



Studies on Variations in Physico-chemical, Biochemical and Biological Characteristics at Different Maturity Stages of Segregated and Unsegregated Urban Solid Waste of Drum Compost

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Improper disposal of solid waste is one of the main causes of environmental pollution. Converting solid waste into compost and using it as an organic fertilizer in agriculture are an effective waste management method. Quality of such fertilizer may affect both human and environmental health. Therefore, in this study, compost from segregated and unsegregated urban solid waste compost was analyzed for its physical-chemical, biochemical, biological characteristics and the results were compared with the standards. In this descriptive-analytical study, compost samples were collected

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throughout a 3-month period at intervals of 20 days (2 methods, S₁-Segregated, S₂-Unsegregated urban compost) for physico-chemical analysis. In the present study, physical parameters such as moisture content, temperature and bulk density were 23.65%, 31 (°C) and 1.01 (g/cm⁻³). Chemical parameters such as pH, EC, C/N ratio, organic carbon, Total Nitrogen, Phosphorus, Potassium, Ca, Mg, S, Fe, Mn, Cu, Zn, Ni, Pd and Cr content were 7.75, 1.12 (dS m⁻¹), 17.78, 29.16, 1.64, 0.45, 1.11, 1.47, 0.74, 0.76%, 3529.11, 350.67, 41.11 and 118.07(mg kg⁻¹), respectively. The heavy metal concentration viz., nickel, lead, chromium content were 12.75, 23.87 and 12.53 (mg kg⁻¹), respectively. Heavy metals concentration was detected at all the decomposition stages of composting and were to found to be within the permissible limits of Ohai-EAP standards. From the results, it can be concluded that, segregated urban waste composting could produce acceptable quality of compost, which can be used as fertilizer or soil amendment.

Keywords: *Physico-chemical; heavy metals; biochemical; biological characteristic; urban solid waste drum compost.*

1. INTRODUCTION

“MSW has become one of the significant environmental issues, particularly in developing countries. The solid waste generation mainly consists of biodegradable and non-biodegradable waste materials produced due to several societal activities [1,2]. The improper dumping of solid waste pollutes the air, soil, and water. The BBMP with an area of 2190 km² and a population of about 10.18 million generates around 5000 metric tons per day of waste at an average generation rate of 0.5 kg per capita per day (kg/capita/d). Presently, Bengaluru is facing significant problems due to existing disposal practices of generated waste incurring high cost due to lack of proper infrastructural facilities also the open dumping in the expanding zone of the city poses severe problems to the structures constructed on these old dumps [3,4,5]. In the meantime, groundwater quality deteriorated due to improper leachate management” [6].

“Urban solid waste can be defined as any solid or semi-solid substance or object resulting from human or animal activities, discarded as useless or unwanted materials. It is an extremely mixed mass of wastes, which may originate from household, commercial, industrial or agricultural activities. Municipal solid waste (MSW) composting, however, has proved to be a safe and effective way to accelerate the decomposition and stabilization of biodegradable components of bio-waste from MSW, leading to production of compost for soil amendment or as an organic nutrient source” [7,8].

“Composting is gaining interest as a suitable alternative for chemical fertilisers with environmental profit, since this process eliminates or reduces toxicity of MSW [9,10] and leads to a final product which can be used in

improving and maintaining soil quality”. “Many studies have shown that the compost improves physical and chemical properties of soils by increasing nutrient content, organic matter, water holding capacity and cation exchange capacity. Thus, contributing to an improvement of crop yield and quality” [11,12]. Urban solid waste compost consists about 51 percent of organic waste, utilizing it in agriculture not only improves soil fertility but also can save chemical fertilizers [13,14], if it is utilised scientifically through segregation and composting which results in mitigating environment pollution [15-17]. Keeping these points in view, the present investigation was studied aiming to partially replace chemical fertiliser with segregated and unsegregated urban solid waste studies on variations in physico-chemical, biochemical and biological characteristics different maturity stages of composting.

2. MATERIALS AND METHODS

2.1 Collection of Compost Samples

City solid waste is obtained from in and around GKVK Bengaluru for the preparation of segregated and unsegregated composts, during the month of July 2015. Segregated urban solid waste such as vegetables, fruits, flower, dry leaves and saw dust are dumped into the drum composters and composting is done with microbial consortia (*Trichoderma viridae*, *Trichoderma harzianum*, *Pseudomonas fluorescense*, *phaenerochate chryosporium*, *Bacillus subtiles*) without contact with other urban dry waste. Whereas unsegregated urban waste as such available as waste without segregation and vegetables, fruits, flower, leaf litter along with solid dry waste like metals, papers, medicines, cosmetics etc. are dumped into the drum composters and composting is done with the use

of microbial consortia. The segregated and unsegregated samples were collected during drum composting at different intervals of 20th, 40th, 60th and 80th days of compost.

2.2 Working of Drum Bio Composter

- 1) Segregated urban / municipal waste were filled into capacity drum composter.
- 2) Microbial consortia at 1% by weight of wet waste.
- 3) The urban waste was allowed to decompose.
- 4) Initially (1-14 days) leachate (brown liquid) produced from the decomposing urban waste was collected in the trays. The collected leachate was again put back to the drum to maintain the nutrient balance.
- 5) The drums were rotated at 15-20 rounds in the morning and evening daily to facilitate aeration.
- 6) With progress in decomposition, the volume reduces and colour of the urban waste changes to brown and dark brown. Within sixty days the composting would be reaching advanced stages of compost.

- 7) Sufficient moisture (50-60 %) was maintained during composting to ensure a better
- 8) Microbial degradation of the urban waste.

2.3 Analysis of Compost Samples

2.3.1 Physico-chemical analysis

The collected segregated and unsegregated samples were analyzed for various physico-chemical characteristics such as Moisture content (Pressure plate apparatus method); Bulk densities (Keen's cup method); pH (1:5 water extract by pH meter); Electrical conductivity (1:5 water extract, conductivity meter); Calcium and Magnesium (1N ammonium acetate, EDTA method); organic carbon (Dry combustion); Total nitrogen (Microkjeldahl Digestion and Distillation); Total phosphorus (Vanadomolybdic yellow colour spectrophotometry) Total potassium (Flame photometry), Sulphur (Turbidimetry), Micronutrients (Atomic absorption spectrophotometry). The C/N ratio was calculated by using standard procedures for analysis [18].

Table 1. Physical composition of segregated and unsegregated urban solid waste

Composition segregated urban solid	Percentage
Vegetables, fruits and flower	71
Kitchen waste	19
Dry leaves and grass	7
Saw dust	3
Composition unsegregated urban solid waste	Percentage
Vegetables, fruits and Kitchen left over paper	52,15
Rags	2.5
Bones, glass, metallic pieces, medicines, and cosmetics	11
Sand	9.5
Plastic	10



UAS (B) Drum Composter

Fig. 1. A simple technology of composting urban waste and its use in agriculture

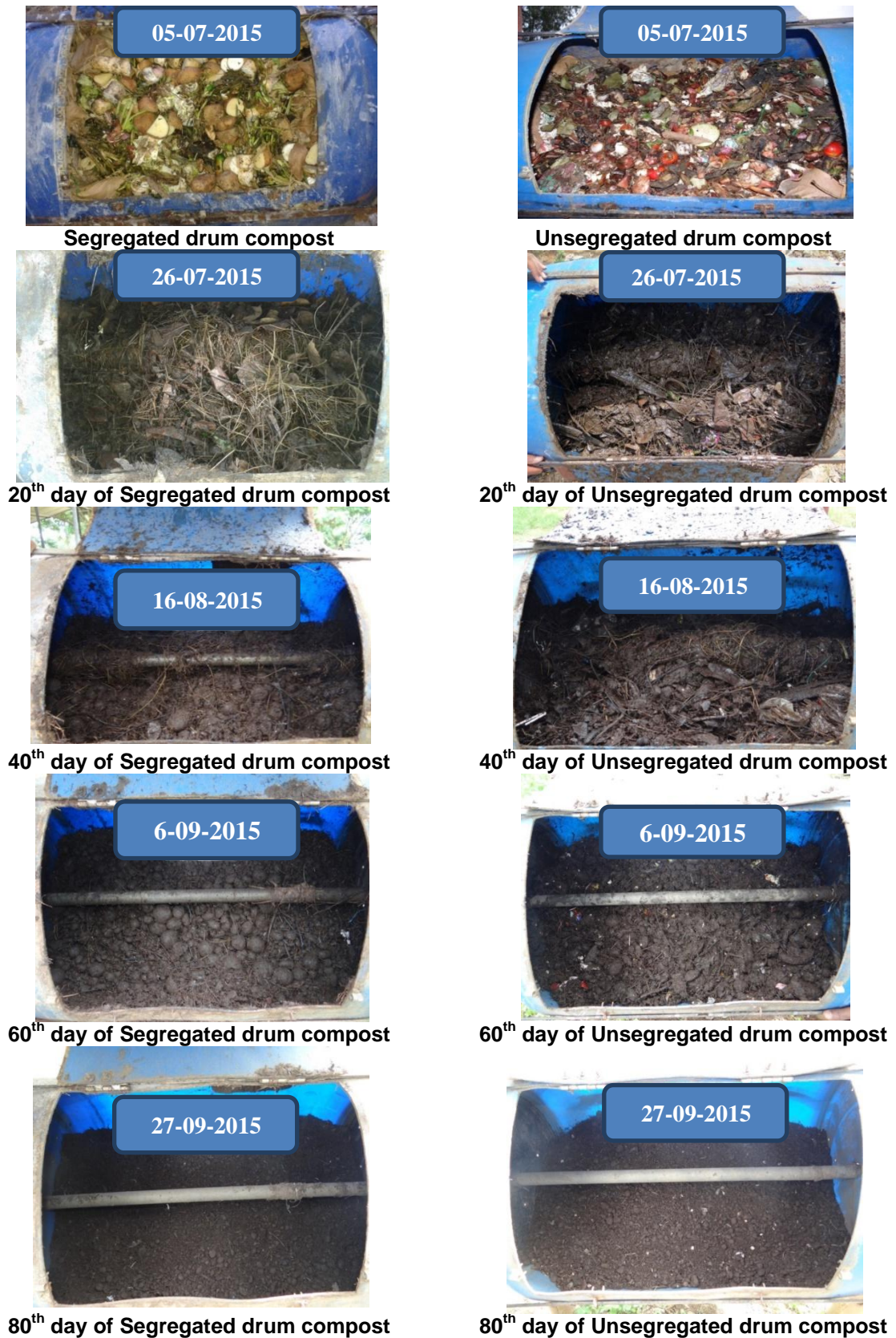


Fig. 2. Changes during composting of segregated and unsegregated urban solid waste at different days of intervals

2.3.2 Biochemical analysis

Lignin and cellulose Determination of lignin and cellulose was carried out by adopting the methodology given by Van Soest and Wine [19].

2.3.2.1 Acid Detergent Fibre (ADF)

One gram of sample was taken in a 250 ml round bottom flask and 100 ml acid detergent solution (Cetyl trimethyl ammonium bromide) was added. The contents of the flask were boiled for 10 minutes and refluxed for one hour after the onset of boiling. Later the contents were cooled and filtered through pre weighed Gooch crucible by suction and washed with hot water twice, again washed with acetone to break the lumps. It was then dried to 100 °C in a hot air oven for 12 hours and weight was recorded after cooling.

2.3.2.2 Acid Detergent Lignin (ADL)

The residue from ADF was transferred to 100 ml beaker containing 50 ml of 72 percent H₂SO₄ and allowed to stand for three hours and boiled for 4 hours after diluting. The contents were cooled and filtered through preweighed Whatman No. 1 filter paper. The residue was washed several times with distilled water to get rid of acid. Filter paper along with residue was dried at 100 °C and weight was recorded after cooling the desiccator. The filter paper along with residue was transferred to pre-weighed silica crucible and contents were ashed in muffle furnace kept at 550 °C for 3 hours. Weight of the crucible was recorded after cooling in desiccators and the ash content was calculated.

The lignin and cellulose were calculated using formulae

Lignin= Residue after extraction with 72 percent H₂SO₄- Ash

Cellulose= ADF - Residue after extraction with 72 percent H₂SO₄

2.3.3 Extraction, fractionation and quantification of humic substances

2.3.3.1 Extraction of humic substances

Ten gram of air dried compost sample was taken in 250 ml conical flask to which 100 ml of 0.1 M NaOH in 0.1 M sodium pyrophosphate was added, stoppered and shaken for 24 hours. The dark colored supernatant was separated by

centrifugation and collected. The extraction was repeated thrice with 50 ml of extractant for complete extraction of the humic substances.

2.3.3.2 Fractionation of humic substances

The pooled alkali extracts were acidified to pH 2.0 with 2 N HCl, stirred well and allowed to stand at room temperature for 24 hours. Then the soluble fulvic acid was separated from the coagulated humic acid fraction by centrifugation. The process of precipitation and centrifugation were repeated to attain partial purification of humic acid fraction as described by Schnitzer [20]

2.3.4 Purification and quantification of organic matter fractions

2.3.4.1 Purification of humic acid

Humic acid was further purified by treating the extracted humic acid fraction with HCl-HF mixture (5 mL each of HCl and HF acids were dissolved in 990 mL of double distilled water) for 24 hours. The acid mixture was separated by centrifugation. This treatment was repeated thrice in succession. Finally, the residue was thoroughly washed with distilled water and freeze dried. The sample weights were recorded before using it for the further analysis.

2.3.4.2 Purification of fulvic acid

The purification of fulvic acid was done as outlined by Wander and Traina (1996). The fulvic acid fraction was transferred to 100 mwco dialysis bags and dialysed against double distilled water for 24 hours. The dialyzed fraction was evaporated under low temperature and finally freeze dried. The dried sample were weighed and stored for further analysis.

2.3.5 Characterization of humic acid and fulvic acid

Purified samples of humic and fulvic acids extracted from matured composts were subjected to E₄/E₆ ratio using the procedure outlined by Schnitzer [20] E₄/E₆ ratio: The degree of humification and aromaticity of humic acid was measured using E₄/E₆ ratios. A known quantity of the sample was taken and dissolved in 10 mL of 1x10⁻² M NaHCO₃ solution. The absorbance's at 465 and 665 nm was measured using UV-VIS scanning spectrophotometer and the absorbance ratio was recorded.

2.4 Bacteriological Analysis

2.4.1 N fixer and P solubilize

The microbial load of compost was analysed for N fixer and P solubilizer by following the standard dilution plate count technique. Combined carbon media for N fixers and Sperber's medium for PO_4 -solubilizers were used for enumeration of microbial population. The petri plates containing media for N-fixers and P solubilizer were incubated at $300^\circ C$ for three to six days and population was counted and expressed per unit dry weight of substrate.

2.5 Heavy Metal Analysis

The 1g of oven dried sample was transferred to 100 ml beaker. A tri acid mixture (10 ml) consisting of HNO_3 , H_2SO_4 and $HClO_4$ in the ratio 9:2:1 was added to each of the flasks with 100 ml of distilled water and digested on hot plate until the dense fumes of $HClO_4$ cease, to get a clear extract. The beakers were then allowed to cool and the extracts were filtered with Whatman No.42 filter paper. The filtrates were diluted to 100 ml in standard flasks to have an adequate volume of solution for analysis. The dilution factor was noted. The water soluble and acid digested extracts were analyzed for quantitative estimation of heavy metals (cadmium, lead, chromium and nickel) using atomic absorption spectrophotometer [18].

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics

3.1.1 Moisture content

The moisture content decreased in both methods with increasing days of interval (Table 2). The moisture ranged from 47.50 percent (S_1) to 45.33 percent (S_2) on 20th day and on 80th day from 23.65 percent (S_1) to 22.03 percent (S_2) (Table 2). Among the methods segregated (S_1) recorded higher moisture content over unsegregated (S_2) method at all interval of days.

Moisture content of the composting blend is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of micro-organisms [21].

In comparison with recommended standards [22] except 60 and 50 days compost sample, in all the maturity stages, moisture content percentage

was found to be high and during different degradation stages decrease in moisture content has been observed from 10 days to 60 days which can heat generated by biological metabolism and air flow increases the water evaporation in the bioreactor, consequently decreasing the moisture content. Decline in the moisture content percentage during the thermophilic phase of composting due to high evaporating rates has been recorded by Larney and Blackshow [23].

3.1.2 Temperature

The temperature which was initially $35^\circ C$ in both of compost was increased to $61^\circ C$ and $65^\circ C$ on the 40th day of composting and later the temperature gradually stabilizing at ambient temperature of $31^\circ C$ and $35^\circ C$ in segregated and unsegregated drum compost, respectively at 80th of composting (Table 2).

As the decomposition is microbial mediated the microbial respiration accompanied by release of energy during decomposition and due to the compaction of overlying decomposable materials the temperature increases. As the decomposition was microbially mediated, the microbial respiration accompanied by the release of carbon dioxide and energy during decomposition and due to the compaction of overlying decomposable materials the temperature increases then stabilized. Similar results were reported by Narkhede et al. [24].

3.1.3 Bulk density

The bulk density of the segregated and unsegregated urban solid waste ranged from 1.14 (S_1) to 1.34 g/cm^3 (S_2) on 20th day and 1.01 (S_1) to 1.04 g/cm^3 (S_2) on 80th days of composting (Table 2). The bulk density of segregated and unsegregated urban compost is defined as its weight per unit volume. During the present investigation the bulk density ranged from 1.34 to 1.04 g/cm^3 . The results were in conformity with findings of Brinton [25] who reported that during the composting process, microbial activity break down the loosely combined raw materials into smaller pieces after degradation resulting in decreased bulk density.

3.2 Chemical Characteristics

3.2.1 pH

The pH of the segregated and unsegregated urban solid waste ranged from 7.40 (S_1) to 7.74

(S₂) on 20th day and 7.35 segregated (S₁) to 7.84 unsegregated drum compost (S₂) on 80th day of composting (Table 3). The increase in the pH is attributed the dissociation of organic acids to carbon dioxide. The slow increase may be due to disappearance of organic acids to form less acidic intermediates or due to buffering action of humic substances.

The findings of this study concurred with the result of Shyamala and Belagali [26] who indicated that during biological conversion of waste to humus the acid forming bacteria brought the drop in pH and this was followed by an increase in pH to alkaline condition due to ammonia formation which finally stabilizes at near neutral condition. In comparison with recommended standards (Bordna Mona, 2003), except 40, 50 and 60 days old compost samples, pH values were found to be higher than the normal range which implies that, during different degradation stages decrease in pH has been observed from 10 days to 60 days which can attributed to the produce CO₂ from organic acids and loss of nitrogen [27]

3.2.2 Electrical Conductivity (EC)

The electrical conductivity (dS m⁻¹) of the two methods ranged from 4.10 (S₁) to 4.41(S₂) on 20th day and decreased to 1.12 segregated (S₁) to 1.51 unsegregated (S₂) on 80th day of composting (Table 3). The findings of this study concurred with the result of Seema [28] Reddy et al. [29] assessed the feasibility of composting separated organic matter of municipal solid waste (MSW) generated in low, middle and high income areas of Karachi city with a population over 14 million. The soluble salts 3.90-5.10 mS cm⁻¹. The electrical conductivity

decreases might be due to the concentration of ions and soluble salts reduced during the composting process.

3.2.3 Organic carbon and C/N ratio

The data recorded on the changes in organic carbon and C:N ratio of the decomposing materials at different intervals of composting are given in (Table 3).

The organic carbon content decreased during composting irrespective of the treatments. The organic carbon values of segregated and unsegregated urban solid waste ranged from 38.10 (S₁) to 37.52 (S₂) percent on 20th days and decreased from segregated 29.16 (S₁) to 24.17 percent unsegregated (S₂) on 80th day. Among the methods (S₂) segregated recorded least organic carbon 24.17 compared to unsegregated drum compost.

The C: N ratio decreased over the time in both the methods. The C:N ratio ranged from 38.48 (S₁) to 41.68 (S₂) on 20th day and decreased with time interval and recorded 17.78 (S₁) to 19.81 (S₂) on 80th day. Among the methods (S₂) unsegregated recorded higher C: N ratio as compared to segregated compost.

The losses of organic carbon were significantly affected by composting. It was found that, the percentage of organic carbon decreased, which shows the decomposition of waste by microbial population [30]. The percentage of organic carbon decreased, which shows the decomposition of waste by microbial population. Part of the carbon in the decomposing residues evolved as CO₂ and a part was assimilated by the microbial biomass [31]

Table 2. Changes in moisture, temperature and bulk density during composting of segregated and unsegregated urban solid waste in drum composting at different intervals of days

Days	Moisture (%)				Temperature (°C)				Bulk density (g/cm ³)			
	20	40	60	80	20	40	60	80	20	40	60	80
Segregated drum compost (S ₁)	47.5	38.52	26.64	23.65	44	61	52	31	1.14	1.07	1.02	1.01
Unsegregated drum compost (S ₂)	45.33	32.91	25.60	22.03	47	65	56	35	1.34	1.28	1.12	1.04

Table 3. Changes in the pH, EC, organic carbon and C/N ratio during composting of segregated and unsegregated urban solid waste

Methods	pH				Electrical conductivity (dSm ⁻¹)				Organic carbon (%)				C/N ratio			
	20	40	60	80	20	40	60	80	20	40	60	80	20	40	60	80
	Days				Days				Days				Days			
S ₁	7.4	8.11	7.71	7.35	4.1	2.36	1.24	1.12	38.1	34.12	31.25	29.16	38.48	25.8	21.85	17.78
S ₂	7.74	8.26	8.04	7.84	4.41	3.27	2.42	1.51	37.52	31.84	27.4	24.17	41.68	31.2	23.82	19.81

* Note: S₁= Segregated drum compost S₂= Unsegregated drum compost

C/N ratio is one of the most important parameters that determine the extent of composting and degree of compost maturity. These results are in line with reports of Ayesha [32] Jadia and Fulekar [33] reported that the decrease in C:N ratio could be due to respiratory activity of microorganisms and increase in total nitrogen by mineralization of organic matter.

3.2.4 Nitrogen

The nitrogen content of the decomposing material increased during composting period. The nitrogen content ranged from 0.99 segregated (S₁) to 0.86 percent unsegregated on 20th day and the values increased with time intervals as recorded 1.64 segregated (S₁) to 1.22 percent unsegregated (S₂) on 80th day (Table 4). Among the methods, segregated (S₁) recorded higher percentage of nitrogen.

In mature composts, most of the nitrogen is in organic form. The increase in nitrogen concentration during composting will be caused by the decrease of substrate carbon resulting from the loss of CO₂ because of the decomposition of the organic matter, which is chemically bound to nitrogen. Dimambro et al. [34] described that the increase in nitrogen content during composting was due to nitrogen release by micro-organism's metabolic products and dead tissue. Loss of organic carbon might be responsible for nitrogen addition in the form of mucus nitrogenous excretory substances, growth stimulatory hormones and enzymes [35,26].

3.2.5 Phosphorus

The phosphorus increased in both the methods with time. The phosphorus content ranged from 0.28 (S₁) to 0.19 (S₂) percent on 20th day and higher values of 0.45 (S₁) to 0.32 percent segregated (S₂) on 80th day (Table 4). Among the methods (S₁) recorded higher percentage of phosphorus. In comparison with recommended standards [35,26] the phosphorous were found higher in all the samples. The phosphorous

content gradually increased during composting process and water solubility of phosphorous decreases with humification so that; phosphorous solubility during the decomposition was subjected to further immobilization factor [21]

3.2.6 Potassium

The potassium increased in the all both methods of composting. During the composting period, the potassium content ranged from 0.72 (S₁) to 0.62 (S₂) percent on 20th day and higher values of 1.11 segregated (S₁) 0.91 to percent unsegregated (S₂) on 80th day (Table 4). Among the methods (S₂) recorded lower percentage of potassium. In the present study, composts might be due to quick microbial activity leading to decrease in volume of the material and also observed higher amount of K content in compost. Shabani et al. [31] stated that the increase in potassium in the compost might be attributed to increased mineralization of these elements due to enhanced microbial and enzyme activity. The results are in conformity with findings of Reddy et al. [29].

3.2.7 Calcium and Magnesium

The calcium content of both the methods increased with time which ranged from 1.23 (S₁) to 0.73 (S₂) percent on 20th day and increased to 1.47 segregated (S₁) to 0.95 percent unsegregated (S₂) on 80th day (Table 5). The magnesium content ranged from 0.49 (S₁) to 0.34 (S₂) percent on 20th day and from 0.74 segregated (S₁) to 0.56 percent unsegregated (S₂) on 80th day.

In both methods of compost calcium and magnesium content increases with increasing days of interval. Increased calcium and magnesium content of composts during composting might be due to production of calcium and magnesium oxides and hydroxides during decomposition of the organic matter there by increase in the calcium and magnesium content in compost [36,26].

Table 4. Changes in nitrogen, phosphorus and potassium contents during drum composting of segregated and unsegregated urban solid waste

Methods	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	20	40	60	80	20	40	60	80	20	40	60	80
Days of composting												
S ₁	0.99	1.32	1.43	1.64	0.28	0.35	0.41	0.45	0.72	0.87	0.93	1.11
S ₂	0.86	1.02	1.15	1.22	0.19	0.24	0.29	0.32	0.62	0.72	0.85	0.91

Table 5. Changes in calcium, magnesium and sulphur contents during drum composting of segregated and unsegregated urban solid waste

Methods	Calcium (%)				Magnesium (%)				Sulphur (%)			
	20	40	60	80	20	40	60	80	20	40	60	80
Days of composting												
S ₁	1.20	1.40	1.40	1.50	0.50	0.60	0.70	0.70	0.50	0.60	0.60	0.76
S ₂	0.70	0.80	0.90	1.00	0.30	0.40	0.50	0.60	0.30	0.50	0.60	0.64

3.2.8 Sulphur

The sulphur content increased in both the methods during the composting. The sulphur content ranged from 0.45 (S₁) to 0.31 (S₂) percent on 20th day and increased to 0.76 segregated (S₁) to 0.64 percent unsegregated (S₂) on 80th day (Table 5). Among the methods (S₁) recorded higher percentage of calcium, magnesium and sulphur as compared to unsegregated compost.

The present investigation on soluble sulphate varied from 16.36 to 61.95 per cent the minimum percentage of soluble sulphate was recorded in 10 days old compost sample with 16.36 percent and maximum for 60 days old compost sample with 61.95 percent.

The variation of sulphate concentrations mainly depends on the decomposition of organic matter present in the solid wastes. In anaerobic decomposition of solid wastes, sulphate is reduced to hydrogen sulphide, causing obnoxious odors and promotes corrosion [37]

3.2.9 Micronutrients

The micronutrient content increased in both composting methods during drum composting. The zinc content in both the methods varied from 67.13 (S₁) to 129.93 ppm (S₂) on 20th day and on 80th day it ranged from 118.07 segregated (S₁) to 143.17 ppm unsegregated (S₂) (Table 6). The iron content in both the methods varied from 3242.60 (S₁) to 3445.52 ppm (S₂) on 20th day and on 80th day it ranged from 13529.11 segregated (S₁) to 3752.2 ppm unsegregated (S₂).

The copper content in both the methods varied from 22.80 (S₁) to 28.21 ppm (S₂) on 20th day and on 80th day it ranged from segregated 44.23 (S₁) to 42.11 ppm unsegregated (S₂). The manganese content in both methods varied from 267.21 (S₁) to 313.33 ppm (S₂) on 20th day and on 80th day it ranged from segregated 350.67 (S₁) to 366.33 ppm unsegregated (S₂). The unsegregated compost was having higher

concentration of micronutrients compared to segregated compost. Source segregated composts should contain low level of micronutrients, while higher level can be excepted in mixed MSW compost. Increased micronutrients content in both methods of composts might be due to organo-metallic chelation of micronutrients [26]. The concentration of the micronutrients in the raw materials used for the composting also one of the cause increased micronutrients in the composts [35].

3.2.10 Heavy metals

The lead content increased in during the composting lead content increase in both the segregated and unsegregated composting method (Table 7). The lead content in both treatments ranged from 10.20 (S₁) to 34.27 ppm (S₂) on 20th day and on 80th day it ranged from 23.87 segregated (S₁) to 43.62 ppm unsegregated (S₂).

The chromium content in both segregated and unsegregated composting varied from 6.21 (S₁) to 18.32 ppm (S₂) on 20th day and on 80th day it ranged from 12.53 segregated (S₁) to 23.21 unsegregated (S₂). The nickel content in both methods varied from 5.26 (S₁) to 15.54 ppm (S₂) on 20th day and on 80th day it ranged from 10.71 segregated (S₁) to 23.42 ppm unsegregated (S₂). The cadmium was not detected in both methods.

The unsegregated compost was having higher concentration of heavy metals compared to segregated compost. Source segregated composts should contain low level of toxic element, while higher level can be accepted in mixed MSW compost. Heavy metals are sourced from batteries, solder, wine bottle cap; circuit stabilizers in plastics may contain potentially toxic elements [35]. Stephen [38] who reported that the compost prepared from municipal solid waste had higher concentration of heavy metal elements. Manju et al. [39] also reported that municipal solid waste compost contains the concentration of heavy metals as per the Indian standards.

Table 6. Changes in micronutrients content during composting of segregated and unsegregated urban solid waste

Methods	Zinc (ppm)				Iron (ppm)				Copper (ppm)				Manganese (ppm)			
	20	40	60	80	20	40	60	80	20	40	60	80	20	40	60	80
Days of composting																
S ₁	67.13	92.73	108.07	118.07	3242.6	3362.21	3437.71	3529.11	22.8	28.42	36.87	44.23	267.2	275.4	341.6	350.67
S ₂	129.93	133.47	135.2	143.07	3445.5	3561.3	3604	3752.2	28.21	32.67	38.24	42.11	313.33	330.67	357.33	366.33

Table 7. Changes in heavy metals contents during composting of segregated and unsegregated urban solid waste

Methods	Pb (ppm)				Cr (ppm)				Cd (ppm)				Ni (ppm)			
	20	40	60	80	20	40	60	80	20	40	60	80	20	40	60	80
Days of composting																
S ₁	10.2	16.4	20	23.9	6.2	8.3	11	12.5	ND	ND	ND	ND	5.3	7	9.3	13
S ₂	34.3	39.2	41	43.6	18	20	21	23.2	ND	ND	ND	ND	16	18	20	23

*Note: S₁-Segregated drum compost S₂-Unsegregated drum compost

3.3 Biochemical Characteristics

3.3.1 Cellulose and lignin

The cellulose content of segregated and unsegregated urban solid waste compost subjected to different methods of composting was decreased with time (Table 8). The cellulose content ranged from 48.38 (S₁) to 44.43 (S₂) percent on 20th day and from 28.12 segregated (S₁) to 25.26 percent unsegregated drum compost (S₂) on 80th day.

The lignin content of the decomposing of segregated and unsegregated urban solid waste subjected to different methods of composting decreased with time. The lignin content ranged from 32.65 (S₁) to 30.10 (S₂) percent on 20th day and from 21.87 segregated (S₁) to 19.32 percent unsegregated drum compost (S₂) on 80th day.

The segregated and unsegregated compost changes in the content of cellulose and lignin over the period of time and due to the different methods of composting. The Solid urban wastes are known to be made up of different organic compounds which vary in their degree of being decomposed. Some compounds such as simple sugars and proteins are degraded at a faster rate followed by hemi cellulose, cellulose and lignin [40,41].

Since composting is a microbial mediated process these organisms act upon the easily degradable materials first, followed by hard to degrade materials because of their complex chemical structure as in the case of cellulose and lignin. Microbial succession ensures the breaking down of such compounds over a period of time [42,43]. The results clearly showed that microbial inoculation has enhanced the degradation of cellulose and lignin over a period of time. The results clearly indicate that the segregated compost was having higher cellulose and lignin content than unsegregated compost.

Biochemical properties showed that the degradation of cellulose was marginally higher

than lignin [44]. However, lignin to cellulose ratio was more in FYM and compared to segregated and unsegregated urban compost and might be due to the presence of fairly good amount of lignin and cellulose which is highly resistant to decomposition.

Lignin content attributed the decrease in to weakening of lignin structures to be the cause for reduction in the lignin content over a period of time [45]. Cellulose hydrolysis-fermentation process involving the breakdown of cellulose in to component glucose molecules is as a result of microbial inoculation [34].

3.3.2 Humic acid

The humic acid content of the composting of segregated and unsegregated urban solid waste subjected to different methods of composting increased with time. The humic acid content ranged from 1.13 (S₁) to 0.94 (S₂) percent on 20th day and from 8.02 segregated (S₁) to 6.45 percent unsegregated drum compost (S₂) on 80th day (Table 9). The humic fractions were more in segregated and unsegregated compost compared to FYM which indicates better decomposition and maturity of compost as reported by Marta et al. [44].

3.3.3 Fulvic acid

The fulvic acid content of the composting of segregated and unsegregated urban solid waste subjected to different methods of composting increased with time. The fulvic acid content ranged from 0.53 (S₁) to 0.23 (S₂) percent on 20th day and from 2.42 segregated (S₁) to 1.96 percent unsegregated drum compost (S₂) on 80th day (Table 9). A survey of MSW compost reported that the majority of the humic substances found in MSW compost were identified as humic acid, with a humic acid to fulvic acid ratio of 3.55 [46,44].

Table 8. Changes in cellulose and lignin properties of during drum composting of segregated and unsegregated urban solid waste

Methods	Cellulose (%)				Lignin (%)			
	20	40	60	80	20	40	60	80
	Days							
S ₁	48.38	38.67	32.18	28.12	32.65	27.32	23.05	21.87
S ₂	44.43	35.41	29.32	25.26	30.10	23.52	21.12	19.32

Note: S₁-Segregated drum compost S₂-Unsegregated drum compost

Table 9. Changes in biochemical properties of during drum composting of segregated and unsegregated solid waste

Methods	Humic acid (%)				Fulvic acid (%)				Humus index				E ₄ /E ₆ ratio			
	20	40	60	80	20	40	60	80	20	40	60	80	20	40	60	80
	Days of composting															
S ₁	1.13	3.32	5.67	8.02	0.53	1.32	1.97	2.42	2.13	1.68	2.87	3.31	0.58	2.01	3.54	4.12
S ₂	0.94	2.54	4.75	6.45	0.23	0.75	1.21	1.96	4.08	3.38	3.92	3.33	0.49	1.03	2.13	3.43

Table 10. N fixers and P solubilizer population in drum compost of segregated and unsegregated urban solid waste at different days of interval

Methods	N fixers (cfu × 10 ⁵ g ⁻¹ compost)				P solubilizers (cfu × 10 ⁵ g ⁻¹ compost)			
	20	40	60	80	20	40	60	80
	Days							
S ₁	6.27	12.42	28.42	21.72	75.2	150.33	311.92	234.56
S ₂	5.25	11.34	25.3	19.85	62.73	120.53	297.3	225.23

3.3.4 Humus index

The humus index of the composting of segregated and unsegregated urban solid waste subjected to different methods of composting increased with time. The humus index ranged from 2.13 (S₁) to 4.08 (S₂) on 20th day and from 3.31 segregated (S₁) to 3.29 unsegregated (S₂) on 80th day (Table 9). A survey of MSW compost reported that the majority of the humic substances found in MSW compost were identified as humic acid, with a humic acid to fulvic acid ratio of 3.55 [46,44].

3.3.5 E₄/E₆ ratio

The E₄/E₆ ratio of the composting of segregated and unsegregated urban solid waste subjected to different methods of composting increased with time. The E₄/E₆ ratio ranged from 0.58 (S₁) to 0.49 (S₂) on 20th day and from 4.12 (S₁) to 3.34 (S₂) on 80th day (Table 9). E₄/E₆ ratio is an indicator of degree of aromatic city of composts and it ranged from 2.12, 4.12 and 3.43 FYM, segregated and unsegregated urban compost, respectively. which indicates better decomposition and maturity of compost as reported by Marge et al. [46].

3.4 Biological Properties

The biological studies recorded the N fixers population ranges from 21.72 segregated (S₁) to

19.85 cfu × 10⁵ g⁻¹ in unsegregated drum compost (S₂) on 80th day of maturity of compost (Table 10). The biological studies recorded the P solubilizer population ranges from 234.56 segregated (S₁) to 225.23 cfu × 10⁵ g⁻¹ in unsegregated drum compost (S₂) on 80th day of maturity of compost.

These observations are in conformity with those obtained by other authors [47,48,49].The decrease of microbial diversity in the composting mass could be due to the high temperature and the bacterial viable counts are more for 10, 20, 30, 40 days compost samples compared to 50 and 60 days old compost samples.

4. CONCLUSION

The study's findings clearly demonstrate that composting of urban solid waste, whether segregated or unsegregated, leads to drum compost production with desirable physico-chemical characteristics. This includes appropriate moisture content, temperature, bulk density, pH, electrical conductivity (EC), organic carbon, C/N ratio, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur levels according to recommended standards. The biochemical properties, such as cellulose, lignin, humic acid, fulvic acid, humus index, and E₄/E₆ ratio, showed that the compost's quality

improved significantly on the 80th day of composting of segregated urban waste.

The biological study focused on the increase and subsequent decrease of N fixer and P solubilizer populations in a compost sample over a period of 80 days. The compost sample was found to contain micro nutrients and heavy metals such as lead, nickel, and chromium within acceptable limits at all stages of maturation. However, there was no detection of cadmium. The study suggests that the use of segregated drum compost could produce acceptable quality compost, which can be used as fertilizer or soil amendment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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