94.80
BOD/COD	0.18	0.21
AT_4, mg $O_2 \cdot g$ d.m.$^{-1}$	1.70 ± 0.5	1.90 ± 0.4
Conductivity, $\mu S \cdot cm^{-1}$	450.00	537.00
Turbidity, NTU	16.20	17.60

An important aspect related to the use of compost as an organic fertilizer is its stability, which will ensure that biological processes do not continue (to a large extent) after its application, leading to a number of undesirable effects, such as the formation of odors, hazardous substances and pathogens and the associated occurrence of insects and flies (Kalamdhad & Kazmi, 2008). Therefore, it is important to know the amount of readily biodegradable organic substances (Bernai et al., 1998). The indicators used for this purpose, such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) or respiratory activity AT_4, can significantly facilitate the interpretation of the possibility of safe use of the produced compost. The analyzed samples of vegan and traditional materials were characterized by low levels of BOD_5 and COD_{Cr}, while in the case of the latter indicator the difference between composts was greater, and the plant-based material showed a higher level (109.60 mg $O_2 \cdot dm^{-3}$ compared to 94.80 mg $O_2 \cdot dm^{-3}$, Tab. 1). Nevertheless, it can be noted that the compost samples produced during the 12 weeks of the process differed significantly in terms of these two parameters from the results obtained by other researchers. BOD values of vegan and traditional composts were approx. 5.4x lower than the final result for vegetable waste, cattle manure and sawdust composted for 20 days (Kalamdhad & Kazmi, 2009b), 6.6x lower than during poultry litter composting for 30 days (Gupta & Doherty, 1990), 10.3x lower compared to the food mix and vegetable waste with grass cuttings and 17.1x lower compared to compost made from cattle manure, food waste, vegetable waste, paper waste and sawdust (20 days for both experiments, Kalamdhad & Kazmi, 2009b). Slightly lower variability can be observed when comparing the COD index; other researchers obtained about 4.5-5x higher values (Kalamdhad & Kazmi, 2008; Kalamdhad & Kazmi, 2009b). Importantly, however, the vegan and traditional composts produced as a result of the research were characterized by a low BOD/COD ratio, reaching 0.18 for the vegan compost and 0.21 for the traditional compost. These results prove that the produced composts consist of organic matter with low potential for further decomposition, i.e. they are microbiologically stable (Mangkoedihardjo, 2006). This is confirmed by (Kalamdhad & Kazmi, 2008), considering their BOD/COD rate of 0.23 at the end of the process as a sign that only non-biodegradable parts remained in the compost. Higher requirements for the stability of this organic material are made by (Borglin et al., 2004), considering the BOD/COD ratio ≤0.1 limit as safe.

Considering the respiratory activity of the analyzed compost samples expressed as the AT_4 index, a similar conclusion can be reached as in the case of the BOD/COD ratio. Vegan and traditional materials showed low AT_4 levels, on average close to 1.70 and 1.90 mg O_2·g d.m.$^{-1}$ respectively (Table 1). This means that after 12 weeks of the process, the intensive decomposition of easily biodegradable organic matter and the related development of microorganisms slowed down, and the composts had a greater proportion of mineral fractions, attesting to the stabilization of this organic material (Kilian & Macedowska-Capiga, 2011). This is also highlighted by the comparison of the obtained results with the guidelines developed for the processing of the biodegradable fraction of municipal waste, according to which the limit value for stabilized waste is AT_4 <10 mg O_2·g d.m.$^{-1}$ (Siemiątkowski, 2012). Moreover, the respiratory activity is always connected with moisture content in feedstock (Villaseñor et al., 2011). In this study low AT_4 level was observed when dry matter content was ~80%, which did not provide an optimal environment for the further development of microorganisms. The obtained values are also consistent with the own research conducted previously on a technical scale, during which, in the spring and summer period, turned piles of bio-waste with sewage sludge obtained AT_4 below 2 mg O_2·g d.m.$^{-1}$ after 43th day of the process (Stegenta et al., 2019).

Electrical conductivity (EC) is the most frequently mentioned parameter of compost samples (Agnew & Leonard, 2003), indicating total salt/electrolyte content in this organic material (Epstein, 2017). Here, EC was higher for traditional compost (537.00 µS·cm^{-1} compared to 450.00 µS·cm^{-1} for vegan sample, Table 1). Similar values were also obtained for pruning waste compost (Benito et al., 2006), however, in most studies, the conductivity range for waste materials is much higher, reaching from 1.1-1.9 mS·cm^{-1} in the case of yard waste compost (Campbell & Tripepi, 1991), through 2.8-4.6 mS·cm^{-1} for aerobic sewage sludge (García et al., 1991) up to 5.42 mS·cm^{-1} for separated cattle manure (Inbar et al., 1993), 7.8-9.8 mS·cm^{-1} for organic city refuse or even 7-12 mS·cm^{-1} for urban refuse composts (García et al., 1991; Villar et al., 1993), respectively. The tested traditional and vegan composts with a significantly lower EC level showed no phytotoxic effect (section 3.3), which is in line with the suggestion of (Epstein, 2017), that the limit value of non-toxic impact on plants is 5 mS·cm^{-1}. This is also in assent with the results obtained by Ringer et al. (1997). In this research, the extract from manure compost showed an EC of 0.7-1.5 mS·cm^{-1}, while having no phytotoxic effects in the soil. The analyzed samples also fall within the range indicated by the authors.

3.2 Heavy Metals Content

The content of heavy metals (Ni, Cd, Cr, Pb) in the compost and their possible release into the soil during its application as a fertilizer raise the greatest doubts about the ecological effect of this organic material, especially in the case of its excessive use in arable fields (Iwegbue et al., 2007). Danger resulting from the accumulation of heavy metals in plant tissues and the related contamination of the human and animal food chain has led in many countries to the development of strict guidelines for the use of composts, specifying limit values for the level of these elements in the material (Iwegbue et al., 2007). However, certain heavy metals are essential elements for plant growth as micronutrients, although they show very low levels in soil under natural conditions (Rosen & Chen, 2014). That is why it is so important to control the product of the composting process in terms of the content of these elements and thus create optimal conditions for the development of crops.

Traditional and vegan compost did not differ greatly in their heavy metal content; the largest difference between the samples was noted for nickel (6.06 and 4.20 mg·kg d.m.$^{-1}$, respectively, Table 2). Traditional compost also showed a higher concentration in the case of lead, but with the minor difference (11.76 mg·kg d.m.$^{-1}$ in case of the first and 11.55 mg·kg d.m.$^{-1}$ for the latter). Of the four non-nutrient heavy metals measured, lead was also the element having the largest content in the produced composts; cadmium was the least recorded, with levels close to 3 mg·kg d.m.$^{-1}$ for both materials. Comparing the obtained values with the legal requirements for composts in Poland (The Ministry of Agriculture and Rural Development, 2008), none of the tested heavy metals exceeded the permissible values, indicating that both types of compost are ready to be used as an organic fertilizer (Table 2). Moreover, the content of Ni, Cd, Cr and Pb in the vegan and traditional compost samples were much lower than those reported by other researchers. Green waste (GWC) and municipal solid waste (MSWC) composts analyzed by (Farrell et al., 2010) were characterized by high levels of lead, nickel and chromium; in the case of MSWC they exceeded, respectively, approx. 77x, 14x and 7.5x the maximum values obtained in this study, while for GWC, despite lower pollution levels, the exceedances were 3.4x, 5.2x and 5.8x, respectively. A similar trend can also be observed in the case of the Ni and Pb content studied by (Kalamdhad & Kazmi, 2009b) in three types of produced compost. The values for the first element reported by the authors ranged from 18.9 to 39 mg·kg^{-1}, while in the case of lead from 19.2 to 142 mg·kg^{-1}.

The biggest difference that was noted between the two types of compost in the case of Ni can be related to the granulometric composition of both materials. The higher content of this heavy metal in traditional compost, char-

TABLE 2: Heavy metals content.

	Vegan compost, mg·kg d.m.$^{-1}$	Traditional compost, mg·kg d.m.$^{-1}$	Limit value, mg·kg d.m.$^{-1}$ (The Ministry of Agriculture and Rural Development, 2008)
Ni	4.20	6.06	60.00
Cd	3.03	2.87	5.00
Cr	6.42	6.25	100.00
Pb	11.55	11.76	140.00

acterized by a higher proportion of fine fractions (<3.15 mm), is consistent with the reports by (Kupper et al., 2014). In the conducted research, the authors concluded that the content of heavy metals in the material sieved to the fraction <20 mm is higher when comparing the results with unsieved material. Additionally, the results obtained by (Paradelo et al., 2011) and (Veeken & Hamelers, 2002) agree with this. However, the outcomes reported here do not follow the trend observed by (Qiao & Ho, 1997) that Ni changes to a more accessible form at lower pH; traditional compost, for which the content of this metal was higher at the same time was characterized by higher pH than in the case of vegan material.

The obtained differences in the content of heavy metals between vegan and traditional compost could also be influenced by the substrates used in their production. The higher levels of chromium in the plant-based material were probably associated with the high proportion of vegetables. Heavy metals are accumulated in the tissues of these plants, both in their edible and inedible parts (Guerra et al., 2012). This is related to the uptake of these elements by crops from the soil, but also from the air - sediments can form a layer of pollutants directly on plant tissues (Zurera-Cosano et al., 1989). Related problems are reported by researchers around the world who are warning of the need to monitor the heavy metal content of vegetables and fruits, especially with the reference to vegetarian and vegan diets based on these products (Guerra et al., 2012; Islam et al., 2007). This need may be justified by the results obtained by (Guerra et al., 2012), who during their research noticed exceeding the permissible Cr content in 44.2% of the tested vegetables, mainly in green ones. In turn, in the analysis conducted by (Islam et al., 2007) it was observed that Cd can accumulate both in roots and in shoots of Chinese cabbage, winter greens and celery. The vegan compost produced here was based on the use of vegetables, including the types mentioned by the authors, which may explain the increased concentrations of Cd and Cr compared to traditional compost.

When considering traditional compost, a higher Pb content might be associated with the addition of animal waste, such as dairy products (yoghurt, cheese) and eggshells. Dairy products, although not containing many heavy metals in its primary form (milk) may be contaminated with them during product processing and packaging (Enb et al., 2009); a possible reason for the presence of elements such as Ni or Pb in dairy products may also be the supply of previously contaminated feed to dairy animals (Abou-Arab, 1997). According to a study of (Enb et al., 2009) on heavy metals behavior during processing of milk products such as yoghurts made from buffalo's and cow's milk, lead is one of the main contaminating elements. This is also confirmed by the analysis of (Shahbazi et al., 2016), who found Pb not only in yoghurt, but also observed a significant content in the case of white cheese. The authors explained this relationship by the presence of casein, a milk protein that tends to bind Pb. A similar effect was noted by (Meshref et al., 2014); the lead content in their milk and dairy products samples exceeded the permissible limit in all cases. Apart from dairy products, the presence of eggshells may also be responsible for the higher Pb level in traditional compost. (Waegeneers et al., 2009) concluded that the major source of this element in eggs is contaminated soil ingested by chickens; the average concentration of Pb in fresh eggs may be even 10x higher than in the case of the content of Cd (Fu et al., 2014). However, the problem of heavy metals content in eggshells is not fully understood; most authors claim that different paths of contamination should be checked before defining the main source (Grace & MacFarlane, 2016).

3.3 Physicochemical Composition

The issue of nitrogen transformation in the waste mass during the composting process is discussed, in particular, due to the possible associated emission of harmful gases, such as NH_3 and N_2O, but also due to the loss of this element during the decomposition of organic matter and the reduction of the fertilizing properties of the final product (de Guardia et al., 2010). In the conducted tests, a higher total nitrogen content was found in traditional compost (38.15 mg $N{\cdot}dm^{-3}$ compared to 27.30 mg $N{\cdot}dm^{-3}$ for vegan samples, Table 3). However, for both types of materials, nitrate nitrogen was predominant over organic and ammonium nitrogen, reaching for traditional and vegan compost 34.69 $N_{NO3}{\cdot}dm^{-3}$ and 21.93 mg $N_{NO3}{\cdot}dm^{-3}$, respectively. Considering the Kjeldahl nitrogen for both types of material, it

TABLE 3: Physicochemical composition of vegan and traditional composts.

Indicator	Vegan compost	Traditional compost
Total nitrogen, mg $N{\cdot}dm^{-3}$	27.30	38.15
Kjeldahl nitrogen, mg$N{\cdot}dm^{-3}$	5.01	3.44
Organic nitrogen, mg $N_{org}{\cdot}dm^{-3}$	4.37	3.15
Ammoniacal nitrogen, mg $N_{NH4}{\cdot}dm^{-3}$	0.64	0.29
Nitric nitrogen, mg $N_{NO3}{\cdot}dm^{-3}$	21.93	34.69
Nitrite nitrogen, mg $N_{NO2}{\cdot}dm^{-3}$	0.36	0.02
Phosphates, mg $P{\cdot}dm^{-3}$	11.15	8.61
Total phosphorus, mg $P{\cdot}dm^{-3}$	13.82	9.36
Dissolved oxygen, mg $O_2{\cdot}dm^{-3}$	7.50	7.80
Total dry residue, mg$\cdot dm^{-3}$	450.00	490.00
Dry mineral residue, mg$\cdot dm^{-3}$	230.00	200.00
Dry organic residue, mg$\cdot dm^{-3}$	220.00	290.00
General dissolved substances, mg$\cdot dm^{-3}$	415.00	460.00
Dissolved mineral substances, mg$\cdot dm^{-3}$	225.00	190.00
Dissolved organic substances, mg$\cdot dm^{-3}$	190.00	270.00
General suspensions, mg$\cdot dm^{-3}$	35.00	30.00
Mineral suspensions, mg$\cdot dm^{-3}$	5.00	10.00
Organic suspensions mg$\cdot dm^{-3}$	30.00	20.00
Sulphates, mg $SO_4{\cdot}dm^{-3}$	20.60	19.70
Chlorides, mg $Cl{\cdot}dm^{-3}$	7.60	14.80
Sodium, mg $Na{\cdot}dm^{-3}$	1.90	7.40
Potassium, mg $K{\cdot}dm^{-3}$	95.80	70.60
Magnesium, mg $Mg{\cdot}dm^{-3}$	7.30	11.20

can be observed that approx. 85% and 90% was organic nitrogen for composts based on plant substrates and plant plus animal origin, respectively. This could be explained by the activity of microorganisms which, initially carried out the ammonification reaction, then immobilized the formed dissolved ammonium and, by using it as a nitrogen source and the associated transformation, returned it as organic nitrogen (Sánchez-Monedero et al., 2001). This is in line with the observations of (Li et al., 2013) who noted an increase in NH_4-N content in the initial stage of composting (day 3 and 4 of the analysis), which quickly turned into a decline until the end of the process. In turn, the high content of nitrate nitrogen in the analyzed total nitrogen of the composts produced may indicate the occurrence of favorable conditions for the activity of nitrifying bacteria during the 12 weeks of the process, such as temperature below 40 °C and adequate access to oxygen (Sánchez-Monedero et al., 2001). A similar ratio of N_{NO3} to N_{NH4}, where the former significantly exceeded the amount of the latter, was also noted in the analysis of (Bueno et al., 2008). The observation of such a trend in traditional and vegan composts highlights the possibility of their effective use in agriculture, due to the best bioavailability of this form of nitrogen for the plant root system (Sánchez-Monedero et al., 2001). For both types of materials, the lowest share was nitrite nitrogen (approx. 1.3% for vegan compost and 0.05% for traditional compost), which is consistent with the observations mentioned earlier (Li et al., 2013).

Phosphorus is one of the key elements influencing plant development and quality; due to its scarcity, the yields of 30-40% of arable land in the world are below optimal (Malhotra et al., 2018). Its comprehensive activity is based on its participation in every stage of plant development. The content of this element plays an important role in seed germination, where grains with initially more P help the seedlings grow and mature faster (Y.-G. Zhu & Smith, 2001). Additionally, it contributes to cell enlargement and division, influencing plant height or the number and area of leaves (Assuero et al., 2004). Thanks to P, plant reproduction is also increased, resulting from the stimulation of flower and seed formation (Malhotra et al., 2018). However, composting, apart from increasing the availability of this element for plants, may also be responsible for the environmental risk associated with its leaching (Hashimoto et al., 2014), based mainly on the eutrophication of water bodies (Eneji et al., 2003) or erosion. It is therefore necessary to control the P content during decomposition of organic matter in the compost to ensure sustainable distribution practices for this element.

Among the tested samples, vegan compost showed a higher content of both phosphates and total phosphorus, while for the second factor the difference between the composts was greater (13.82 mg P·dm^{-3} compared to 9.36 mg P·dm^{-3} for the traditional material, Table 3). The obtained values were much lower than those recorded by other researchers, which, as in the case of material moisture, can be explained by the relatively long duration of the composting process and the progressive loss of organic phosphorus through mineralization and its microbiological consumption (Haug, 1993) or leaching. The values indicated in the literature are several dozen times higher, but in the case of composting of vegetable waste with cattle manure and sawdust lasting 20 days, the difference is smaller than for the same substrates within 15 days (approx. 3.5 g·kg^{-1} and 3.8 g·kg^{-1}, respectively (Kalamdhad & Kazmi, 2008; Kalamdhad & Kazmi, 2009a), which may indicate the dependence of the P content on the duration of the process and its progressive decrease. This is also confirmed by the research conducted by (Wei et al., 2015), where the availability of P showed a decrease from 44% to 36% after the thermophilic phase of composting in each of the six prepared composts (made of pig and chicken manure, municipal solid waste, green waste, straw and fruits and vegetables waste). This decrease was related to the presence of available phosphorus in the treated waste (water soluble P, Olsen P, citric acid P); at the same time, an increase in the content of moderately available and inaccessible variant of this element was observed (from 48% to 59%). Low P content in vegan and traditional compost probably related to its transformation into a more resistant and less soluble fraction, as (Eneji et al., 2003) confirmed in the analysis, which leads to the conclusion that longer maturing compost, compared to fresh material, may limit the spread of P impurities after its application.

Vegan compost was characterized by a higher content of total suspended solids, with more organic solids (1:6 ratio of mineral to organic suspended solids), which was also visible in the case of traditional compost (ratio 1:2, Table 3). The maximum value recorded for the material based on plant waste (35.00 mg·dm^{-3}) did not exceed the values indicated in the literature (approx. 3x and 9x higher results obtained by Gupta & Doherty, 1990 for poultry litter compost). Contrary to the total suspended solids, the traditional compost was characterized by a higher total dry residue (490.00 compared to 450.00 mg·dm^{-3} for vegan compost) and total dissolved solids (460.00 and 415.00 mg·dm^{-3}, respectively). However, a similar trend was noted for both groups, where vegan compost is characterized by a higher proportion of mineral, and the traditional material – organic compounds.

Among the analyzed sulphates, chlorides, sodium, magnesium and potassium, vegan compost was characterized by a higher content of sulphate and potassium (Table 3). This may be an important aspect taking into account its fertilizing nature and the supply of these nutrients to soil poor in these compounds. Sulphates are important biogenic elements in the primary metabolism of plants; they take part in many basic processes in their cells, including photosynthesis and the metabolism of carbon and nitrogen (Droux, 2004). Similarly, K plays many roles inside the plant (including cell turgor building and cell membrane potential control) and is present in a number of its activities, being responsible, among others, for the regulation of stomatal aperture or leaf movements (Nieves-Cordones et al., 2016). Therefore, it is worth noting that despite the vegan nature of the compost, the content of sulphate and potassium did not decrease, contrary to the experience of (Storino et al., 2016) who attributed an increase in these ions to the presence of meat in the composted waste. On the other hand, in the case of Na and Cl there was agreement with the authors' observations; for these elementsthe greatest difference between the samples was noted (values of about 3.9x and 1.9x higher for traditional material). It is related to the substrates of the traditional compost the meat, poultry, and eggs that build it, which are considered to be one of the three main groups of sodium-contributing food (Engstrom et al., 1997). Much of this is due to the widespread use of sodium chloride in meat processing to improve its taste, texture and shelf life (Ruusunen & Puolanne, 2005). In addition, animal-based material had a higher Mg content than vegan compost, which in turn can be explained by the lack of eggshells in the latter. Magnesium, right after Ca and carbonate, are their main inorganic component (Cusack et al., 2003), and they enrich the final product of the composting process.

3.4 Phytotoxicity

Phytotoxicity is considered to be one of the most important elements in assessing compost's quality and usefulness for the potential use of it as a plant support agent in agriculture and horticulture (Barral & Paradelo, 2011). Biological tests based on the use of plants with rapid germination and growth, such as *Lepidium sativum L.*, are used to assess the overall impact of compost on the plant, resulting from a number of possible factors such as heavy metals, salt, contaminants and other phytotoxic factors (Emino & Warman, 2004).

In comparison to the control sample, which was the reference soil soaked with distilled water, traditional and vegan compost stimulated the growth of *Lepidium sativum* roots, which reached the length longer by an average of 6.36 and 5.08 mm (Table A.2, Supplementary content). When analyzing the effect of water extracts from composts on plant germination, it was noted that in the case of vegan compost all the seeds used have grown up; a lower and thus equal result was obtained for the traditional compost and the control sample (93.33%). The difference between plant- and animal-based material may be due to their different conductivity; the ions present in the compost may influence the regulation of the osmotic potential and the redox potential, thus influencing seed germination (Ibrahim, 2016). According to (Zhu et al., 2016) the high concentration of salt ions has an inhibitory effect on this process, which may happen with traditional compost with a higher EC value. The lack of phytotoxic effects of compost from plant waste is also consistent with the observations of (Gavilanes-Terán et al., 2016). Inhibition of the seed germination can also be a a result of nitrogen imbalance, when it is not in equilibrium (Song et al., 2021). A significant difference in nitric nitrogen levels between the vegan and traditional compost samples were noted here (21.93 and 34.69 mg $N_{NO3}\cdot dm^{-3}$, respectively, Table A.2); at the same time other nitrogen forms were at similar level, which could contribute to the problem with germination.

The trend towards a 100% germination efficiency of plants from the use of compost has already been reported in the literature (Ait Baddi et al., 2004; Jouraiphy et al., 2008; Yangui et al., 2009). As in the case of vegan compost, the researchers observed the highest level of germination in the final product, thus recording the lowest phytotoxicity at the end of the process (He et al., 2009), including the *Lepidium sativum* used in this study (Selim et al., 2011). Researchers associated this effect with the compost cooling phase (2nd and 3rd month of composting), during which not only the number of phytotoxic lipids is reduced, but also the amount of stable organic matter and humic substances increases (El Fels et al., 2014). The humic acid fraction is indicated as the one that incorporate and immobilize phytotoxic substances such as heavy metals and pesticides through sorption and complexation (Smith, 2009; Zucconi et al., 1985).

4. CONCLUSIONS

Due to its pro-environmental character, composting has become a technology perceived as one of the basic tools of the circular economy, where the amount of directed waste has recently increased (Ros et al., 2006). Along with the growing trend of using a vegan diet observed in more and more countries it can be expected that the popularity of this method of kitchen and food waste processing will not decrease, and will also develop towards home composting. However, to ensure the environment friendly nature of this process, it is important to control the quality of the final product in order to provide valuable fertilizer material that can be used for home-garden purposes, and to introduce a household circular economy.

Plant-based kitchen waste without the addition of animal-origin product has been proven to be a valuable substrate to produce vegan compost during home and backyard composting. Studies have shown that vegan compost meets the criteria of an organic fertilizer and does not contain increased concentrations of heavy metals. Due to the lack of phytotoxic effects and to the stimulation of plants' growth, it can be successfully and safely used for their cultivation. Compared to the traditional compost, it is also characterized by a higher content of phosphorus, which is crucial for plant development, as well as by lower leachability of nitrates. Respiratory activity of this material after 12 weeks of the process indicates its good stability. In addition, it does not tend to rot anaerobically, which eliminates any problems associated with odors. Moreover, the process does not require a technological system or technologically advanced composters. Considering the content of cadmium and nickel which verged on the limit values, it is recommended that the share of vegetable waste from the cruciferous and celery families shoud not be dominant and, at the same time, it is suggested to use the substrates that are not too fragmented.

This preliminary research proved that vegan households, restaurants, and cafes are not disqualified from implementing a circular economy by using kitchen waste as a secondary material. However, it is worth noting that due to the possible increase in the amount of vegan waste in the coming years, this analysis should be extended to complete monitoring and controling the potential environmental impact of the vegan composts used, not only in terms of their impact on the crops grown, but also on such elements of the environment as soil and groundwater.

ACKNOWLEDGEMENTS

The presented article results were obtained as part of the activity of the leading research team – Waste and Biomass Valorization Group (WBVG).

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SUPPLEMENTARY CONTENT

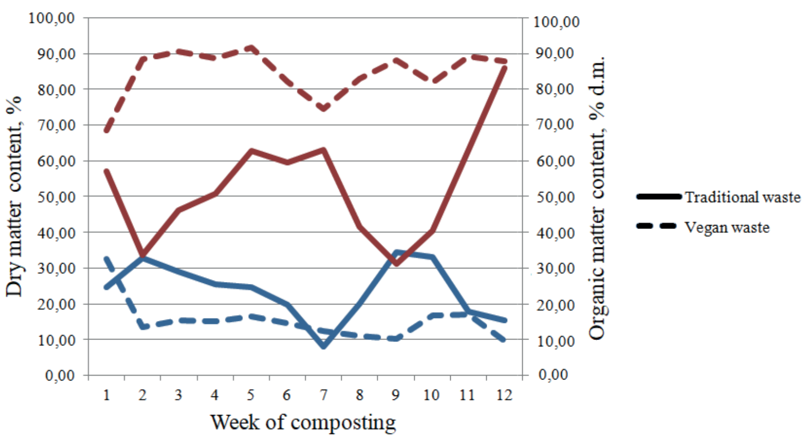

FIGURE A.1: Properties of traditional and vegan waste added to backyard composting; blue colour – dry matter content, red – organic matter content, % d.m. (dry matter).

TABLE A.1: Determination methods of water extracts physicochemical composition.

Indicator	Determination method
pH	PN-EN ISO 9963-1:2001 (Polish Committee for Standardization, 2001a)
Conductivity, μS·cm^{-1}	PN-EN 27888:1999P (Polish Committee for Standardization, 1999a)
Turbidity, Nephelometric Turbidity Units (NTU)	PN-EN ISO 7027-1:2016-09 (Polish Committee for Standardization, 2016)
Total nitrogen, mg N·dm^{-3}	The sum of all forms of nitrogen
Kjeldahl nitrogen, mgN·dm^{-3}	PN-EN 25663:2001 (Polish Committee for Standardization, 2001b)
Organic nitrogen, mg N_{org}·dm^{-3}	Indirectly (difference between Kjeldahl and ammonium nitrogen)
Ammoniacal nitrogen, mg N_{NH4}·dm^{-3}	PN-C04576-4:1994 (Polish Committee for Standardization, 1994)
Nitric nitrogen, mg N_{NO3}·dm^{-3}	PN-C-04576-08:1982 (Polish Committee for Standardization, 1982)
Nitrite nitrogen, mg N_{NO2}·dm^{-3}	PN-EN 26777:1999 (Polish Committee for Standardization, 1999b)
Phosphates, mg P·dm^{-3}	ISO 6878/1:2006 (International Organization for Standardization, 1986)
Total phosphorus, mg P·dm^{-3}	PN-EN 1189-2000 (Polish Committee for Standardization, 2000)
Dissolved oxygen, mg O_2·dm^{-3}	PN-EN ISO 5814:2013-04E (Polish Committee for Standardization, 2013a)
BOD_5, mg O_2·dm^{-3}	PN-EN 1899-1:2002 (Polish Committee for Standardization, 2002, p. 2002)
COD_{Cr}, mg O_2·dm^{-3}	PN ISO 15705:2005 (Polish Committee for Standardization, 2005)
Total dry residue, mg·dm^{-3}	PN-EN 12880:2004 (Polish Committee for Standardization, 2004a)
Dry mineral residue, mg·dm^{-3}	Weight loss after ignition at 550°C
Dry organic residue, mg·dm^{-3}	Indirectly, difference between dry total residue and dry organic residue
General dissolved substances, mg·dm^{-3}	By weight, after evaporation of the filtered sample
Dissolved mineral substances, mg·dm^{-3}	By weight, after roasting at 600°C
Dissolved organic substances, mg·dm^{-3}	Indirectly, difference between general solutes and organic solutes
General suspensions, mg·dm^{-3}	PN-EN 872:2007 (Polish Committee for Standardization, 2007)
Mineral suspensions, mg·dm^{-3}	Indirectly, difference between total suspensions and organic suspensions
Organic suspensions mg·dm^{-3}	By weight, after roasting at 600°C
Sulphates, mg SO_4·dm^{-3}	PN-ISO 9280:2002 (Polish Committee for Standardization, 2013b)
Chlorides, mg Cl·dm^{-3}	PN-ISO 9297:1994 (Polish Committee for Standardization, 2004b)
Sodium, mg Na·dm^{-3}	Atomic emission spectrometry (AAS, according to standards provided by Spectro-Lab Ltd.)
Potassium, mg K·dm^{-3}	
Magnesium, mg Mg·dm^{-3}	
Nickel (Ni), mg·kg d.m.$^{-1}$ (dry matter)	
Cadmium (Cd), mg·kg d.m.$^{-1}$	
Chromium (Cr), mg·kg d.m.$^{-1}$	
Lead (Pb), mg·kg d.m.$^{-1}$	

TABLE A.2: Phytotoxicity of composts.

	Vegan compost	Traditional compost	Reference soil (control sample)
Seed germination, %	100.00	93.33	93.33
Root elongation inhibition, %	-6.19	-7.75	–
Average root length, mm	87.13 ± 5.87	88.41 ± 7.29	82.05 ± 4.45