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ORIGINAL PAPER

Characterization of high rate composting of vegetable market waste using Fourier transform-infrared (FT-IR) and thermal studies in three different seasons

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Abstract Fourier transform-infrared (FT-IR), Thermogravimetry (TG), Differential thermal analyses (DTA) and Differential Thermogravimetric (DTG) studies of a mixture of vegetable waste, saw dust, tree leaves and cow dung for microbial activity (feedstock) and their compost were reported in three different seasons i.e. winter, spring and summer. The correlation between spectral studies and compost composition provide information regarding their stability and maturity during composting. FT-IR spectra were conferred the functional groups and their intensity and TG, DTG and DTA for wt. loss, rate of wt. loss and enthalpy change in compost. Weight loss in feedstock and compost at two different temperatures 250–350 and 350–500°C was found 38.06, 28.15% for inlet and 14.08, 25.67% for outlet zones in summer and 50.59, 29.76% for inlet and 18.08, 25.67% in outlet zones in spring season, higher (5–10%) than winter. The corresponding temperatures in DTA in the samples from inlet to outlet zone were; endotherm (100–200°C), due to dehydration, exotherm (300–320°C), due to peptidic structure loss and exotherm (449–474°C) due to the loss of polynuclear aromatic structures, which were higher by 4°C and 10–20°C and rate of wt. loss was higher by 5–10% in spring and summer season, respectively than winter season composting, reported regardless of the maturation age of the compost. Relative intensity of exotherms (300–320/449–474°C) gave the thermally more stable fractions of organic compound. Our results indicated that the rotary drum composting of organic matters in spring and summer season gave higher molecular complexity and stability than the winter season.

Keywords FT-IR · Thermogravimetry · Differential thermogravimetric · Differential thermal analyses · Rotary drum composting

Introduction

The organic fraction recycling process of municipal solid waste (MSW) is the preferred concept in waste management. In India, the organic solid waste fraction of the total waste makes up 40–85% (National Solid Waste Association of India, 2003), depending on the income and the life style of the population (Lardinois and van de Klundert 1993). The humification and transformation process might differ depending upon raw materials used in composting (Huang et al. 2006). The changes in compost stability can be predicted with C/N ratio in the solid phase, soluble organic carbon content in water extract

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(Inbar et al. 1993), plant growth bioassay, NMR and IR spectroscopy (Chen and Inbar 1993). Several studies have investigated organic matter transformation during composting of municipal solid waste, municipal sewage sludge and separated cattle manure using chemical, spectroscopic, thermogravimetry and microbiological methods (Chefetz et al. 1996; Chen and Inbar 1993; Iannotti et al. 1994; Hsu and Lo 1999; Adani et al. 2001; Gea et al. 2004; Jouraiphy et al. 2005; Huang et al. 2006). The understanding of organic matter transformation throughout the composting process and their evaluation of compost stability and maturity are essential for successful utilization of composts. There are many methods for evaluating the maturity of compost. These include: (i) physical parameters-temperature, odor, color, particle size, water and air retention capacities (Garcia et al. 1992); (ii) chemical parameters-C/N ratio in solid and water phases, cation exchange capacities, elemental concentrations, organic matter level, water-soluble organic matter and humification indexes (Hsu and Lo 1999; Jimenez and Garcia 1992); (iii) spectroscopic analysis: NMR, FT-IR and fluorescence (Chefetz et al. 1996; Chen and Inbar 1993); (iv) biochemical parameters-total and specific enzyme activity (Diaz-Burgos et al. 1994; Garcia et al. 1992); (v) microbiological parameters-oxygen and CO_2 respirometry (Iannotti et al. 1994) and (vi) bioassay responses-germination index and plant growth bioassays conducted in saturated extracts of compost or in compost filled pots (Chefetz et al. 1996; Inbar et al. 1993). In recent years, spectroscopic techniques such as FT-IR, fluorescence spectroscopy, ESR and NMR have been used as characterization tools for studying the transformation of organic matter and along with evaluating the maturity of the compost (Chen 2003; Inbar et al. 1989; Hsu and Lo 1999).

The above mentioned investigations generally dealt with the windrows and static piles types of composting for various kinds of waste. However, the organic matter transformation in high rate composting such as rotary drum (in-vessel) for the mixed organic vegetable waste and municipal solid waste composting is rather limited. No literature found like seasonal variation in in-vessel and vermicomposting, but some spectroscopic and thermal study was carried out on conventional composting like windrow composting (Susan Tandy et al. 2010), and study in in-vessel composting (Mondini et al. 2003). It is reasonable to expect that the transformation process might differ depending on the raw material(s) used for composting.

Therefore, our aim of the study is to know the chemical transformation (functional groups) and thermal stability of initial, middle and final region products during rotary drum composting of vegetable market waste amended with cattle manure and saw dust in different seasons like winter, spring and summer by FT-IR and thermal methods (TG, DTG & DTA).

Materials and method

The study was carried out in three different seasons using various combinations of waste materials. Raw material was not the same during whole year, but before feeding the waste was homogenized by adding cow dung, saw dust and tree leaves in required proportion. Mixed vegetable waste, cattle dung (C/N = 20) and saw dust (C/N = 540) were collected from institute campus. Prior to composting, the maximum particle size of the mixed waste was restricted to approximately 1.0–2.0 cm in order to provide better aeration and moisture control. The shredded mixed organic waste (Table 1) is loaded into the drum by means of plastic container on daily basis. The prepared feedstock was composted in full-scale rotary drum composter of 3.5 m^3 capacity (Fig. 1). To reach the stabilization phase, the retention time was kept as 8 days. One rotation at a time

Table 1 Waste proportion and physico-chemical characteristics

	Feedstock material	Weight (kg)	Percentage (%)
1.	Cattle manure	30.00	34.48
2.	Mixed vegetable waste	50.00	57.47
3.	Saw dust	7.00	8.04
4.	Total weight of mixture	87.00	100.00
5.	Initial moisture content	66.99	77.21
6.	Total solids	20.01	23.00
7.	Initial ash content	11.41	57.23
8.	Initial total organic carbon	7.00	35.36
9.	Initial total nitrogen	0.27	1.37

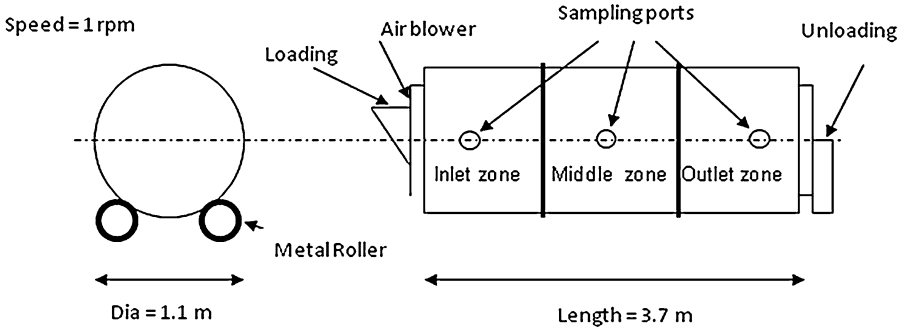

Fig. 1 Schematic labeled diagram of the rotary drum composter

on daily basis was made to ensure that the material on the top portion moved to the central portion, where it will be subjected to higher temperature. Thereafter aerobic conditions were maintained by opening the air blower.

Sampling

Triplicates homogenized samples were collected and stored for maximum 2 days at 4°C. Three grab samples from inlet, middle and outlet ports were collected from full-scale rotary drum composter every alternate day. Sub-samples were air dried immediately, ground to pass through 0.2-mm sieve and stored for further analysis. Each sub-sample was analyzed for the physico-chemical and spectroscopic studies.

Physico-chemical analysis

During full-scale rotary drum composting, temperature readings were taken directly using handheld analog thermometer, inserted into the composting mass in three different locations at 24 h time interval. Triplicates homogenized samples were collected from rotary drum for their analysis of moisture contents (105°C for 24 h). Ash content and organic matter were calculated according to reported in literature (Kalamdhad et al. 2008).

Fourier-transform infrared (FT-IR) spectroscopy

The FT-IR spectra were obtained on wave number range of 400–4,000 cm^{-1} on a Perkin Elmer GX FT-IR system equipped with OMNIC software. The sub-samples were prepared for analysis by mixing 40–50 mg of dried KBr with approximately 7–10 mg of sub-sample and compressing the mixture to pellets.

Thermal analysis

Thermogravimetry (TG) and Derivatives thermogravimetry (DTG) were carried out with a Mettler TG20 Thermobalance, TA 3000 system. A calibration with trafoperm, nickel and isotherm contemporarily, followed by a check with nickel, was performed before the analysis. The following conditions were adopted for all TG and DTG analyses: heating rate of 10°C/min from 25 to 800°C, oxidizing atmosphere for static air, and sub-samples weights of about 10 mg. Differential thermal analyses (DTA) was carried out with a Mettler TA-STAR 821. A total calibration with indium or zinc, followed by a check DTA exo-indium, was performed before the analysis. The following conditions were adopted for DTA analyses: heating rate of 5°C/min from 45 to 550°C, oxidizing atmosphere for static air, and sub-samples weights of about 10 mg. Measurements were repeated at least three times.

Results and discussion

Temperature

The heat evolution during active composting in the rotary drum composter is presented in Fig. 2. Microbial growth started within hour of rotary drum operation, which resulted in the temperature rise. In winter season, the observations were recorded since the beginning of the November month, and temperature increased initial 20 days followed by decrease

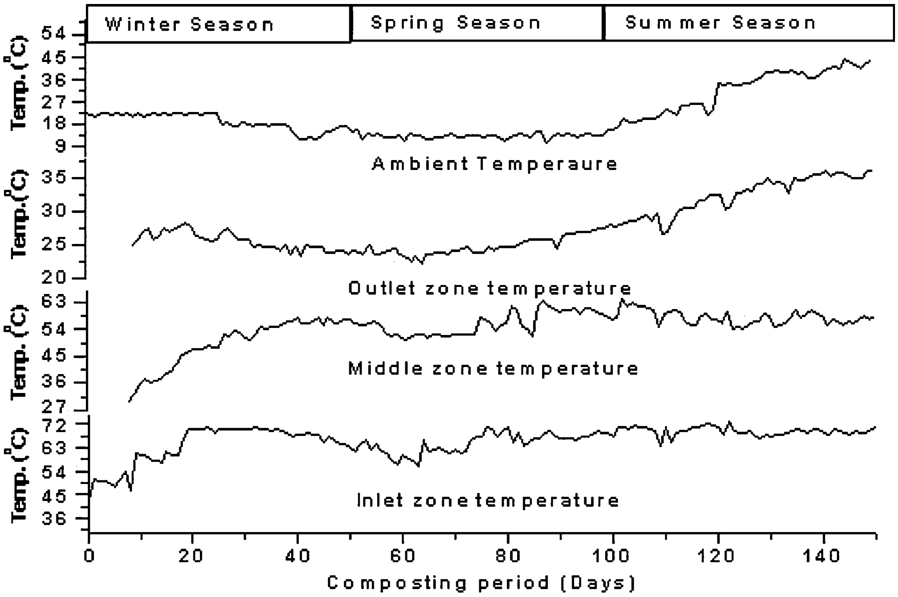

Fig. 2 Temperature profile in spring, winter, and summer seasons in rotary drum composting

after 50 days along with decrease in ambient temperature. Furthermore, the temperature increased up to 70°C in summer season since April. The maximum temperature in the rotary drum inlet zone varied between 60 and 70°C depending upon the ambient temperature. Temperatures from 52 to 60°C are useful to maintain the greatest thermophilic activity in composting systems. In continuously thermophilic composting systems, carbon dioxide evolution has been found to be sub-maximal at 64°C and above. The temperature in the middle zone of the drum varied between 50 and 60°C indicated the lower microbial activities compared to inlet. The temperature at the outlet zone of the drum was equal to ambient or slightly more (4–10°C) indicated the end of active thermophilic phase.

Water content in winter, spring and summer composting

Moisture loss during active composting can be viewed as an index of decomposition rate, since the heat generation which accompanies decomposition drives the vaporization. However, the composting material should have certain amount of moisture content in it for the organism to survive. Moisture content in the outlet zone was about 22.01, 29.36 and 19.15 kg, respectively in winter, spring and summer seasons as that of the inlet zone (average 64.57, 62.37 and 63.48 kg, respectively, Fig. 3). This, indicating that during the controlled composting process in the drum the air supply was low in spring season compared to other seasons. The time period of aeration through air blower was increased up to 24 h during the whole study period in spring and winter seasons. After through mixing by rotating the drum, the differences in the moisture content leveled out and the temperature rises again, which indicated that composting process was still proceeding very actively.

Organic matter profile in winter, spring and summer composting

Total organic matter is useful for estimating the age and physical properties of the compost. During the composting process, carbon dioxide is emitted from the composting mass as a metabolic end product. Thus, the organic matter content decreased as the composting progressed. Changes in the total organic matters (TOMs) content during the drum composting are detailed in Fig. 3. Initially, the average amount of organic matters at inlet zone was 7.89, 9.87 and 7.93 kg in winter, spring and summer seasons, which was reduced to 3.56, 3.40 and 3.71 kg, respectively to proper conditions for microbial degradation. Waste material was retained at inlet after turning serve as an inoculum for the incoming material. It can be observed that the organic carbon content decreased with the drum composting, which reflects a notable mineralization of organic matters.

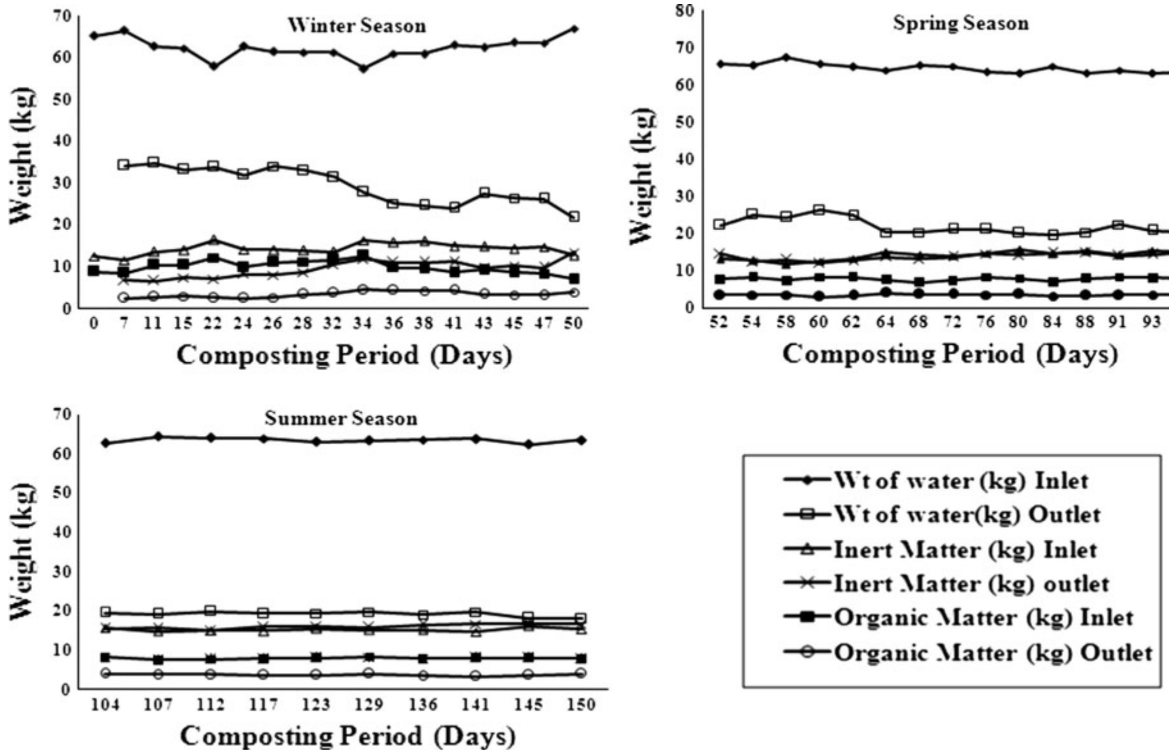

Fig. 3 Mass balance of water content, organic and inert matters in winter, spring and summer season composting

Inert matter profile in winter, spring and summer composting

Organic compounds are either decomposed or volatilized at high temperature the remaining residue is the inert matter. This residue consists of phosphates, chlorides, sulfates, and other halides and cations of sodium, potassium, calcium, magnesium, iron, and manganese. During rotary drum composting, the average yield inert matter in inlet zone was 14.17, 14.31 and 15.22 kg (Fig. 3). Due to variable vegetable waste in raw material and the outlet ash content 13.87, 9.45 and 15.00 kg, respectively in winter, spring and summer seasons. In spring and winter seasons the inert matter (9.45 and 13.87 kg) more reduced due to some leachate generation and the fraction of inert matter was drained in leachate.

Infrared spectroscopy study of composting in winter, spring and summer season

FT-IR spectra of the compost were recorded in three different seasons (winter, spring and summer) and three different stages during composting (inlet, middle and outlet zones). Literature revealed some characteristic changes in the functional groups present in organic and inorganic matters in composting for example, peaks at 3,400 cm^{-1} [may be due to alcoholic OH, phenol, carboxylic (COOH) or N–H (amides) groups]; peaks at 2,930 and 2,850 cm^{-1} (due to C–H asymmetric, C–H stretch of –CH aliphatic); peak at 2,365 cm^{-1} (due to CO_2); peak at 1,630–1,660 cm^{-1} (due to aromatic structure, COO^- and $C = O$ (e.g., amides, ketones and quinines) groups; peak at 1,560 cm^{-1} (due to amide II bonds); peaks at 1,420–1,430 cm^{-1} (due to absorbance of several aliphatic structures, phenolic OH groups, COO^- groups, stretching vibrations of aromatic rings and carbonates); peaks at 1,510, 1,462, 1,454 and 1,420 cm^{-1} (due to aromatic rings of lignin); peak at 1,380 cm^{-1} (due to ammonium carbonate formed by reaction of ammonia and CO_2) and a broad peak at 1,030 cm^{-1} assigned to C–O stretch of polysaccharide, Si–O asymmetric stretch of silicate impurities (Bellamy 1975). A band was found at around 1,429 cm^{-1} due to the O–H in-plane bend of carboxylic acids, the CO_2 stretch of carboxylates and the aliphatic CH_2 group of alkanes (Hesse et al. 1995; Smith 1999; Smidt et al. 2002; Chen and Inbar 1993; Hsu and Lo 1999; Jouraiphy et al. 2005; Huang et al. 2006; Grube et al. 2006). In addition, the absorption peaks at 600–500 cm^{-1} due to the phosphate in the form of orthophosphoric acid is present in compost (Smith 1999) and peaks at 778, 722, 560 and 536 cm^{-1} are due to aromatic ring and halogens (chloro-compounds) and some metal halogen bonds. In our study, we have shown the functional group peak intensity and their variations in different seasons and chemical changes during three different composting stages.

Winter season composting

During composting in winter season, aliphatic CH_3 stretching and CH_2 (methylene) bands at 2,923 and 2,850 cm^{-1} were appeared in inlet zone but when the material reaches to middle zone (4th day) their band intensity decreased (8.62 and 2.69%), respectively at same wave number (Fig. 4). The degraded material reached to outlet zone (8th day), peak intensity further reduced (8.48 and 5.23%), respectively. However, inlet peaks at 1,650 cm^{-1} due to aromatic $C = C$ bond and $C = O$ group was observed at 1,639 cm^{-1} in middle and outlet zone with high peak intensity (4.27 and 11.03%), respectively due to amides or carboxylates. The decrease and increase in peak intensity reflects decomposition of waste material and new products formation. An inlet band was found at 1,429 cm^{-1} due to OH group in-plane bend of carboxylic acids, CO_2 stretch of carboxylates and the aliphatic CH_2 group of alkanes. The $C = O$ stretch vibration of carbonates also contributed to this band which was also found in middle and outlet zones at 1,424 and 1,440 cm^{-1}, respectively with same peak intensity. Because of the organic compounds decrease and inorganic components increase relatively during decomposition, so that nitrate band at 1,380 cm^{-1} was visible in outlet zone. An inlet peak at 1,344 cm^{-1} was disappeared and no peak at this wave number was appeared in middle zone. A broad peak at 1,030 cm^{-1} was found in inlet due to C–O stretching of polysaccharides or polysaccharide-like substances, and Si–O asymmetric stretch of silicate impurities which was disappeared in middle zone and a new peak appeared at 1,038 cm^{-1} with higher peak intensity due to some biochemical changes in polysaccharides degradation. This was further disappeared in outlet zone and a new peak at 1,048 cm^{-1} was found with less intensity than the middle and inlet zone. In addition, peaks at 850, 600 and 550 cm^{-1} were found in inlet due to aromatic ring and halo-compounds and some metal-halogen bonds, which were found at same wave number in middle zone and further shifted to 789 and 586 cm^{-1} in outlet zone.

Spring season composting

During composting in spring season, aliphatic CH_3 stretching and CH_2 (methylene) bands were appeared at 2,923 and 2,850 cm^{-1} in inlet zone but when the material reaches to middle zone (4th day) their band intensity decreased (6.19 and 4.73%), respectively at same wave number (Fig. 5). The degraded material reached to outlet zone (8th day), peaks intensity

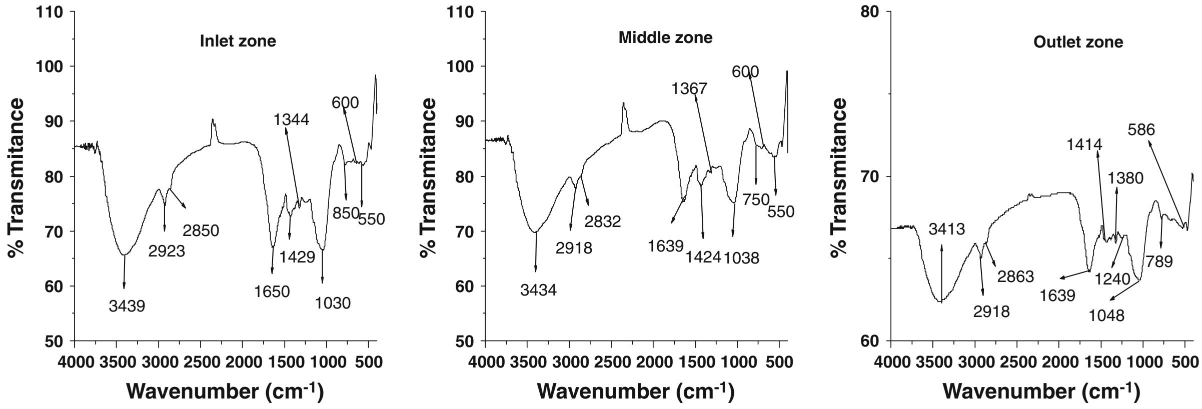

Fig. 4 FT-IR spectra of *inlet*, *middle* and *outlet* zones of rotary drum compost in spring seasons

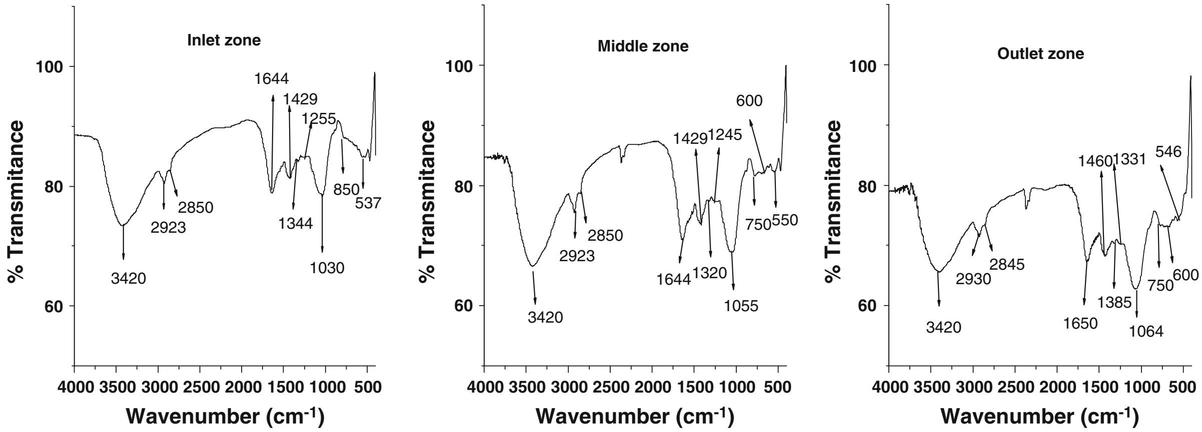

Fig. 5 FT-IR spectra of *inlet*, *middle* and *outlet* zones of rotary drum compost in winter seasons

further reduced (11.12 and 10.6%), respectively. However, inlet peak at 1,644 cm^{-1} due to aromatic C = C bond and C = O group was observed at 1,644–1,650 cm^{-1} in middle and outlet zones with high peak intensity due to amides or carboxylates (14.76 and 10.09%), respectively. The increase and decrease in peak intensity reflects decomposition of waste material and new products formation. An inlet peak was found at 1,429 cm^{-1} due to OH group in-plane bend of carboxylic acids, CO_2 stretch of carboxylates and the aliphatic CH_2 group of alkanes. The C = O stretch vibration of carbonates also contributed to this band which was also found in middle and outlet zones at same wave number and peak intensity. A new peak was appeared at 1,460 cm^{-1} due to lignin content when the material goes to outlet zone. Because of the organic compounds decrease and inorganic components increase relatively during decomposition so that nitrate band at 1,385 and 1,331 cm^{-1} was visible in outlet zone. An inlet peak at 1,344 cm^{-1} was disappeared and new peak at 1,320 cm^{-1} appeared in middle zone due to primary and secondary aromatic amines. A broad peak at 1,030 cm^{-1} was found in inlet due to C–O stretching of polysaccharides or polysaccharide-like substances, and Si–O asymmetric stretch of silicate impurities which was disappeared in middle zone and a new peak appeared at 1,053 cm^{-1} with higher peak intensity due to some biochemical changes in polysaccharides degradation. This was further disappeared in outlet zone and a new peak at 1,064 cm^{-1} was found with less intensity than the middle and inlet zone. In addition, peaks at 850, and 537 cm^{-1} were found in inlet due to aromatic ring and halo-compounds and some metal-halogen bonds, which were shifted to 750, 600 and 550 cm^{-1} and 750, 600 and 516 cm^{-1}, respectively in middle and outlet zones.

Summer season composting

During composting in summer season, aliphatic CH_3 stretching and CH_2 (methylene) bands were appeared at 2,928 and 2,832 cm^{-1} in inlet zone but when the material reaches to middle zone (4th day) their band intensity decreased (4.37 and 3.12%), respectively at 2,928 and 2,863 cm^{-1} (Fig. 6). The degraded material reached to outlet zone (8th day) peaks intensity further reduced (8.00 and 10.08%), respectively. However, inlet peak at 1,650 cm^{-1} due to aromatic C = C bond and C = O group was observed at 1,650–1,637 cm^{-1} in middle and outlet zone with high peak intensity (8.60 and 13.92%) due to amides or carboxylates. The increase in peak intensity from inlet to middle and outlet zones reflects new products formation. An inlet peak was found at 1,424 cm^{-1} due to OH group in-plane bend of carboxylic acids, CO_2 stretch of carboxylates and the aliphatic CH_2 group of alkanes. The C = O stretch vibration of carbonates also contributed to this band which was also found in middle and outlet zones at same wave number and peak intensity. Because of the organic compounds decrease and inorganic components increase relatively during decomposition so that nitrate band at 1,380 cm^{-1} was visible in outlet zone. An inlet peak at 1,320 cm^{-1} was disappeared

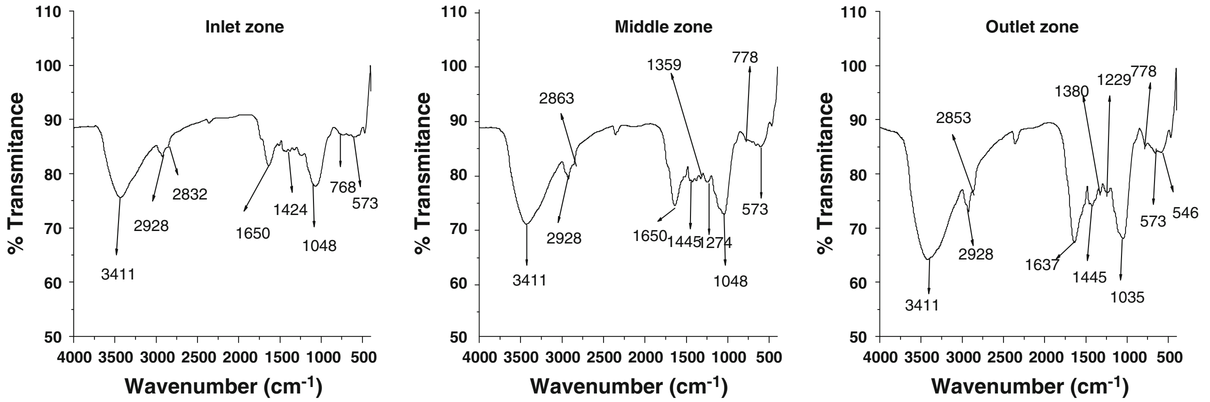

Fig. 6 FT-IR spectra of *inlet*, *middle* and *outlet* zones of rotary drum compost in summer seasons

and new peak at 1,359 cm^{-1} appeared in middle zone due to primary and secondary aromatic amines. A broad peak at 1,030 cm^{-1} was found in inlet due to C–O stretching of polysaccharides or polysaccharide-like substances, and Si–O asymmetric stretch of silicate impurities which was disappeared in middle zone and a new peak appeared at 1,048 cm^{-1} with higher peak intensity due to some biochemical changes in polysaccharides degradation. This was further disappeared in outlet zone and a new band at 1,035 cm^{-1} was found with high intensity than the middle and inlet zone. In addition, peaks at 768, and 573 cm^{-1} were found in inlet due to aromatic ring and halo-compounds and some metal-halogen bonds, which were shifted to 778, 573 and 778, 573 and 546 cm^{-1}, respectively in middle and outlet zone.

Thus, in rotary drum composting FT-IR spectra showed that the spring and summer seasons gave better and stable compost than winter season because of the fast rate of decomposition indicated at 1,650 cm^{-1} increase (humic acid formation) and at 2,930 and 2,850 cm^{-1} decrease (carbohydrates and proteins depletion).

Thermal analysis study of composting in winter, spring and summer season

The compost maturity was also characterized on thermal techniques such as DTA (Otero et al.2002) or differential scanning calorimetry (DSC) and thermo gravimetric analysis (TGA) (Dell'Abate et al. 2000; Melis and Castaldi 2004; Gomez et al. 2005; Smidt and Lechner 2005). In the presence of atmospheric oxygen two exothermic phenomena may occur in compost characterization such as volatilization of aliphatic compounds (Dell'Abate et al. 2000) or carbohydrates (Orteo et al. 2002) and the oxidation of high molecular weight compounds. TG, DTA and DTG analysis were performed under an oxidant air (combustion condition). In an oxidant atmosphere, TG, DTA, and DTG data were reported (Figs. 7, 8, 9; Tables 2, 3, 4) from inlet, middle, and outlet zone in winter, spring and summer seasons, respectively for rotary drum composting. Endothermic peaks were observed between 50 and 200°C due to dehydration (water loss) and 600 and 750°C attributed to the carbonates thermal degradation. Similarly, two exothermic peaks were obtained in the range of 200–600°C which corresponds to the degradation of organic matter. The first peak at 250–350°C corresponds to the combustion of carbohydrates such as cellulose and lignocelluloses and the second peak at 350–500°C corresponds to the degradation of complex aromatic structures.

Winter season composting

During composting in winter season, the percentage mass loss, rate of mass loss and enthalpy change are given in Tables 2, 3, 4, and Fig. 7. Mass loss at 200–400°C was 57.79, 55.0 and 53.6% and at 400–600°C 16.13, 19.53, and 21.53% in inlet, middle, and outlet zones, respectively. The overall mass loss from Inlet to outlet zone was 4.19% however; the increment in mass from inlet to outlet zone was 5.4% due to less amount of aromatic fraction in compost. DTA curve (Fig. 7) shows two exothermic peaks, first peak shows decrease 9°C from inlet to outlet zone due to less availability of carbohydrates such as cellulose and lignocelluloses and second peak shows 5°C

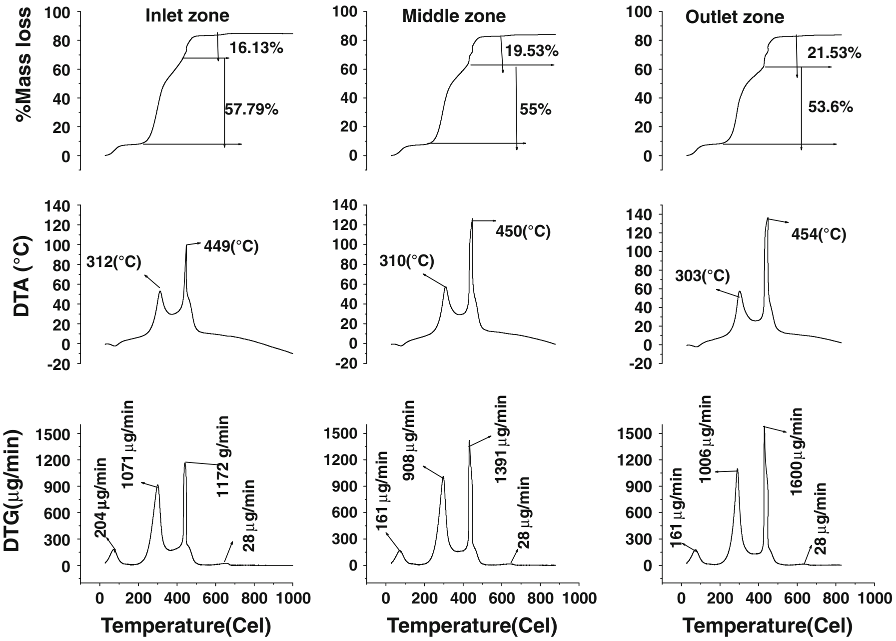

Fig. 7 Mass loss (%), DTA, and DTG curve of *inlet*, *middle*, and *outlet* zone compost of rotary drum in spring season

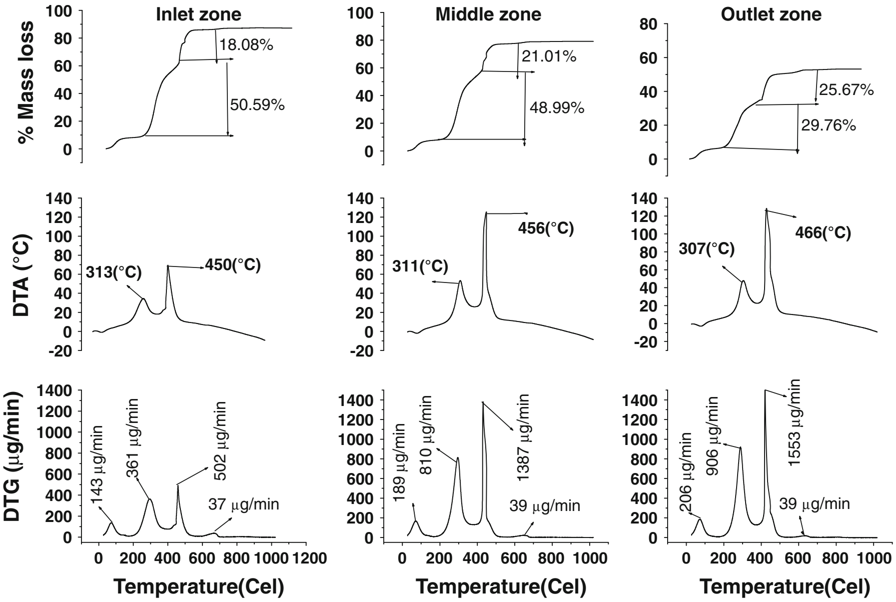

Fig. 8 Mass loss (%), DTA, and DTG curve of *inlet*, *middle*, and *outlet* zone compost of rotary drum in winter season

increment from inlet to outlet zone due to present of less availability of highly complex aromatic compounds which take more energy for decomposition. Similarly, in DTG profile (Fig. 7) decrease the rate of combustion of carbohydrate 65 μg/min from inlet to outlet zone due to less availability of easily degradable material (carbohydrates and protein) and decrease the rate of combustion of aromatic complex compounds 428 μg/min from inlet to outlet zone during rotary drum composting.

Fig. 9 Mass loss (%), DTA, and DTG curve of *inlet*, *middle*, and *outlet* zone compost of rotary drum in summer season

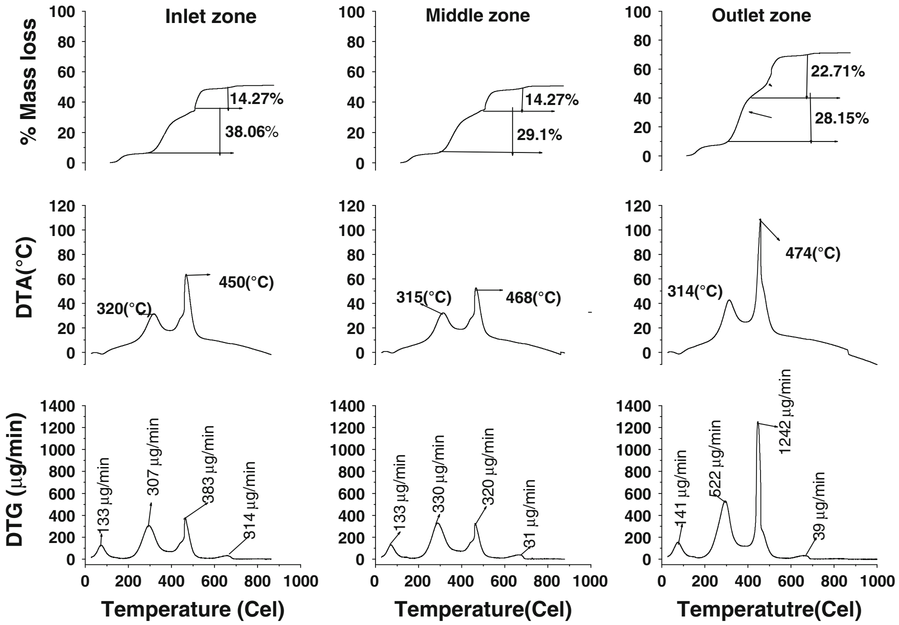

Table 2 % Mass loss at 200–400 and at 400–600°C of TG curve in inlet, middle, and outlet zone

% Mass loss	Spring season			Winter season			Summer season		
	Inlet zone	Middle zone	Outlet zone	Inlet zone	Middle zone	Outlet zone	Inlet zone	Middle zone	Outlet zone
At 200–400°C	50.59	48.99	29.76	57.79	55.0	53.6	38.15	29.1	28.71
At 400–600°C	18	21.01	25.67	16.08	19.53	21.53	14.27	14.27	22.71

Table 3 Change in enthalpy and relative intensity (RI) in spring, winter and summer season composting

Seasons/zones	1st exothermic peak	2nd exothermic peak	ΔH (J/mg) 1st peak	ΔH (J/mg) 2nd peak	Relative intensity (RI)
Spring Season					
Inlet zone	312	449	6.58	1.04	1.49
Middle zone	311	452	9.29	1.18	1.46
Outlet zone	303	454	8.68	1.65	1.47
Winter Season					
Inlet zone	313	466	8.36	8.93	1.44
Middle zone	311	452	8.13	1.23	1.46
Outlet zone	307	450	8.34	1.36	1.50
Summer Season					
Inlet zone	314	459	7.07	1.28	1.46
Middle zone	315	468	5.97	8.87	1.49
Outlet zone	320	474	6.3	1.21	1.48

Spring season composting

During composting in spring season, the percentage mass loss, rate of mass loss and enthalpy change were given in Tables 2, 3, 4, and Fig. 8. Mass loss at 200–400°C was 50.59, 48.99 and 29.76% and at 400–600°C, 18.08, 21.01, and 25.67% in inlet, middle, and outlet zones, respectively. The overall

Table 4 Derivative thermogravimetry analysis in spring, winter and summer season composting

Exothermic peaks DTG curve (µg/min)	Winter season			Spring season			Summer season		
	Inlet zone	Middle zone	Outlet zone	Inlet zone	Middle zone	Outlet zone	Inlet zone	Middle zone	Outlet zone
At 50–200°C (Moisture)	204	161	161	143	189	206	133	133	141
At 200–400°C	1,071	908	1,006	361	810	906	307	330	522
At 400–600°C	1,172	1,331	1,600	502	1,387	1,553	383	320	1,242
At 600–750°C (Carbonate)	28	28	28	37	39	39	31.43	31	39

mass loss from inlet to outlet zone was 20.83% however; the increase in mass loss from inlet to outlet zone was 7.59% due to sufficient amount of aromatic fraction in compost. DTA curve (Fig. 8) shows two exothermic peaks, first peak shows decreased in temperature 6°C from inlet to outlet zone due to less availability of carbohydrates such as cellulose and lignocelluloses in outlet zone and second peak shows 16°C increment in temperature from inlet to outlet zone due to highly complex aromatic compounds which take more energy for decomposition. Similarly, in DTG profile (Fig. 8) decrease the rate of carbohydrate combustion (65 µg/min) from inlet to outlet zone and increases the rate of aromatic complex compounds combustion (428 µg/min) from inlet to outlet zone during rotary drum composting.

Summer season composting

During composting in summer season percentage mass loss, rate of mass loss and enthalpy change were given in Tables 2, 3, 4, and Fig. 9. Mass loss at 200–400°C was 38.06, 29.1 and 28.15% and at 400–600°C 14.27, 14.27, and 22.71% in inlet, middle, and outlet zones respectively. The overall mass loss from Inlet to outlet zone was 9.91% however the increment in mass from inlet to outlet zone was 8.44% due to present of high aromatic fraction in outlet zone. DTA curve (Fig. 9) shows two exothermic peaks first peak shows decrease 6°C from inlet to outlet zone due to less availability of carbohydrates such as cellulose and lignocelluloses and second peak shows 24°C increment from inlet to outlet zone due to present of highly complex aromatic compounds which take more energy for decomposition. Similarly, in DTG profile (Fig. 9) decrease the rate of combustion of carbohydrate 215 µg/min from inlet to outlet zone and increases the rate of combustion of aromatic complex compounds 859 µg/min from inlet to outlet zone during rotary drum composting. In contrast to the other season i.e. winter, summer and spring season have optimum conditions for the rotary drum (high rate) composting.

Conclusion

In rotary drum composting process, various physico-chemical and spectroscopic analyses were reported for the compost characterization to monitor the evolution and transformation of organic matters (OMs) in different composting periods and seasons. FT-IR, TG, DTG and DTA were used for quality and maturity evaluation of composted materials will stimulate their demand and acceptability. Our results showed that the composting time and seasonal variation determines an increase of the molecular complexity of compost by decreasing the aliphatic and polysaccharide components while increasing the oxygenated group content and the aromatic complex compounds. FT-IR spectroscopy was also found a promising technique for functional group identification in composting. New peaks and their intensity in FT-IR indicate composted material stability and maturation time. For example, presence of bands at 778, 722, and 560 cm^{-1} is due to aromatic ring, halogen-compounds and some metal-halogen bonds. On that basis, a higher maturity degree was achieved in spring and summer season composting in terms of mass loss (TG), rate of mass loss (DTG), enthalpy change (DTA) in final compost compared to winter season. The novelty of rotary drum composting is their efficiency; it takes 7–8 days for composting and environmental friendly (no leaching). It takes less space for operating plant and gave stable and mature compost in all seasons.

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