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Drum Composting of Food Waste: A Kinetic Study

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Abstract

Drum composting is a potential mean to recycle the food waste (FW) at the source of generation in developing countries. The present study reports the kinetics of the composting process conducted in three plastic drums each of 125 L capacity. To facilitate natural aeration, 10 mm diameter holes were provided on the periphery of two drums while one drum was used as control (i.e., without any hole). Moreover, yard waste (YW) was also added to the feed as bulking agent (FW: YW = 2.5: 1 by wt.). The effect of turning and natural aeration was studied during 60 days of composting of food waste. Various physical, chemical and biological parameters were monitored routinely. The time-based organic matter degradation data was used to determine the kinetic parameters according to the first order rate equation. The reaction rate was found to be 0.0105 day^{-1} (R^2 = 0.9605) in the modified drum with regular sample turning. The principal component analysis (PCA) and hierarchial cluster analysis (HCA) were used as statistical tools to evaluate the variation between the measured parameters.

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Keywords:Composting, Food waste, Bulking agent, Reaction kinetics, Principal component analysis, Hierarchial cluster analysis;

1.0 Introduction

Composting of organic fraction of municipal solid waste (MSW) is a major route for its recycling. Composting is a controlled microbial aerobic decomposition process of organic waste which results in the stable product that may be used as soil amendment or organic fertilizer (Xi et al., 2005). The final product can be used for beneficial uses (Kulcu and Yaldiz, 2004).

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Drum or bin composting is practised in different parts of the world. Such practise is encouraged in developing countries to encourage recycling oforganic waste at the source of generation. An extensive study would be required to design such systems which can be used in a society.For efficient composting, better air circulation and frequent turning of waste is needed. The composting process requires the optimum level of moisture content (40 – 60%) and C/N ratio (~25) for efficient microbial activities (Garg and Tothill, 2009).The water content is an important parameter in composting since the microorganisms utilizes the nutrients through this media. Generally, the moisture in food waste (FW) which is a major component of MSW, exceeds its optimum level. The higher level may result in the anaerobic conditions, whereas lowermoisturelevels may lead to inactivation of microorganisms. To achieve the optimum moisture level in the feed, bulking agents has beenadded to the wastepreviously(Chang and Chen, 2010). Bulking agents such as yard waste (YW), saw dust, bio char etc.havebeenused in composting process. Apart from optimizing moisture level, these bulking agents will facilitate better air circulation between the particles which is very important for effective aerobic stabilisation of the waste.

The kinetic study of the biodegradation of waste is necessary to design the composting systems(Sadef et al., 2014). Few studies have shown that the organic degradation follows first order equation (Kulcu and Yaldiz, 2004; Baptista, 2010).The multivariate statistical analyses such as principal component analysis (PCA) and hierarchial cluster analysis (HCA) were used by several studies to understand the variability between the parameters or variables (He et al., 2013). PCA results in the grouping of parameters based on factor loadings which can be obtained by forming correlations between the parameters and principal components. HCA technique is widely used for pattern recognition in statistical analysis. This can be used to determine the relationships between the parameters based on the squared Euclidean distance.

The present study was aimed at the kinetic studies of the composting of FW mixed with YW as bulking agent. The results were subjected to multivariate statistical analyses such as PCA and HCA to evaluate the parameters variations.

2.0 Materials and methods

2.1 Sampling

FW and YW were collected from IIT Bombay, Mumbai campus, India in sufficient quantity. The major components of FW were the leftover cooked vegetables, rice, noodles, curries, rotis, fruits peelings and salads from a local mess. YW comprised of green (fresh) and brown (dry) leaves, grass trimmings and parts of plants. Both FWand YW were mixed in appropriate ratio (1:1 by volume which corresponds to ~ 2.5:1 by weight) to ensure homogeneity. The resulting waste was termed as mixed waste (MW).

2.2 Design of composting drums

The composting was carried out in three plastic drum of 125 L capacity. Two drums were suitably modified for air circulation. Drum 1 was used as a control (i.e., with no modification) while the drums 2 and 3 were modified by providing 10 mm equidistant holes in six layers on the circumference of the drums using a hand driller to facilitate the air circulation inside the drums. Two sampling windows (one each at middle and bottom part)were provided in all the three drums to collect the periodic sample for analysis. The image of the modified drum is shown in Figure 1. The provision for the leachate collection from the bottom of the drums was also provided. An additional modified drum was used for the turning of sample from drum 3. The different configurations of the composting drums are listed in Table 1.

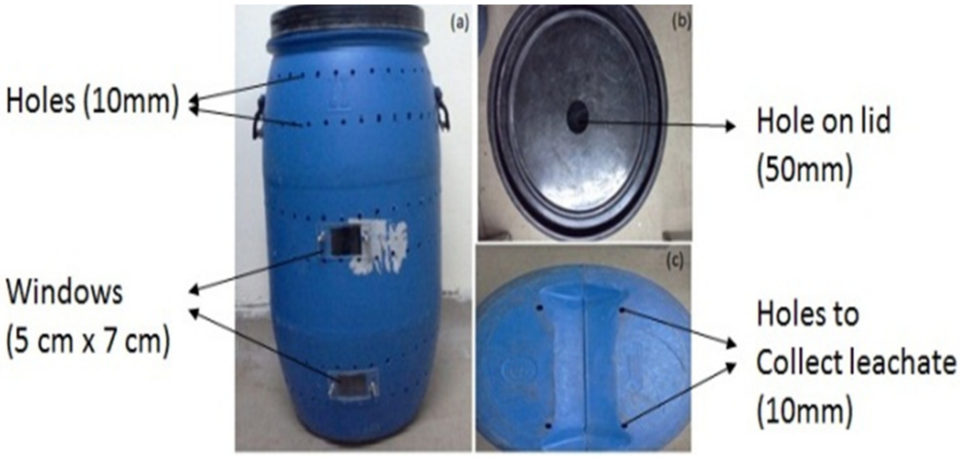


Fig. 1.(a) Image of modified composting drum; (b) Top view of the drum; (c) Bottom view of the drum

Table 1: Configurations of different drums used for food waste composting process

Configurations	Drum 1 (Control)	Drum 2	Drum 3
Hole on the cover lid	✓	✓	✓
Holes on the circumference	X	✓	✓
Turning	X	X	✓
Leachate collection	✓	✓	✓

✓ - Yes, X – No

2.3 Composting process

The composting process was carried out in open space to allow the natural aeration. The drums were supported on the bricks and the plastic trays were kept below the drums for the collection of leachate. For the study, around 80 kg of the homogenized MW sample was added in each of the three drums. Various operating and product quality parameters such as pH, electrical conductivity (EC), moisture content (MC), total organic matter (TOM), C/N ratio, humic acid (HA), fulvic acid (FA), lignin (lig), cellulose (cel) and hemicellulose (hem)were monitored for 60 days. Temperature in all the drums was measured at middle and bottom portions once in a day using a battery operated hand held thermometer (Minitherma type K thermometer). TOM of the samples was determined by ‘Loss on ignition’ method (Lopez et al., 2010). In this method, 1 g of dried powdered sample was kept in a muffle furnace at 550°C temperature for 4 h. The sample was allowed to cool up to room temperature before weighing. TOM was measured as percentage of weight loss.

2.4 Kinetic studies

The experimental data obtained in the present study was fitted in the following pseudo first-order kinetic model equation:

$$\frac{dC}{dt} = -kC \quad (1)$$

where C is the biodegradable volatile solids, k is the degradation rate constant (day^{-1}) and t is the time (days). Integrating the above equation and letting $C = C_0$ initially when t = 0, it gives,

$$\ln\frac{C}{C_0} = -kt \quad (2)$$

The reaction rate constant (k) was obtained by plotting ln (C/C_0) versus time data for all three drums.

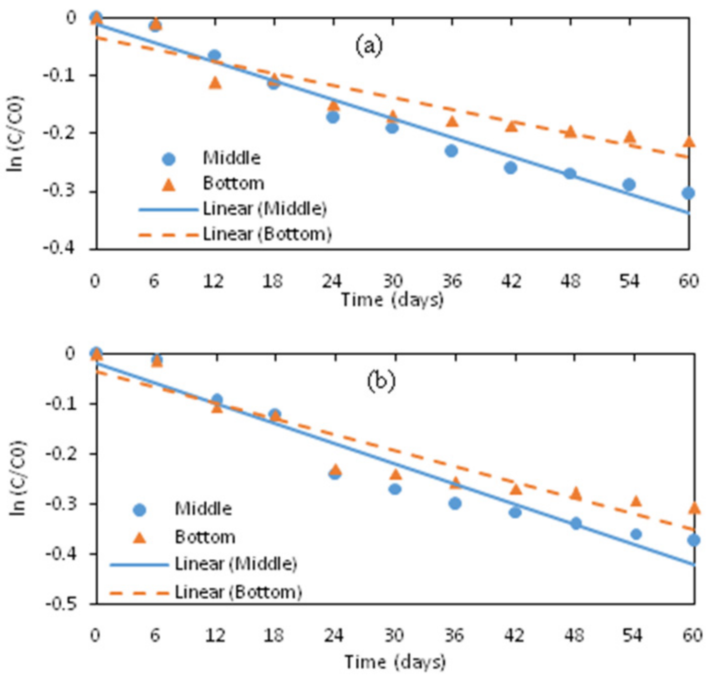
2.5 Statistical analyses

The experimental data was subjected to the statistical analyses to understand the variation and correlation among the different parameters from 60 days composting process. PCA and HCA were conducted using XLSTAT software.

3.0 Results and discussion

3.1 Kinetic studies

During 60 days of composting process, the organic matter was reduced with time due to the microbial metabolism activities. The results from kinetic study are presented in Figure 2 and Table 2. In drum 1 (i.e., control), the reaction rate (k) was found out to be 0.0054 and 0.0035 d^{-1} at middle and bottom part, respectively. Due to the unmodified drum design, the circulation of air was not present in control drum which probably resulted in the less degradation of organic matter. The reaction rate at middle part is slightly higher than in bottom part due to the degradation of organic matter by fungal activities. In the drum 2 (without turning operation), slightly higher reaction rates i.e. 0.0067 and 0.0053 d^{-1} were observed at middle and bottom parts, respectively. This should be due to the modification of drums for air circulation. Due to the compaction of waste in drum 2 and no turning of waste, the microbial activity appeared to be decreased despite the provision for natural air ventilation. In the other modified drum in which waste was also turned (i.e., drum 3), the highest reaction rate was observed (0.0101 d^{-1} and 0.0108 d^{-1} at middle and bottom parts, respectively). The kinetic data was reasonably fit well to first order reaction as shown by R^2 value (~ 0.85-0.96).



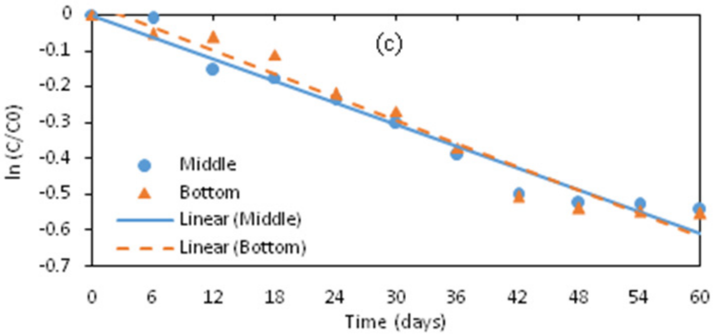


Fig. 2.Pseudo first order curve fitting for composting performed in (a) drum 1; (b) drum 2; and (c) drum 3

Table 2: Reaction rates from composting of FW indifferent drums

	Drum 1		Drum 2		Drum 3	
	Middle	**Bottom**	**Middle**	**Bottom**	**Middle**	**Bottom**
Reaction rate k(day $^{-1}$)	0.0054	0.0035	0.0067	0.0053	0.0101	0.0108
R^2	0.9617	0.8523	0.9304	0.8834	0.9636	0.9574

3.2 Principal Component Analysis (PCA)

To evaluate the maturity and stability of compost, various parameters have to be determined since several authors have reported that a single parameter is not sufficient to evaluate compost quality (Gómez-Brandón et al., 2008). Based on the PCA results, two principal components (F_1 and F_2) with an eigenvalue ≥ 1 were extracted. The results are presented in Figure 3. All the parameters were observed in a circular-arc shape which explains the high correlation between the variables. F_1 and F_2 explain the majority of the convergence and divergence between the parameters. The parameters present far away from the origin represents higher correlation and thus responsible for variation in the process.

In drum 1 middle sample analysis, F_1 and F_2 corresponds to 93.75% variations. The most influential parameters in F_1 were lig, TOM, cel, hem, MC, C/N ratio, HA and FA. On the other hand, in F_2, only EC causes the variation. In drum 1 bottom sample, the two principal components, F_1 and F_2, accounts for 89.36%. The F_1 component was attributed to lig, cel, hem, C/N ratio, TOM, HA and FA. For drum 2 (middle sample), PCA extracted two principal components F_1 and F_2 accounting for 90.05%. The main parameters which affect the variation in composting process are lig, cel, hem, C/N ratio, TOM, MC and HA, and FA. For drum 2 bottom sample, similar pattern was observed with a variation of 89.16%. For drum 3 (middle and bottom samples), the extracted components were accounted for 96.64% and 97.04%, respectively. In both the samples, the F_1 corresponds to lig, cel, hem, C/N ratio, TOM, MC (reduction in the process) and HA, FA and pH (increase in the process), whereas F_2 corresponds to EC.

3.3Hierarchical Cluster Analysis (HCA)

HCA partitions all parameters into smaller groups or clusters of similar parameters that are dissimilar to other groups (Xi et al., 2012). The dendrogram are illustrated in Figure4. The parameters are more similar if the squaredeuclidean distances (x-axis) are lower. In drum 1 at the middle portion, cel, lig and MC formed a cluster, whereas hem, C/N ratio and HA formed another cluster with FA, pH and EC. Similar grouping was observed for the samples of drum 1 bottom portion. The similar results were obtained for drum 2. The dendrogram of drum 3 middle and bottom samples were different from other two drums. In drum 3 at the middle part, cel, lig, MC and HA formed a cluster which makes group with TOM. EC, pH and FA formeda group with hem and C/N ratio. In the bottom sample of drum 3, three groups were observed:(i) Cel, lig and HA, (ii) EC, pH, FA, hem, C/N ratio and (iii) TOM and MC.

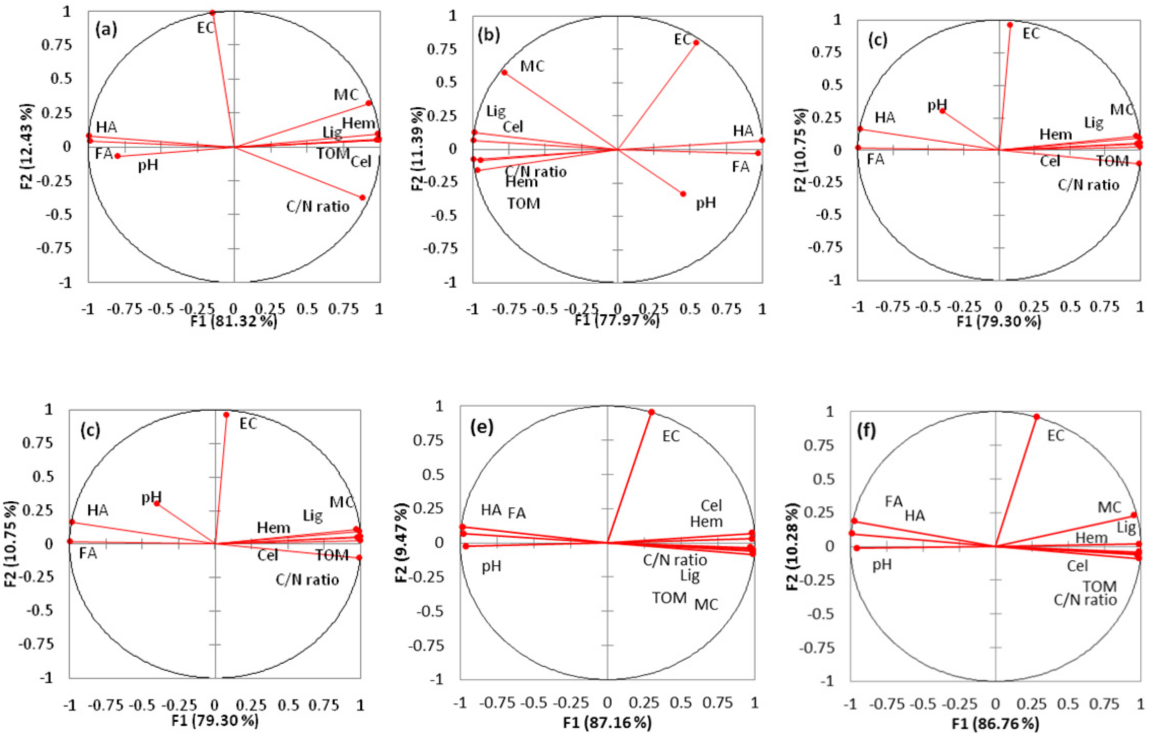
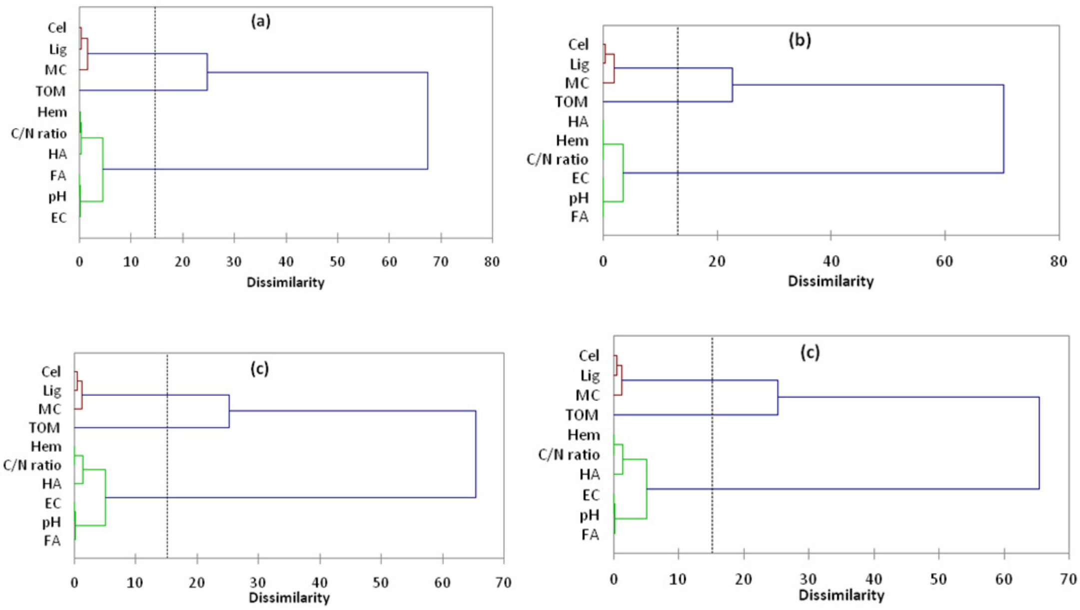


Fig. 3. PCA of (a) drum 1 - middle; (b) drum 1 - bottom; (c) drum 2 - middle; (d) drum 2- bottom; (e) drum 3 - middle; and(f) drum 3 - bottom



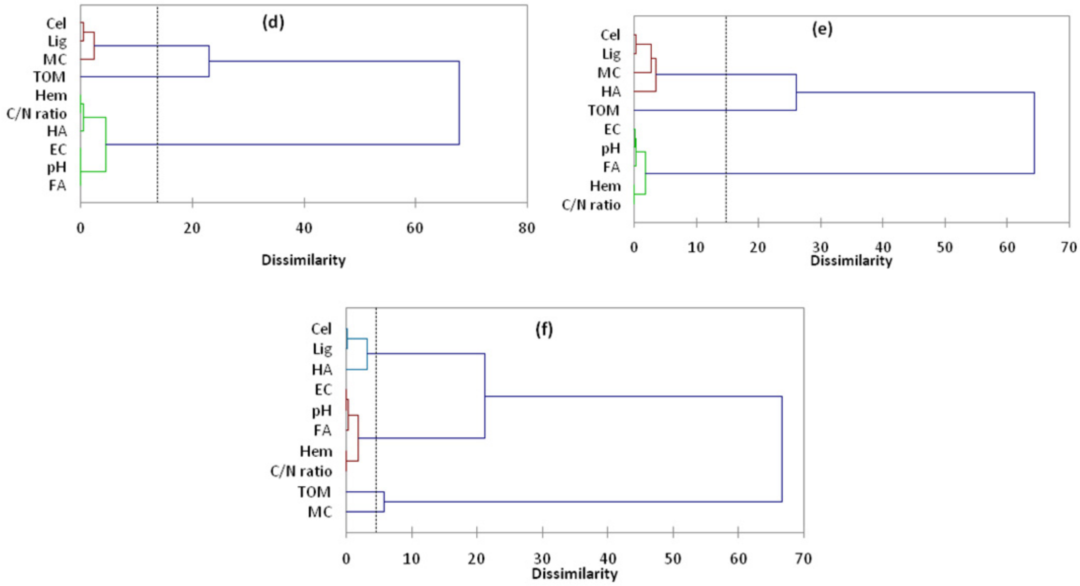


Fig. 4.Dendrogram of (a) drum 1 - middle; (b) drum 1 - bottom; (c) drum 2 - middle; (d) drum 2 - bottom; (e)drum 3 - middle and (f) drum 3 - bottom

4.0 Conclusion

The composting of the food waste (a major component of MSW) along with yard waste as bulking agent was carried out for 60 days in differently configured drums. In this period, the effect of aeration and turning on the composting process was seen by determining several physical, chemical and biological parameters of the waste samples. To understand the degradation rate of organic waste, the kinetic study was performed. The pseudo first order kinetics was fit well to the experimental data obtained in the present study. Out of three drums, the drum with modification for air circulation and frequent turning of sample showed in higher degradation rate constant (k) at both middle and bottom sampling points. This indicates that regular turning of waste is an important activity to achieve better microbial degradation of biodegradable waste fraction. The variability between parameters is essential to understand the correlation between the parameters in order to design the experiment. The multivariate analyses showed that the reduction in TOM, lignin, cellulose, hemicellulose and C/N ratio resulted in increase of HA and FA which is an indication of production of compost at the end of 60 days process. From these results, it can be concluded that usage of modified drums or bins for composting of FW in a community can assist in the significant diversion of waste from landfills.

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