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ORIGINAL PAPER

Composting of sewage sludge with mole cricket: stability, maturity and sanitation aspects

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Abstract

The composting of sewage sludge is constrained by structural insufficiencies such as high water retention, reduced free air space and limited compaction. To overcome these hindrances, this study investigates application of bioconversion method to compost sewage sludge. The bioconversion method uses insect mole cricket that provides benefits such as improved aeration by 32%, enhanced organic matter transformation, stability and maturity of the end product. Bioconversion method was compared with vermicomposting and conventional aerated composting methods. Comparison of the results among the three methods showed that the end product was mature with germination index (GI) > 80%, humification index (E4/E6) < 8, dissolved organic carbon < 10 mg kg^{-1} and C/N < 15. However, the end product of the bioconversion method had the highest GI of 140, cation exchange capacity of 91.7 and the lowest C/N ratio of 14 indicating that this compost was relatively more stable than the composts produced by the other two methods. The number of faecal coliforms in mature compost samples was 210, 230 and 750 CFU g^{-1} for the bioconversion, vermicomposting and conventional composting methods, respectively. The results highlight that bioconversion method produces a non-phytotoxic and microbiologically safe compost that can be considered as a reliable alternative for composting of sewage sludge.

Keywords Wastewater sludge · Hazelnut husk · Composting · Mole cricket · Vermicompost

Introduction

Due to the increased quantities of residual sewage sludge from wastewater treatment, their safe disposal is one of the major environmental and social concerns throughout the world. Currently, there are limited disposal alternatives including soil application, landfill and incineration (Ramdani et al. 2015). Land application of biosolid is the most cost-effective disposal method because it covers both disposal and recycling objectives (Ozdemir et al. 2014). Alternatively, composting is accepted as a stabilizing and sanitizing practice to use sewage sludge as soil amendment via enriching of soil organic matter and improving physical conditions (Karak et al. 2017).

Aerobic composting of municipal sewage sludge with the addition of crop residues is a well-established technology to decompose organic matter, to eliminate odour-producing compounds, to remove faecal microorganisms and to degrade the fraction of nitrogen-immobilizing organic matter (Ozdemir et al. 2014; Frac et al. 2017; Pan et al. 2017). Therefore, composting of sewage sludge provides multiple environmental benefits such as soil enrichment with organic matter, soil organic carbon sequestration, plant nutrients and reduction of municipal waste (Sinha et al. 2010; Ozdemir et al. 2017; Karak et al. 2017).

On the other hand, composting of sewage sludge is constrained by relatively high moisture content (e.g. 80%) of dewatered sludge cake. Aeration problems, difficulties in gas exchange and temperature increase in compost pile are among the issues associated with high moisture of sewage sludge (Ozdemir et al. 2014; Tremier et al. 2005). For efficient composting, sewage sludge must be mixed with large amounts of dry bulking materials such as sawdust to absorb the high water content, and frequent mixing is

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required to assure optimum conditions for microbial biodegradation of organic matter (Pan et al. 2017; Rasapoor et al. 2016). Because of the requirements such as bulking material, extensive labour and energy cost, the conventional composting method becomes an unfeasible alternative for municipal sewage sludge management (Favarial et al. 2016).

In this context, the application of a vermicomposting process of animal and household waste is considered to be a more beneficial strategy in waste management due to the relatively low energy requirement and lower maintenance cost, and contributes as a valuable soil amendment and source of nutrients (Kizilkaya and Türkay 2014; Sinha et al. 2010). Furthermore, concerning the global rise in demand for worm casts (Ceyhan et al. 2015) and the growing concern over greenhouse gas emissions leads vermicomposting of organic residues to stand out as a sustainable resource recovery method (Kalamdhad et al. 2009; Karak et al. 2017).

Large-scale vermicomposting is rather slow process and needs relatively stable environmental precautions such as substrate composition, moisture content, temperature and pH (Kizilkaya and Türkay 2014) compared to the commercialized composting methods such as tunnel or in-vessel systems. The vermicomposting process, through initial 3-week conditioning to remove odour from decomposing waste and following 105 days for compost production, is progress at a slower rate and susceptible to high rate (e.g. > 30–40%) of sludge in compost blend, otherwise cause high rate of worm mortality in compost pile (Kizilkaya and Türkay 2014; Suthar 2010). In vermicomposting process, worm acts as mechanical blenders as they modify the biological, physical and chemical states of the organic matter and increase the interfacial surface area for microbial biodegradation of organic content (Yadav and Garg 2011). Similar to earthworms, macro-organisms particularly insect species play a vital role in natural decomposition of unstable organic matter and is drawing increasing attention nowadays in municipal waste management applications (Cai et al. 2017; Cickova et al. 2015). Overcoming the common process management failures of the vermicomposting, scavenger macro-organisms could be beneficially used to create more optimum environmental conditions and accelerate composting of sewage sludge (Lalander et al. 2016). One such macro-organism candidate is the omnivore insect mole cricket (*Gryllotalpa gryllotalpa*) which can be easily found worldwide. It is a burrowing insect and feeds on a variety of organisms while commuting, especially in decomposing organic waste materials. Although the mole cricket is known as a critical plant pest, it can serve beneficially to enhance aeration, mix sludge compost, provide gas exchange and increase microbial contact with substrates for biodegradation. The mole cricket has a 2-year life cycle, and it can be separated easily from the compost pile for re-use in new compost processes.

To the best of authors' knowledge, there are no studies that investigated the use of mole cricket for compost preparation, and for the effects of mole cricket on stability, maturity and sanitization parameters of sludge composting. For this reason, the objective of the present study is to test the hypothesis that mobility of mole cricket in sludge compost pile will alter the composting conditions via providing better aeration and accelerate compost formation and sanitization by reducing the sludge microorganism via direct ingestion and excretion antimetabolites. Accordingly, we tested our hypothesis by conducting experimental to compost sewage sludge with hazelnut husk and with mole cricket. This approach is a novel and an efficient strategy for organic waste management, and our results indicate various benefits for sustainable management of biosolids through this novel composting method.

Materials and methods

Experimental procedure

Dewatered municipal wastewater sludge cake containing 20% dry matter (DM) and a dry harvest residue of hazelnut was used for preparation of compost mixtures. Hazelnut husk was collected from a nearby farm (with latitude 41°05′90″ north and longitude 30°34′24″ east, and elevation 50 m above sea level, located in Sakarya Province, Turkey). The husk was dried and crushed to obtain a size of less than 1.0 cm in order to assure better surface contact, aeration and moisture control in sludge composting. Municipal sewage sludge was obtained from Municipal Waste Water Treatment Plant, Sakarya, Turkey. The mixing ratio of hazelnut husk as bulking agent to dewatered sludge was 1:1 (v/v), as previous studies reported this to be the optimum ratio for such mixtures (Tremier et al. 2005). The hazelnut husk and dewatered sewage sludge were thoroughly mixed and 24 L of sub-samples subsequently placed in experimental composter (30 cm width, 40 cm length and 20 cm height, total volume 24 L). The main selected physico-chemical properties of the experimental materials and initial compost mixture are presented in Table 1.

Experiments were designed to assess the effects of three different composting techniques: (1) mole cricket compost, (2) vermicompost and (3) conventional aerobic compost as control treatment. The worm and mole cricket compost mixtures were partially air-dried for 3 days to prevent any methane and hydrogen sulphide generation which could be harmful to macro-organisms. The worm species *Eisenia fetida* was collected from the previous vermicompost experiment and introduced to compost mixture at a density of 3 kg worm m^{-2} (Sinha et al. 2010). Mole crickets (*Gryllotalpa gryllotalpa*) were collected as eggs from nests in a

Table 1 Selected physico-chemical characteristics of dewatered sludge, hazelnut husk and initial compost mixture

Parameters	Sewage sludge	Hazelnut husk	Initial compost mixture
pH	6.76 ± 0.19	4.94 ± 0.18	6.58 ± 0.25
EC (dS m^{-1})	0.95 ± 0.02	2.97 ± 0.04	0.58 ± 0.08
Moisture (%)	79.80 ± 0.62	9.24 ± 0.12	11.39 ± 0.54
Organic matter (%)	65.63 ± 0.82	92.48 ± 0.20	78.07 ± 1.87
TOC (%)	35.14 ± 0.09	47.65 ± 0.24	42.19 ± 1.42
N (%)	3.24 ± 0.07	0.65 ± 0.09	1.68 ± 0.11
C/N	12 ± 0.13	62 ± 0.11	32 ± 0.21
Faecal coliforms (CFU g^{-1} DM)	1.32×10^6	–	3.02×10^4

Values are indicated by mean ± standard deviation for triplicate determinations

cow dung dump area. Laboratory-hatched young cultured crawlers were introduced to experimental compost boxes for the mole cricket experiments. Three sets of experimental composters were prepared for the insect, vermicompost and conventional compost treatments (Fig. 1) and arranged in a complete randomized design.

The composting containers were kept in shaded conditions at room temperature (25 ± 2 °C) in the laboratory conditions for better insect larvae and worm activity within compost pile. Moisture content was kept approximately at 65–70% by spraying tap water on top as necessary. The composting process lasted for 60 days to obtain mature end product. The control treatment was manually turned over daily during the initial 30 days of the experiment. This conventional system must be aerated thoroughly during early days, and then, the compost matures until the end of the experiment. The worm and insect treatments were allowed to ventilate through mixing by their organisms, i.e. worm and insect crawlers. Hence, there was no temperature rise in insect and vermicompost treatments. The samples from the treatments were collected at 0, 7, 14, 21, 28, 35, 42, 49, 56 and 60th day for the determination of stability parameters.

Physical, chemical and microbiological analysis

Free air space (FAS) of compost pile was estimated by using the following equation (Zhao et al. 2011).

$$\mathrm{FAS} = 1 - \mathrm{BD} \times \left[(1 - \mathrm{DM}/d\mathrm{w}) + (\mathrm{DM} \times \mathrm{VS}/d\mathrm{vs}) + (\mathrm{DM} \times (1 - \mathrm{VS})/d\mathrm{ash})\right] \quad (1)$$

where BD is the bulk density on a wet basis (kg m^{-3}), VS is the volatile solids, and *d*w, *d*vs and *d*ash are the densities of water, volatile fraction and inorganic fraction, respectively. Particle density was determined by the calculation of organic matter and ash content. The bulk density (BD) was determined by dividing the total mass of sample by its volume occupied, which was quantified through the moisture absorption process (Ozdemir et al. 2017).

Compost samples were air-dried and ground to estimate the following parameters: moisture content at 105 °C for 24 h and total organic matter (%) loss on ignition at

Fig. 1 View of mole cricket and worm species in the sludge compost

550 °C for 4 h (Kulcu and Yaldiz 2007). The pH and electrical conductivity (EC) were measured in a 1:10 aqueous extract (w/v) method as described by European Standards (EN13037 1999; EN13038 1999). Nitrogen content of compost samples was determined by the Kjeldahl digestion procedure. TOC (total organic carbon) was measured by using a sample of compost–water mixture at 1:10 (w/v) ratio. Similarly, DOC (dissolved organic carbon) measurements were taken on centrifuged/filtered sample of the above mixture. TOC and DOC contents were quantified by using a TOC analyser (Shimadzu, VCSH). The C/N ratios were estimated by dividing the total organic carbon (%) by the Kjeldahl nitrogen (%).

The cation exchange capacity (CEC) was determined using the $BaCl_2$ compulsive exchange method (Ozdemir et al. 2017). To describe the humification indexes (E4/E6) of the composted samples, the absorbance of compost samples at 465 nm (E4) and 665 nm (E6) was measured using a spectrophotometer (Hewlett-Packard Company, Wilmington, DE, USA) following the NaOH extraction method (Zbytniewski and Buszewski 2005). The phytotoxicity of compost samples was evaluated by germination index (GI) test and by using cress seed (*Lepidium sativum*) according to Zucconi et al. (1981). The GI index values were then computed using the formula:

$$\mathrm{GI} = \frac{\text{Number of germinated seeds in sample}}{\text{Number of germinated seeds in control}} \times \frac{\text{Mean root length in sample}}{\text{Mean root length in control}} \times 100 \quad (2)$$

Faecal coliform bacteria enumeration was performed at the end of the composting experiments, according to the US EPA Method 1681 (2005). The formulation of brilliant green bile broth was used as the growth medium. Bacteria populations are presented as colony-forming unit (CFU) per gram of compost dry weight. For Fourier transform infrared (FTIR) spectroscopy analysis, dry compost samples were finely ground and 100 mg of sample pressed into tablets with dry 1 mg KBr powder and analysed through a Shimadzu IR Prestige 21 FTIR Spectrophotometer.

Statistical analysis

The composting experiment was conducted in a completely randomized design with three replicates per treatment. The physico-chemical characteristics during the composting period and maturity parameters of end products were statistically analysed using analysis of variance (ANOVA) to check any difference between the treatment means. An alpha (α) level of 0.05 (or confidence level of 95%) was used to assess the statistical significance in all analyses.

Results and discussion

Compost physico-chemical properties

Table 2 compares physical properties of the three treatments as the mole cricket compost, the vermicompost and the conventional compost. The data in Table 2 illustrate that physico-chemical conditions of the three treatments were within the optimal range for that parameter as defined by past studies. The tested composting alternatives significantly ($p < 0.01$) affected the bulk density and FAS of sludge compost. The FAS for the insect and vermicompost significantly reduced the bulk densities of those treatments, when compared with the conventional compost treatment (Table 2). Mole cricket compost has an appreciably higher free air space than the vermicompost. This finding highlights the positive contribution of insect compost to constant aeration within the other piles. The burrowing activity was more visible in the mole cricket than in the vermicompost. In the mole cricket treatment, the tunnelling, crushing and eating behaviour, together with digestion of organic matter, created

Table 2 The main initial and final physical properties, stability, maturity and sanitization parameters of mole cricket, worm and conventional compost treatments compared to the optimum range for matured compost

Parameter	Initial compost		Final compost				Optimum range
	Insect	Worm	Conv.	Insect	Worm	Conv.	
Particle density (g cm^{-3})	1.80 ± 0.10	1.81 ± 0.07	1.78 ± 0.09	1.79 ± 0.06	1.80 ± 0.05	1.80 ± 0.06	1.4–2.0
Bulk density (g cm^{-3})	0.83 ± 0.04	0.82 ± 0.05	0.82 ± 0.05	0.69 ± 0.01	0.72 ± 0.01	0.79 ± 0.04	0.6–0.8
FAS (%)	14 ± 1.29	13 ± 1.30	14 ± 1.30	32 ± 1.51	27 ± 1.48	17 ± 1.93	> 30
E4/E6	24.14 ± 2.03	24.42 ± 1.85	24.68 ± 2.06	5.70 ± 0.42	4.75 ± 0.39	8.88 ± 1.11	< 8
CEC (meq 100 g^{-1})	28.5 ± 3.12	29.2 ± 2.26	28.0 ± 2.74	91.7 ± 1.44	86.3 ± 1.51	68.5 ± 1.82	> 60
GI (%)	42 ± 4.52	43 ± 4.47	42 ± 3.68	140 ± 2.86	97 ± 4.27	82 ± 4.94	> 80
Faecal coliforms (CFU g^{-1} DM)	90,000 ± 100	91,000 ± 100	91,000 ± 100	210 ± 50	230 ± 50	750 ± 50	< 1000 CFU/g

Values are mean ± standard deviation ($n = 3$). E4/E6 = ratio of absorbance's at 465 and 665

CEC cation exchange capacity (pH 7.0), *GI* germination index, *CFU* colony-forming unit favourable environmental conditions, which is especially crucial for enhancing microbial biodegradation reactions (Yadav and Garg 2011). Previous studies have also indicated that the improved porosity of municipal sludge compost pile accelerates the composting parameters necessary for compost microbes (Ozdemir et al. 2014; Tremier et al. 2005). Kulcu and Yaldiz (2007) suggested the maintaining of FAS values above 30% for sufficient gas exchange within compost pile. Mole cricket profoundly influenced the FAS and ensured the sufficiency rate with 32%, while the FAS values of vermicomposting and conventional compost treatment were 27 and 17%, respectively, which were below ideal ranges of FAS (> 30%) for composting (Table 2).

The pH and EC results show some difference between treatments, which may be due to the rate of mineralization and the eventual end product. The EC increased slightly during the composting for all treatments because of the mineralization of organic matter and release of different minerals salts, such as phosphate, ammonia and potassium. (Suthar 2010). However, the final compost EC values were about 2.7, 2.4 and 2.6 dS m^{-1} in insect, vermicompost and conventional compost treatments, respectively. For the application of mature compost to the land, it is suggested that the maximum tolerance limit of plants for EC is 4.0 mS cm^{-1} (Dede and Ozdemir 2015).

The total amount of nitrogen (TN) concentration was significantly increased ($p < 0.01$) during the composting process (Fig. 2a), most probably due to net loss of organic matter in terms of CO_2 irrespective of the treatment. The TN concentration increase was sharp in the beginning of experiment in all treatments; however, after initial phase the increase was gradual until the end of composting process. The final TN concentration of conventional aerobic compost treatment was not different from the initial concentration. This might be due to ammonia volatilization from composting system, which frequently observed as odour emission during composting.

The C/N ratio usually has a decreasing tendency as the composting process progresses (Sülük et al. 2017; Ekinci et al. 2018), due to primarily loss of carbon content in the form of CO_2 and CH_4. It is reported that a C/N index ratio less than 20 is considered as satisfactory for compost maturity when the starting value is between 25 and 30 (Karak et al. 2017). All the compost treatments reduced the C/N ratio to mature compost range (Fig. 2b), but the rate was significantly higher for both the insect and vermicomposts,

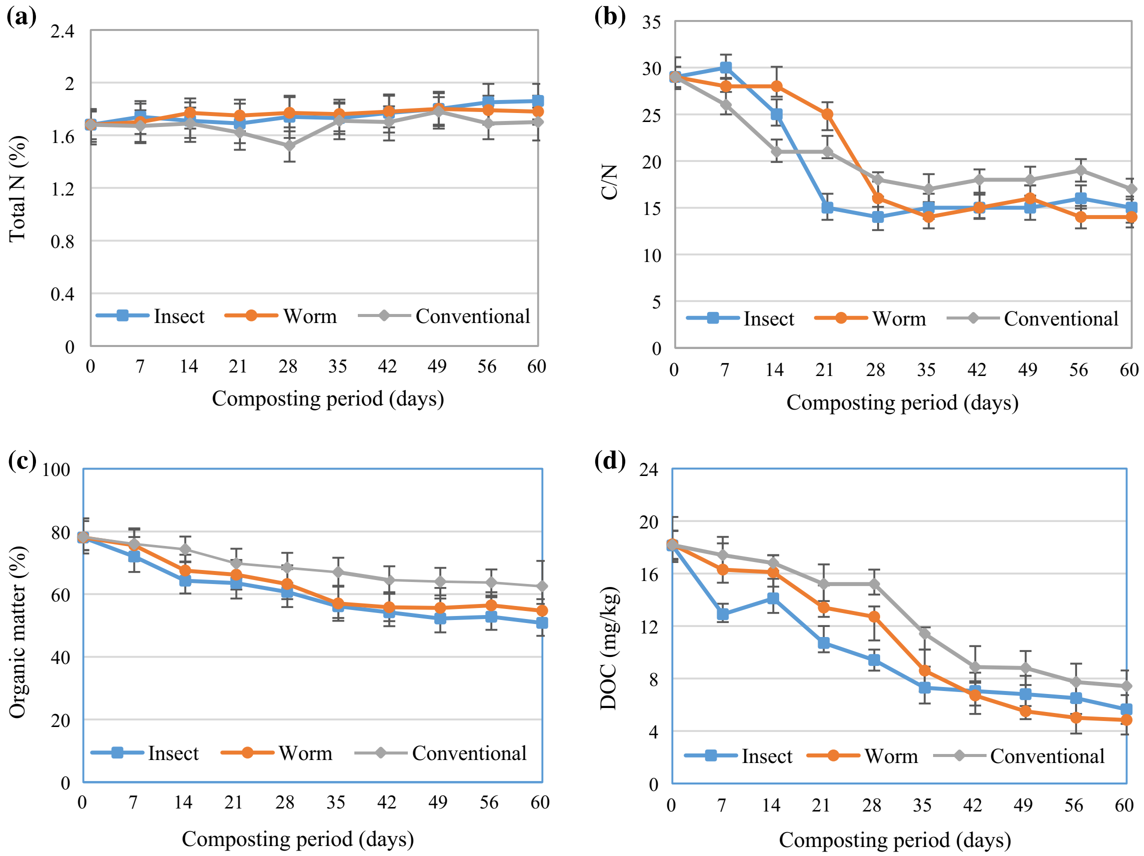

Fig. 2 Variation of **a** total nitrogen, **b** C/N ratio, **c** organic matter and **d** dissolved organic carbon (DOC) content during the composting process. Error bars represent standard deviation

most probably due to the better aerobic conditions and mixing created by the organisms. Due to the low organic carbon versus the high Kjeldahl N, the C/N ratio was significantly lower in the insect and vermicompost. The C/N ratio reduced from initial values of 28, 29 and 28 to C/N 14, 14 and 15 for the mole cricket, vermicompost and conventional compost, respectively, during the composting process.

The changes in organic matter content during composting were significant ($p < 0.001$). Figure 2c depicts the decreasing trend of organic matter content during decomposition process. The organic matter reduction during composting depends on both its convenience for microbial degradation and optimum composting conditions (Tremier et al. 2005; Rasapoor et al. 2016). The maximum reduction of organic matter content was observed in vermicompost (35%) followed by mole cricket (30%) and conventional compost (20%). This is explained by the presence of macro-organisms in the sludge compost pile, which improved the aerobic biodegradation interface, enabling high levels of OM removal to occur in the insect and vermicomposts (Cai et al. 2017). Relatively less odour production during the initial phase of composting also concurred with the optimum aerobic conditions, which decrease the organic matter content of the final compost.

DOC is the most dynamic part of the carbon fraction in the organic matter pool, and it has been noted that a decrease in DOC is an indicator of decreased soluble organic compounds that are transformed into the more complex low-soluble substances, resulting in a good composting, and stability and quality of the final compost product (Gomez-Brandon et al. 2008). A DOC content of 4–10 g kg^{-1} was suggested as the indicator of stable–mature compost (Nahum et al. 2005). Considering these values, it can be interpreted that the vermicompost and insect composts indicated intense organic matter transformation assisted by the bioconversion of both macro- and microorganisms. The DOC level of the conventional compost treatment was also within the suggested range, but had a significantly higher ($p < 0.01$) index value than those of the bioconversion methods. Overall, the DOC concentration of the initial sludge compost (16.60 g kg^{-1}) was significantly decreased in all three composting methods (Fig. 2d).

Stability, maturity and sanitization parameters

During the composting process, organic matter is continuously decomposed and transformed into stable humic substances that affect stability parameters (Ekinci et al. 2018). Hence, indicator parameters such as humification index E4/E6 and germination index were analysed to express the compost's maturity, stability and toxicity (Table 2).

E4/E6 is the ratio of absorbance at 465 nm to at 665 nm and describes the humification index between actively degrading (rich in oxygen and poor in carbon) and fully degraded organic matter (rich in carbon and poor in oxygen), where lower values of the index are indicative of strongly humified material (Zbytniewski and Buszewski 2005). The E4/E6 ratio differed between the composting treatments ($p < 0.01$). The higher values of E4/E6 ratio (index value 8.88) of conventional compost may be indicative of the presence of O-containing functional groups (Zbytniewski and Buszewski 2005). The E4/E6 values were lower in the mole cricket (5.75) and vermicompost (4.75) due to the optimum biodegradation environment created by the waste scavenger organisms. However, E4/E6 ratio of each treatment was within the reported ranges of 3.23–8.8 and is in good agreement with results reported for organic waste composts (Amir et al. 2003; Li et al. 2011; Zbytniewski and Buszewski 2005). In general, composting processes reduce the E4/E6 ratio and the reduction rate depends on both bulking material and sludge (Li et al. 2011).

The CEC is another widely used chemical parameter to identify the stability and maturity of compost. High values of CEC indicate stable and mature compost without any phytotoxic compound release (Ozdemir et al. 2014). Humification of organic matter produces humic substances, and these raise the CEC in composted organic materials (Karak et al. 2017). The CEC values varied as 91.7 ± 1.44 for insect, 86.3 ± 1.51 for worm and 68.5 ± 1.82 conventional compost samples, and there were statistically significant ($p < 0.01$) differences among them. A high CEC value is desired for the retention of nutrients in the medium and the compost-treated soil for the efficient plant uptake (Ozdemir et al. 2017). For mole cricket and vermicompost, the relatively high CEC values may be attributed to the more humified by-products specifically stimulated by insect and worm metabolites (Sinha et al. 2010).

More than 80% germination index (GI) indicates phytotoxic-free and stable compost, whereas if the value is below 50%, the compost contains a high level of phytotoxic compounds (Zucconi et al. 1981). The cress seed germination test results indicated that during the 2-month composting, all the compost treatments removed phytotoxic compounds. The GI values were 140 ± 2.86, 97 ± 4.27 and 82 ± 4.94 in mole cricket, vermicompost and conventional compost samples, respectively (Table 2). These results revealed that the treatments mole cricket and worms remove hindrances to seed germination and seedling growth, which is thought to be due to the decomposition and detoxification of phytotoxic compounds (Gomez-Brandon et al. 2008; Sinha et al. 2010; Yadav and Garg 2011). Considering the GI parameter, the mole cricket compost and vermicompost proved to be more suitable for agronomic applications compared to the conventional compost.

Sewage sludge can contain excess number of faecal microorganisms, which highlights the requirement for efficient sanitization before safe disposal (Sinha et al. 2010). A significant minimization in faecal coliform numbers was observed in all investigated compost treatments (Table 1, Table 2), reaching a 4-log reduction in 60 days. The faecal bacteria limits must be less than 1000 g^{-1} in sludge compost (Ogleni and Ozdemir 2010). Reduction of faecal coliform numbers in the insect- and worm-treated composts was significantly higher than in the conventional compost treatment. Previous studies reported that composting reduced or totally eliminated sludge pathogens, producing an environmentally safe product (Suthar 2010; Frac et al. 2017). Mole cricket activities decreased the faecal coliform number similarly to the vermicompost treatment, which might be by the same mechanisms of feeding and the potency of antimicrobial metabolite segregation (Sinha et al. 2010).

Attenuated total reflectance Fourier transform infrared (ATR FTIR) analysis

The measurements of FTIR spectroscopy were taken between the ranges of 4000–400 cm^{-1} for each sample using KBr pellets. Comparison of the FTIR spectra of the conventional, vermicompost and mole cricket compost materials presents similarity as shown in Fig. 3. All fractions exhibited absorption bands of the same functional groups of humic substances. This means that the humification processes of the samples were similar to each other. This finding agrees with those of past studies such as by Dizman et al. (2015). Generally, the peaks overlapped in the region of 3900–2000 cm^{-1}. The most significant differences in FTIR bands were found in the region of 1800–850 cm^{-1}. A similar differentiation in the intensities of the IR bands of the conventional sample and mole cricket compost sample was also observed with the vermicompost samples. However, the spectrum of these two samples is more similar than the spectra of the vermicomposting sample.

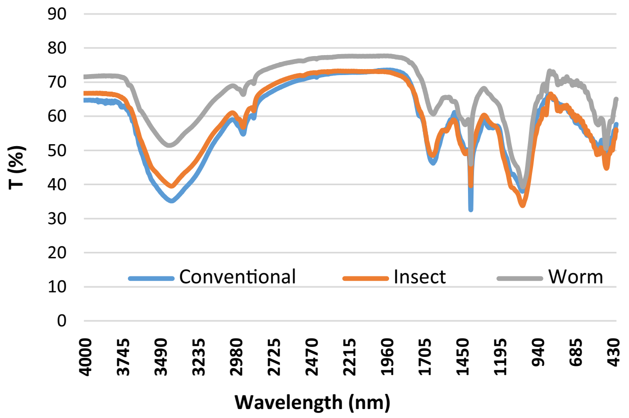

Fig. 3 Fourier transform infrared (FTIR) spectra of conventional compost, mole cricket compost and worm compost

There is a very large and broad band centred on 3440 cm^{-1} due to the hydrogen vibrations of hydroxyl groups (–OH), e.g. phenol or carboxyl groups (COOH). The two distinct peaks at 2920 and 2850 cm^{-1} were an aliphatic C–H stretching vibration. The moderate absorption band at wave number 2500 cm^{-1} indicated the phosphorus groups. The strong absorption band at wave number 1650 cm^{-1} was the C=C stretching of aromatic compounds. The wave number of 1555 cm^{-1} indicated the presence of amide II bonds (N–H bending proteins). The moderate absorption band at wave number 1435 cm^{-1} showed the C–H for CH_2 and CH_3 groups. The wave number of 1385 cm^{-1} indicated the presence of COO^- ions symmetrical stretching of fatty acids resulting from the conservation of humic and fulvic acids to their salts (Dizman et al. 2015). The moderate to weak absorption bands at 1238 and 1234 cm^{-1} showed the presence of amine for C–O stretching. These peaks described generally the aliphatic CH_2, OH, or C–O groups (Dizman et al. 2015). A broad peak at 1110 and 1040 cm^{-1} represents the C–O stretching of polysaccharide and Si–O asymmetric stretching of silicate impurities. A sharp absorption band appeared at 870 cm^{-1}, which is due to the stretching of C–O vibrations belonging to Si–O bonds.

In particular, there was a drop in the abundance of structures absorbed in the aliphatic region at around 2920 and 2850 cm^{-1} in all samples; however, this decrease was relatively high for the mole cricket compost and conventional sample. A significant increase in the height of the peak at 1650 cm^{-1} occurred in the insect and conventional samples, but a small drop was observed in the vermicompost sample. This can be explained by the use of aliphatic and peptide structures and carbohydrates such as polysaccharides, cellulose and hemicellulose by the microbes to meet their energy needs (Kalamdhad et al. 2009).

The FTIR spectra results indicated that easily biodegradable organic components such as aliphatic chains, polysaccharides, alcohols and proteins are decomposed, and therefore, the mature compost contained more aromatic structures of higher stability. A similar outcome was observed by Kalamdhad et al. (2009).

Conclusion

Stability, maturity and toxicity indicators collectively illustrated that insect mole cricket accelerated the decomposition of organic matter when compared to the conventional aerobic compost treatment. The improved physical condition such as FAS > 30 and reduced bulk density created by mole cricket within compost pile was positively correlated with composting parameters. Therefore, mole cricket compost distinctively exhibited a high level of end product stability and maturity properties such as GI 140, C/N 14, DOC 5.64 mg kg^{-1} and E4/E6 5.70, along with vermicompost 97, 14, 4.84 mg kg^{-1} and 4.75, respectively. The relatively high GI in bioconversion compost, appropriate sanitization and C/N, DOC, E4/E6, CEC indicated that the compost products can be used for agricultural purposes without adverse effects on germination, crop production and the environment. Our findings highlight that bioconversion methods could be an alternative for sludge composting, because these methods achieved the highest level of organic matter stabilization and the least phytotoxicity in the final compost products.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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