Bioresource Technology 114 (2012) 382–388

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Additives aided composting of green waste: Effects on organic matter degradation, compost maturity, and quality of the finished compost

Jagdish Gabhane [a], SPM. Prince William [a,*], Rajnikant Bidyadhar [b], Priya Bhilawe [a], Duraisamy Anand [a], Atul N. Vaidya [a], Satish R. Wate [a]

[a] Solid and Hazardous Waste Management Division, National Environmental Engineering Research Institute, Nehru Marg, Nagpur, Maharashtra, India
[b] Abhijeetgroup, Chaklabana, Chandwa, Jharkhand, India

ARTICLE INFO

Article history:
Received 28 October 2011
Received in revised form 6 February 2012
Accepted 8 February 2012
Available online 25 February 2012

Keywords:
Additives
Compost
Jaggery
Polyethylene glycol
Gradation test

ABSTRACT

The effect of various additives such as fly ash, phosphogypsum, jaggery, lime, and polyethylene glycol on green waste composting was investigated through assessing their influence on microbial growth, enzymatic activities, organic matter degradation, bulk density, quality of finished compost including gradation test, heavy metal analysis, etc. A perusal of results showed that addition of jaggery and polyethylene glycol were helpful to facilitate composting process as they significantly influenced the growth of microbes and cellulase activity. The quality of finished compost prepared from jaggery and polyethylene glycol added treatments were superior to other composts, wherein reduction in C/N ratio was more than 8% in jaggery treatment. All other parameters of compost quality including gradation test also favored jaggery and polyethylene glycol as the best additives for green waste composting.

1. Introduction

Composting is one of the best-known processes for the biological stabilization of solid organic wastes by transforming them into a safer and more stabilized material (compost) that can be used as a source of nutrients and soil conditioner in agricultural applications (Garcıá-Gó mez et al., 2005; Kuhlman, 1990). Normally, composting is a labor intensive and time consuming process which makes it unattractive for entrepreneurship prospects. However, recent days have witnessed a renewal of interest in composting due to the advancements in composting technology. Techniques such as mechanical–biological composting (MBC), co-composting using additives, rapid composting using accelerators and microbial inoculums have made composting easy and opened avenues for entrepreneurship in waste management sector.

Additives are usually mixtures of different amounts of various microorganisms, mineral nutrients, or readily available forms of carbon, enzymes and pH-balancing compounds that are meant to enhance microbial activity when the additive is in contact with the waste material (Himanen and Hänninen, 2009). The effects chemical additives such as coal fly ash, wood ash, green liquor dregs, bauxite, natural zeolites, and kaoline on composting of municipal solid waste, green waste, sludge, catering waste have been extensively studied by different researchers (Belyaeva and Haynes, 2009; Koivula et al., 2004; Kurola et al., 2011; Villaseñor et al., 2011; Wong et al., 1997; Zambrano et al., 2010). Wong and Fang (2000) found a positive effect of lime on composting by increasing temperature and CO_2 evolution without any negative effects on microbial community. Himanen and Hänninen (2009) studied the effect of commercial additives containing sulfates and oxides of iron, magnesium, manganese, and calcium hydroxide on composting. Similarly, Yu and Huang, 2009 studied the effect of sodium acetate on composting of food waste and found an increase in microbial activity as the result of sodium acetate application.

Although various chemical additives have been tested for their efficiency in composting, use of sugar as an additive in composting process has not been explored so far. Sugar as a carbon source can promote the growth of degrading microbes and hasten composting process. Similarly, the role of surfactants on composting process also needs to be explored further, although its role on cellulase activity has been studied extensively. Application of polyethylene glycol in enzymatic hydrolysis of lignocellulose is studied by Borjesson et al. (2007), he found that polyethylene glycol increased the rate of enzymatic conversion of cellulose and decreased the amount of enzyme needed. However, its effects on composting are not known.

Addition of surfactant Tween 80 and biosurfactant rhamnolipid to the composting substrate had stimulatory effects on the microbial population of bacteria, actinomycetes and fungi, and composting occurs rapidly (Shi et al., 2006). Although previous works have

* Corresponding author. Tel./fax: +91 712 2249752.
E-mail address: prince14271@yahoo.com (SPM.P. William).

0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2012.02.040

clearly indicated that additives could be beneficial for composting process, a comprehensive study comprising the effectiveness and mode of action of different additives on composting process has not been carried out.

Therefore, the present investigation aims at studying the effects of various additives such as fly ash, lime, phosphogypsum, polyethylene glycol, and jaggery on composting process through assessing their influence on organic matter degradation, compost maturity and the quality of finished compost. It is also proposed here the most effective additives for rapid composting and production of quality compost from green wastes.

2. Methods

2.1. Collection and processing of composting material

The green waste (GW) consisting of grass cuttings and fallen leaves collected from the garden area of National Environmental Engineering Research Institute (NEERI) was used as the raw material for composting in the present investigation. After initial screening, GW was sun dried for 3 days and pulverized to the size of 10–25 mm for further experiments. Known quantity of this powdered material was subjected to initial compositional analysis and the remaining for composting experiments.

2.2. Experimental set up

Composting experiments were carried out in thermocol boxes of 1 kg capacity. One kilogram of dried and shredded material was taken in a tray, sprinkled with water and added 5% of each additive on a dry weight basis. Three replicates were maintained for each additive and necessary care was taken to minimize any external disturbance affecting the composting process.

The experiments were carried out in the laboratory with an average room temperature of 25 ± 3 °C and relative humidity as 60%. Samples were collected from all treatments once in 3 days up to 21 days and were analyzed for physical, chemical and biological parameters. Changes in temperature during composting were recorded using a mercury thermometer kept permanently in the composters.

2.3. Chemical analysis

All the chemical analyses were performed on dried and powdered samples. The pH of compost was determined in deionized water with 1:10 (W/V) compost: water ratio (Sasaki et al., 2003). The organic carbon content of compost was estimated by combustion method (Nelson and Sommers, 1982).The total nitrogen (TN) content of the sample was estimated using LECO Protein-Nitrogen Analyzer (Model FP528). The cellulose concentration of compost was estimated by HNO_3-ethanol method of Liu (2004). Lignin content of sample was estimated by 72% (v/v) H_2SO_4 method according to Liu (2004). The concentration of potassium was estimated using flame photometer (Systronics-Model-128). Phosphate estimation was carried out by stannous chloride method using UV spectrophotometer at 690 nm. For heavy metal analysis, samples were digested with triple acid (nitric, sulfuric and perchloric) mixture in the ratio of 9:2:1 and the digestate was analyzed using ICP (Perkin Elmer- Model OES -4100 DV).

2.4. Physical analysis

2.4.1. Particle size determination

Particle size determination was carried out by sieve analysis method where compost samples were sieved through sieves of different mesh sizes (0.5–15 mm) until the amount retained becomes more or less constant. The sieved particles of different fractions were weighed separately and using their weights the cumulative passing percentage (CPP) was calculated as:

$$\mathrm{CPP} = 100 - \%\mathrm{retention}$$

where

$$\%\mathrm{retention\ is\ equal\ to} = \frac{\mathrm{Wt.\ of\ sample\ retained\ in\ sieve}}{\mathrm{Total\ wt.\ of\ sample}}$$

2.4.2. Bulk density determination

Bulk density was determined by using pycnometer method (Blake et al., 1986) and calculated using the formula:

$$\mathrm{Bulk\ density}(\mathrm{g/cm^3}) = \frac{\mathrm{Weight\ of\ sample\ in\ gram}}{\mathrm{Volume\ in\ sample}(\mathrm{cm^3})}$$

2.5. Biological parameter

2.5.1. Cellulase activity

The activity of cellulase was determined in fresh samples (1 g) after 3 days interval up to 21 days by filter paper assay of Adney and Baker (1996). The activity is reported in FPU/g/h. The value of 2.0 mg of reducing sugar as glucose from 50 mg of filter paper (4% conversion) in 60 min has been designated as the intercept for calculating filter paper cellulase units (FPU) as per IUPAC standards.

2.5.2. Estimation of microbial population

Total microbial biomass of compost samples was determined by serial dilution method. One gram of compost sample on dry weight basis was taken and serially diluted in sterile distilled water. One milliliter from each dilution was plated onto potato dextrose agar media and incubated at 30 °C for 48 h. The colony forming units (CFU) were counted and the values were multiplied with dilution factor and expressed in CFU/g of compost.

2.5.3. Dehydrogenase activity (DA)

Dehydrogenase activity was determined according to standard procedures (Method 05.04-B) provided by the US Department of Agriculture and US Composting Council (2001). Values of DA are expressed as mg of triphenyl formazan (TPF) released/g dry matter/h.

2.6. Statistical analysis

All the experimental analyses were carried out in triplicate and the mean values with standard deviation are presented. The data of dehydrogenase activity and bulk density were statistically analysed by one way ANOVA and Duncan's Multiple Range Test (DMRT) using SPSS software (Version 11.5). Graphical presentation of C/N ratio, cellulose activity, cellulose reduction and microbial biomass (CFU) were also statistically interfaced with error bars.

3. Results and discussion

3.1. Characterization of raw material and additives

The composting material used in the present investigation was green waste (GW) consisting of vegetable waste and garden biomass in equal (1:1) ratio. It contained 50.92% of organic carbon, 2.91% of total nitrogen, 16.17% of protein, 47.49% of cellulose, 19.5% of lignin, and 16.12% of hemicellulose. The initial C/N ratio of GW was 17.49. Similarly different additives (jaggary, polyethylene glycol, phosphogypsum, lime and fly ash) used in the present investigation were also characterized for different parameters such as organic matter, organic carbon, total nitrogen, ash content, and C/N ratio. Among the additives tested, jaggery and polyethylene glycol being organic in nature, found to contain higher (98.02% and 99.92%, respectively) amounts of organic matter. All other additives showed only negligible amounts of organic matter and organic carbon contents. The total nitrogen content of different additives was also found to be insignificant in most of the additives except jaggery and polyethylene glycol, wherein it was around 0.1%. The ash content was high in polyethylene glycol, fly ash and lime due to their high back ground concentration of minerals.

3.2. Effects of additives on temperature during composting

The change in temperature as observed in control and additive composting is presented in Fig. 1. There was an increase in thermophilic temperature (°C) in jaggery and polyethylene glycol treatments. The maximum temperature during thermophilic phase (TP) observed in case of jaggery and polyethylene glycol treatments were 53 and 51 °C, respectively. The duration of TP in these cases also extended up to 5 days against the normal duration of 3–4 days in other treatments including control. The early start and extended duration of TP in jaggery treatment could be due to the instant supply of sugars by jaggery to the composting matrix that swiftly boosted the growth of microbes leading to an increase in microbial metabolism and consequent metabolic heat as suggested by Jang et al. (2002) and Raut et al. (2008). Similarly, polyethylene glycol is also a readily available carbon source that can facilitate fast growth of microbes and microbial metabolism leading to an increase in temperature during TP. Phosphogypsum and lime did not show any stimulatory or inhibitory effects on temperature profile. However, fly ash addition inhibited the rise in temperature during thermophilic phase. Belyaeva and Haynes (2009) reported that addition of fly ash in compost can decrease the thermophilic phase by increasing the water holding capacity of the compost.

3.3. Effect of additives on pH during composting process

Fig. 2 illustrates the influence of additives on pH during composting process. The initial pH of different treatments was in the range of 5.80–5.94, excepting lime treatment wherein it was 11.21 was due to lime addition. Similar results were observed by Fang and Wong (1999) who reported that addition of 1.63% lime increased the initial pH of composting mixture effectively to 9.2.

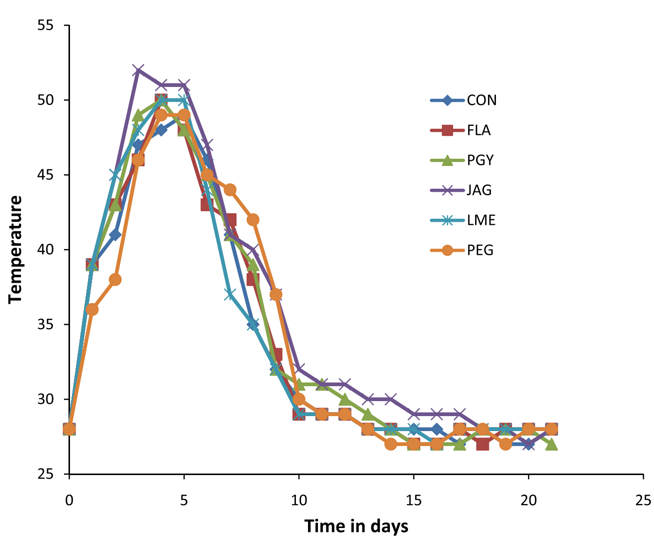

Fig. 1. Effect of additives on temperature during composting.

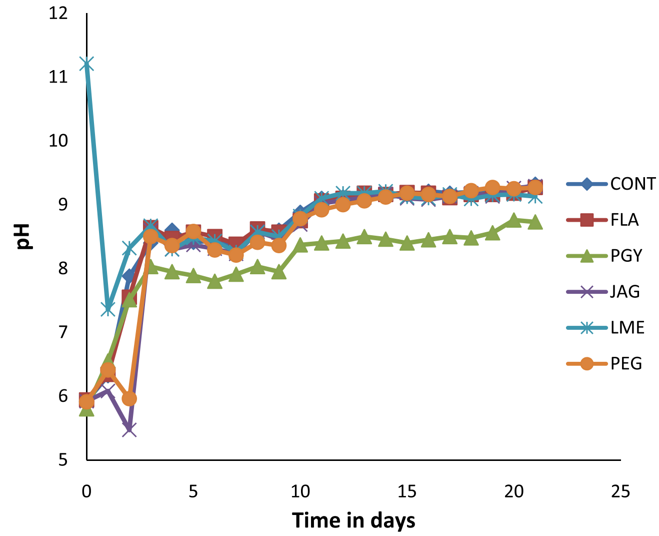

Fig. 2. Effect of additives on pH during composting.

An increase in pH was noted in all treatments right from the second day of composting including lime treatment. Notably, in lime treatment its initial pH of 11.21 reduced to 7.36 within 24 h and started rising from the second day onwards as with other treatments. Among all the additives, phosphogypsum maintained a lower range of pH throughout the composting period, probably because of its acidic (pH 4.5) nature.

3.4. Effect of additives on TOC, TN, and C/N ratio

The effect of additives on total organic carbon (TOC), total nitrogen (TN) and C/N ratio is presented in Fig. 6. Among the treatments, maximum reduction of TOC was observed in phosphogypsum (20.22) followed by fly ash (19.41). All other treatments (lime, polyethylene glycol and jaggery) showed more or less same rate of TOC reduction in the range between 14 and 16 percentages. Conversely, an increase in total nitrogen content was observed in jaggery and polyethylene glycol treatments, which indicates faster rate of organic matter degradation. As a result, C/N ratio of finished compost in these cases showed significant reduction. The reduction in C/N ratio in jaggery treatment is almost 8% as compared to other treatments.

3.5. Effect of additives on cellulose degradation

The reduction in cellulose concentration during composting is mainly due to the cellulolytic action of microbes. An increase in cellulase activity suggests the breakdown of cellulose and the recovery of cellulose after cellulolytic action would normally be low. However, in the present investigation an increase was observed in the concentration of cellulose (cellulose recovery) after cellulolytic activity (Fig. 3). Although there cannot be any further increase in the total or original concentration of cellulose after pretreatment, the relative increase in the concentration of cellulose after cellulolytic activity is due to the removal of early degradables such as proteins, lipids, and starch along with lignin and hemicellulose, wherein hemicelluloses are converted into sugars (Martin et al., 2007). Among the different additives, jaggery applied treatment showed maximum (27.02) reduction in cellulose concentration followed by polyethylene glycol (24.74) and fly ash (21.72). Jaggery as a source of sugar could have increased the numbers of microorganisms leading to an increase in cellulase activity and rate of cellulose degradation.

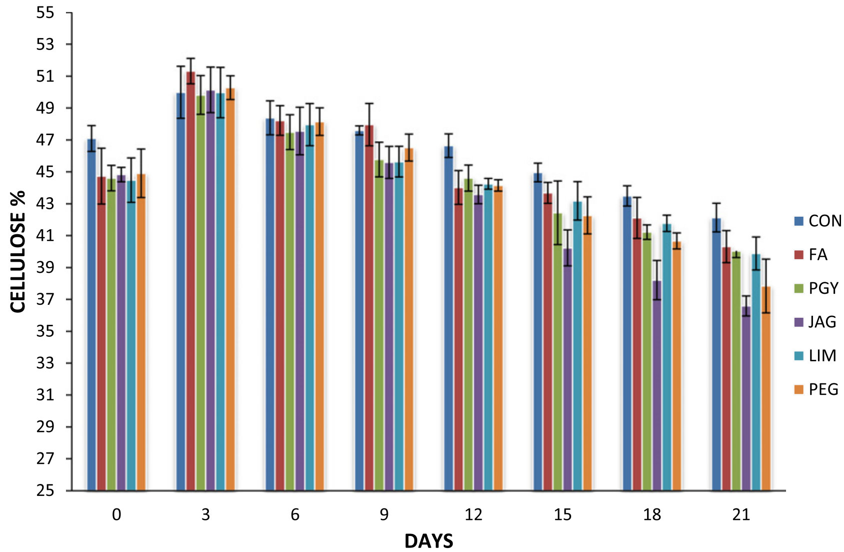

Fig. 3. Effect of additives on cellulose degradation during composting.

3.6. Influence of additives on cellulase activity and microbial biomass

Figs. 4 and 5 illustrates changes in cellulase activity and microbial biomass as induced by additives. Additives exerted significant stimulatory effects on enzymatic activity and microbial biomass. Among the additives, jaggery and polyethylene glycol, recorded highest values for cellulase activity and microbial biomass. It was observed that the growth of microbes and activity of cellulase in jaggery treatment significantly increased within three days from the start of the experiment and then declined slowly. The sudden increase in microbial biomass and cellulase activity could be due to the supply of carbon, nitrogen and other nutrients to cellulolytic microbes by jaggery. Jaggery is a high calorific energy substrate for microorganism. It consists of 50–70% sugar, 20–25% invert sugar, 4–6% protein, sufficient amount nutrients and vitamins (Rao et al., 2007). Polyethylene glycol treatment despite having low microbial biomass its cellulase activity was significantly high compared to control; probably due to the stimulatory action of polyethylene glycol on cellulase production (Reese and Manguire, 1969; Pardo, 1996). Lime and fly ash also contain vital nutrients useful for microbial growth, however, they could not increase the microbial biomass and enzymatic activity, may be because their high pH. At high pH the activity of cellulase and microbial growth are very slow because it creates an uncongenial condition for cellulase activity and for the growth of cellulose decomposers (Rao and Radhakrishna (2008)).

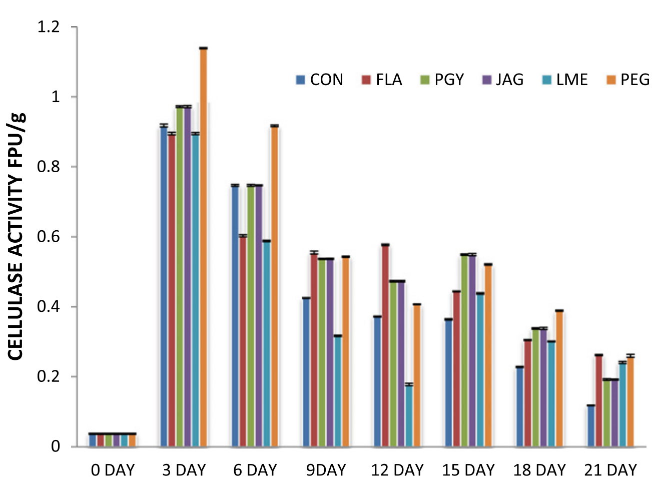

Fig. 4. Effect of additives on cellulase activity during composting.

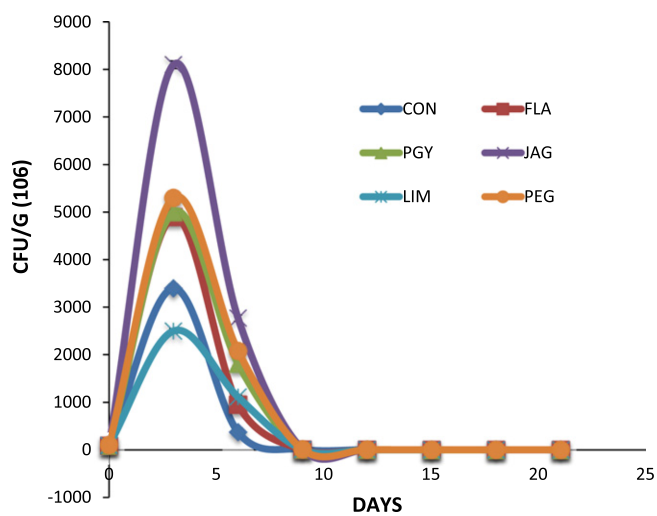

Fig. 5. Effect of additives on microbial biomass during composting.

3.7. Effect of additives on dehydrogenase activity

Dehydrogenase activity is a measure of overall heterotrophic microbial inhabitants in soils and composts (Alef, 1995; Tiquia et al., 1996). In the present study, the dehydrogenase activity was its highest (19.5 mg TPF g^{-1} 24 h^{-1}) at the beginning of composting process (Table 1) up to 6th day and thereafter it rapidly decreased and level off from 18th day. Thus, the overall activity of dehydrogenase was high during the thermophilic phase and it declined towards mesophilic phase. These results confirm the studies of Barrena et al. (2007) who found a positive correlation between dehydrogenase activity and temperature. Decreasing numbers of heterotrophic microbial population indicates the succession of cellulolytic ones. It also signifies the degradation of substrates other than cellulose such as starch, proteins, fat.

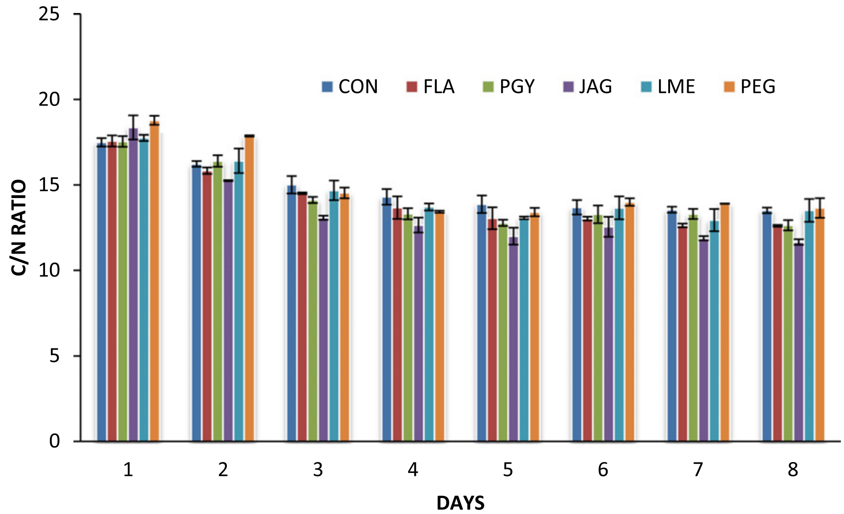

Fig. 6. Effect of additives on C/N ratio.

Table 1
Effect of additives on dehydrogenase activity.

Days/treatments	0 (initial)	3	6	9	12	15	18	21
CON	19.5 ± 0.60	12.19 ± 1.10a	1.235 ± 0.21a	0.720 ± 0.22ab	0.481 ± 0.08a	0.238 ± 0.06a	0.024 ± 0.00ab	0.024 ± 0.002b
FLA	19.5 ± 0.60	17.72 ± 1.14c	1.890 ± 0.11b	0.990 ± 0.05c	0.663 ± 0.05bc	0.265 ± 0.02a	0.030 ± 0.003b	0.028 ± 0.004b
PGY	19.5 ± 0.60	20.49 ± 0.93e	1.860 ± 0.08b	0.675 ± 0.03a	0.661 ± 0.03bc	0.298 ± 0.03a	0.060 ± 0.006c	0.049 ± 0.003c
JAG	19.5 ± 0.60	19.62 ± 0.47de	1.998 ± 0.04b	1.250 ± 0.10d	0.729 ± 0.01c	0.305 ± 0.03a	0.090 ± 0.003d	0.078 ± 0.005d
LME	19.5 ± 0.60	15.12 ± 0.53b	1.455 ± 0.09a	0.720 ± 0.06ab	0.602 ± 0.01b	0.282 ± 0.03a	0.015 ± 0.003a	0.015 ± 0.001a
PEG	19.5 ± 0.60	18.00 ± 1.11 cd	1.796 ± 0.16b	0.900 ± 0.05bc	0.485 ± 0.03a	0.278 ± 0.04a	0.098 ± 0.014a	0.075 ± 0.008d

CON, control; FLA, fly ash; PGY, phosphogypsum; JAG, jaggery; LME, lime; PEG, polyethylene glycol.
Data are means ± SD (n = 3).
Means followed by the same letter in a column are not significantly different at $P \leqslant 0.05$ by DMRT.

3.8. Effect of additives on particle size distribution and bulk density of finished compost

Gradation test is used to assess the particle size distribution (also called *gradation*) of a granular material (Mcglinchey, 2005). It is one of the simple measures of organic matter degradation. Gradation test is of great relevance to compost maturity analysis as it indicates the extent of degradation of complex substances. Normally, best compost should have 90% cumulative passing through 12.6 mm sieve (Darlington, 2001).The cumulating passing more than 15 mm sieve is not good for a compost to be applied into field. However, excessive dust fraction (particles less than 500 μm) cause difficulties in handling and can also be an indication of low organic content. In the present study 0.5–15 mm size sieves were used to fractionate the material and to calculate cumulative passing percentage. Accordingly, it was found that Jaggery and Poly ethylene glycol treatments were better than other treatments (Table.2).

The initial BD of the substrate used in the present investigation was 0.56 (Table 3.), which at the end of composting process increased to the range between 0.76 and 0.82 in all treatments. However, maximum increase in BD was observed in case of jaggery (0.82). Other treatments also showed significant increase in BD

Table 3
Effect of additives on the bulk density of finished compost.

Treatments	Bulk density (g/cm^3)
Initial	0.5655 ± 0.008a
CON	0.7611 ± 0.009b
FLA	0.8225 ± 0.014c
PGY	0.8056 ± 0.016c
JAG	0.8221 ± 0.144c
LME	0.8141 ± 0.029c
PEG	0.8118 ± 0.044c

CON, control; FLA, fly ash; PGY, phosphogypsum; JAG, jaggery; LME, lime; PEG, polyethylene glycol.
Data are means ± SD (n = 3).
Means followed by the same letter in a column are not significantly different at $P \leqslant 0.05$ by DMRT.

Table 2
Effect of additives on the particle size distribution of finished compost (gradation test).

	Initial	CON	FA	PGY	JAG	LIM	PEG
Fraction I (0.5)	34.16	24.35	30.57	35.04	46.99	30.65	40.17
Fraction II (1.68)	90.57	76.36	81.65	82.58	90.15	83.77	84.07
Fraction III (3.55)	99.86	88.45	90.49	91.65	98.99	90.29	98.99
Fraction IV (8)	100	100	100	100	100	100	100
Fraction V (15)	100	100	100	100	100	100	100

Table 4
Micronutrient and heavy metal content of finished compost.

Parameters	CON	FLA	PGY	JAG	LME	PEG
Organic matter (%)	75.06	67.41	67.34	73.19	70.83	74.88
Ash content (%)	24.94	32.59	32.66	26.81	29.17	25.12
TOC (%)	43.53	39.10	39.06	42.45	41.08	43.43
TN (%)	3.22	3.10	3.09	3.64	3.04	3.18
C/N ratio	13.57	12.61	12.64	11.66	13.51	13.65
Cellulose (%)	42.13	40.31	40.04	36.59	39.88	37.84
Sodium (mg/l)	350	370	790	900	220	224
Potassium (mg/l)	1198	1267	2790	2830	1270	980
Phosphorus (mg/l)	401	331	227	487	172	439
Concentration of heavy metals						
Zn (1000)	0.212	0.212	0.234	0.230	0.209	0.305
Pb (100)	0.235	0.235	0.132	0.045	0.232	0.162
Cd (5)	0.098	0.098	0.112	0.126	0.170	0.078
Ni (50)	0.007	0.007	BD	BD	BD	BD
Co (–)	0.064	0.064	0.111	0.105	0.075	0.085
Mn (–)	1.18	1.18	1.23	1.16	1.16	1.25
Fe (3000)	16.2	16.2	21.8	25.1	17.4	17.6
Cr (50)	0.138	0.138	0.097	0.12	0.194	0.158
Cu (300)	0.201	0.201	0.238	0.205	0.252	0.212

CON, control; FLA, fly ash; PGY, phosphogypsum; JAG, jaggery; LME, lime; PEG, polyethylene glycol.

compared to control, not because of improved rate of degradation, but for the bulking effect of additives.

3.9. Effect of additives on mineral nutrient and heavy metal content of the finished compost

Table 4 shows the availability of different heavy metals in the finished compost. A perusal of the results showed that the concentration of different heavy metals in the finished compost was not alarming and were within the permissible limits according to US composting council (1997), Similarly, concentration of different mineral nutrients (Table 4) such as Nitrogen (N), Phosphorus (P) and Potash (K) in the finished compost were also analyzed. The results showed that the availability of these essential nutrients were good in the case of jaggery and polyethylene glycol as the result of increased rate of organic matter degradation. Other additives such as phosphogypsum and fly ash also showed an increase in the overall concentration of N, P, and K in their respective compost samples. However, increasing concentrations of N, P and K in these cases is not because of organic matter degradation but due to the bulking effect of these additives that influenced the percentage calculation of these nutrients in the finished compost.

4. Conclusion

The results of the present study indicated the scope of additives aided composting process. Among the different additives, jaggery shown to influence the process of composting comparably better than any other additives tested. Jaggery enhanced composting process through increasing microbial biomass and by stimulating its enzymatic activities. This in turn reflected on the rate of organic matter degradation and quality of the finished compost as well. Apart from Jaggery and polyethylene glycol, few other additives also influenced both composting process and the quality of finished compost; however, the cost effectiveness of these additives is not encouraging.

Acknowledgements

The work is a part of CSIR-Supra Institutional Projects in Molecular Environmental Sciences (SIP-MES, Activity 4.8). The authors acknowledge the Council of Scientific and Industrial Research (CSIR) and CSIR-NEERI for the financial assistance provided.

References

Adney, B., Baker, J., 1996. Measurement of Cellulase Activities. Laboratory Analytical Procedure 006.
Alef, K., 1995. Dehydrogenase activity. In: Alef, K., Nanniperi, P. (Eds.), Methods in Applied Soil Microbiology and Biochemistry. Academic Press, London, pp. 228–231.
Barrena, R., Vazquez, F., Sanchez, A., 2007. Dehydrogenase activity as a method for monitoring the composting process. Bioresour. Technol. 99, 905–908.
Belyaeva, O.N., Haynes, R.J., 2009. Chemical, microbial and physical properties of manufactured soils produced by co-composting municipal green waste with coal fly ash. Bioresour. Technol., 5203–5209.
Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis, Part I. Physical and Mineralogical Methods: Agronomy Monograph No. 9, second ed. pp. 363–375.
Borjesson, J., Engqvist, M., Sipos, B., Tjerneld, F., 2007. Effect of poly(ethylene glycol) on enzymatic hydrolysis and adsorption of cellulase enzymes to pretreated lignocelluloses. Enzyme Microbol. Technol. 41, 186–195.
Darlington, W., 2001. Compost – A Guide for Evaluating and Using Compost Materials as Soil Amendments. Soil & Plant Laboratory, Inc., Orange Office (714) 282-8777.
Fang, M., Wong, J.W.C., 1999. Effects of lime amendment on availability of heavy metals and maturation in sewage sludge composting. Environ. Pollut. 106, 83–89.
Garcıá-Gó mez, A., Bernal, M.P., Roig, A., 2005. Organic matter fraction involved in degradation and humification processes during composting. Compost. Sci. Utiliz. 13, 127–135.
Himanen, M., Hänninen, K., 2009. Effect of commercial mineral-based additives on composting and compost quality. Waste Manage. 29, 2265–2273.
Jang, J.C., Shin, P.K., Yoon, J.S., Lee, I.M., Lee, H.S., Kim, M.N., 2002. Glucose effect on the biodegradation of plastics by compost from food garbage. Pol. Degrad. Stab. 76, 155–159.
Koivula, N., Raikkonen, T., Urpilainen, S., Ranta, J., Hanninen, K., 2004. Ash in composting of source-separated catering waste. Bioresour. Technol. 93, 291–299.
Kuhlman, L.R., 1990. Windrow composting of agricultural and municipal wastes. Resour. Conserv. Recycl. 4, 151–160.
Kurola, J.M., Arnold, M., Kontro, M.H., Talves, M., Romantschuk, M., 2011. Wood ash for application in municipal biowaste composting. Bioresor. Technol. 102, 5214–5220.
Liu, S., 2004. Analysis and Measurement in Papermaking Industry. Chemical Industry Press, Beijing, China.
Martin, C., Klinke, H.B., Thomsen, A.B., 2007. Wet oxidation as a pretreatment method for enhancing the enzymatic convertibility of sugarcane bagasse. Enzyme Microb. Technol. 40, 426–432.
Mcglinchey, D., 2005. Characterisation of Bulk Solids. CRC Press, p. 231.
Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon and organic matter. In: Page, A.L. (Ed.), Methods of Soil Analysis Part II. American Society of Agronomers, Madison, pp. 539–579.
Pardo, A.G., 1996. Effect of surfactants on cellulose production by Nectriacatalinensis. Current Microbiol. 33, 275–278.
Rao, J., Das, M., Das, S.K., 2007. Jaggery– a traditional Indian sweetener. Indian J. Tradit. Knowl. 6, 95–102.
Rao, R., Radhakrishna, D., 2008. Dynamics of cellulase activity during composting of municipal solid waste. EJEAFChe 7 (9), 3191–3198.

Raut, M.P., William, P., Bhattacharyya, J.K., Chakrabarti, T., Devotta, S., 2008. Microbial dynamics and enzyme activities during rapid composting of municipal solid waste – a compost maturity analysis perspective. Bioresour. Technol. 99, 6512–6519.

Reese, E.T., Manguire, A., 1969. Surfactants as stimulants of enzyme production by microorganisms. Appl. Microbiol. 17, 242–245.

Sasaki, N., Suehara, K.I., Kohda, J., Nakano, Y., Yano, T., 2003. Effects of CN ratio and pH of raw materials on oil degradation efficiency in a compost fermentation process. J. Biosci. Bioeng. 96, 47–52.

Shi, J.G., Zeng, G.M., Yuan, X.Z., Dai, F., Liu, J., Wu, X.H., 2006. The stimulatory effects of surfactants on composting of waste rich in cellulose. World J. Microbol. Biotechnol. 22 (11), 1121–1127.

Tiquia, S.M., Tam, N.F.Y., Hodgkiss, I.J., 1996. Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. Bioresour. Technol. 55, 201–206.

US Composting Council, 1997. Test Methods for the Examination of Composting and Compost (Interim Draft), Bethesda, Maryland.

US Department of Agriculture and US Composting Council, 2001. Test Methods for the Examination of Composting and Compost, Edaphos International, Houston.

Villaseñor, J., Rodríguez, L., Fernández, F.J., 2011. Composting domestic sewage sludge with natural zeolites in a rotary drum reactor. Bioresour. Technol. 102, 1447–1454.

Wong, J.W.C., Fang, M., Li, G.X., Wong, M.H., 1997. Feasibility of using coal ash residues as co-composting materials for sewage sludge. Environ. Technol. 18, 563–568.

Wong, J.W.C., Fang, M., 2000. Effect of lime addition on sewage sludge composting process. Water Res. 34 (15), 3691–3698.

Yu, H., Huang, G.H., 2009. Effects of sodium acetate as a pH control amendment on the composting of food waste. Bioresour. Technol. 100, 2005–2011.

Zambrano, M., Pichún, C., Alvear, M., Villarroel, M., Velásquez, I., Baeza, J., Vidal, G., 2010. Green liquor dregs effect on Kraft mill secondary sludge composting. Bioresour. Technol. 101, 1028–1035.