International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 8, 2025
https://theaspd.com/index.php

Harnessing Urban-Academic Sector Waste: Analysis Of Compost Quality And Potential

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Abstract: *Composting is an effective green practice and a sustainable solution to solid waste management. At the educational institutes on an everyday basis, huge amounts of solid waste are generated from the horticulture, cafeteria and mess. These issues can be handled conveniently in an eco-friendly way by collecting and converting the waste into a useful soil improvement additive, i.e. compost. However, concerns remain for the issues associated with production of compost such as foul smell and long mineralization time. To offer sustainable solutions for waste management, a composting unit has been set up at the college campus. Compost is produced through a modified form of Aerated Static Pile Composting. In the present investigations, physical-chemical characterization of the compost generated at the campus was carried out. Some of the parameters studied included bulk density, particle size, total organic carbon, total sulphide, total nitrogen, total phosphate, total potash, C/N ratio, conductivity and heavy metal contents. To further characterize the compost, spectroscopic analyses were also carried out.*
Keywords: *C/N ratio, heavy metals, nutrients, spectral analysis, waste management*

1. INTRODUCTION

A large amount of degradable and non-degradable waste is generated daily due to population boom, modernization, and industrialization (Kaza et al., 2018; Thakur et al., 2021; Moubareck et al., 2023; Manea et al., 2024). In addition, the waste is disposed of in an improper manner. Also, the waste management methods such as incineration, uncontrolled dumping and land filling are causing several environmental and health issues (Hajam et al., 2023; Meena et al., 2023).

Composting is a technique which has been used for a long time to manage organic waste in an eco-friendly manner (Chadar et al., 2018; Hassan et al., 2023). Compost can be used as a fertilizer, and also for controlling plant diseases and weed management (Chakravorty et al., 2024). Addition of compost to soil improves its biodiversity as well as protects the environment from the hazards of chemical fertilizers' utilization. Compost can improve plant growth and soil health provided it has optimum concentration of important elements (Robinson et al., 2024). Nitrogen is one such major element required for plant growth. Nitrogen deficiency causes impaired plant growth and development (Khater, 2015; Qureshi et al., 2025). For composting, the C/N (carbon to nitrogen) ratio is an important parameter (Ho et al., 2022). It has been observed that the microbial communities mostly carry out the decomposition of the initial substrate at a steady C/N ratio of 30:1. A ratio below 15 is desirable at the time of maturation (Rubio et al., 2024). The energy requirements of aerobic communities are high as it provides support to their high rate of decomposition. This is met by a high C/N ratio, wherein C provides energy and N is used for protein and nucleic acid synthesis (Azim et al., 2018). High C/N ratio with low levels of N causes slower decomposition rates. Compost is also a good source of phosphorus and potassium required for healthy plant growth. Certain drawbacks of composting include odor production, long time period required for its maturation along with occurrence of pathogens and less amount of nutrients (Ayilara et al., 2020).

An Organic Waste Composting Setup (Wet-waste/Food-waste and Horticultural Waste) was installed at the Recycling and Solid Waste Management Facility of the college campus. The composting plant machinery was procured from a local manufacturer which included a crusher for food waste and a shredder for horticultural waste. The crushed food waste from the Hostel mess and the leaf mulch from the college gardens are co-disposed aerobically in a static composting set up to produce compost which is used for gardening and landscaping purposes within the college. However, in order to make the in-house compost production process more effective, it is crucial to characterize the compost so that it may be used in a sustainable manner.

The current study was undertaken to carry out physico-chemical characterization (Khaing et al., 2019) of in-house produced compost and to understand its biochemistry. Accurate characterization of the compost quality is important to assess the possible adverse outcomes of compost utilization in the environment. The various parameters studied included C/N ratio, levels of nutrients and heavy metals. To determine the quality of compost, all the parameters were matched with the Indian Fertilizer Control Order-1985. The compost maturity was also analysed using spectroscopy techniques such as UV-vis spectroscopy, X-Ray Diffraction, DLS, Fourier Transform Infrared and Field Emission Scanning Electron Microscopy. These spectroscopy methods are considered to be useful as comparative and descriptive tools to monitor the process of composting that enable the complementing of results (Biyada et al., 2020). The composting unit at college campus can serve as a prototype for a decentralized organic waste-to-compost system.

2. MATERIALS AND METHODS

2.1 Physical-chemical characterization of compost

The physical-chemical characterization of compost was performed as per the specifications laid down in the Schedule-IV, Clause 2(h) and (q); FCO-1985 (Amended upto 2024) at the Shriram Institute for Industrial Research, Delhi. The technique and instrumentation involved for potassium (K) was flame photometry on a PerkinElmer PinAAcle Atomic Absorption Spectrophotometer (AAS) Super 900F while other heavy metals cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and lead (Pb) were analyzed by Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES) using Agilent, ICP-OES 5800. For the analysis of phosphorus (P), Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES) was used (Agilent, ICP-OES 5800). Heavy metals, arsenic (As) and mercury (Hg) were estimated by Inductively Coupled Plasma Mass Spectrophotometry (ICP-MS) on a Thermo Scientific, ICAP Q, ICP-MS system.

The obtained results were compared to the recommended reference range by the Fertilizer Control Order (FCO).

2.2 Spectroscopic studies

The below mentioned spectral and microscopic analyses were carried out at Maharishi Markendeshwar University, Mullana, Ambala, Haryana, India.

UV-visible spectroscopy

UV-visible spectroscopy is widely used to characterize metal nanoparticles by measuring their Surface Plasmon Resonance (SPR), which reflects particle size, shape and concentration. A sharp peak indicates uniform, well-dispersed nanoparticles, while a broad or shifted peak suggests agglomeration or size variation.

Polydispersity Index (PDI)

For the size distribution, mean size, and Polydispersity Index (PDI) of the polymeric micelles, Dynamic Light Scattering (DLS) measurements were performed using the Photon Correlation Spectroscopy (PCS) in a Zetasizer Malvern Panalytical (MAL1278078, Malvern). Three different batches were processed and analyzed.

Fourier Transform Infrared Spectroscopy (FT-IR)

Fourier Transform Infrared (FTIR) spectrum of the compost samples was measured using a FTIR spectroscope using (Thermo Model 6700) with diamond Attenuated Total Reflection (ATR). The spectrum was recorded at a wavelength of 4000-500 cm^{-1}.

Field Emission Scanning Electron Microscopy (FESEM)

The morphology and size of the Void micelles were characterized by Hitachi S-4800 FESEM.

X- Ray Diffraction (XRD)

Powder XRD spectra for both void polymeric micelles and (ATPEA-25) loaded polymeric micelles were taken on Malvern Pananlytical (Empyrean) spectrophotometer to analyze the crystalline or amorphous nature of the compost.

3. RESULTS AND DISCUSSION

3.1 Physical-chemical characterization of compost

The feedstock formulations and the composting techniques are critical for the C/N ratio and bio-available concentrations of macro- and micro-nutrients required for plant growth. These also impact soil diversity as well as micro-structure and texture of the compost (Bernal et al., 2009; Wang et al., 2021). Several analytical quantitative techniques based on chromatography and spectroscopy such as mass spectrometry, NMR-, FT-IR- and ICP-AES spectroscopy, and isotopic tracer studies, are employed to identify and estimate the chemical nature and concentrations of compost constituents (Soni et al., 2023).

Major parameters used in the present study for the assessment of compost quality are presented in Tables 1 and 2. The total organic carbon estimated on a dry basis was 19.1 % which is well above the recommended minimum of 12% as per the FCO regulation 1985 (Table 1). Moisture content, crucial for storage and transport of end-product was found to be slightly higher at 40.2 % but within the reported literature values of 3.6 to 45.4% across municipal samples in Indian cities (Manea et al., 2024). The determined pH value of 7.6 falls within the alkaline-neutral range, confirming the decomposition of organic matter. The electrical conductivity was observed to be optimum at 1.6 dS/m. This parameter is important for determining the salinity of the compost which affects the water uptake near the root zone from the soil-compost solution (Sharma & Kumar 2021).

The Total Organic Carbon (TOC) was 19.1% while the macronutrients nitrogen, phosphorus and potassium, relevant for compost's fertilizer potential were 1.6, 0.5 and 0.45%, respectively by weight (Table 1).

Table 1: Physico-chemical characterization of compost.

S. No.	Parameter	Observations
1	Moisture Content (at 65 ± 1°C)	40.2
2	Bulk Density, g/cm^3	0.9
3	Particle Size, (material passing through 4.0mm IS Sieve)	95
4	Total Organic Carbon[1], (on dry basis)	19.1
5	Total Sulphide[1] (as S)	BQL[#]
6	Total Nitrogen[1] (as N)	1.6
7	Total Phosphate[1] (as P_2O_5) (on dry basis)	0.5
8	Total Potash[1] (as K_2O) (on dry basis)	0.4
9	pH of solution (1:2 Ratio)	7.6
10	Conductivity, dS/m (1:5 Ratio)	1.6
11	C/N ratio	12
12	Total Viable Count per gram (cfu)	2.2×10^8 on PCA agar at 30°C for 7 days by serial dilution using plate pour method

All results are average of triplicates.
[#]Quantification limit 0.001%
[1]Results are expressed as % by weight

The C/N ratio of 12% was found to be within the recommended range for city compost criteria of FCO. In general, it was observed (Table 2) that the concentrations of heavy metals of the compost were well below the prescribed FCO limits. Such low concentrations of heavy metals signify a greater value of Clean Index (CI) indicating lesser polluting potential of the compost (Sharma et al., 2018). The total viable count per gram (cfu) was 2.2×10^8 on PCA agar.

Table 2: Heavy metal analysis of compost.

S. No.	Heavy Metal	Wavelength	Levels (mg/kg)
1	Arsenic (As_2O_3)	254 nm	1.0
2	Cadmium *	214.439 nm	BQL#
3	Chromium *	267.16 nm	41.0
4	Copper *	327.39 nm	32.0
5	Nickel *	231.604 nm	15.0
6	Lead *	220.353 nm	2.0
7	Mercury *	23.7 nm	0.13
8	Zinc *	213.857 nm	210

* on dry basis
#quantification limit-1mg/kg
All analyte calibrations were performed with coefficient of calibration >0.99
All results are average of triplicates.

3.2 Spectroscopic studies

In addition to the physical and chemical characterization, to evaluate the compost maturity, different types of spectroscopic analyses were carried out (Figures 1-5; Martin et al., 2023; Chenna & Chouksey, 2024). These included UV-vis spectroscopy analysis, Polydispersity Index (PDI), Fourier Transform Infrared (FTIR) spectroscopy, FE-SEM analysis and XRD analysis. The details are as follows:

UV-vis spectroscopy analysis

The light absorption pattern of the plant biomass was kinetically monitored with the help of UV-vis measurement. The spectra showed a well-defined surface plasmon band for the compost. The band corresponding to the Surface Plasmon Resonance (SPR) for compost occurred at 400 nm (Figure 1).

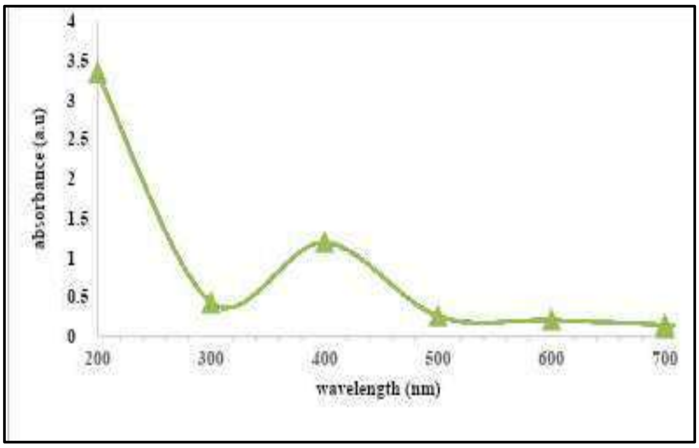

Figure 1: UV-vis spectroscopy analysis.

Polydispersity Index (PDI)

The particle size of compost and their distribution was confirmed by the DLS technique (Figure 2). The peak number and peak amplitude obtained gave an important explanation for size and size distribution of compost sample. The Polydispersity Index (PDI) was 39.1.

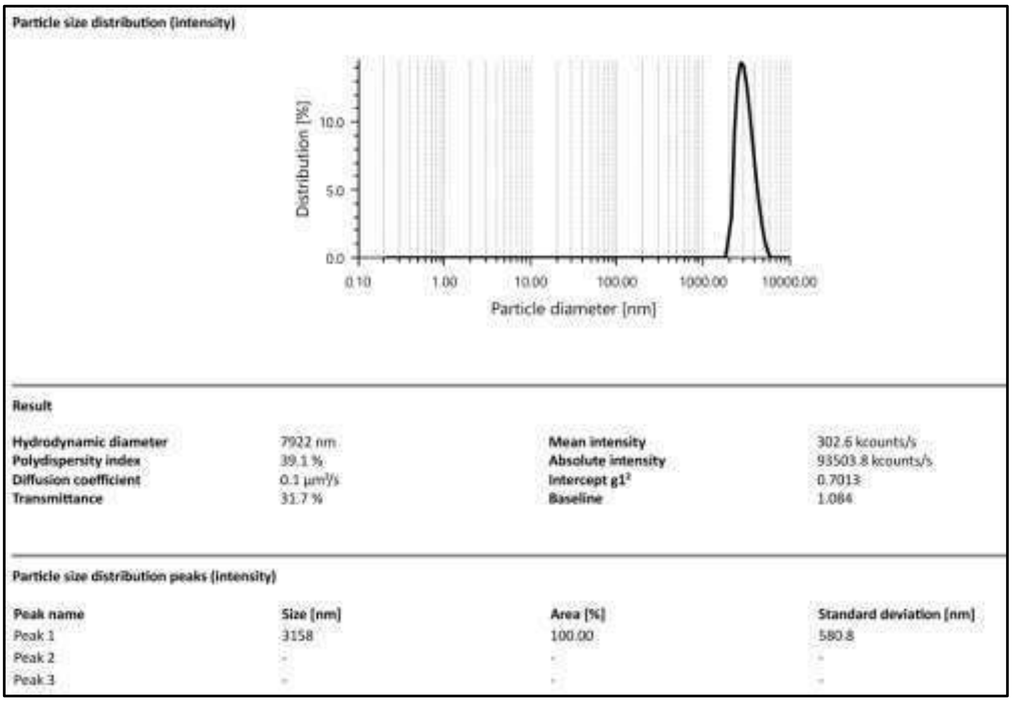

Figure 2: DLS size distribution of compost.

Fourier Transform Infrared Spectroscopy (FTIR)

The infrared spectrum of compost was obtained in the wavelength between 4000-500 cm^{-1} by using Fourier Transform Infrared Spectroscopy. As seen in the Figure 3, four centred main peaks at 3301, 2345, 2034 and 1635 cm^{-1} were obtained**.** The widest absorption peak at wave number of 3301 cm^{-1} was related to the hydroxyl group (O-H). Furthermore, a minor centred peak at 2034 cm^{-1} was attributed to the alkenes, corresponding to proteins which have key role in the decomposition process during composting.

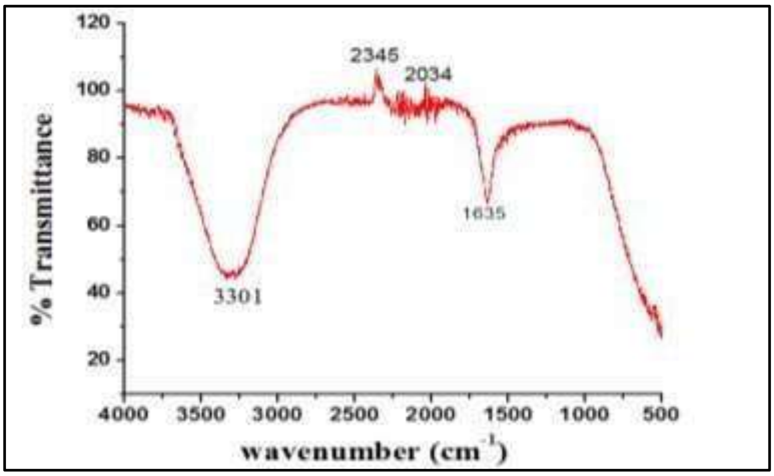

Figure 3: FTIR spectra of compost sample.

FESEM analysis of compost samples

The Field Emission Scanning Electron Microscope (FESEM) image showed that the compost particles were highly polydisperse in nature. A mixture of plate spherical and spheres were obtained in the range of 10-50 nm (Figure 4). Large quantities of small compost particles with an average size of 100 nm were found.

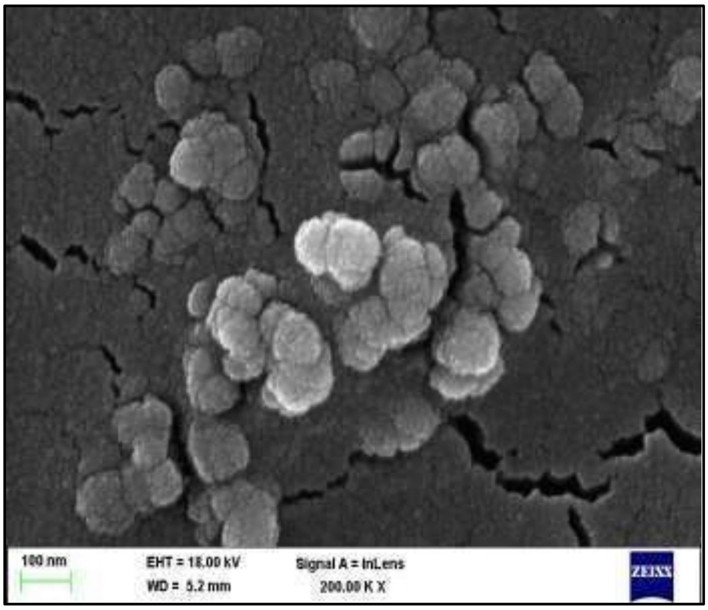

Figure 4: The Field Emission Scanning Electron Microscopy (FESEM) image of compost.

XRD analysis of compost samples

The Figure 5 revealed the XRD analysis about pattern and crystallinity of compost. The well-defined peaks corresponded to polycrystalline nature of the material at 2^{θ} values of 21.23°, 27.00°, 29.81°, 31.24°, 39.85°, 42.78° and 50.46° corresponding to (210), (226), (124), (140), (170), (160) and (170). Results for the acute peaks in data image indicate that each sharp and strong peak is representing the plane of a crystal for composting pile. The strong peaks of the sample spectra of XRD exposed the occurrence of some metals like silver, some composites like calcium carbonate, silicon oxide, sulphides, etc. and various minerals. The sharp and low intensity peaks (below than 1000 counts such as 29.08°, 43°, 46°, 55.77°, etc.) of XRD analysis confirm the presence of minerals indicating biodegradation processes in the compost.

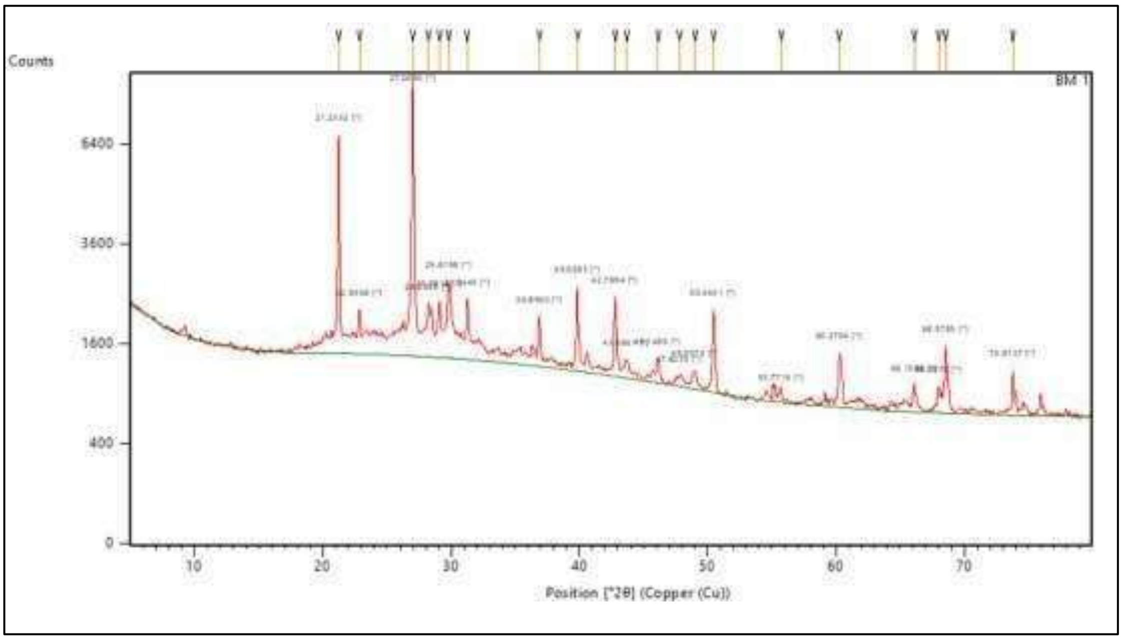

Figure 5: The XRD image of Compost.

4. CONCLUSION

Composting is a simple, traditional process that produces natural organic nutrient rich organic fertilizer. It is an effective sustainable organic waste management system. The end application of compost depends upon its nutrient composition, in particular the nitrogen, phosphorus, and potassium (NPK) (Arrobas et al., 2022). The physical properties concerning the organic matter content, C/N ratio, and pH are also crucial determinants (Azim et al., 2018). In the present study based on the analysis, it was found that the quality of the campus produced compost was suitable for use in horticultural purposes. The essential physico-chemical characteristics were found to be well within the recommended range of the Indian Fertilizer Control Order (FCO) 1985. The pH, electrical conductivity and particle size were within the permissible limits. The heavy metal concentrations were well below the permissible limits as prescribed by FCO. The analysis revealed that the TOC was within the recommended reference range. However, the characterization revealed that significantly higher amounts of moisture were present in the compost. Also, levels of important macronutrients K were critical and required additions. The performed spectroscopic studies also confirmed the biodegradative processes in the compost. Such considerations would enhance the microbial activity, stability, and maturity of the waste by composting. Hence, to harness the potential of composting as a sustainable waste management practice further investigations and improvements are required.

Acknowledgements: This study was made possible by the R&D-12/2024 grant from Miranda House R&D cell. Authors also acknowledge the support of Principal Miranda House, Professor Bijayalaxmi Nanda.

Author's contribution: SB: Conceptualization, original draft writing, editing and experimentation; SJ: Conceptualization, original draft writing, editing and experimentation; SS: Proof reading and editing; SMS: Proof reading and editing; SKU: Proof reading and editing; MS: Experimentation, proof reading and editing and DY: Proof reading and editing.

Funding Sources: The study received all required funding from R&D Cell, Miranda House, University of Delhi, Delhi under the project number R&D-12/2024.

Competing interests: The authors declare there are no competing interests.

Availability of Data and Materials: Available on appropriate request to the authors.

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