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ORIGINAL PAPER

Qualitative investigation of sewage sludge composting: effect of aerobic/anaerobic pretreatments

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Abstract

Treatment and recycling of organic waste play important roles in an integrated waste management system by producing a stabilized material that can be utilized as a source of nutrients and as a soil conditioner. In this study, the viability of composting for the recycling of sewage sludge and also the possible effects of pretreatment under various conditions on the quality of the end-product were examined. Waste sewage sludge was obtained from a wastewater treatment plant in Hamedan, Iran, and was subjected to aerobic and anaerobic digestions. After analyzing the physicochemical properties of the digest, both treated sludges were composted. A third reactor was also set as control by direct composting of sewage sludge without pretreatment. The composting process was controlled by the measurement of the physicochemical properties of the substrate during and at the end of the process. The results of the analyses showed a substantial decrease in the C/N ratio, pH, volatile solids (VSS), total organic carbon, as well as pathogenic populations; however, a significant increase was observed in the ash and nitrogen contents in the compost obtained after anaerobic digestion. Accordingly, it was decided that the compost obtained, especially after anaerobic digestion, showed adequate degrees of maturity and stability and reflected characteristics, which based on national and international standards made it suitable for agricultural use.

Keywords Composting · Anaerobic digestion · Aerobic digestion · Sewage sludge · Organic fertilizer

Introduction

Growing environmental awareness has led to an increasing number of wastewater treatment plants worldwide (Iranzo et al. 2004). However, management, treatment, and disposal of huge quantities of sewage sludge produced as a by-product of wastewater treatment are major concerns in the modern society. Traditionally, the sludge has been handled through open dumping, land filling, and incineration; however, as the waste sludge includes a large amount of biodegradable organic matter, its direct discharge will cause a heavy pollution in the environment (Wei et al. 2003; Wani and Mamta 2013). On the other hand, it is well-established that the sludge contains valuable organic matter and plant nutrients which are essential for soil fertility (Molina et al. 2013).

Therefore, stabilization of sewage sludge through elimination or reduction of hazards and by decreasing the microbial activities or the concentration of labile components is considered a vital strategy for disposing and/or recycling of waste materials and for providing a safe and healthy environment.

Aerobic and anaerobic digestions are two mainstream technologies for the stabilization of sewage sludge. Aerobic digestion decomposes the organic matter using oxygen. In this process, aerobic microbes use oxygen to feed upon organic materials mainly nitrogen, phosphorus, and some carbon containing substances which are present in the raw material of the compost leading to the break down and decomposition of the organic matter (Cadena et al. 2009). The short time of sludge retention, high decomposition rate, and efficient destruction of pathogens are the main advantages of aerobic digestion of sludge treatment (Zhang et al. 2016), while in an anaerobic process, which is one of the most cost-effective technologies in terms of the high resource and energy recovery from sewage sludge, biodegradation of the organic matter occurs without the participation of oxygen by employing anaerobic

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microorganisms (Cayuela et al. 2012). Nevertheless, studies have indicated that the end-product of digestion may be not fully stabilized and may have high moisture content and a large quantity of potential phytotoxic compounds or may release noxious odors. These characteristics restrict the recycling of the residual sludge and its direct application in agricultural soils (Teglia et al. 2011; Wang et al. 2017). The residual sludge can be further treated through composting to mineralize the remaining degradable organic matters and to remove the potential pathogens that have survived the digestion process (Nakasaki et al. 2009). The composting process includes the aerobic decomposition, mineralization, and humification of organic waste biomass using aerobic microorganisms which convert the organic matters into carbon dioxide leaving relatively stable and odor-free products (Demirbas et al. 2017). The humification process during composting would improve the quality of the final product so that it could be used on farmlands as a high-quality hygienic fertilizer. Generally, composting is considered as an efficient, cost-effective, and sustainable methodology that has been widely used for management and reuse of various organic wastes including livestock manure, municipal solid waste, and sewage sludge (Bernal et al. 2009; Onwosi et al. 2017; Poluszyńska et al. 2017; Cerda et al. 2018; Li et al. 2018).

Despite various studies regarding the treatment of sewage sludge through aerobic digestion, anaerobic digestion, and composting (Hernández et al. 2006; Uçaroğlu and Alkan 2016) worldwide, few studies have been carried out in Iran since more than 80% of the produced sewage sludge is landfilled (Feizi et al. 2019). Likewise, in the city of Hamedan, Iran, the waste sewage sludge produced in wastewater treatment plant is kept in open ponds for spontaneous dewatering through evaporation without any chemical, physical, and biological treatments. The dewatered sludge is finally released and landfilled around the city or is sometimes used as organic fertilizer without any environmental considerations. Therefore, with the aim of examining the potentials of the waste sewage sludge for recycling and its utilization for agricultural use, the present study chose composting chosen as a sustainable and affordable waste management technique. Furthermore, the impact of pretreatment via aerobic and anaerobic digestion on the characteristics of the final product was investigated. Finally, the obtained results were compared against national and international standards to confirm their suitability for agricultural applications.

Material and methods

Study area

The experiments were performed at the wastewater treatment plant in Hamedan, Iran, in the time interval of June to December 2018. Hamadan wastewater treatment plant is located 10 km away from the end of the wastewater network in a land with an area of about 100 ha.

The plant is designed in two sludge and liquid sections with 4 modules, two of which have a flow rate of 640 L/S to serve 250,000 people and the other two have a flow rate of 1280 L/S to serve a population of 500,000 people. The input wastewater is a combination of domestic, industrial, and hospital waste and is currently treated based on the step-feed method producing a daily amount of about 500 m^3 excess sludge. Fig. 1 shows the study area.

Experimental design

To determine the best condition for the composting of the sewage sludge and also to investigate the effect of pretreatment on the quality of the final products, three treatment processes were designed. One for composting the sewage sludge after aerobic digestion (treatment 1), another for composting after anaerobic digestion (treatment 2), and a third one, which was considered as the control treatment, involved composting the sludge without digestion.

For anaerobic digestion, a pilot-scale stainless-steel rotary drum with a capacity of 1000 L was designed and fabricated based on the specifications found in the related literature (Tchobanoglous et al. 2013). The drum was equipped with an automatic rotator for mixing and homogenizing the drum contents. The fresh sewage sludge was introduced through a valve on the top and the excess water was discharged via an output valve at the bottom. Another valve was embedded on the top of the reactor to remove the excess gas. A temperature sensor was immobilized on the center axis of the bioreactor. To start with, the drum was filled with water to ensure reactor sealing. Then, the reactor was filled with waste sewage sludge up to three-quarters of its capacity and the headspace was aerated by nitrogen gas for 5 min to remove the oxygen (O_2). The oxygen content was continuously controlled by the measurement of oxidation-reduction potential (ORP). The ORP was kept in a standard range of (−330)–(−300). By considering the low reaction rate as well as high heat generation, the whole process was carried out in 60 days. The generation of methane as a result of organic matter degradation was considered as an index for the successful completion of digestion. Similarly, an aerobic digestion reactor was designed and fabricated using an open stainless-steel rotary drum with 1000 L capacity (Tchobanoglous et al. 2013). The reactor had inlet and outlet valves for introducing fresh sludge and removing excess water and a temperature sensor immobilized on its central axis. The operation was carried out under the auto-control static forced-aeration process. To provide ventilation in the reactor, a stainless-steel wire plate was installed under the vessel. The aeration rate

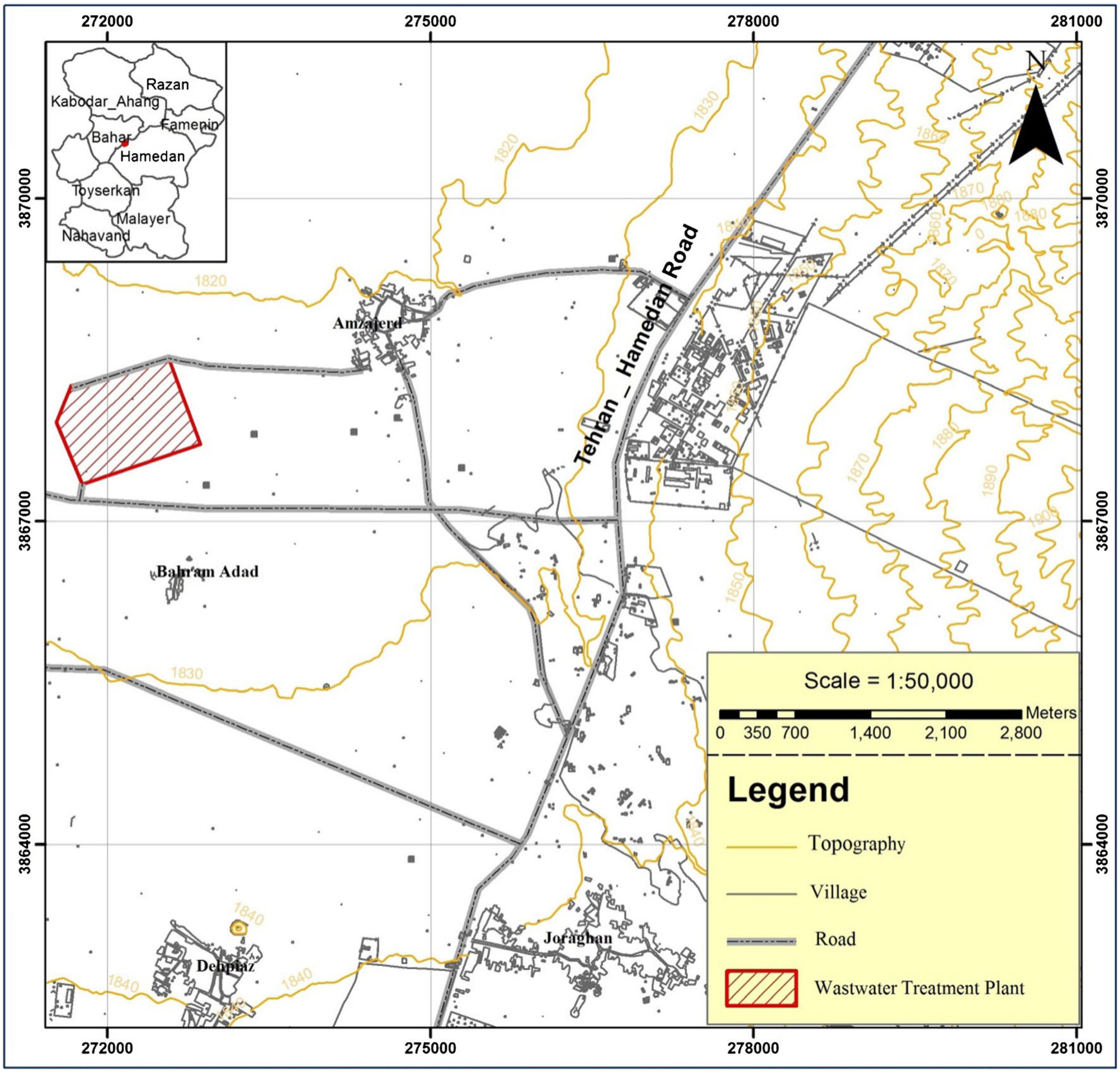

Fig. 1 Map of the study area

was automatically adjusted in proportion to the rate of oxygen consumption and temperature. The reactor was checked for leakage by filling it with water. Then, it was filled with sewage sludge at the three-quarters of its capacity. Both the aerobic and anaerobic processes were carried out based on one stage continuous complete mixed method to achieve a desirable amount of digested sludge. Waste sewage sludge was added continuously to the reactors every day. The characteristics of the sewage sludge were evaluated before and after each digestion process, the results of which are summarized in Table 1.

The composting process was carried out in a roofed place with a cement floor with an appropriate slope. For this purpose, three pilot-scale culture beds were fabricated by windrow method with the length, width, and height of 3 m × 1.5 m × 1 m. The floor in each reactor was covered by appropriate amounts of straw and rice bran as bedding substrate. Several hollow polyethylene pipes were embedded under the substrates to provide appropriate aeration. Equal amounts of aerobic digest, anaerobic digest, and nondigested sewage sludge were transferred to each container. Considering the high moisture content, the sludge was initially mixed with soft sawdust and rice straw as bulking materials at a math ratio of 1:3 (material:sludge) to balance the moisture and nutrient content and also to provide desirable porosity (Karanja et al. 2019). The characteristics of the digested and nondigested sewage sludges after addition of bulking materials are summarized in Table 1. The reactors were covered by a plastic mesh blanket to avoid the freezing of the sludge due to the cold season. To ensure adequate aeration and mixing, the prepared piles were manually stirred 3–4 times a week to prevent anaerobic decomposition and reduce annoying odors. The process was carried out during 15 weeks at ambient temperature and no new sludge was introduced into the reactors throughout the experiments.

Table 1 Main physicochemical characteristics of the sewage sludge at the initial stage, after aerobic digestion, anaerobic digestion, and after addition of bulking materials (BK)

Parameter	pH	Moisture (%)	Ash (%)	DS (%)	C (%)	N (%)	P (%)	C/N (%)	ORP	EC (ds/m)	Total Col. MPN/100 ml	*E. coli* MPN/100 ml
Waste sludge	7.51	87.8	74.8	14	79.3	2.4	1.1	33.03	−300	0.9	> 1100	> 1100
Aerobic digest	7.35	84.6	64	12.9	75.5	2.3	1.0	32.82	−295	1.59	> 1100	> 1100
Anaerobic digest	6.3	83.2	76	12.5	70	2.2	0.9	31.81	−290	1.4	> 1100	> 1100
Waste sludge + BK	7.6	76	75.1	14	78	2.39	0.92	32	−298	1.65	> 1100	> 1100
Aerobic digest +BK	7.5	75	65	13.6	76	2.9	1	26.2	−298	1.57	> 1100	> 1100
Anaerobic digest + BK	6.5	65	87.7	13	71	2.8	1.1	25.3	−292	1.45	> 1100	> 1100

Physical-chemical analysis

Composting process was controlled by monitoring the main physicochemical characteristics including temperature on a daily basis, dry solids (DS) at the beginning of the experiment, heavy metals and pathogen content at the beginning as well as at the end of the process, and other parameters such as moisture content, oxidation-reduction potential (ORP), volatile solids (VS), ash, pH, electrical conductivity (EC), total phosphorous (P), total carbon (C), total nitrogen (N), and C/N ratio on a weekly basis. All analyses were performed in accordance with the standard methods recommended by the American Public Health Association (APHA) and United States Environmental Protection Agency (EPA). Sampling, sample storage, and transportation to the laboratory were all carried out according to the EPA standard method 365.4.

Dry solids (DS) content was measured in the fresh sludge based on standard method 2540 B. Oxidation-reduction potential (ORP) was determined based on the APHA 2580 standard method or by utilizing a portable probe. The temperature was monitored three times a day with a mercury thermometer. For this purpose, the temperature was measured at five different sites and the average value was recorded. Moisture content was determined based on the weight loss standard method 2540 G by drying at 105 °C for about 24 h. A 1:10 solution of fresh sample water (w/v) was prepared and used for EC and pH measurements. pH was measured based on national standard method 6831, using a Metrohm pH meter, model 820. Volatile solids were determined according to standard method 2540 E via combustion of the dried sample at 550 °C for 60 min and measurement of the remaining ash in the muffle furnace. The ash content was measured based on EPA-821-R-01-015, No. 1684 method by drying the sludge at 105 °C, followed by calcination at 550 °C for 1 h and at 750 °C for 2 h. Total carbon (C) content was calculated through the following formula:

$$C = 100 - \text{ash}\ (\%)/1.8$$ (USEPA 1983, 2007).

Total nitrogen (N) content was measured based on the modified Kjeldhal method (Standard Methods TCW1:2003-E) by digestion in salicylic acid-thiosulfate medium, followed by steam distillation and titrimetric analysis. The C/N ratio was determined by dividing the amounts of the total carbon and nitrogen contents. Heavy metal contents were also measured based on TCW1:2003-E standard method by atomic absorption spectrometer (PG Instrument, T60) after appropriate extraction. Total sodium (Na), phosphorous (P), and calcium (Ca) concentrations were computed according to 3500-Na B (flame emission photometric method), EPA standard method 365.4, and 3500-Ca B (EDTA titrimetric analysis), respectively. Magnesium (Mg) concentration was measured through atomic absorption spectrometry. Total phosphorous content was measured based on the EPA standard method 365.4. Fecal and total coliforms were determined according to the MPN method (most probable number) based on SM 9221 C and SM 9222 B, respectively.

Statistical analysis

Data were analyzed using SPSS for Windows, version 21.0 (SPSS, Chicago, USA) and diagrams were plotted using Excel software (Microsoft, Inc., Redmond, WA, USA). To check the statistical significance of the findings, the *t*-test was run at a significance level of $P > 0.05$. Pearson correlation coefficient (R^2) at a 95% level of confidence was used to investigate the linear correlation between two parameters.

Results and discussion

An overview of the main physicochemical characteristics of waste sewage sludge generated from the wastewater (Table 1) revealed that it was not suitable for direct application as fertilizer. Accordingly, composting as the most well-established method for the production of organic fertilizers was considered. However, the efficiency and success of composting are highly dependent on the quality of the substrate. To determine the best condition for composting and to analyze the effect of pretreatment on the quality of the final products, waste sewage sludge was initially subjected to aerobic and anaerobic digestions. Aerobic digestion is a bacterial process in which the breakdown of organic matter occurs via the presence of oxygen. Under aerobic conditions which resemble the continuation of the activated sludge process, the organic matter is rapidly consumed by bacteria and is converted to carbon dioxide. Once the organic matter is all consumed, the bacteria die and are eventually used as food by other bacteria in a stage known as endogenous respiration leading to significant decrease in the participants (Demirbas et al. 2017). The optimum amount of oxygen as well as biological oxygen demand (BOD) were determined to be 2 kg per each kg of volatile solids and 1.6–1.9 kg O_2 per kg of the decomposed sludge, respectively. On the other hand, anaerobic digestion is a stepwise decomposition of complex organic materials via a multistep process by the association of microorganisms under anoxic conditions. The process typically involves hydrolysis, acidogenesis, acetogenesis, and methanogenesis steps each performed by groups of microorganisms that eventually produce a biogas mixture mainly containing carbon dioxide and methane as well as a microbial biomass. The microorganisms driving anaerobic digestion process are mainly divided into two groups of acidogens or acid producers and methanogens or methane producers that differ physiologically and have different growth rates and exhibit different sensitivities to operational conditions (Fagbohungbe et al. 2017). Table 2 summarizes the main effective parameters and their corresponding optimum values required by microorganisms in the main stages of anaerobic digestion which were tightly controlled in this experiment. Comparison of the main physicochemical characteristics of the digested products with the raw sewage sludge (Table 1) demonstrated the sludge quality improvement due to a decrease in dry solids, moisture, total carbon, and ash content as well as pathogenic population. Considering the extreme sensitivity of anaerobic digestion to the presence of oxygen, the significant decrease in ORP at the end of the anaerobic digestion indicated that the condition for microorganisms' activity during digestion was suitable.

The changes in the physicochemical properties of the sludge during composting in all treatments are represented in Tables S1, S2, and S3 while the properties of the final products are given in Table 3. Composting compromised the biological degradation of sewage sludge under controlled, aerobic conditions. The traditional composting process involves an initial stage implemented at a moderate temperature of 10–40 °C. During this stage, the labile organic matter is rapidly consumed by mesophilic microorganisms. The next stage is when the temperature rises to 60 °C due to the activity of thermophilic microorganisms leading to the consumption and break down of complex carbohydrates, proteins, and lipids. By cooling down the substrate at the final stage of curing, mesophilic organisms would be able to break down and recolonize the remaining persistent organic matter.

Temperature variation provides the first index to evaluate the degree of composting success. In this experiment, the temperature was found to increase in all the treatments (Fig. 2), indicating the sufficiency of composting substrate and biodegradation of the organic matter in each compost mixture. The sufficient organic matter for microbial growth would enhance the biological activities and thereby the release of CO_2 and heat. It is suggested that such a rise in temperature may significantly enhance the sanitization of the compost in terms of pathogens. The average temperature reached 64 °C after the first week in treatment 2 and after the third week in treatments 1 and 3 implying the higher activity of microorganisms in aerobic digestion.

pH directly affects the microbial population by limiting the availability of nutrients to microorganisms. pH in the range of 6.0 to 7.5 has been considered as optimal for appropriate microbial growth in the composting substrate (Mehta and Sirari 2018). As the pH diagram in Fig. 2 shows, the increase of pH during the thermophilic phase was followed by a decrease in its rate in such a way that the final pH values of 6.0, 7.4, and 7.1 obtained in the control, treatment 1, and treatment 2 respectively were all in the optimal range. The same trend of initial increase followed by decrease towards neutral values

Table 2 Effective parameters on the anaerobic digestion and corresponding optimum values

Parameter	Stage	
	Hydrolysis/acidogenesis	Methanogenesis
Temperature (°C)	25–35	Mesophyll: 30–40 Thermophile: 50–60
pH	5.2–6.3	6.7–7.5
C/N ratio (%)	10–45	20–30
ORP	(−300)–(+400)	< −250
C/N/P/S ratio (%)	500/15/5/3	600/15/5/3
Essential elements (mg/kg)	-	Ni, Co, Mo, Se
Temperature (°C)	25–35	Mesophyll: 30–40 Thermophile: 50–60

Table 3 Main physicochemical characteristics of the sewage sludge after composting in all treatments along with the values recommended by national standard

Parameter	Treatment 1	Treatment 2	Treatment 3	NST[a]
pH	7.4	7.1	6.00	6–8
EC (ds/m)	3.28	3.2	4.1	8–14
Moisture (%)	39	38	39.2	15–35
Volatile solid (%)	55.8	53	45.45	35
C/N ratio (%)	15.4	12.3	18.2	10–15
C (%)[b]	48.00 ± 48.00	50.00 ± 7.00	76.30 ± 23.42	25
N (%)[b]	1.7 ± 0.81	1.70 ± 0.95	2.40 ± 0.61	1.25–1.66
P (%)[b]	2.35 ± 0.34	1.80 ± 0.62	1.10 ± 0.15	1–3.8
Na (%)[b]	0.06 ± 0.02	0.60 ± 0.30	0.60 ± 0.30	1
Mg (%)[b]	3.16 ± 1.36	3.16 ± 1.70	3.16 ± 1.70	4–8
Ca (%)[b]	2.65 ± 0.85	2.60 ± 1.44	2.40 ± 0.88	2–6

[a] National Standard No.10716

[b] Mean value ± standard deviations achieved in three replicated measurements

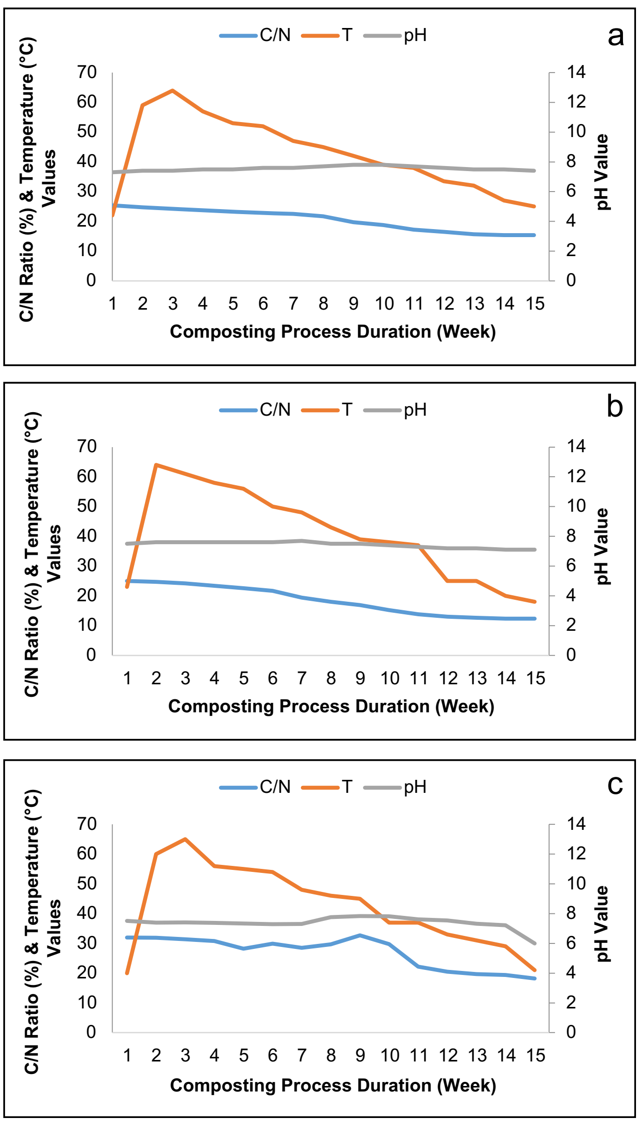

Fig. 2 Temporal profile of pH, temperature (T), and C/N ratio in treatment 1 (**a**), treatment 2 (**b**), and treatment 3 (**c**)

has also been reported in other studies during composting of sewage sludge (Li et al. 2001; Yañez et al. 2009). The mineralization of N and P compounds and the production of CO_2 and organic acids due to microbial metabolism have been considered as the possible reasons for the decline of pH (Suthar et al. 2012). Meanwhile, the electrical conductivity (EC) increased in all treatments. The increase in EC might have been associated with the release of soluble salts and inorganic ions such as nitrate, phosphate, and ammonium via decompaction of organic compounds. However, higher EC in treatment 2 demonstrated the higher rate of organic matter mineralization resulting in converting insoluble matters into soluble ones (Tang et al. 2011; He et al. 2016). The increase in EC of sewage sludge after composting was also reported by Li et al. (2001).

The moisture content is a critical variable since it provides a medium for the transportation of essential dissolved nutrients to microorganisms. Moisture content in the range of 40–60% has been determined as an optimum value for composting (Gea et al. 2007; Nakasaki et al. 2009). Moisture contents lower than 40% may limit the rate of composting while the higher contents may lead to unstable composting products. Considering the high moisture content of the initial sludge (87.8%), fresh sawdust and rice straw were added to balance it. Monitoring the moisture content during the composting process (Tables S1, S2, and S3) showed that the moisture content decreased during composting in all treatments mainly due to temperature elevation, aeration, and matrix turning. However, the content was maintained around the optimum range in the active phase of composting in all treatments.

The carbon (C) content decreases as a result of biodegradation and decomposition of organic matter during composting. Although the total carbon content decreased in all treatments, more decrease was observed through composting of anaerobic digest (Tables 1 and 3). In contrast, the ash content increased in all treatments which again occurred due to the decomposition of the organic matter. As expected, more increase in ash content was observed in treatment 2 (Tables S1, S2, and S3). The nitrogen (N) content also decreased in treatments 1 and 2 but remained almost unchanged in the control condition. The nitrogen content usually decreases during the process of composting mostly due to ammonia volatilization. These results are similar to findings of Li et al. (2018) who reported decreases in total nitrogen and carbon contents and increases in the ash contents. Although nitrogen and carbon are the main nutrients in the compost substrate, carbon to nitrogen (C/N) ratio is considered as a limiting factor in conducting the composting process. High C/N ratio (higher than 40/1) demonstrates an excess of carbon and a limited amount of nitrogen which restricts the microorganisms' growth and decomposition of the substrate. On the other hand, a lower value of C/N ratio means an escape of nitrogen as nitrous oxide or ammonia and nonsufficient amount of N in piles. Generally, the C/N ratio is an important variable since a lower C/N ratio indicates not only a higher decomposition rate of organic matter but also a higher nitrogen production rate due to nitrification by microorganisms and also a higher ash production rate.

In our study, the initial C/N ratio of the sewage sludge was 33.03. As can be seen from Fig. 2 and Tables S1, S2, and S3, this amount decreased in all treatments and reached up to 15.4, 12.3, and 18.20, in treatments 1, 2, and 3, respectively. The lower C/N ratio in treatment 2 exhibited higher decomposition rate of the substrate. Jouraiphy et al. (2005) also reached C/N ratio of 12 during composting of the mixture of sewage sludge and green waste (Jouraiphy et al. 2005).

A decrease in the volatile solids (VS) content is considered as an indicator of compost maturity. The volatile solids content reduced to 55.8% in treatment 1, to 53% in treatment 2, and 60% in control. Therefore, more maturity of compost was achieved in composting of anaerobically digested sewage sludge in comparison with the aerobic digest.

Unlike organic matter, heavy metals cannot be degraded and their cleanup requires further treatments like immobilization, reduction, or removal of toxicity. Low doses of some heavy metals are essential for plants, but their high doses may lead to metabolic disorders and inhibition of plant growth (Sinha et al. 2005). The results of this study indicate that despite insignificant changes in the control condition, the concentration of heavy metals in the two other treatments especially in treatment 2 was significantly higher than that in the initial stages ($P > 0.05$). This observation is consistent with that of Cai et al. who reported a significant increase in heavy metal contents of sewage sludge after composting (Cai et al. 2007). Thus, it can be argued that the reduction in the feed material weight and volume due to the decomposition of organic compounds during the composting process may be a reason for the increase in heavy metal concentrations (Bakar et al. 2011).

Table 4 summarizes the data pertaining to the heavy metal contents in the waste sludge at the initial stage, pre-, and post-composting in all treatment conditions along with the maximum contaminant levels (MCLs) specified by the United States Environmental Protection Agency (EPA) and national standard (NST). It can be observed in the data presented in the table that the heavy metal contents of both treatments 1 and 2 are far lower than the specified MCLs.

Pearson correlation coefficients between the main physicochemical characteristics of compost obtained in all treatments are listed in Tables S4, S5, and S6. As indicated in Table S4, the correlations between C/N ratio, temperature and pH, temperature and C/N ratio, moisture, ash, and volatile solids content, pH and C/N ratio, moisture and ash, and temperature and pH were all positive ($P < 0.05$). However, no significant correlations were found between the C/N ratio and moisture with ash and volatile solids contents and also between pH and volatile solids content ($P > 0.05$). Based on Table S5, in anaerobic digested compost, C/N ratio with temperature, temperature with C/N ratio, pH and moisture content with ash content and volatile solids, and also pH and moisture with temperature were positively correlated ($P < 0.05$). Likewise, no positive correlation was observed between the C/N ratio, pH and moisture with ash, and volatile solid contents ($P > 0.05$). In control (Table S6), there was a positive correlation between C/N ratio and temperature, temperature and C/N ratio, moisture, ash, and volatile solids content, moisture and temperature, pH and moisture, and ash and volatile solids content ($P < 0.05$). Also, there was no significant correlation between the C/N ratio and moisture and ash and volatile solids content ($P > 0.05$). These results confirm the existence of significant interactions among parameters such as temperature, C/N ratio, pH, and volatile solids content and their important roles in the implementation of the composting process. The correlations between pH, temperature, and moisture with heavy metal content were also investigated. Based on the data presented in Table S7, in treatment 1, there was a positive correlation between temperature and pH, with the concentration of all heavy metals and also between moisture and the concentration of all metals except Ni. In treatment 2 (Table S8), a significant correlation ($P < 0.05$) was observed between pH, moisture, and temperature with the concentration of all heavy metals. In treatment 3 (Table S9), a significant correlation ($P < 0.05$) was observed between temperature and the concentration of all metals, pH and the concentration of all metals except Cd, and between moisture and the concentration of all metals except zinc. In all the tables, minus values mean a negative correlation between corresponding parameters.

The presence of coliforms in environmental waters, soil, or compost products is often considered as an index for overall sanitary quality. Table 5 summarizes the microbiological parameters including total coliforms and fecal coliforms at pre- and post-composting along with MCL EPA regarding class A and B. It can be seen that coliforms were significantly reduced

Table 4 The heavy metal contents at the initial stage, pre-, and post-composting in different treatments along with maximum contaminant levels recommended by EPA and NST

Fertilizer	Heavy metal (mg/kg)	Initial stage[a]	Pre-[a]	Post-[a]	EPA	NST[b]
Treatment 1	Cu	53	50	58.00 ±15.39	100	650
	Cd	< 0.02	Trace	0.019 ± 0.002	10	10
	Ni	< 0.035	< 0.024	0.034 ± 0.01	200	120
	Pb	17	15	19.00 ± 8.00	100	200
	Zn	75	51	77.00 ± 24.02	2000	1300
Treatment 2	Cu	53	46	38.00 ± 7.54	100	650
	Cd	< 0.02	Trace	0.001 ± 0.001	10	10
	Ni	< 0.035	< 0.024	0.026 ± 0.004	200	120
	Pb	17	13	15.00 ± 1.12	100	200
	Zn	75	48	52.00 ± 9.36	2000	1300
Treatment 3	Cu	53	53	53.00 ± 9.64	100	650
	Cd	< 0.02	< 0.02	0.012 ± 0.007	10	10
	Ni	< 0.035	< 0.035	0.035 ± 0.005	200	120
	Pb	17	17	17.00 ± 7.54	100	200
	Zn	75	75	75.00 ± 42.46	2000	1300

[a] Mean value ± standard deviations achieved in three replicated measurement

[b] National Standard No.10716

during composting especially after anaerobic digestion indicating the effectiveness of the employed process in inactivating pathogens. This may be ascribed to the high temperature and thereby unfavorable conditions during the thermophilic phase of composting (Hassen et al. 2001; Bazrafshan et al. 2016). Based on the data summarized in Table 5, both composts obtained after digestion fell into class A while the compost in the control fell into class B signifying the necessity of digestion before composting.

Conclusions

In this study, the viability of composting for the recycling of waste sewage sludge of wastewater treatment plant and the influence of pretreatment under various digestion conditions on the quality of the end-product were examined. For this purpose, the waste sewage sludge was subjected to aerobic and anaerobic digestions. The comparison of physicochemical characteristics of digested products with the initial substrate shows that digestion significantly improves the main characteristics of the sludge providing a favorable environment for the activity of microorganisms and successful composting. Further analyses of the compost prepared from digested and nondigested processes confirm the importance of pretreatment in the final products. The heavy metal and nutrient contents of the obtained products meet the national and international standards for a fertilizer. Furthermore, the rises in the temperature resulted from the metabolic heat generated during the thermophilic phase of composting is highly effective in inactivating pathogens, allowing the end-product to be safely utilized as a soil conditioner. Overall, the results of this study indicate that the combination of anaerobic digestion with composting can so effectively decompose organic matter and inactive pathogens that the final mature and stable product can reflect favorable characteristics for agricultural purposes.

Table 5 Microbiological parameters pre- and post-composting along with EPA maximum contaminant levels (MCLs)

Pathogen Treatment		Total coliform MNP/100 ml	Fecal coliform MNP/100 ml	MCL, EPA class A	MCL, EPA class B
Treatment 1	Pre-	> 1100	8E02	< 1000	< 2E06
	Post-	6.5E02	6.5E02		
Treatment 2	Pre-	> 1100	5.4E02		
	Post-	6.61E02	4.6E02		
Treatment 3	Pre-	> 1100	> 1100		
	Post-	8.6E04	7.4E04		

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12517-021-07232-x.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

References

Bakar AA, Mahmood NZ, Teixeira da Silva JA, Abdullah N, Jamaludin AA (2011) Vermicomposting of sewage sludge by *Lumbricus rubellus* using spent mushroom compost as feed material: effect on concentration of heavy metals. Biotechnol Bioproc Eng 16(5): 1036–1043

Bazrafshan E, Zarei A, Kord Mostafapour F, Poormollae N, Mahmoodi S, Zazouli MA (2016) Maturity and stability evaluation of composted municipal solid wastes. Health Scope 5(1):e33202

Bernal MP, Alburquerque JA, Moral R (2009) Composting of animal manures and chemical criteria for compost maturity assessment. A review Biores Technol 100(22):5444–5453

Cadena E, Colón J, Artola A, Sánchez A, Font X (2009) Environmental impact of two aerobic composting technologies using life cycle assessment. The Int J Life Cycle Assess 14(5):401–410

Cai Q-Y, Mo C-H, Wu Q-T, Zeng Q-Y, Katsoyiannis A (2007) Concentration and speciation of heavy metals in six different sewage sludge-composts. J Hazard Mater 147(3):1063–1072

Cayuela ML, Sánchez-Monedero MA, Roig A, Sinicco T, Mondini C (2012) Biochemical changes and GHG emissions during composting of lignocellulosic residues with different N-rich by-products. Chemosphere 88(2):196–203

Cerda A, Artola A, Font X, Barrena R, Gea T, Sánchez A (2018) Composting of food wastes: status and challenges. Biores Technol 248:57–67

Demirbas A, Coban V, Taylan O, Kabli M (2017) Aerobic digestion of sewage sludge for waste treatment. Energy Sourcet A: Recover Utiliz Environ Effect 39(10):1056–1062

Fagbohungbe MO, Herbert BMJ, Hurst L, Ibeto CN, Li H, Usmani SQ, Semple KT (2017) The challenges of anaerobic digestion and the role of biochar in optimizing anaerobic digestion. Waste Manage 61: 236–249

Feizi M, Jalali M, Renella G (2019) Assessment of nutrient and heavy metal content and speciation in sewage sludge from different locations in Iran. Nat Hazard 95(3):657–675

Gea T, Barrena R, Artola A, Sánchez A (2007) Optimal bulking agent particle size and usage for heat retention and disinfection in domestic wastewater sludge composting. Waste Manage 27(9):1108–1116

Hassen A, Belguith K, Jedidi N, Cherif A, Cherif M, Boudabous A (2001) Microbial characterization during composting of municipal solid waste. Biores Technol 80(3):217–225

He X, Zhang Y, Shen M, Zeng G, Zhou M, Li M (2016) Effect of vermicomposting on concentration and speciation of heavy metals in sewage sludge with additive materials. Biores Technol 218:867–873

Hernández T, Masciandaro G, Moreno JI, García C (2006) Changes in organic matter composition during composting of two digested sewage sludges. Waste Manage 26(12):1370–1376

Iranzo M, Cañizares JV, Roca-Perez L, Sainz-Pardo I, Mormeneo S, Boluda R (2004) Characteristics of rice straw and sewage sludge as composting materials in Valencia (Spain). Biores Technol 95(1): 107–112

Jouraiphy A, Amir S, El Gharous M, Revel J-C, Hafidi M (2005) Chemical and spectroscopic analysis of organic matter transformation during composting of sewage sludge and green plant waste. Int Biodeter Biodegr 56(2):101–108

Karanja AW, Njeru EM, Maingi JM (2019) Assessment of physicochemical changes during composting rice straw with chicken and donkey manure. Int J Recycl Organ Waste Agr *8*(1):65–72

Li G, Zhang F, Sun Y, Wong JWC, Fang M (2001) Chemical evaluation of sewage sludge composting as a mature indicator for composting process. Water Air Soil Pollut 132(3):333–345

Li Y, Luo W, Li G, Wang K, Gong X (2018) Performance of phosphogypsum and calcium magnesium phosphate fertilizer for nitrogen conservation in pig manure composting. Biores Technol 250:53–59

Mehta CM, Sirari K (2018) Comparative study of aerobic and anaerobic composting for better understanding of organic waste management: a mini review. Plant Arch 18(1):44–48

Molina MJ, Desamparados Soriano M, Ingelmo F, Llinares J (2013) Stabilisation of sewage sludge and vinasse bio-wastes by vermicomposting with rabbit manure using *Eisenia fetida*. Biores Technol 137:88–97

Nakasaki K, Hong Tran LT, Idemoto Y, Abe M, Palenzuela Rollon A (2009) Comparison of organic matter degradation and microbial community during thermophilic composting of two different types of anaerobic sludge. Biores Technol 100(2):676–682

Onwosi CO, Igbokwe VC, Odimba JN, Eke IE, Nwankwoala MO, Iroh IN, Ezeogu LI (2017) Composting technology in waste stabilization: on the methods, challenges and future prospects. J Environ Manage 190:140–157

Poluszyńska J, Jarosz-Krzemińska E, Helios-Rybicka E (2017) Studying the effects of two various methods of composting on the degradation levels of polycyclic aromatic hydrocarbons (PAHs) in sewage sludge. Water Air Soil Pollut 228(8):305

Sinha S, Pandey K, Gupta AK, Bhatt K (2005) Accumulation of metals in vegetables and crops grown in the area irrigated with river water. Bull Environ Contam Toxicol 74(1):210–218

Suthar S, Mutiyar PK, Singh S (2012) Vermicomposting of milk processing industry sludge spiked with plant wastes. Biores Technol 116: 214–219

Tang Z, Yu G, Liu D, Xu D, Shen Q (2011) Different analysis techniques for fluorescence excitation–emission matrix spectroscopy to assess compost maturity. Chemosphere 82(8):1202–1208

Tchobanoglous G, Stensel H, Tsuchihashi R, Burton F, (2013) Wastewater engineering: treatment and resource recovery, 5th edition. 2013: McGraw-Hill Education, pp 484-488.

Teglia C, Tremier A, Martel J-L (2011) Characterization of solid digestates: part 2, assessment of the quality and suitability for composting of six digested products. Waste Biomass Valor 2(2): 113–126

Uçaroğlu S, Alkan U (2016) Composting of wastewater treatment sludge with different bulking agents. J Air Waste Manage Assoc 66(3):288–295

USEPA (1983) Methods for chemical analysis of water and wastes. In: Cincinnati, Ohio, 315 p

USEPA (2007) Standards for the use or disposal of sewage sludge. Part 503. Washington DC. USEPA. (1994). Plain English guide to the EPA Part 503 biosolids rule US EPA/832/r-93/003. Washington, DC: United States Environmental Protection Agency Office of Wastewater Management

Wang T-T, Wang S-P, Zhong X-Z, Sun Z-Y, Huang Y-L, Tan L, TangY-Q KK (2017) Converting digested residue eluted from dry anaerobic digestion of distilled grain waste into value-added fertilizer by aerobic composting. J Clean Prod 166:530–536

Wani KA, Mamta RRJ (2013) Bioconversion of garden waste, kitchen waste and cow dung into value-added products using earthworm *Eisenia fetida*. Saudi J Biol Sci 20(2):149–154

Wei Y, Van Houten RT, Borger AR, Eikelboom DH, Fan Y (2003) Minimization of excess sludge production for biological wastewater treatment. Water Res 37(18):4453–4467

Yañez R, Alonso JL, Díaz MJ (2009) Influence of bulking agent on sewage sludge composting process. Biores Technol 100(23):5827–5833

Zhang Z, Zhou Y, Zhang J, Xia S, Hermanowicz SW (2016) Effects of short-time aerobic digestion on extracellular polymeric substances and sludge features of waste activated sludge. Chem Eng J 299:177–183