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ORIGINAL RESEARCH

Additive effect of cow dung slurry and cellulolytic bacterial inoculation on humic fractions during composting of municipal solid waste

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Abstract

Purpose The work aimed to investigate the effect of cow dung and cellulolytic bacteria on humic characteristics during municipal solid waste composting. Four *Bacillus* isolates (*B. subtilis, B. tequilensis, B. venezuelans* and *B. amyloliquefaciens*) sourced from dumpsite soil were formulated as consortium for the study.

Methods Four treatments were considered with addition of bulking agents (ratio 1:7:6) to 15 kg MSW. Treatment Cs_1 (control): only MSW, Cs_2: MSW + cellulolytic bacterial inoculum @ 5 ml (2×10^9 CFU ml^{-1}); Cs_3—MSW + cow dung slurry @ 1 kg (1:100 based on wet weight) and Cs_4—MSW + cellulolytic bacterial inoculum @ 5 ml (2×10^9 CFU ml^{-1}) + cow dung slurry @ 1 kg (diluted 1:100 based on wet weight). The analyses of humic acids were done by elemental analyzer, UV and Fourier transform infrared spectroscopy during 90 days of composting.

Results MSW amended with consortia of effective microorganisms and cow dung slurry projected highest humification degree at 82.4% ($P<0.01$). Highest temperature (63 °C) was recorded in the treatment Cs_4 during composting. The data corresponded to an increase in H/C ratio (0.9%) with a decrease in C/N (14.8%) and O/C ratio (0.5%). In addition, most stabilized values for E_4/E_6 ratio (4.1) and E_2/E_3 ratio (2.1) were observed in Cs_4. The humification indices manifest positive regression values (F (4, 1) = 0.007; $P<0.01$) and 99% significant model.

Conclusion In the study, bio-augmentation (bacterial consortia and cow dung slurry) to MSW composting facilitates early maturity compared to other inoculated/uninoculated treatments. The result substantiates the effect of temperature on the humification rate of composting.

Keywords Municipal solid waste · Composting · Cellulolytic bacteria · Humic acids · Cow dung · Spectroscopy

Introduction

Escalated urbanization and development have modified the framework of cities in India. Pressure on the resources and infrastructural services has intensified due to a constant increase in urban migration. Migrants generate immense municipal solid waste (MSW) on a day-to-day basis; however, the chunk of land available limits the treatment and safe disposal of such waste (Joshi and Ahmed 2016). A major part of these wastes in India consists of degradable organic material (50–55%). We can recycle and dispose them through the economic and ecofriendly technique of composting (Annepu 2012). In composting, the organic matter humidifies into a stable, organic humic product through sequential microbial activities (Pare et al. 1998). The application of a humified product (humus) improves soil texture by augmenting the micro-nutrient deficiencies (Rastogi and Nandal 2018).

Extensive research by various organizations in India is yet to explore the key issue of improving process efficiency. Two main factors identified for influencing the efficacy of process are C/N ratio (18) and temperature. Furthermore, additives in form of effective microbes (EMs) or cow dung (a low-cost and available bio-resource) had accelerated the waste treatment (Adegunloye et al. 2007). Diverse microflora (bacilli, lactobacilli, fungi, and yeasts) enter the compost matrix through these additives. It results in a series of microbial oxidation reactions and raised process temperature. This intensified the process of

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composting and enhanced the waste degradation rate. Several researchers followed the above-mentioned approach for MSW composting (Manu et al. 2016; Varma et al. 2017; Nakasaki and Hirai 2017; Voberkova et al. 2017).

Compost fertility defines the quality of product by assessing a stable fraction of residue, humic substance (HS). They are stable heterogeneous organic compounds of humus with a high molecular weight (Smidt et al. 2008). HS enhances crop fertility and productivity by balancing the soil nutrients (Scotti et al. 2015). The three main components of humic substances are humic acid (HA), fulvic acid (FA) and non-humic fractions. At the latter stage of compost, HS undergoes structural and chemical changes that correspond to compost maturity. Evaluation of HS chemistry is essential to assess compost quality and substantiate stability and maturity. Former term defines the rate of biological decomposition during the composting process (Barren et al. 2006), evaluated by determining the humification index (HA:FA) of the compost. The latter verifies the suitability of compost for crops by measuring the ratio of carbon in total humic matter and humin (DeNobili and Petrussi 1988). Various spectral techniques are currently in practice to characterize HS chemistry, such as elemental analysis. It determines the elemental composition and structural changes in HS during composting (Adani et al. 2006). Fourier transform infrared (FTIR) and UV spectroscopy are other nondestructive methods to assess the chemical complexity of the HS (Leal et al. 2015). The derived peaks or UV absorption spectra (E_2/E_3 and E_4/E_6) for HS denoted humidified aromatic material in the composted material (Chen et al. 1977).

The study investigated MSW dumped on an open waste disposal site near Sunaria village at Rohtak (a city in India). The site is under development to set up an engineered sanitary landfill facility. Landfilling with non-recyclable waste stays restricted under Schedule II of Indian MSW Rules, 2000. Conventional landfilling restrains sustainable waste management and generate toxic emissions. It may contaminate soil and groundwater through leaching as well. Composting seems to be a good pretreatment method in case of landfilling, to stabilize the MSW and reduce harmful emissions (Mahar et al. 2009). In addition, inoculation of effective microbes or supplements to waste material showed positive results. Composting with exclusive addition of cellulolytic bacteria and cow dung to MSW has been unreported. Thus, the passive bin-composting study monitored MSW, for the effect of inoculations and/or cow dung slurry on the HS. We studied the HS chemistry using elemental analysis, UV and Fourier transform infrared (FTIR) spectroscopy. Lastly, we compared the HS profiles to validate its authenticity as a maturity marker.

Materials and methodology

Each treatment bin (1.5 m × 0.6 m) with 40 circular holes (dia-50 mm) and perforated PVC pipe (dia-38 mm) was packed with 15 kg MSW (Fig. 1). Bulking agents (sawdust, fresh leaves and dry brown twigs, grass) were added in all the treatments in ratio (1:7:6). We developed a potent cellulolytic consortium [*Bacillus subtilis* (2.0 ml), *B. tequilensis* (1.0 ml), *B. venezuelans* (1.0 ml) and *B. amyloliquefaciens* (1.0 ml)] sourced from dumpsite soil. Total 5 ml of inoculum (2×10^9 CFU ml^{-1}) was sprayed on the feed stock material of each bin after mixing it with distill water in ratio 1:5 (v/v). A slurry of 1 kg fresh cow dung diluted with distill water (1:100 w/v) was added to bin Cs_3 and Cs_4. The four maintained MSW treatments were:

Compost

Cs_1 (control), 15 kg MSW and bulking agents (1:7:6:0:0)—MSW only and no inoculation.

Cs_2, 15 kg MSW and bulking agents (1:7:6:1:0)—MSW and only inoculation of bacterial consortium.

Cs_3, 15 kg MSW and bulking agents (1:7:6:0:1)—MSW and only cow dung slurry.

Cs_4, 15 kg MSW and bulking agents (1:7:6:1:1)—MSW with both cow dung slurry and inoculation of bacterial consortium.

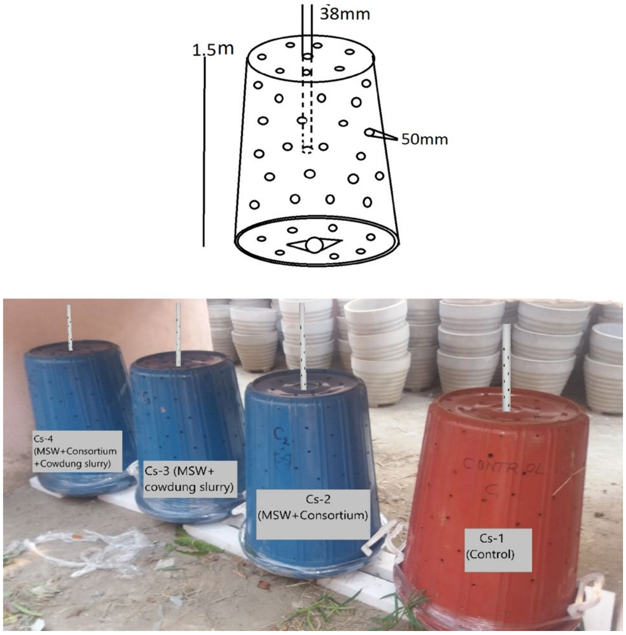

Fig. 1 Experimental setup of passive aerobic bin composting

We maintained the same level of moisture content in all the treatments by adding requisite amount of water, in place of inoculum/cow dung slurry. The compost mixture was regularly turned to provide sufficient aeration and maintain the temperature. Sampling of the generated MSW compost was done at 15, 30, 60 and 90 days until the waste got stabilized. Temperature of the bin was monitored daily by a digital thermometer during MSW composting.

Extraction of the humic substances

Thirty grams of each compost sample was washed with distill water to flush the non-HS fraction. For extraction of HA, the washed compost samples were dried and sieved through a 2-mm sieve. 2 g dried and sieved compost in a 250-ml Erlenmeyer flask with 40 ml of NaOH (0.1 M) were extracted. The supernatant was centrifuged at 4000×*g* for 15 min and filtered through Whatman paper (no. 42). The precipitation of humic acids from the solution was proceeded by adding 1.5 M H_2SO_4 for 24 h at 4 °C (Serra-Wittling et al. 1996). The FA was extracted from the supernatant by reabsorption through 0.1 M NaOH. Humic solutions were dialyzed against distilled water to eliminate the excess salts. Obtained humic solution was lyophilized by freeze-drying. The lyophilized humic acid (HA) was subjected to elemental and spectroscopic analysis to calculate the compost maturity parameters as described below.

Elemental analysis

Elemental analysis (C, H, O, and N) was done on freeze-dried (HA) samples of compost (0.5–1 mg) by an Elemental analyzer (Perkin-Elmer, 2400 Series).

Spectroscopic analysis

The HA samples (2 mg) of compost were dissolved in 0.05 M $NaHCO_3$ and analyzed for UV–Vis spectra by measuring the absorbance (190–400 nm) in a 1-cm quartz cuvette using spectrophotometer (Thermoelecron make). E_4/E_6 ratio is an indicator of condensation in the humic molecules (Stevenson 1982) while E_2/E_3 ratio relates to the molecular size of the humic substances (Agren et al. 2008). The E_4/E_6 ratio is the ratio of absorbance at 465 nm and 665 nm and E_2/E_3 ratio is the absorbance ratio at 265 and 365 nm (Chen et al. 1977).

The maturity indices were determined using the following methods:

(a) Humification (Δ log *K* coefficient), $\Delta \log K = \log A_{400} - \log A_{600}$ (Fong et al. 2006).

(b) Humification index (HI) = “C_{HA}/C_{FA}” or “C_{FA}/C_{HA}” (Jimenez and Garcia 1992); (where HA is humic acid and FA is fulvic acid).

(c) Humification degree $(HD\%) = (C_{THM}/C_{HU}) \times 100$ (DeNobili et al. 1986); (where C_{THM} is carbon of total humic matter and C_{HU} is carbon of humin).

HA-FTIR spectroscopy

A homogenized mixture of freeze-dried HA sample of MSW compost (2 mg) and 200 mg KBr (FTIR grade) was prepared. The KBr pellets were pressed under vacuum over the 4000–400 cm^{-1} range at 0.5 cm s^{-1} (Smidt and Meissl 2007). Infrared spectra were recorded on a FTIR spectrophotometer (Perkin-Elmer, 2000). The average (50 scans) for each spectrum was recorded with correction against the ambient air. The mean values were estimated from the triplicate readings.

Statistical analyses were carried out by SPSS-23.0 on the averages of $n = 3 \pm$ standard deviations. The quantification of the maturity parameters was done at *P* level of 0.01 or 0.05 of standard deviation (SD).

Results and discussion

Humic substances

Elemental analysis

The atomic O/C, C/H, and C/N ratios are often used to monitor structural changes of HS (Adani et al. 2006). A decline in the C/N and O/C ratios in all the MSW treatments, Cs_1, Cs_2, Cs_3, and Cs_4 was observed (Table 1). The decreased C percentage was ascribed to the substitutions of aliphatic chains by aromatics and evolution of carbon dioxide, whereas O (oxygen) percentage increased due to enhanced oxidation process (Senesi and Brunetti 1996). The N percentage increased for all treatments, being maximum for Cs_4 at 3.1% ($P < 0.05$). The additive, cow dung slurry enriched with carbon and nitrogen, might have played its role (Adegunloye et al. 2007). Cow dung possessed a desirable C/N ratio (19) that resulted in better microbial proliferation. Intensified microbial activity with faster molecular reorganization process resulted in higher condensation of the aromatic compounds. Xiaowei et al. (2011) reported similar increased N percentage (from 4.12 to 5.37%) during the co-composting of sewage sludge and cow dung. The C/H ratio increased for all the MSW treatments during composting. Overall, the highest C/H ratio (0.9%) was observed in the treatment Cs_4, ascribed to the fastest organic material decomposition in the treatment during composting.

Table 1 Elemental composition, E_2/E_3, E_4/E_6 ratio and atomic ratio of HA during 90 days of the MSW composting

Treatment	C^a (%)	N^a (%)	H^a (%)	O^a (%)	C/N	C/H	O/C	E_2/E_3	E_4/E_6	Δ Log K (DH)
Initial	49.3 ± 0.02a	2.4 ± 0.15a	7.2 ± 0.15a	34.2 ± 0.08a	20.5 ± 0.01ab	0.6 ± 0.05a	0.7 ± 0.04a	5.3 ± 0.19a	1.8 ± 0.01a	0.6 ± 0.05a
Cs_1	42.3 ± 0.05ab	2.8 ± 0.06b	5.6 ± 0.01b	39.1 ± 0.15b	17.2 ± 0.11b	0.7 ± 0.09b	0.6 ± 0.004b	4.2 ± 0.05a	4.0 ± 0.14a	0.6 ± 0.12bc
Cs_2	41.6 ± 0.09b	2.8 ± 0.17bc	5.1 ± 0.05bd	41.3 ± 0.12a	16.4 ± 0.03ab	0.7 ± 0.14d	0.6 ± 0.16d	3.5 ± 0.11ab	4.2 ± 0.03b	0.7 ± 0.01b
Cs_3	41.1 ± 0.14d	2.9 ± 0.01d	5.2 ± 0.03d	42.9 ± 0.02d	16.6 ± 0.19d	0.9 ± 0.17de	0.6 ± 0.01c	3.1 ± 0.05de	4.6 ± 0.05b	0.9 ± 0.05de
Cs_4	38.1 ± 0.03e	3.1 ± 0.02e	4.9 ± 0.16de	44.8 ± 0.06e	14.8 ± 0.01e	0.9 ± 0.20e	0.5 ± 0.02de	2.4 ± 0.17e	4.9 ± 0.02e	1.0 ± 0.16e
Soil HA	54.6	3.2	4.8	35.5	20.5	1.0	0.5	2.7	5.0	1.1

Data are mean ± SD ($n = 3$). Values followed by the same letter(s) in a column are not significantly different at $P < 0.05$ tested with Duncan's Multiple Range Test (DMRT)

Cs_1—only MSW, Cs_2—MSW + cellulolytic bacterial inoculum; Cs_3—MSW + cow dung slurry and Cs_4—MSW + cellulolytic bacterial inoculum + cow dung slurry

Soil HA not considered in the calculations

[a]% calculated on organic matter basis

The E_4/E_6 and E_2/E_3 ratios during composting reflect the quality and molecular size of the HAs (Albrecht et al. 2011). The results (Table 1) show an increased E_4/E_6 ratio for all MSW treatments at 90 days of composting. Overall, treatment Cs_4 reflected higher aromaticity with maximum value for E_4/E_6 ratio (1.8–4.9; $P < 0.01$) (Boguta et al. 2016). The observed E_4/E_6 ratio for HAs in all MSW treatments (4.0, 4.2, 4.6, and 4.9) is closer to the prescribed limit, 5 (Chen et al. 1977). This reveals the dominance of HAs in the compost samples (Zbytniewski and Buszewski 2005). Sharma et al. (2014) observed an increased E_4/E_6 ratio (4.29–7.71) with additive EMs (effective microorganisms) inoculation at 60 days of composting. Likewise, Sarika et al. (2014) reported an E_4/E_6 ratio within 2.6–5.6 in a rotatory drum composting. The E_2/E_3 ratio for the MSW treatments (Cs_1, Cs_2, Cs_3, and Cs_4) reduced from 5.3 to 4.2, 3.5, 3.1, and 2.4 ($P < 0.01$). De Campos et al. (2017) achieved a decreased E_2/E_3 ratio being 4.3 to 3.3 after 210 days of composting.

The Humification Index (HI) is a reliable parameter to test compost maturity (Jimenez and Garcia 1992). HI was evaluated as the ratio of the C_{HA}/C_{FA} fractions (non-humified to humified organic carbon) in the compost. HI values ranging within 1.6 and 1.9 indicated well humified and mature compost (Francou et al. 2003). In our study, the HI values increased [0.6–1.2, 1.9, 2.3, and 2.8 ($P < 0.05$)] for all the treatments Cs_1, Cs_2, Cs_3, and Cs_4 (Table 2). Chefetz et al. (1996) registered increased HI values (0.91–3.0) at the end of MSW composting. This indicated maturity of generated MSW compost and its suitability for application to agricultural purposes (Raj and Antil 2011).

The Degree of Humification (DH) adds to the information about the maturity of compost (Tomati et al. 2000). In case of MSW, the standard range for DH (Δ log K coefficient) comprises of three categories for the HAs. It includes categories A, B and C with values < 0.6, 0.6–0.8 and 0.8–1.1 (Fong et al. 2006). In study, values for DH in the treatments Cs_1, Cs_2, Cs_3, and Cs_4 were found within 0.6 and 1.0 (Table 1). The observed value for Δ log K coefficient (DH) was highest in the EM and cow dung slurry amended treatment, Cs_4. It ascribes to the enhanced humification due to diverse microbiota and more nutrient availability.

Humification Degree (HD%) is another parameter to verify compost stability. Ciavatta et al. (2001) reported HD greater than 70% indicating a well humified and mature product. In this study, the achieved HD for treated composts ordered as follows; $Cs_4 > Cs_3 > Cs_2$ (82.4%, 77.8%, and 76.4%) compared to control, Cs_1 (60%). The results reflect that EMs and/or cow dung might have intensified the waste humification rate (Song et al. 2014).

The ratio of C_{FA} (fulvic acid) to C_{HA} (humic acid) defines the quality of a compost (Table 2). Throughout the study, we observed increased C_{HA} values, whereas in case of C_{FA} values a decreased trend for all treatments (Cs_1, Cs_2, Cs_3,

Table 2 C_{HA}–C_{FA} values, Humification Index (HI) and Degree of Humification (DH) during 90 days of the MSW composting

Treatments	C_{HA} (%)	C_{FA} (%)	C_{FA}/C_{HA}	HI (C_{HA}/C_{FA})	HD (%)
Initial	2.3 ± 0.17a	3.9 ± 0.11a	1.7 ± 0.08b	0.6 ± 0.03b	20.4 ± 0.11a
Cs$_1$	3.5 ± 0.12bc	2.9 ± 0.05abd	0.8 ± 0.12b	1.2 ± 0.03b	60.0 ± 0.09b
Cs$_2$	4.8 ± 0.07d	2.6 ± 0.21b	0.5 ± 0.04ad	1.9 ± 0.13b	76.4 ± 0.02c
Cs$_3$	5.6 ± 0.01d	2.4 ± 0.19cd	0.4 ± 0.26e	2.3 ± 0.09cd	77.8 ± 0.16d
Cs$_4$	6.1 ± 0.15a	2.2 ± 0.27e	0.4 ± 0.06de	2.8 ± 0.05e	82.4 ± 0.03e

Data are mean ± SD ($n = 3$). Values followed by the same letter(s) in a column are not significantly different at $P < 0.05$ tested with Duncan's Multiple Range Test (DMRT)

Cs$_1$—only MSW, Cs$_2$—MSW + cellulolytic bacterial inoculum; Cs$_3$—MSW + cow dung slurry and Cs$_4$—MSW + cellulolytic bacterial inoculum + cow dung slurry

and Cs$_4$) was reported. MSW treatment Cs$_4$ showed maximum increase in C_{HA} (2.3% to 6.1%), at 90 days of composting. This is ascribed to larger loss of aliphatic groups, with compost maturity (Senesi and Brunetti 1996). Chefetz et al. (1996) reported increased C_{HA} values from 7 to 12% in the mature compost, prepared from MSW. Huang et al. (2006) observed a similar increase in the C_{HA} values from 2.05 to 3.79% throughout 63 days of composting. During MSW composting, the values of C_{FA} decreased for all the treatments at 90 days. The observed value of C_{FA} was the least for Cs$_4$ treatment (2.2%) followed by Cs$_3$, Cs$_2$, and Cs$_1$ (2.4%, 2.6%, and 2.9%) on Day 90 of composting. Barje et al. (2013) observed a similar trend for C_{FA} values throughout MSW composting. This confirmed the role of additives, EM's and cow dung in enhanced stability of compost.

Correlation analysis among the humification indices

The Δ log K coefficient positively correlated ($P < 0.05$; $P < 0.01$) with all the maturity indices in Table 3. A positive correlation between E_4/E_6 ratio ($r = 0.965$, $P < 0.05$) and Δ log K coefficient indicated good humification. The results favor aggregation of the molecules and increased degradation of aliphatic structures. Temperature shows a significant negative correlation with E_4/E_6 ratio ($r = 0.998$, $P < 0.05$) and Δ log K coefficient ($r = 0.979$, $P < 0.05$). This implies a negative influence of the decreased temperature on the humification indices. In addition, Δ log K coefficient positively correlated ($r = 0.936$, $P < 0.01$) with the atomic C/H ratio. These statistical observations reconfirm the role of commixture (EM and cow dung) in accelerating the waste degradation process.

UV–Vis spectroscopic analysis

Three major peaks were noticed in MSW treatments, Cs$_1$, Cs$_2$, Cs$_3$ and Cs$_4$ (Fig. 2). A peak exhibited near 205–210 nm shifted to 215 nm, 220 nm, 225 nm and 220 nm during MSW composting. This shift in peaks is due to the increased content of inorganic nitrogen. The MSW treatment, Cs$_4$ with EM and cow dung slurry shows the highest protein degradation. Li et al. (2014) reported similar increase in the values from

Table 3 Correlation between elemental composition, E_2/E_3, E_4/E_6 ratios, atomic ratios, Δ log K of HA and temperature during 90 days of the MSW composting

	C (%)	N (%)	H (%)	O (%)	C/N	C/H	O/C	E_2/E_3	E_4/E_6	Δ Log K	Temperature
C (%)	1.000										
N (%)	−0.991*	1.000									
H (%)	0.970*	−0.937**	1								
O (%)	−0.971*	0.974*	−0.956**	1							
C/N	0.993*	−0.982*	0.960*	−0.972*	1						
C/H	−0.891**	0.902**	−0.900**	0.972*	−0.889	1					
O/C	0.957**	−0.971*	0.863^{ns}	−0.919**	0.967*	-0.813^{ns}	1				
E_2/E_3	0.965*	−0.971*	0.935**	−0.995*	0.976*	−0.960*	0.938**	1			
E_4/E_6	−0.986*	0.960*	−0.991**	0.949**	−0.968*	0.873^{ns}	−0.897**	−0.929**	1		
Δ Log K	−0.983*	0.970*	−0.973*	0.989**	−0.991*	0.936**	−0.933**	−0.989*	0.965*	1	
Temperature	0.992*	−0.971*	0.992*	−0.965*	0.980*	−0.893**	0.915*	0.950*	−0.998*	−0.979*	1

*Correlation is significant at the 0.05 level (two tailed), **correlation is significant at the 0.01 level (two tailed), *ns* not significant

ANOVA—F (4, 1) = 0.007; $P < 0.01$; $P < 0.05$; $R^2 = 0.9999$; 99% significant

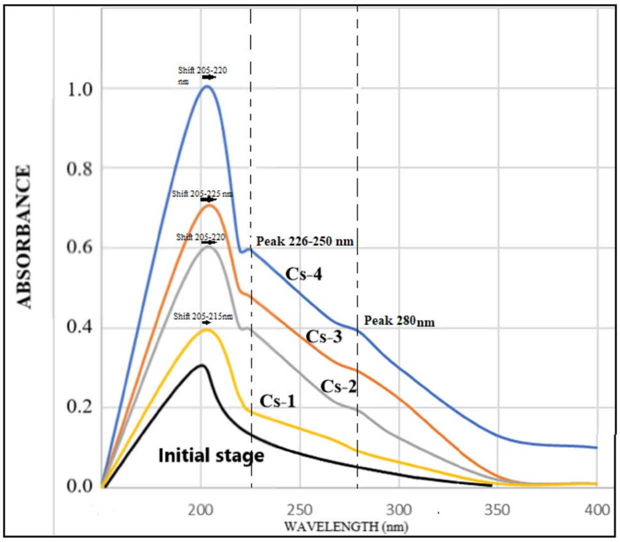

Fig. 2 HA-UV spectra at the initial and final stages of MSW composting

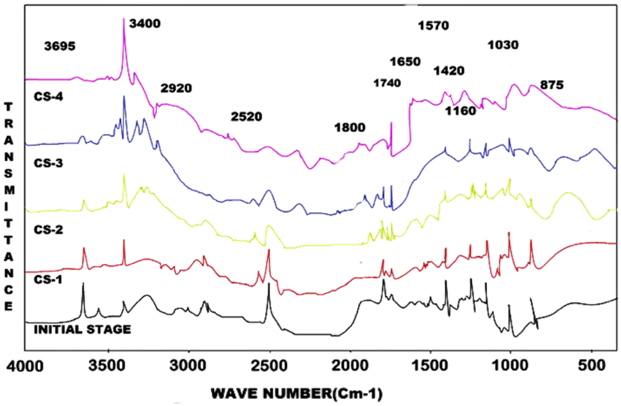

Fig. 3 HA-FTIR spectra at the initial and final stages of MSW composting

0.927 to 6.127 nm in absorption peaks at 200–226 nm. The spectrum range between 226 and 250 nm reflects stability of the organic matter (Vieyra et al. 2009). The unsaturated π–π* transition related to the polar functional groups define the spectrum. The peak near 226 nm represents an increased value for the MSW treatments, Cs_1, Cs_2, Cs_3 and Cs_4 at 0.19, 0.4, 0.49 and 0.61. The third peak at 280 nm is related to the size, aromaticity and humification of the molecules. In our study, we observed an increased value for treatments Cs_3 (0.4) and Cs_4 (0.31) at 280 nm in 90 days during composting. Li et al. (2010) reported an increase from 0.008 to 0.03 at $SUVA_{280}$ as composting proceeded with time.

Infrared spectroscopy is a qualitative tool to analyze the chemistry of HA complexes. The band patterns exemplified the complex interactions between the degrading molecules (Smidt 2011). In our study, the MSW treatments (Cs_1, Cs_2, Cs_3 and Cs_4) show broad absorption bands for the extracted HA (Fig. 3). A strong absorption peak at 3400 cm^{-1} (O–H stretching) confirmed the presence of OH and amino groups. Absorption peak observed at 2920 cm^{-1} (C–H stretching) relates to aliphatic methylene groups. This constant band region (2920 cm^{-1}) confirms stabilization of organic matter during composting. Two disproportional bands at 2520 and 1800 cm^{-1} were assigned to carbonate addition. Peaks observed at 1740, 1650 and 1425 cm^{-1} (C=O stretching) were due to generation of metabolites.

The decrease in polysaccharides was visible by peaks at 1160, 1060 and 1030 cm^{-1} (C–O stretching). At last, few disproportional peaks at 3695 cm^{-1}, 1060 cm^{-1}, and 1030 cm^{-1} impute clay minerals (Smidt et al. 2008). All the MSW compost treatments depicted similar FTIR spectra for HA. Certain absorption peaks indicated variable structures with different number of functional groups. A peculiar peak (1384 cm^{-1}) in the MSW treatment Cs_4 explains evolution of nitrates due to N–O stretch. EM and cow dung slurry also endorsed the condensation process for nitrate production. Figure 3. HA-FTIR spectra at the initial and final stages of MSW composting.

A relative intensity ratio of the absorption bands defines the HA spectra. During MSW composting, the absorption ratio (2920/1650) decreased from 0.81 to 0.75 for treatment Cs_3. The absorption ratio (2920/1650) was lowest (0.61–0.56) for EM and cow dung slurry amended treatment (Cs_4) after 90 days. This was due to higher degradation of the aliphatic compounds. Sarika et al. (2014) reported a decreased absorption ratio from 0.82 to 0.78 and 0.96–0.93 in a rotary drum composting. The aromatic C/poly C ratio (1650/1160) increased from 5.9 to 6.8, 6.3–7.5, and 6.9–7.8 in MSW treatments Cs_2, Cs_3 and Cs_4. The reduced polysaccharides supplemented energy to the microbes throughout composting. This led to an increase in the concentration of aromatics (Zhou et al. 2014). It is suggestive of an enhanced degradation of aliphatic compounds due to EM and cow dung slurry. Results from the study of humic substances verify the stability and maturity of MSW compost. Wei et al. (2007) reported similar findings in the extracted fractions of HS during MSW composting.

Temperature

In this study, a decline in temperature was observed between Day 0 and Day 15 during MSW composting (Fig. 4). The temperature of all the treatments subsequently increased between Day 15 and Day 30 (mesophilic phase). This increase continued until Day 45 (thermophilic stage) during MSW composting. A reduction in temperature during maturation (Day 90) exhibited a typical biodegradation curve. The attained temperature was highest for the Cs_4 treatment

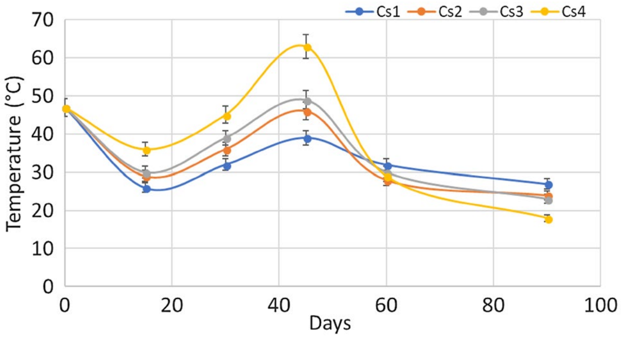

Fig. 4 Changes in temperature in MSW treatment piles during 90 days of composting

(63 °C) followed by Cs$_3$, Cs$_2$, and Cs$_1$ (49 °C, 46 °C, and 39 °C, respectively) by Day 45. This temperature increase is ascribed to the oxidation reactions caused by thermophilic microbes. The microbiota increased the degradation rate, releasing more heat (Singh and Kalamdhad 2015). At the end of composting (maturation phase), the temperature ranged from 18 to 27 °C. In this study, the temperature settled above 55 °C in the thermophilic phase (Day 45) of composting. This confirms a good sanitation degree for the generated compost (Barren et al. 2006).

Conclusion

Elemental analysis, UV and FTIR spectra of the humic fractions showed early maturity for MSW composting, with additives. The commixture of EM and cow dung derived better stability in MSW compost, over other inoculated and non-inoculated treatments. Above study also identified the role of temperature in intensified microbial activity and accelerated compost maturation. This research could provide a useful theoretical and practical foundation for small-scale MSW composting in India.

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