


Co-composting of cow dung, municipal solid waste, roadside pond sediment and tannery sludge: role of human hair

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Abstract In general, farmers from developing countries often use several feeding mixtures based on materials available in their vicinity resulting in a final poor-quality compost product. Human hair as a composting feed could impact on the nutrient status in prepared compost. In this study, the effect of different amount of human hair to tannery sludge, roadside pond sediment, municipal solid waste and cow dung was investigated during 70-day composting cycle. Human hair addition increased N, P and K from 1.36 to 22.85, 53.06 to 189.80 and 4.13 to 39.26%, respectively, over control. Total metal and arsenic contaminations were significantly higher than in control but

lower than the Indian permissible limit. Highest amount of human hair in composting feed indicated that the germination index for tea seed (*Camellia sinensis* L.) was less than 80% reflecting the possible remaining phytotoxic substances. Redundancy analysis revealed that there was a significance influence of the physico-chemical variables on bacterial community.

Keywords Compost maturity · Enzyme activities · Heavy metals · Microbial population · Redundancy analysis

Introduction

The search of economically viable and sustainable alternative composting feeding materials in small farming communities in developing countries remains a continuous effort for compost production as a strategy for addressing soil fertility challenges on crop lands. Composting in India is an age-old practice, and farmers often prefer traditional techniques of pit composting procedure that freely rely on the use of zero cost locally available raw materials to obtain immediate economic return. Several literatures abound that focus on the addition of microbial consortium which can increase the nutrients concentration in the final compost product (Awasthi et al. 2015, 2016; Kumari et al. 2016 and references therein). However, the potential use of this composting approach is hindered by unavailability of such type of consortium.

Living standard coupled with population growth is the direct influencing factors of waste generation not only in developed country but also in developing countries such as India. Among the generated wastes, municipal solid waste (MSW) constitute very serious threats to the environment in India, and the problem is severely acute particularly in

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metropolitan cities. Besides MSW, tannery sludge (TS) produced from about 3000 tanning industry, which accounts 10% of the world's leather production in India, is also known to be highly polluting (Vig et al. 2011). The predominant mode of disposal of generated wastes in India is open dumping, and this constitutes 94% of the total generated MSW with only 5% of the MSW used for composting (Karak et al. 2012). Compost produced from several unutilized wastes not only produces valuable amendment for agricultural produce but also provides an eco-friendly management of wastes as well as helps overcome the challenge of obtaining different composting feed mixtures. Recent studies suggest that direct addition of pond sediment (PS) in agricultural land can enhance crop production and the use of PS with MSW can provide good quality compost (Karak et al. 2013a, b, 2014a). Zheljzakov et al. (2008a, b) reported that human hair (HH) generated in barbershops can be safely used for horticultural crops as composting feed. Zheljzakov (2005) also reported that addition of HH waste to MSW compost (MSWC) can be safely used as nutrient source for different crops. However, HH is a keratinaceous material and often very resistant to degradation (Zheljzakov 2005; Zheljzakov et al. 2009). Its co-composting with other organic composting feeds might enhance the degradation procedure to maintain carbon-to-nitrogen ratio (C:N), the reduction in NH_3 emissions and control the odorous compounds generated during the thermophilic and mesophilic phases of composting (Awasthi et al. 2015).

Generally, most of the generated MSW is contaminated with heavy metals (HMs), and therefore, its sole use as a composting feed is highly restricted. Similarly, the high metal content in TS (Ruiz-Aguilar et al. 2015) has also imposes limitation on its sole use as composting feed or as bulking agents for the preparation of compost (Karak et al. 2013a). On the other hand, Karak et al. (2014a) reported that segregated MSW can be used as composting feed with other raw materials such as pond sediment, tea garden wastes, cow dung (CD) and termite mound that have less amount of HMs. This will not only decrease the HM contents in the finished product but also increase its nutrient contents. It has also been reported that the preparation of quality compost from contaminated raw materials should be avoided during the composting scheme in line with national or international quality standards (Awasthi et al. 2015; Karak et al. 2015). Composts prepared from different organic wastes differ in their quality and stability, which further depends upon the composition of raw material used for the compost production (Karak et al. 2014b). Furthermore, several physical, chemical, biological and phytotoxicity changes during the composting process are common phenomenon (Varma and Kalamdhad 2015). Various physical and chemical as well as bioindices are

often assessed to ascertain the degree of stability and the desired level of compost maturity. Such measured physical parameters include temperature, volume reduction and bulk density (Karak et al. 2014a), while chemical parameters such as pH, electrical conductivity (EC), cation exchange capacity (CEC), total organic carbon (TOC), oxidizable carbon (OXC), water-soluble carbon (WSC), total nitrogen (TN), NO_3^- -N, NH_4^+ -N, total potassium (TK), total phosphorus (TP) and total HMs have been assessed and documented (Karak et al. 2014b; 2015; Lim et al. 2015; Şevik et al. 2016; Varma and Kalamdhad 2015). Bioassays such as germination index (GI), enzymatic activity and microbial parameters are also well documented (Awasthi et al. 2015; Zhang et al. 2014). However, there is no information on changes occurring to these parameters during co-composting of MSW, TS, PS and CD, blended with HH. Furthermore, the development of suitable composting mixture for a well-balanced nutrient product for use as a sustainable plant growth promoter is an important task while minimizing the detrimental effect of HMs in the environment.

The present working hypothesis is that co-composting of a freely available CD, MSW, TS, PS mixture as well as HH could result in a production of compost with Indian standard prescribed by Fertilizer Control Order of India (FCOI 1985). Therefore, the objective of this paper was to evaluate and compare the performance of composts produced from different waste mixtures (MSW, PS, TS and CD) with HH through pit composting method. This will be achieved by assessing the changes in different physico-chemical, microbial and bioassay properties of the composting feeds during composting and its subsequent maturation using a combination of statistical approaches. The composting exercise was done during the month of March–May 2015 at the composting unit situated at Kalyani, district Nadia, West Bengal, India.

Materials and methods

Raw materials, amalgamation, composting procedure and sampling

Non-segregated MSW was collected in the first week of January 2015 from Dhapa (latitude: 22.54°N; longitude: 88.41°E) solid waste dumping ground where the solid wastes of the city of Kolkata are dumped. Biodegradable part of the collected MSW was segregated following the procedure described by Karak et al. (2014a). Tannery sludge was collected in the second week of January 2015 near Park Circus region in Kolkata, India, while HH waste was simultaneously collected from the men barber shop in Kolkata during the collection of TS. Collected waste hair was further cut into

small parts (1–2 mm length) prior to its analysis and used as composting feed. Pond sediment was collected from the suburban area of Kolkata following the procedure described by Karak et al. (2013a). Fresh CD was collected from the dairy farm situated at Jadabpur region of Kolkata. Five composting modes were prepared with each mode representing a combination of below-ground pit with above-ground windrow composting piles, and each replicated three times. Details of each composting pit, composting procedure and set-up, turning frequency, sampling (0, 14, 28, 42, 56 and 70 days of composting) and duration of composting were followed as previously outlined by Karak et al. (2014b). In this study, the total volume of composting pit was 2.5 m³ consisting of below-ground pit with dimension of: 2.50 m length, 0.94 m breadth and 0.51 m depth, and the above-ground triangular prism-shaped heap with the dimension of 2.50, 0.94 and 0.27 m for length, base and height, respectively. The composting exercise was done during the month of March–May 2015. The proportions of the individual feedstock component in the MSW:TS:PS:CD:HH mix ratio per volume are 1:1:1:1:0, 1:1:1:1:0.10, 1:1:1:1:0.20, 1:1:1:1:0.30 and 1:1:1:1:0.40, respectively, for pit 1, 2, 3, 4 and 5. These ratios represented 718:613:466:484:0, 701:598:455:473:48, 684:584:444:461:93, 668:570:434:451:136 and 653:557:424:440:178, respectively, on weight (kg) ratio basis.

Physico-chemical analyses and seed germination index

Several physico-chemical parameters were assessed as per Indian compost regulations FCOI (1985) following standard methodologies as described by Karak et al. (2014a) and Karak et al. (2015). These parameters included temperature, volume reduction, bulk density, pH, EC, CEC, TOC, OXC, WSC, TN, NO₃⁻ and NH₄⁺ N, total K, total P, and heavy metal(loid)s specifically As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. The percentage of OM content was estimated from value of TOC by division of TOC by 0.58 (FCOI 1985). Phytotoxicity test was done based on assessment of germination index (GI) of tea (*Camellia sinensis* L.; cv. TV 1) and green pea (*Pisum sativum*; cv. Hortense) seeds using a modified version of the method proposed by Zucconi et al. (1981).

Degradation of human hair (HH)

The morphological features of human hair (at the initial stage of composting and after 70 days of composting) for this study were observed under scanning electron microscope (SEM). The SEM images were recorded on high-resolution Quanta 200 FEG SEM, USA. The powdered HH sample was pasted on a carbon tape and dried overnight under vacuum to ensure complete removal of moisture.

Enzymatic activities

Enzymatic activities, namely amylase, cellulase, protease and phosphatase, at different stages of composting were performed using aqueous extracts of composting samples. The methodologies for this estimation of the various enzymes were as described by Awasthi et al. (2015).

Microbial communities

The protocol described by USEPA was followed for analysing total aerobic mesophiles (TAM), aerobic bacilli (AB), *Salmonella* spp. *Shigella* spp. (SS), yeast and moulds (YM) at different stages of composting (e.g. days 0, 14, 28, 42, 56 and 70 of composting) (USEPA Appendix F, G, I, 1999). A brief description of the procedures as used in this study is available in the article of Kumari et al. (2016).

Data processing and statistical analysis

One-way analysis of variance (ANOVA) was performed to determine the differences between physico-chemical properties, germination index and microbiological as well as enzymatic properties in compost samples. In order to analyse interrelationships among all the variables, Pearson's correlations were computed. In the present experiment, redundancy analysis (RDA) and principal component analysis (PCA) were performed on the obtained data in order to summarize the linear relationships among a set of response variables, determine the set of predictor variables and extract few linear combinations of variables that could explain the maximum amount of variability in the system. While RDA is used to extract, summarize and explain the variation that existed in a set of response variables, PCA on the other hand is considered as one of the best statistical techniques for extracting linear relationships among a set of variables. The varimax rotation in the PCA distributes the PC loadings such that their dispersion is maximized by minimizing the number of large and small coefficients (Richman 1986). In order to obtain homogenous groups of pits, cluster analysis was performed as most widely used technique for unsupervised pattern recognition in chemometrics. Similarly, hierarchical clustering of data was applied based on the core idea that nearby object of objects are more related than those further away. Prior to RDA, PCA and cluster analyses, the datasets were standardized to make the entire variables unit free.

In this study, statistical distributions of the different variables were performed to obtain the best fits to the dataset generated. In most cases, two or more distribution fits were performed and results were compared to select the most valid model using the specific goodness-of-fit (GOF) tests and theoretical (fitted) distribution. Small probabilities indicate poor fit while high probabilities correspond to a good fit (D'Agostino and Stephens 1986). Other tests for

GOF were performed to obtain the best suited fit for the dataset, which included Kolmogorov–Smirnov (K–S) test, Anderson–Darling test and Chi-square test. The use of K–S test in this study was attributed to the fact that it is less affected by the existence of outliers and it is based on the empirical cumulative distribution function (ECDF). It is also useful to establish whether a sample comes from a hypothesized continuous distribution (Van der Vaart 1998). All the statistical analyses were performed using the SPSS 15.0 statistical package (SPSS Inc., Chicago, USA) and SAS software version 9.3 (SAS Institute Inc., NC, USA).

Results and discussion

Characterization of raw materials and feeding mixture

The characteristics of the raw materials used in this investigation varied depending on the type of raw materials (Table 1). All the materials used were neutral to slightly alkaline in nature as the pH ranged between

6.56 ± 0.02 and 8.29 ± 0.05 (Karak et al. 2013a, 2014b, 2015; Zheljzakov et al. 2008b; Zheljzakov 2005). Cow dung contains relatively higher amount of soluble salts with EC value of 8.18 ± 0.06 dS cm⁻¹ followed in a declining order by MSW, PS and TS (Karak et al. 2014b). The pH and EC values of HH were, however, not determined due to its insoluble nature. No significant variation was observed in the bulk densities of the raw materials, whose values ranged between 1.02 ± 0.02 and 1.34 ± 0.03 g cm⁻³. All materials were generally wet as moisture content in raw materials ranged from 12.28 ± 0.29 to 32.45 ± 2.62%. Ash contents was lowest in HH followed by CD, TS, MSW and PS. Total organic carbon ranged from 2.79 ± 0.39 to 48.70 ± 3.09%. Total nitrogen (TN) content in HH and MSW was same (1.28%) but highest in TS (4.34%). As expected, the C:N ratios varied widely among the raw materials used due to variation in TOC content. The C:N ratio in PS was very low (3.44) while CD showed very high value of marginally over 152. The higher amount of P in HH as contained in the table could be attributed to the consumption of higher P-containing food or hair cream.

Table 1 Physico-chemical characteristics of the raw materials (dry weight basis) for preparation of compost (values represents mean of three replications ± standard error of the mean; SE)

Parameters	Raw materials				
	Municipal solid waste (MSW)	Pond sediments (PS)	Tannery sludge (TS)	Cow dung (CD)	Human hair (HH)
pH	7.51 ± 0.05	6.56 ± 0.02	8.29 ± 0.05	7.72 ± 0.28	–
EC (dS cm ⁻¹)	5.72 ± 0.27	4.39 ± 0.04	3.46 ± 0.14	8.18 ± 0.06	–
Bulk density (g cm ⁻³)	1.27 ± 0.03	1.02 ± 0.02	1.34 ± 0.03	1.29 ± 0.13	1.28 ± 0.03
Moisture (%)	18.60 ± 0.40	17.56 ± 0.81	32.45 ± 2.62	20.98 ± 0.69	12.28 ± 0.29
Ash (%)	43.23 ± 4.36	89.97 ± 6.01	23.45 ± 1.92	14.34 ± 0.64	0.53 ± 0.03
Total organic carbon (%)	36.14 ± 2.29	2.79 ± 0.39	23.48 ± 0.77	48.70 ± 3.09	39.60 ± 4.12
Total nitrogen (%)	1.28 ± 0.17	0.82 ± 0.03	4.34 ± 0.07	0.32 ± 0.06	1.28 ± 0.05
C/N ratio	28.23 ± 2.03	3.44 ± 0.59	5.41 ± 0.09	152.19 ± 31.32	30.78 ± 1.98
Total P as P ₂ O ₅ (%)	0.69 ± 0.03	0.82 ± 0.02	0.39 ± 0.05	0.18 ± 0.03	1.13 ± 0.08
Total K as K ₂ O (%)	2.18 ± 0.04	2.29 ± 0.09	1.29 ± 0.07	0.26 ± 0.01	0.69 ± 0.02
Total arsenic and heavy metals (mg kg ⁻¹) ^a					
As	1.19 ± 0.05	0.23 ± 0.02	0.03 ± 0.01	0.02 ± 0.01	0.02 ± 0.01
Cd	0.16 ± 0.04	0.11 ± 0.01	0.11 ± 0.01	ND ^b	0.01 ± –
Cr	12.81 ± 0.94	14.56 ± 0.19	4.59 ± 0.21	ND	0.21 ± 0.01
Cu	118.18 ± 9.34	96.70 ± 2.00	28.76 ± 1.17	12.51 ± 0.73	19.21 ± 1.40
Hg	0.09 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	ND	ND
Ni	9.87 ± 0.38	8.28 ± 0.11	2.46 ± 0.20	0.17 ± 0.01	0.02 ± 0.01
Pb	98.21 ± 4.02	14.70 ± 1.34	6.59 ± 0.42	0.27 ± 0.03	1.42 ± 0.06
Zn	129.24 ± 4.56	132.22 ± 4.54	87.70 ± 1.93	108.00 ± 8.80	207.00 ± 5.06

^a Only those heavy metals have been reported prescribed by FCOI (1985)

^b ND not detectable (detection limit: 0.01 mg kg⁻¹ for As; 0.01 mg kg⁻¹ for Cd; 0.25 mg kg⁻¹ for Cr; 0.05 mg kg⁻¹ for Cu; 0.05 mg kg⁻¹ for Hg; 0.01 mg kg⁻¹ for Ni; 0.01 mg kg⁻¹ for Pb; 0.01 mg kg⁻¹ for Zn)

Among the analysed materials for HM contents, CD showed comparatively lower concentration while MSW, PS, TS and HH showed significantly higher amount possibly due to several contaminations, such as metal-containing wastes for MSW, dying materials for HH, road leachate for PS and soaking materials for TS.

Dynamics of selected physico-chemical parameters during composting process

Figure 1a, b shows SEM images of human hair at the initial stage of composting and after 70 days of composting in pit 4. From this image, it has been observed that HH degraded well within composting mixture. From Fig. 1b, it was also observed that there is detachment of the cuticle layers and its subsequent dissolution in composting mixture which may have influence of nutrient enrichment in prepared compost. Temperature variation during composting among the five pits is depicted in Fig. 2a. At the beginning of composting, recorded temperature reading for pits 1, 2, 3, 4 and 5 was 17.8, 20.0, 18.5, 17.6 and 19.7 °C, respectively, with no significant difference ($p < 0.05$) observed with ambient temperature (17.0 °C). The maximum temperature reading recorded for each compost prior to the first turning was 75.8, 73.6, 77.1, 75.8 and 77.3 °C, respectively, for pits 1, 2, 3, 4 and 5 obtained at 9, 10, 18, 20 and 21 days, respectively. In general, the addition of HH in the compost feeding mixture promoted slow increase in temperature, slowly relative to the control but with longer temperature duration. This could be attributed to higher percentage of

readily available organic substances in pit 1 than other pits, which were degraded faster within a shorter time period. The temperature readings in all composting pits followed thermophilic (>50 °C), mesophilic (>20 to <50 °C) and cooling (<20 °C) phases indicating compost maturity. Among the pits, the thermophilic phase was attained within 5 days for pit 1, 6 days for pit 2, 9 days for pit 3 and pit 4 and 8 days for pit 5, and lasted for about 33 days for pit 1, 34 days for pits 2 and 5, 36 days for pit 3 and 37 days for pit 4. After the first turning, compost temperature in all pits increased rapidly for only one day and thereafter dropped steadily and attained ambient temperature within 65–70 days. Similar temperature profile pattern was reported by several authors when different types of compost feeding mixtures, viz. MSW, biochar, TS, CD, termite mound, struvite were used (Karak et al. 2014b, 2015; Awasthi et al. 2015). Attar et al. (2005) concluded that the persistence of thermophilic temperature for at least two days could have positive effect for compost sanitation. In the present study, all the pits experienced long period of thermophilic phase, which therefore suggest that the composts may have been set free of pathogens, weed seeds and insect larvae.

In all pits, volume reduction was increased when composting proceeded (Fig. 2b). Similar trend in volume reduction was reported by Karak et al. (2015) when struvite was composted with other wastes. However, no significant variation was observed among the five pits. Maximum volume reduction was observed in pit 5 (33.5%) followed by pit 1 (32.9%), pit 2 (23.4%), pit 3 (20.4%) and pit 4

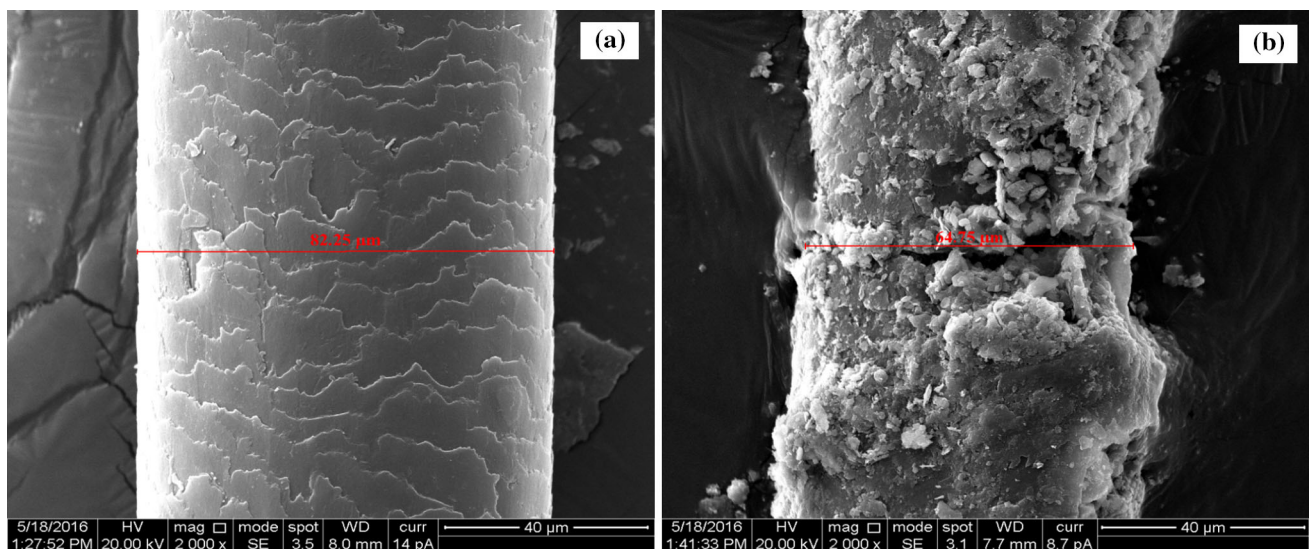


Fig. 1 Images of human hair obtained by scanning electron microscopy (SEM) **a** fresh hair used as composting materials and **b** hair after 70 days of co-composting with municipal solid waste (MSW), tannery sludge (TS), pond sediment (PS) and cow dung (CW) for PIT 4

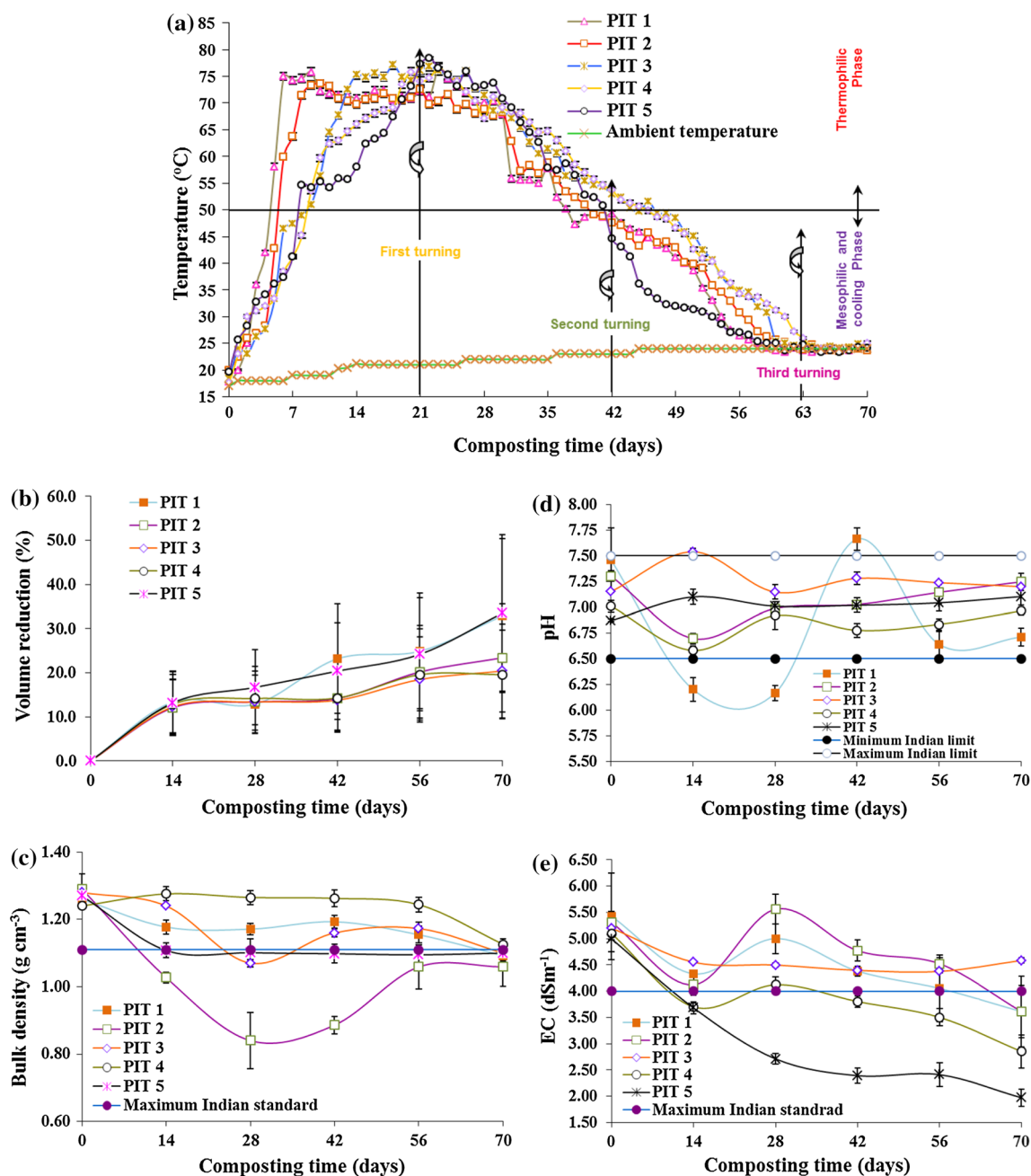


Fig. 2 Dynamic change in **a** temperature, **b** volume reduction, **c** bulk density, **d** pH and **e** electrical conductivity (EC) of five pits during 70 days of co-composting process (results presented here are the mean of three replicates, and *error bars* indicate standard error of

(19.6%). This observation may be attributed to the use of comparatively non-porous bulking agent such as HH, PS and TS. According to Makan et al. (2014), volume reduction in composting mixture increases over time since degradation of organic feeding mixture that decrease initial pore space.

Figure 2c shows that the initial bulk density for pits 1, 2, 3, 4 and 5 was 1.26, 1.29, 1.28, 1.24 and 1.27 g cm⁻³,

mean). PIT 1—MSW:TS:PS:CD:HH::1:1:1:1:0; PIT 2—MSW:TS:PS:CD:HH:: 1:1:1:1:0.10; PIT 3—MSW:TS:PS:CD:HH:: 1:1:1:1:0.20; PIT 4—MSW:TS:PS:CD:HH:: 1:1:1:1:0.30 and PIT 5—MSW:TS:PS:CD:HH:: 1:1:1:1:0.40

respectively. However, substrates degradation and formation of liquid extract inside the composting mixture decreased the initial bulk density of the composting mass generally up to 28 days except pit 4. The present study contradicted earlier works reported by Karak et al. (2014a, 2015) where progressive increase in bulk density was observed with different compost feeding mixtures. Şevik et al. (2016) reported that as co-composting of olive

pomace, sewage sludge, dairy manure, and tomato stalks progressed at different mass ratio, bulk density decrease in a certain period and thereafter increased to a constant value. In their opinion, the formation of liquid substances of lower density at the initial from the composting mixture leads to the decreasing trend in bulk density. However, the observed increase bulk density towards compost maturity phase may be attributed to the shrinking of inner sphere of composting particle leading to decrease in free air spaces as well as intense evaporation of liquid substance. The measured bulk density of pits 1, 2, 3, 4 and 5 after 70 days of composting were found to be 1.09, 1.06, 1.10, 1.13 and 1.10 g cm⁻³, respectively. The maximum permissible limit of compost bulk density prescribed by Indian composting standard at the curing stage is 1.11 g cm⁻³ (FCOI 1985), which suggests that only composting mixtures in pit 4 did not attain the required quality standard even after 70 days of composting.

Figure 2d shows the pH profile for the compost in the five composting pits, and it revealed a stable compost (6.71–7.25) at 70 days in line with Indian permissible standard (6.50–7.50) prescribed by Ministry of Agriculture and Rural Development, Government of India (FCOI 1985). The initial pH value for compost in pits 1, 2, 3, 4 and 5 was 7.46, 7.30, 7.15, 7.01 and 6.87, respectively, but the measured value after 70 days of composting was 6.71, 7.25, 7.20, 6.96 and 7.10, respectively. However, observed pH change during composting showed no there were no particular trend. After two weeks of composting, pH decreased in pits 1, 2 and 4 while the others two pits showed a reverse trend. The initial increase in pH value could be due to formation of organic acids as reported by (Karak et al. 2015). However, the increase in pH value in pit 3 and 5 could be driven by ammonification rather than acidification as reported by Iqbal et al. (2015) during the co-composting of eggshell waste.

The measure of EC content of prepared compost could serve as a good maturity indicator as it monitors composting effects as well as reflects the presence of soluble salt (Karak et al. 2014a, b; Karak et al. 2015). At the commencement of composting, EC values were 5.42, 5.31, 5.20, 5.10 and 5.00 dS m⁻¹ in pits 1, 2, 3, 4 and 5, respectively (Fig. 2e). Significantly higher EC value measured in pit 1 feeding mixture at the initial stage relative to the other pits could be due to the absence of HH that does not contain any soluble salts, thereby reducing the salt content of the compost (Zheljzakov et al. 2008b). When HH was added to the composting mixture, EC decreased significantly ($p < 0.05$) within the first week of composting and showed a positive correlation ($r = 0.96$) with increasing amount of TS, PS and HH. The first turning of composting mixture significantly increase the EC values possibly due to loss of organic matter, the release of highly

conducting ions and lysing of microbial cell from the composting mass (Karak et al. 2010) promoted by the aeration of the compost during turning. At the final stage of composting, measured EC value was in the order of pit 3 (4.59 dSm⁻¹) > pit 1 ~ pit 2 (3.61 dSm⁻¹) > pit 4 (2.85 dSm⁻¹) > pit 5 (1.97 dSm⁻¹). These final EC values for the prepared compost were within the Indian standard (<4.0 dSm⁻¹) except pit 3.

TOC, OXC, WSC, TN, NH₄⁺-N, NO₃⁻-N and nitrification index

Content of TOC at the initial stage of composting was 34.56, 36.27, 37.19, 38.29 and 39.16% in pits 1, 2, 3, 4 and 5, respectively (Fig. 3a). However, TOC decreased significantly ($p < 0.05$) as composting progressed to attain 32.72, 27.20, 25.20, 29.60 and 37.80% after 70 days of composting for pits 1, 2, 3, 4 and 5, respectively. Maximum TOC content decrease (22.98%) was obtained in pit 3 relative to content in control (i.e. pit 1) at 70 days while pit 5 showed 15.53% increase over control. The decrease of TOC could be due to organic matter stabilization. Furthermore, microbial respiration also enhances TOC losses of TOC in the form of CO₂ (Vig et al. 2011). In all composting pits, TOC values were positively correlated with increasing content of HH ($R^2 = 0.96$), TS ($R^2 = 0.81$), MSW ($R^2 = 0.84$) and PS ($R^2 = 0.97$).

The profile of OXC in the different composting pits is depicted in Fig. 3b. Among the composting pits, pit 3 had the highest initial OXC content (34.6%) followed by pit 5 (34.6%), pit 2 (33.5%), pit 4 (32.0%) while pit 1 had the least content (31.8%). The relative significantly higher ($p > 0.05$) amount of OXC in HH amended pits could be due to high content of polymerizable carbonic compound contained in the HH. The content of OXC at the initial stage of composting was 92.0, 92.4, 94.4, 83.6 and 88.4% of TOC in pits 1, 2, 3, 4 and 5, respectively. The content decreased to 81.3, 83.5, 87.7, 83.5 and 74.3%, respectively, over the respective TOC in pit 1, 2, 3, 4 and 5 after 70 days of composting. The decrease in the content of OXC in the final compost suggested that HH played an important role as bottom PS, termite mound and struvite did (Karak et al. 2014b, 2015).

Water-soluble carbon (WSC) represents the most easily available form of TOC while sugars, several low molecular weight organic acids, amino acids as well as phenols are major contributor of WSC in prepared composts. The content of WSC at the initial stage of composting for pits 1, 2, 3, 4 and 5 was 7.43, 10.16, 16.89, 24.30 and 25.72%, respectively (Fig. 3c). WSC content consistently decreased up to 14 days of composting irrespective of the feeding mixture, which could be attributed to the process of compost stabilization. After 14 days, no clearly defined trend

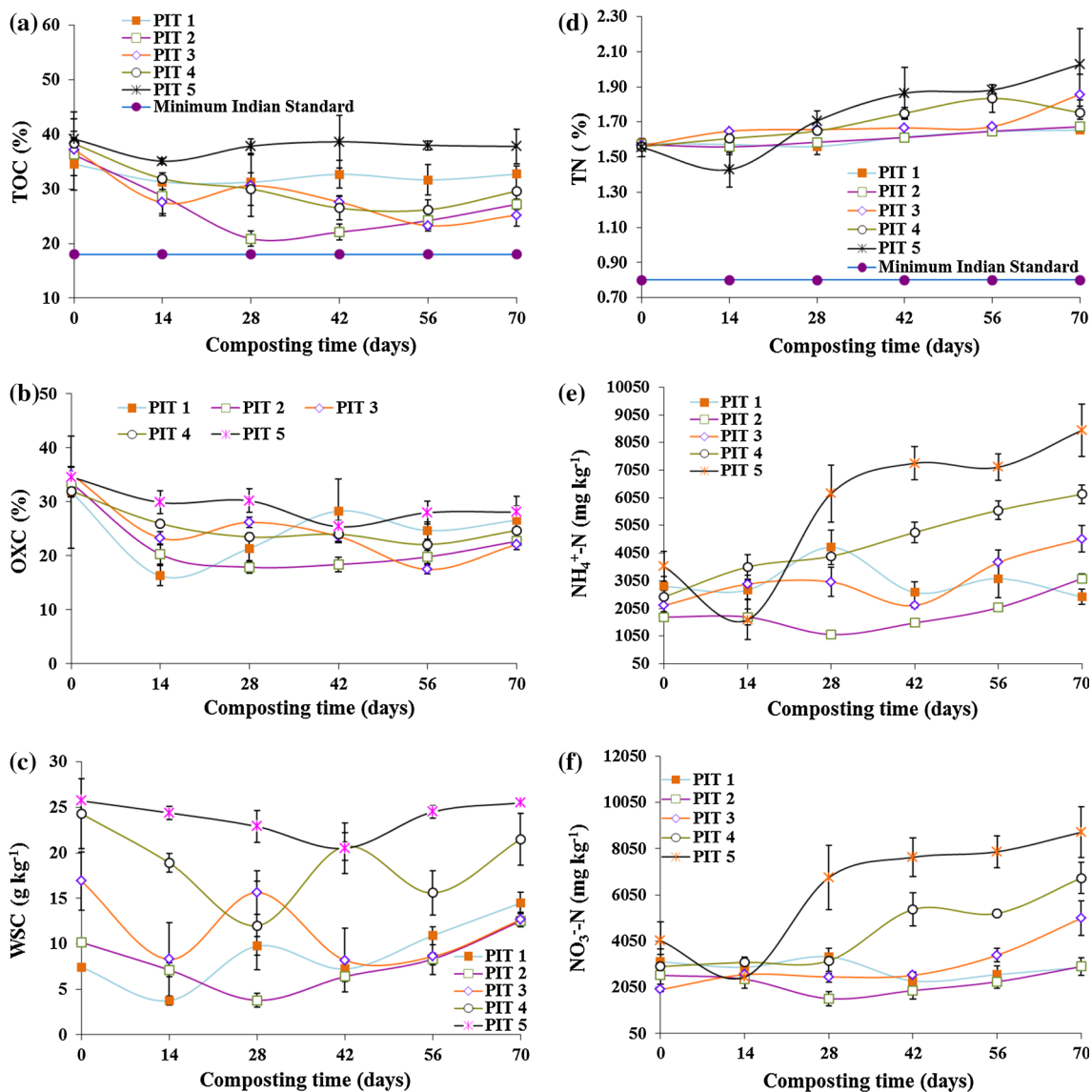


Fig. 3 Dynamic change in **a** total organic carbon (TOC), **b** oxidizable carbon (OXC), **c** water-soluble carbon (WSC), **d** total nitrogen (TN), **e** ammoniacal nitrogen ($\text{NH}_4^+\text{-N}$) and **f** nitrate nitrogen ($\text{NO}_3^-\text{-N}$) of

five pits during 70 days of co-composting process (results presented here are the mean of three replicates, and error bars indicate standard error of mean)

was observed. WSC content decreases after 70 days of composting over their initial respective WSC value for pits 3, 4 and 5. However, pit 1 and 2 showed increment in WSC content over initial WSC contents. This observation is at variance with earlier findings documented by Karak et al. (2015), where continuous decrease of WSC after 28 days of composting was observed. The relatively lowest amount of WSC in HH could be the possible reason for the lowest concentration of WSC in the pits where HH was added despite an increasing amount. Furthermore, the rapid drop in WSC in HH added pits could be due to polymerizable carbonic compound contained in the HH present in composting mixture.

Total organic matter content of the different pits at the onset of composting as well as during composting was calculated from total organic carbon content (data not shown). It was obvious that organic matter profile followed similar trend to that of TOC and also coincided with equal pattern of nitrification ratio. A significant decrease ($p < 0.05$) in per cent organic matter content in all pits was observed after 14 days of composting followed by a remarkable increase at 28 days of composting except in pit 2. This increase according to Karak et al. (2010) could be due to high microbial activities in the presence of considerable amount of organic substrate. After 70 days of composting, organic matter content from pits 1, 2, 3, 4 and

5 were found to be 56.41, 46.90, 43.45, 51.03 and 65.17%, respectively. The per cent OM decrease in over control for pit 2, 3 and 4 was 16.87, 22.98 and 9.54, respectively, but increased by 15.53% in pit 5. Although the decrease in OM content in HH-containing pits was not obvious, the present phenomenon could be attributed to the activities of microbes in TS and PS that gradually release CO₂ from biodegradable portion of feeding mixture.

The changing patterns of TN content of compost in the different pits are presented in Fig. 3d. The TN content at the initial stage of composting was in the order of pit 1 (1.58%) > pit 2 ≈ pit 3 (1.57%) > pit 4 (1.56%) > pit 5 (1.55%), which was dependent on the composition of material used. In all composting pits, TN content increased significantly as composting progressed except in pit 5 at 14 days. The order of TN in different pits at the curing stage of composting was in the order pit 5 (2.03%) > pit 3 (1.86%) > pit 4 (1.75%) > pit 2 (1.67%) > pit 1 (1.65%). The TN content of all the final composts was well within the minimum permissible limit of 0.80% prescribed by the Indian composting regulation (FCOI 1985). Even though the TN content in pit 5 at the initial stage of composting was lowest, content at the final stage was highest among five composting mixtures. The maximum increase in TN at the final stage of compost over the initial TN was 30% for pit 5 and least in pit 1 (5%). A positive correlation was observed on TN at the curing stage with respect to TS, PS and HH but had a negative co-relationship with CD and MSW. Similar observation was documented by Vig et al. (2011) when TS mixed with cattle dung was subjected to composting. From this present experiment, it is obvious that volatilization losses during composting may have been hastened by application of less decomposable HH.

Profile of NH₄⁺-N in the five pits after 70 days of composting is presented in Fig. 3e. The starting NH₄⁺-N concentrations in composting feed were 2.85, 1.74, 2.16, 2.47 and 3.57 g kg⁻¹ for pits 1, 2, 3, 4 and 5, respectively. In all the pits, NH₄⁺-N concentrations generally increased except pit 1 and attained 2.47, 3.13, 4.56, 6.18 and 8.49 g kg⁻¹ for pits 1, 2, 3, 4 and 5, respectively. Overall, 26.72, 84.62, 150.20 and 243.72% increase in NH₄⁺-N content in pits 2, 3, 4 and 5, respectively, was recorded over control. Similarly, a general increase in NH₄⁺-N content during the composting process was recorded except pit 5 where NH₄⁺-N decreases drastically after 14 days of composting. A similar trend was also reported by Maulini-Duran et al. (2015) when hair wastes were co-composting with raw sludge due to provoked formation of NH₄⁺-N mainly by sludge since hair contains slow degradable keratin, a protein produced by the combination of 18 amino acids. Furthermore, higher amount of NH₄⁺-N contents of composting pits (except pit 1) were lower than the initial NH₄⁺-N contents possibly due to lower ammonia

volatilization, fluctuation in NH₄⁺-N content and lower microbial immobilization during HH decomposition (Karak et al. 2014a).

The initial NO₃⁻-N content of the five pits were 3.16, 2.57, 1.95, 2.95 and 4.07 g kg⁻¹ for pits 1, 2, 3, 4 and 5, respectively. In general, NO₃⁻-N in five composting pits followed a similar trend like NH₄⁺-N (Fig. 3f). Among the HH added as composting feed, the least NO₃⁻-N content was in pit 2 (2.95 g kg⁻¹) while the highest was obtained in pit 5 (8.76 g kg⁻¹) after 70 days of composting. The overall increase in NO₃⁻-N content over control (no HH) in pits 2, 3, 4 and 5 was 1.03, 72.60, 132.19 and 200.00%, respectively. The higher amount of NO₃⁻-N obtained at compost curing stage indicates that HH addition possibly created a favourable condition for the production of nitrifying bacteria leading to increased retention of N in final product (Zheljzakov et al. 2008a). The observed gradual increase in NO₃⁻-N content in all pits could be due to steady changes in temperature profile from thermophilic to mesophilic as suggested by Karak et al. (2015).

Nitrification index, represented by NH₄⁺-N/NO₃⁻-N ratio, is a good indicator of compost maturity and compost quality with respect to N (Karak et al. 2014b). Nitrification index was 0.85, 1.06, 0.90, 0.91 and 0.97 for pits 1, 2, 3, 4 and 5, respectively, after 70 days of composting (data calculated from Fig. 3e, f; data not presented). Although FCOI (1985) has no prescribed limit for nitrification index to ascertain compost suitability for field application, Karak et al. (2015) suggested composts can be classified based on nitrification index falls of 0.5–3.0 and >3.0 for mature and immature composts, respectively. Thus, all prepared composts in the present study as per this classification attained maturity within 70-day composting period.

Cation exchange capacity (CEC), C:N ratio, total P and K

CEC plays a pivotal role in compost quality and its maturity. Compost production leads to the formation of humic substances through the humification of biodegradable materials that are present in the composting feeds. The process of humification produces quality compost and also increases the CEC of composting substances. Figure 4a shows the trend of CEC among five composting pits. The initial CEC value of the composting feeding mixtures containing HH had low CEC (15.67–28.50 cmol kg⁻¹). However, the CEC was sharply increased within 14 days of composting in all pits except pit 5. Comparatively higher amount of HH addition in pit 5 imposes longer time for the commencement of decomposition and also exerts effect on CEC variation. Beyond the 14 days of composting initiation, all composting pits showed steady CEC increases at 21 days except in pit 3. This

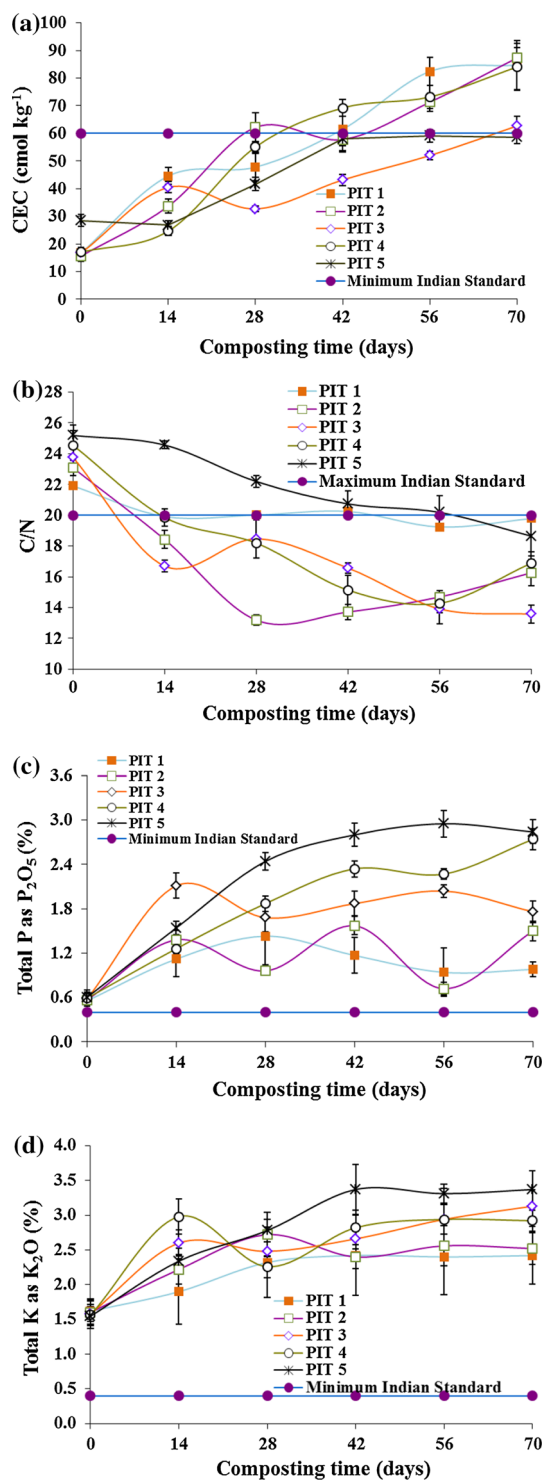


Fig. 4 Dynamic change in **a** cation exchange capacity (CEC), **b** carbon-to-nitrogen ratio (C:N), **c** total P and **d** total potassium of five pits during 70 days of co-composting process (results presented here are the mean of three replicates, and *error bars* indicate standard error of mean). PIT 1—MSW:TS:PS:CD:HH::1:1:1:1:0; PIT 2—MSW:TS:PS:CD:HH:: 1:1:1:1:0.10; PIT 3—MSW:TS:PS:CD:HH:: 1:1:1:1:0.20; PIT 4—MSW:TS:PS:CD:HH:: 1:1:1:1:0.30 and PIT 5—MSW:TS:PS:CD:HH:: 1:1:1:1:0.40

observation could possibly be attributed to the reorganization of non-decomposed mass after first turning. However, a fixed CEC value ($58.7 \text{ cmol kg}^{-1}$) was obtained in Pit 5 from 42 days till 70 days of composting while the other pits showed steady CEC increases until compost maturity at 70 days. Compost CEC was highest in pit 2 ($87.30 \text{ cmol kg}^{-1}$) followed by pit 1 ($84.70 \text{ cmol kg}^{-1}$), pit 4 ($84.00 \text{ cmol kg}^{-1}$), pit 3 ($62.70 \text{ cmol kg}^{-1}$) and pit 5 ($58.7 \text{ cmol kg}^{-1}$) at 70 days. Compost CEC values in all pits were greater than the 60 cmol kg^{-1} prescribed standard by FCOI (1985) for a mature compost except for that produced in pit 5.

The value of C:N ratio is also considered as an important factor for establishing compost maturity. Initial C:N ratio in the five composting pits was in the order of pit 5 (25.19) > pit 4 (24.54) > pit 3 (23.75) > pit 2 (23.07) > pit 1 (21.90) as shown in Fig. 4b. However, at the end of the 70-day composting period, the order of C:N ratio was pit 1 (19.8) > pit 5 (18.6) > pit 4 (16.9) > pit 2 (16.3) > pit 3 (13.6). According to FCOI (1985), the C/N ratio of less than or equal to 20 is considered appropriate for a mature compost. Therefore, all prepared composts in this study are considered mature after 70 days of composting with respect to C:N ratio. The per cent decrease in C:N ratio over control was 17.79, 31.37, 14.65 and 5.74 for pits 2, 3, 4 and 5, respectively. The observed decrease in C:N ratio reflects the strong influence on compost stabilization at maturity by the initial raw materials used, which possibly enhance electrogenesis (Şevik et al. 2016). The decline in the C:N ratio in the composting pits may also be attributed to volatile loss of CO_2 during microbial respiration (Vig et al. 2011).

The dynamics of TP and TK contents in composting pits are presented in Fig. 4c, d, respectively. The initial TP contents of the different mixtures in the five pits ranged from 0.56 to 0.60%. Irrespective of pit mixture, TP increased significantly within the first 14 days of composting with a significant increase following increase HH addition. The highest increase in TP content over the control was recorded in pit 5 while the per cent increase was in the order pit 5 (189.80) > pit 4 (179.59%) > pit 3 (79.59) > pit 2 (53.06). The observed trend of TP increases in the composts suggests that the amount of HH addition could probably influence the stimulation of microbial population. Likewise, TK increases from 1.62 to 2.42, 1.60 to 2.52, 1.58 to 3.13, 1.56 to 2.92 and 1.55 to 3.37% were recorded for pits 1, 2, 3, 4 and 5, respectively, at the end of composting relative to the initial content. The observed increases in TK contents in pits 1, 2, 3, 4 and 5 represented 4.13, 29.34, 20.66 and 39.26%, respectively, over TK content in pit 1. The TK increases as composting progressed as suggested by Vig et al. (2011) could be due to concentration effect that usually occurred when evaluation

of water vapour, carbon dioxide and ammonia gas from H, C and N, respectively, from composting mixture.

Heavy metals (HMs) and arsenic

Most HMs, which are also known as trace elements, are required by living substances in small quantity but their higher concentrations could have adverse effects on plants, human and animals. Therefore, quantification of prescribed limit of HMs and arsenic (As) in prepared compost has been proposed by several regulatory bodies such as FCOI (1985). Table S1 shows the HMs and As concentrations measured at different stages of composting in five composting pits. Analysed metals concentration at the initial stage of composting irrespective of the composting feed followed the trend $Zn (117.04–124.13) > Cu (67.56–71.70 \text{ mg kg}^{-1}) > Pb (33.52–36.27 \text{ mg kg}^{-1}) > Cr (8.20–8.88 \text{ mg kg}^{-1}) > Ni (5.41–5.87 \text{ mg kg}^{-1}) > As (0.41–0.45 \text{ mg kg}^{-1}) > Cd (0.095–0.102 \text{ mg kg}^{-1}) > Hg (0.037–0.040 \text{ mg kg}^{-1})$. Metals and As concentrations at the initial composting stage increased significantly ($p < 0.015$) in all pits but were all within the Indian compost quality regulations (FCOI 1985) except Ni content in pits 4 and 5. Vig et al. (2011) similarly reported an increase in HM concentration as composting progressed with TS with cattle dung mixtures. The observed increased metal concentration was also attributed to increased volume reduction and weight loss (Di Lonardo et al. 2015). In all cases, the Cd/Zn ratio did not exceed 0.5 but increased with increasing amount of TS, MSW and HH addition. Ciavatta et al. (1993) reported that Cd/Zn ratio controls Zn and Cd availability, with high Cd concentration resulting in reduced Zn availability. Furthermore, Zn load equivalence calculated from $Zn \text{ equivalence} = \text{mg kg}^{-1} Zn + 2 (\text{mg kg}^{-1} Cu) + 4 (\text{mg kg}^{-1} Ni) - 200$ (Ciavatta et al. 1993) in pits 1, 2, 3, 4 and 5 was 682, 900, 951, 1168 and 1336, respectively, suggesting that HH plays a pivotal role in Zn dynamics in the prepared composts. Thus, HH addition during composting could be beneficial in increasing Zn and other micronutrients content for sustainable plant growth in micronutrients-deficient soils.

Enzymatic activity and germination index

Amylase activity

Amylase enzyme is reported to be responsible for dextrans, oligosaccharides, maltose and D-glucose production from starchy substrates present in the composting feeds (Awasthi et al. 2015). The profile of amylase activities in the five composting feeds is presented in Fig. 5a. No significant differences ($p < 0.005$) were found in the amylase activity

contents for the starting feeding mixtures of the five composting pits measured at initiation of composting. Amylase production from composting feeds at the initial stage of composting according to Awasthi et al. (2015) was attributed to the presence of naturally microbes that inhabit the composting feeds such as MSW, TS and PS used in the present investigation. Amylase activities in all five experimental pits used increase sharply within 14 days of initiating compost production with maximum activity obtained at 42 days except in pit 3 where the maximum activity was at 21 days. The implication is that 21–42 days of composting in all pits could be considered as the period of highest degradation rate of starch substrates present in the composting feeds. Earlier results by Awasthi et al. (2015) revealed that maximum amylase activity occurred during 14–21 days of composting when organic fraction of municipal solid waste (MSW) was co-composted with wood shaving, agricultural and yard trimming wastes. Amylase activity in all pits from the current study decreased significantly ($p < 0.01$) after 56 days of composting, exhibited positive correlation ($r = 0.929$) with increasing amount of HH but correlated negatively ($r = 0.81$) with TS, MSW and PS. Maximum decline in amylase activity over control at compost maturity was recorded in pit 5 (50.93%) but least in pit 4 (8.53%).

Cellulase activity

Cellulase is an enzyme that decomposes cellulose into simple sugars in composting feeds. In general, cellulase activities showed significant difference ($p < 0.05$, $F = 4.289$) in the five pits (Fig. 5b) and was positively correlated with the proportions of HH ($r = 0.872$) and MSW ($r = 0.927$). A sharp increase in cellulase activity was observed until 42 days of composting except in pit 1 with the maximum cellulase activity was obtained in pit 3 ($8.38 \text{ mg glucose g}^{-1} \text{ dw h}^{-1}$) at 42 days while pit 2 had the least activity ($2.14 \text{ mg glucose g}^{-1} \text{ dw h}^{-1}$) at 70 days of composting. Measured cellulase activity at compost maturity was 7.85 and 27.08% higher in pits 3 and 4, respectively, over the control while pits 2 and 3, respectively, showed 54.37 and 50.96% lower cellulase activities over the control after 70 days of composting. Similar trend was also observed by Awasthi et al. (2015) when organic fraction of MSW mixed with different bulking wastes were co-composted.

Phosphatase activity

The enzyme phosphatase converts phosphatic group from the composting substrates into inorganic available phosphate ion that plants can metabolize (Awasthi et al. 2015). The effect of HH on the changes in the measured level of

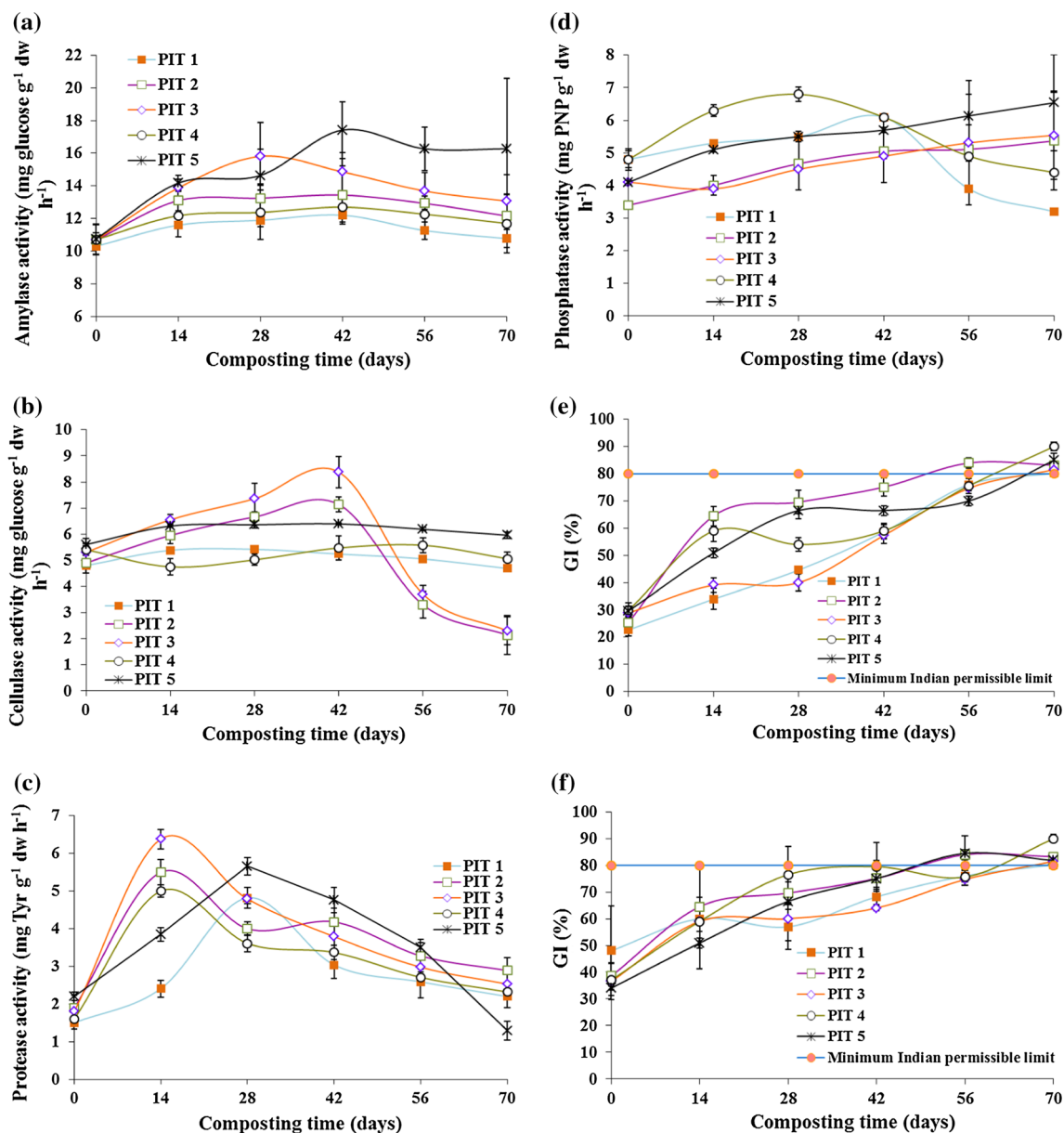


Fig. 5 Dynamic change in **a** amylase activity, **b** cellulase activity, **c** phosphatase activity, **d** protease activity, **e** germination index of tea and **f** germination index of pea of five pits during 70 days of co-composting process (results presented here are the mean of three replicates, and error bars indicate standard error of mean). PIT 1—

MSW:TS:PS:CD:HH::1:1:1:1:0; PIT 2—MSW:TS:PS:CD:HH::1:1:1:1:0.10; PIT 3—MSW:TS:PS:CD:HH::1:1:1:1:0.20; PIT 4—MSW:TS:PS:CD:HH::1:1:1:1:0.30 and PIT 5—MSW:TS:PS:CD:HH::1:1:1:1:0.40

phosphatase activities during composting are shown in Fig. 5c. Phosphatase activities at the start of composting were 4.80, 3.40, 4.10, 4.80 and 4.10 mg PNP g⁻¹ dw h⁻¹ in pits 1, 2, 3, 4 and 5, respectively. Phosphatase activities recorded a sudden increase from 4.00 mg PNP g⁻¹ dw h⁻¹ in pit 2 to 6.30 mg PNP g⁻¹ dw h⁻¹ in pit 4 within 14 days of initiating composting except in pit 3. However, phosphatase activities at compost maturity ranged between 3.20 mg PNP g⁻¹ dw h⁻¹ in pit 1 and 6.54 mg PNP g⁻¹ dw h⁻¹ in pit 5 but increased by from 37.50 to 104.38% over

control at 70 days after initiation of composting with increasing amount of HH addition. Maulini-Duran et al. (2015) reported the production of several enzymes along with phosphatase during composting of HH wastes mixed with raw sludge (1:2; w:w). Besides, Awasthi et al. (2015) and Karak et al. (2015) concluded that MSW, PS and sludge constitute important sources of organic P derived from several P-containing substances including dish-washing powders, detergents and even faeces and urine that facilitate phosphatase activities during composting.



Protease activity

Protease is an enzyme that is involved in nitrogen cycle and performs proteolysis of the peptide bonds that link amino acids. A perusal of Fig. 5d showed that protease activity varied between 1.29 and 6.38 mg Tyr g⁻¹ dw h⁻¹. Maximum protease activity was observed at 14 days of composting (5.00–6.38 mg Tyr g⁻¹ dw h⁻¹) for pits 2, 3 and 4 but obtained at 28 days in pits 1 and 5. Overall, protease activity increases by 31.36, 15.00 and 5.45% over control at 70-day composting in pits 2, 3 and 4, respectively, but decreased by 41.36% in pit 5. The present results agree with the results reported by several researches when MSW, agricultural waste, horse manure, TS and HH wastes used for composting (Vig et al. 2011; Awasthi et al. 2015). The highest decrease in protease activity for pit 5 could be due to the presence of high amount of HH as well as TS as those materials having plenty of nitrogenous compounds.

Germination index of tea and pea

Germination index (GI) is another compost maturity assessment criterion that reflects toxicity pattern with respect to crop. Zucconi et al. (1981) reported that several metabolic compounds are generated during composting that may cause toxicity towards plants. In general, toxicity of composting mass decreases with progress of composting as shown in Fig. 5e, f for tea and pea, respectively. Tea seed (*Camellia sinensis* L.) GI values varied from 22.7 to 30.0% at the starting stage of composting while pea seeds ranged from 34 to 48%. The lower GI values for tea seed could be due to variation in germination rate. Furthermore, the lower GI values at the initial composting stage can be ascribed to the presence of high soluble salts concentration as reflected by high EC value and lower N concentration (Karak et al. 2014b). A negative correlation between EC and GI in the present study reflected the high soluble salt concentration, which hindered seed germination. The value

Table 2 Changes in the microbial (total aerobic mesophile, aerobic bacilli, *Salmonella* spp./*Shigella* spp. and yeast/moulds) count (expressed as log₁₀ of CFU g⁻¹ wet compost) during the progress of composting (values represents mean of three replications ± standard error of the mean)

Pit number ^a	Microbial	Composting time (days)					
		0	14	28	42	56	70
PIT 1	TAM	6.50 ± 0.03	5.44 ± 0.05	4.20 ± 0.02	3.04 ± 0.05	0.97 ± 0.11	0.46 ± 0.09
PIT 2		6.38 ± 0.02	5.28 ± 0.01	3.78 ± 0.01	2.78 ± 0.01	1.78 ± 0.04	1.00 ± 0.05
PIT 3		6.43 ± 0.05	5.32 ± 0.04	4.08 ± 0.15	2.95 ± 0.02	1.85 ± 0.07	1.00 ± 0.05
PIT 4		6.30 ± 0.04	4.95 ± 0.06	4.23 ± 0.03	3.15 ± 0.02	1.30 ± 0.06	0.48 ± 0.09
PIT 5		6.46 ± 0.01	5.23 ± 0.06	3.78 ± 0.09	2.99 ± 0.01	1.95 ± 0.03	0.95 ± 0.03
PIT 1	AB	9.95 ± 0.03	8.27 ± 0.07	7.38 ± 0.02	7.24 ± 0.07	4.76 ± 0.09	2.44 ± 0.05
PIT 2		9.83 ± 0.00	8.58 ± 0.01	7.34 ± 0.03	7.11 ± 0.02	4.78 ± 0.02	2.08 ± 0.02
PIT 3		9.69 ± 0.09	8.66 ± 0.05	7.26 ± 0.01	6.95 ± 0.09	5.18 ± 0.19	2.34 ± 0.14
PIT 4		9.46 ± 0.01	8.79 ± 0.01	6.99 ± 0.03	6.30 ± 0.03	5.53 ± 0.01	2.97 ± 0.03
PIT 5		9.32 ± 0.10	8.72 ± 0.06	7.09 ± 0.07	6.90 ± 0.28	5.43 ± 0.05	2.63 ± 0.22
PIT 1	SS	0.95 ± 0.03	0.95 ± 0.06	0.90 ± 0.03	0.83 ± 0.07	0.76 ± 0.09	–
PIT 2		0.90 ± 0.03	0.85 ± 0.04	0.78 ± 0.09	0.70 ± 0.11	–	–
PIT 3		1.04 ± 0.10	1.04 ± 0.12	0.95 ± 0.16	0.85 ± 0.17	–	–
PIT 4		1.15 ± 0.04	1.08 ± 0.02	1.04 ± 0.05	0.85 ± 0.04	0.60 ± 0.06	–
PIT 5		1.26 ± 0.03	1.08 ± 0.04	1.00 ± 0.05	0.85 ± 0.07	0.78 ± 0.00	–
PIT 1	YM	6.34 ± 0.03	5.14 ± 0.04	4.00 ± 0.03	2.77 ± 0.04	0.94 ± 0.09	0.26 ± 0.14
PIT 2		6.49 ± 0.02	5.38 ± 0.01	4.28 ± 0.03	3.15 ± 0.07	1.00 ± 0.08	–
PIT 3		6.28 ± 0.01	5.46 ± 0.02	4.11 ± 0.02	3.04 ± 0.02	1.70 ± 0.04	0.30 ± 0.14
PIT 4		6.76 ± 0.01	5.77 ± 0.01	4.58 ± 0.01	3.66 ± 0.01	2.18 ± 0.03	1.20 ± 0.02
PIT 5		6.45 ± 0.02	5.63 ± 0.01	4.20 ± 0.02	3.36 ± 0.01	2.04 ± 0.05	0.78 ± 0.04

TAM total aerobic mesophile, AB aerobic bacilli, SS *Salmonella* spp. and *Shigella* spp., YM yeast and moulds

^a Pit 1—MSW:TS:PS:CD:HH::1:1:1:1:0 (i.e. weight ratio in kg; MSW:TS:PS:CD:HH::718:613:466:484:0); Pit 2—MSW:TS:PS:CD:HH::1:1:1:1:0.10 (i.e. weight ratio in kg; MSW:TS:PS:CD:HH:: 701:598:455:473:48); Pit 3—MSW:TS:PS:CD:HH:: 1:1:1:1:0.20 (i.e. weight ratio in kg; MSW:TS:PS:CD:HH:: 684:584:444:461:93); Pit 4—MSW:TS:PS:CD:HH:: 1:1:1:1:0.30 (i.e. weight ratio in kg; MSW:TS:PS:CD:HH:: 668:570:434:451:136) and Pit 5—MSW:TS:PS:CD:HH:: 1:1:1:1:0.40 (i.e. weight ratio in kg; MSW:TS:PS:CD:HH:: 653:557:424:440:178)

of GI of tea seed for all pits at 42 days of composting exceeded 50% while pea seed attained 50% GI within 14 days of composting for all pits. It has been documented that $GI < 25\%$ is described as very phytotoxic while GI range from >25 to $<65\%$ is described as phytotoxic even though at 50% plants could withstand. However, compost with GI range from >65 to $<100\%$ can be considered as non-phytotoxic and stable for agricultural uses while compost with $GI \geq 100$ represents as phytonutrient–phytostimulant that can be used as agricultural amendments for

fertilizer. Therefore, composts produced from pits 4 and 5 in this study can be regarded as the best quality compost considering their GI values for tea and pea seeds that were 109.2 and 106.5% for tea and 103.2 and 105.4% for pea seeds, respectively, at 70 days of composting.

Microbial activities

The microbial counts, namely total aerobic mesophiles (TAM), aerobic bacilli (AB), *Salmonella* spp./*Shigella* spp.

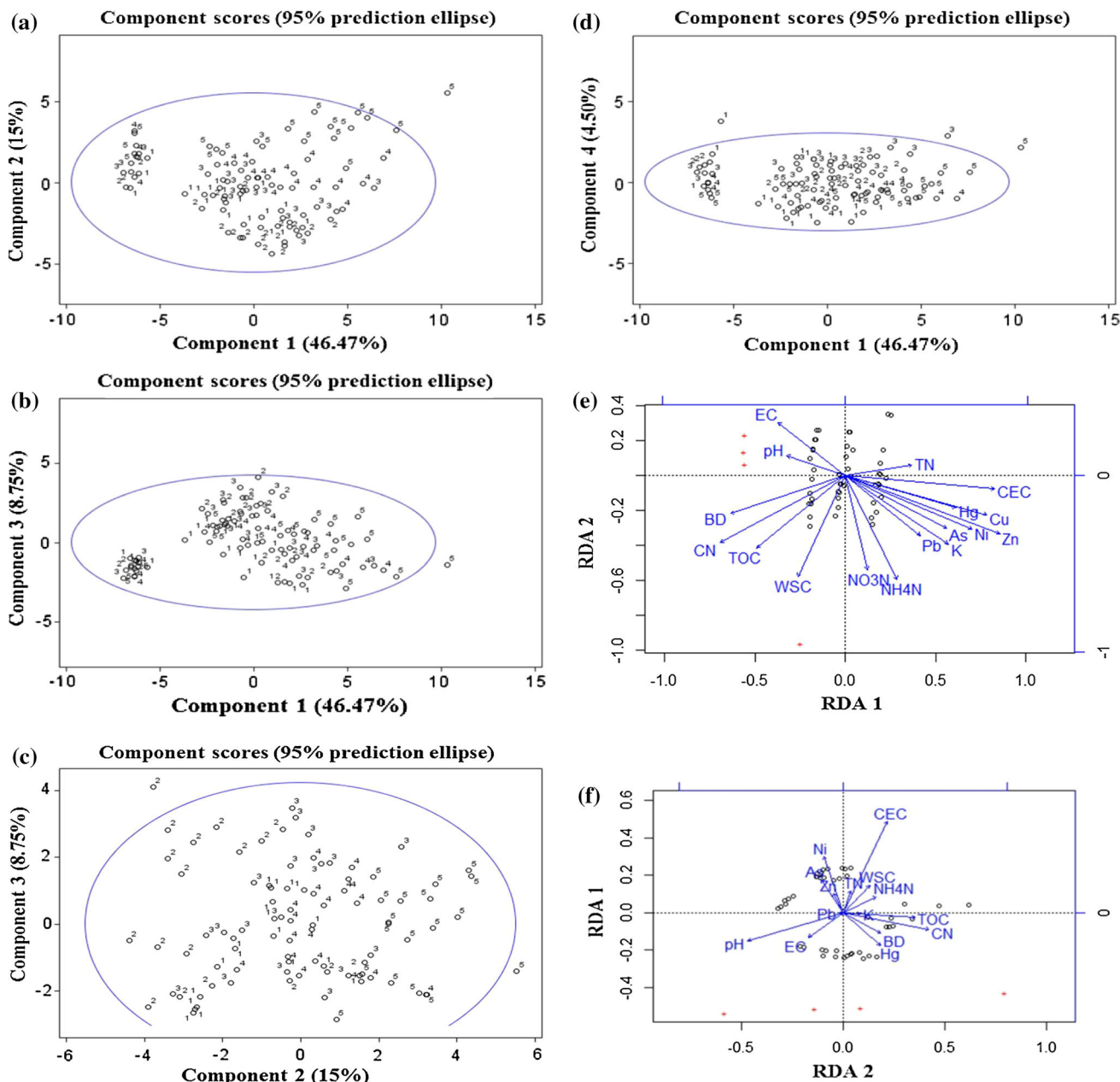


Fig. 6 95% Prediction ellipse in the varimax rotation **a** PC1 versus PC2, **b** PC1 versus PC3, **c** PC2 versus PC3, **d** PC1 versus PC4 and redundancy analysis (RDA) of microbial communities and soil

physico-chemical properties for **e** 0–41 days and **f** 42–70 days (“+” indicates the microbial communities and the “o” indicates the day of sampling)

(SS) and yeast/moulds (YM), during composting are shown in Table 2. The measured total microbial counts during the initial composting stage showed that the composting pits that received higher amount of TS, MSW and PS recorded significant count decreases as composting progressed. Varma and Kalamdhad (2015) attributed the drop in microbial count to nutrient exhaustion and higher temperature during the thermophilic phase.

Statistical interpretation

The Pearson’s correlations as reported in Table S2 indicated that most of the reported variables are significantly correlated among themselves. The sign of the correlation coefficients denotes the nature of association, i.e. positive or negative. The repeated measures analysis revealed that the responses of all the variables are significantly different in the five pits.

In the RDA, we consider the variables TAM, AB, SS and YM as the response variables and all other variables as predictor variables. RDA can also be considered as a constrained version of PCA, wherein canonical axes—built from linear combinations of response variables—must also be linear combinations of the explanatory variables. The RDA approach generates one ordination in the space defined by the matrix of response variables and another in the space defined by the matrix of explanatory variables (Legendre and Legendre 1998).

RDA produces an ordination that summarizes the main patterns of variation in the response matrix which can be explained by a matrix of explanatory variables. Choosing an appropriate scaling and interpreting this ordination are very important. The total variance of the dataset is

partitioned into constrained and unconstrained variances. This result shows how much variation in the response variables was redundant with the variation in the explanatory variables. If the constrained variance is much higher than the unconstrained variance, the analysis suggests that much of the variation in the response data may be accounted for by explanatory variables. In the present datasets, for 0–28 days temperature-constrained variance constitutes 98.2% of the total variance and the remaining by unconstrained variance, whereas in 42–70 days temperature-constrained variance constitutes 99.2% of the total variance and the remaining by unconstrained variance. In both the cases, the models are highly significant. RDA ordinations may be presented as a biplot (Fig. 6). The interpretation of these plots depends on what scaling has been chosen. In general, type II scaling is used if the correlative relationships between variables are of more interest. In the present case, type II scaling has been used. In Fig. 6, the RDA biplot ordines objects as points while the response or explanatory variables serve as vectors. Levels of nominal variables were plotted as points.

The Kaiser–Meyer–Olkin (KMO) test for sample adequacy showed the appropriate application of principal component for the present dataset. First five PCs (eigenvalues greater than one) expressed about 79% of the total variability present in the system. The varimax rotated factors were extracted through PCA method and they are displayed in Fig. 6.

Hierarchical cluster analysis resulted in three distinct homogenous groups of the pits based on all the standardized variables. Pits 1, 2 and 3 collectively form a homogenous group, whereas pits 4 and 5 form the second and third group, respectively. The dendrogram is displayed in Fig. 7.

Fig. 7 Dendrogram of the 5 pits based on soil physico-chemical properties

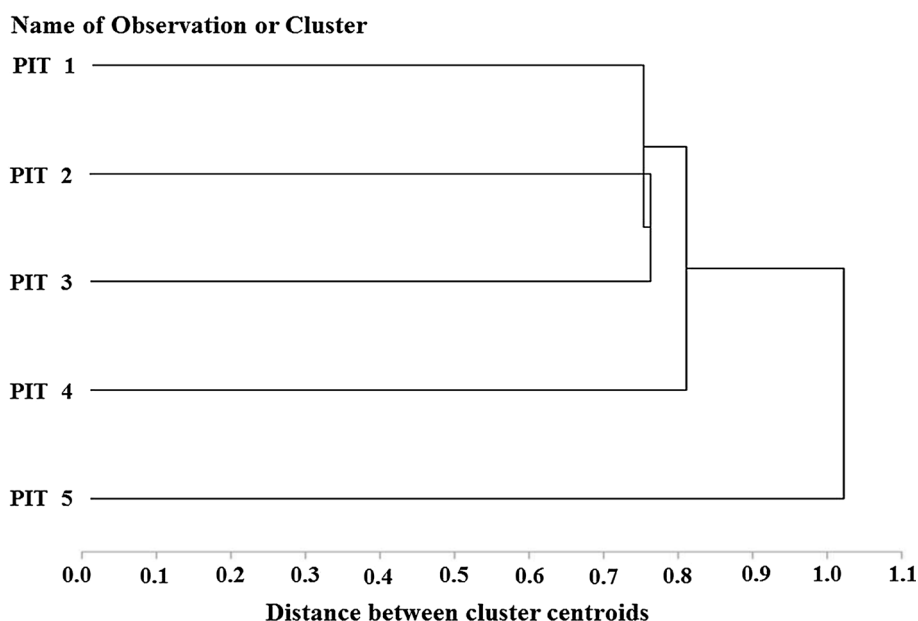


Table 3 Best fitted probability distribution of different variables

Variable	Distribution	Parameters	K–S statistics	<i>p</i> value
Volume reduction	Cauchy	$\sigma = 0.43053, \mu = 1.5319$	0.091	0.415
Bulk density	Burr	$k = 309.07, \alpha = 12.797, \beta = 1.8738$	0.063	0.836
pH	Dagum	$k = 0.55712, \alpha = 48.635, \beta = 7.1543$	0.048	0.978
Electrical conductivity (EC)	Dagum	$k = 0.23859, \alpha = 15.906, \beta = 5.0648$	0.086	0.496
Total organic carbon (TOC)	Gen. gamma (4P)	$k = 3.9286, \alpha = 0.41373, \beta = 20.81, \gamma = 17.967$	0.062	0.857
Oxidizable carbon (OXC)	Johnson SU	$\gamma = -2.2576, \delta = 2.7979, \lambda = 12.037, \xi = 13.753$	0.041	0.997
Water-soluble carbon (WSC)	Johnson SB	$\gamma = 0.2545, \delta = 0.65958, \lambda = 27.982, \xi = 2.187$	0.057	0.913
Cation exchange capacity (CEC)	Johnson SB	$\gamma = 0.18642, \delta = 1.1099, \lambda = 116.03, \xi = -3.5514$	0.045	0.990
Total nitrogen (TN)	Gen. extreme value	$k = 0.12489, \sigma = 0.092, \mu = 1.599$	0.108	0.232
Ammoniacal nitrogen (NH ₄ ⁺ -N)	Lognormal	$\sigma = 0.56147, \mu = 8.0485$	0.048	0.980
Nitrate nitrogen (NO ₃ ⁻ -N)	Burr	$k = 0.41205, \alpha = 5.5513, \beta = 2362.3$	0.066	0.809
Carbon-to-nitrogen ratio (C/N)	Johnson SB	$\gamma = 0.10705, \delta = 1.0409, \lambda = 17.929, \xi = 10.218$	0.049	0.974
P as P ₂ O ₅	Gen. Pareto	$k = -0.74981, \sigma = 2.1469, \mu = 0.34584$	0.049	0.975
K as K ₂ O	Dagum	$k = 0.25641, \alpha = 12.853, \beta = 3.151$	0.045	0.990
As as As ₂ O ₃	Gen. Pareto	$k = -0.3717, \sigma = 2.468, \mu = 0.20877$	0.055	0.934
Cd	Dagum	$k = 0.19858, \alpha = 4.0036, \beta = 2.5057$	0.079	0.608
Cr	Dagum	$k = 0.24442, \alpha = 7.743, \beta = 36.215$	0.070	0.738
Cu	Chi-squared (2P)	$\nu = 2046, \gamma = -1884.3$	0.049	0.975
Hg	Weibull	$\alpha = 3.9516, \beta = 0.07118$	0.060	0.886
Ni	Dagum (4P)	$k = 0.1595, \alpha = 7.4739, \beta = 32.249, \gamma = 2.2157$	0.052	0.955
Pb	Gen. gamma (4P)	$k = 3.5761, \alpha = 0.53601, \beta = 50.729, \gamma = 19.881$	0.041	0.997
Zn	Gen. extreme value	$k = -0.44726, \sigma = 213.37, \mu = 411.45$	0.086	0.487
GI of tea seed	Gen. Pareto	$k = -1.4925, \sigma = 100.32, \mu = 18.622$	0.063	0.848
GI of pea	Dagum	$k = 0.12296, \alpha = 24.441, \beta = 87.511$	0.049	0.975
Amylase activity	Inv. Gaussian (3P)	$\lambda = 46.961, \mu = 6.8663, \gamma = 6.0383$	0.036	1.000
Cellulase activity	Log–logistic (3P)	$\alpha = 1.7620E + 8, \beta = 1.2921E + 8, \gamma = -1.2921E + 8$	0.067	0.788
Protease activity	Johnson SB	$\gamma = 0.63725, \delta = 1.0869, \lambda = 7.3589, \xi = 0.5655$	0.032	1.000
Phosphatase activity	Pearson 6	$\alpha_1 = 17.867, \alpha_2 = 116.5, \beta = 32.532$	0.039	0.999
TAM	Gen. Pareto	$k = -0.96577, \sigma = 6.7109, \mu = 0.0818$	0.063	0.850
AB	Gen. extreme value	$k = -0.55962, \sigma = 2.6195, \mu = 6.134$	0.099	0.319
SS	Gen. Pareto	$k = -2.0555, \sigma = 2.8087, \mu = -0.22202$	0.051	0.965
YM	Gen. Pareto	$k = -1.1939, \sigma = 8.5747, \mu = -0.33293$	0.051	0.967

To this end, several probability distributions were fitted to individual variables. The results are depicted in Table 3. A perusal of Table 3 indicates that pH, EC, K, Cd, Cr, Ni and GI pea follow Dagum distribution; BD and NO₃⁻-N follow Burr distribution; volume reduction follows Cauchy distribution; TOC and Pb follow generalized Gamma distribution; OXC, WSC, CEC and C/N follow Johnson distribution; TN, Zn and AB follow generalized extreme value distribution; P, As, GI of tea seed, TAM, SS, YM follow generalized Pareto distribution; NH₄⁺-N, Cu and Hg follow lognormal, Chi-square and Weibull distribution, respectively.

Conclusion

The present study revealed that HH can be successfully composted with other wastes such as MSW, CD, PS and TS. Analysis of several physical, chemical, enzymatic, microbial activities and germination index confirmed that matured compost can be produced within 10 weeks. Analysis of repeated measures revealed significant differences in the responses of measured variables among different pits. The RDA model was highly significant for mesophilic and thermophilic compost temperatures indicating the predictability of response variables based on

predictors. Hierarchical cluster analysis formed three distinct homogenous groups of the pits. Five PCs could expressed around 79% of the total variability in the system.

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Compliance with ethical standards

Conflict of interest The authors declare no competing financial interest.

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