



Sustainable management of an invasive and noxious weed *Parthenium* using rotary drum composter

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Abstract

Sustainable solid waste management is the need of time and composting is one of the most effective methods to manage organic waste. In this study, the composting of *Parthenium* weed has been done for 20 days in combination with cow dung and sawdust in three different ratios. The profiling of different physical and chemical parameters was done for 20 days including temperature, pH, soluble chemical oxygen demand (sCOD), and electrical conductivity (EC) along with moisture content (MC), volatile solid (VS) and ash content. Maximum temperature (55-57°C) in all the three temperature was achieved in initial 4-5 days. EC, MC, and sCOD showed a decreasing trend from 0 to 20 day. The concentration of macronutrient was found increasing with increasing composting time and maximum concentration of Na (10.16 g/Kg), Ca (27.68 g/Kg) and K (11.72 g/Kg) was found in run C, in which highest amount of cattle manure was added. After 20 days of composting, the morphological and structural composition of the final product and initial feedstock mixture was compared through different analytical techniques that suggested decomposition of weed.

Keywords: *Parthenium*, composting, physico-chemical parameters, solid waste, waste management.

1. Introduction

The solid fraction of discarded matters from various sources such as domestic, industrial, commercial and agricultural area is called solid waste. Its composition is highly heterogeneous and varies at different places and seasons (Ramachandra et al., 2018). In 2057, the global population is estimated to be more than 10 billion which will simultaneously increase the amount of municipal solid waste (MSW) to huge amount posing a critical risk to its sustainable management. Global annual generation of MSW is ~2 billion tonnes out of which only 67% is managed (Shah et al., 2021). The current environmental problem that emerging economies are facing is the generation of enormous amount of MSW out of which 57 % is green waste and 75% of the generated waste ends up in landfills. India is a rapidly growing country in terms of economy, urbanization and industrialization. Its per capita generation of MSW is 0.17 to 0.62 kg per day and annual increase in 1.33 %. In India, around 90% of the MSW is dumped in local and nearby undesignated open areas in an unscientific manner (Srivastava et al., 2020; Kumar et al., 2017; Joshi and Ahmed, 2015). An open and improper dumping of MSW in landfills is one of the major source of methane in the atmosphere, it accounts for 3-19 % of methane generation through manual activities around the world. In the year 2000, the generation of methane from MSW in India was 0.93 Tg. The generation of methane from only Gazipur landfill area of Delhi is estimated to be 15.3 Gg/Year by first order decay model as per the studies. The estimation of annual emission of methane from landfills in India is 1.25-1.68 Tg (Mathur et al., 2020). Improper landfilling of MSW also causes surface and ground water pollution due to rain and leaching of its components (Rajesh, 2019).

Sustainable solutions to combat this problem includes minimization and recycling of waste, recovery of emitted gases

from landfills, composting and energy recovery that reduces the waste amount to be landfilled (Shah et al., 2021; Atelge et al., 2019) and also process around 23% of the waste in India (Kulkarni, 2020). Around 30-40% part of the MSW is comprised of organic waste (in Europe) having higher amount of moisture and biodegradability as well. These kinds of wastes require segregation on the source and the processing for energy and material recovery. Composting is one of the best suiting and sustainable method which is applied worldwide for the management of organic waste due to ease of operation and implementation (Cesaro et al., 2019). The recovery of energy and material from organic waste close the loop of circular economy for which new and efficient technology and chemical routes are essential (Guo et al., 2019).

The decomposition of organic waste through the process of composting is a promising, sustainable and environmental friendly technique for the management of green and organic waste such as, food waste, garden waste and agriculture waste (Ajmal et al., 2020; Meng et al., 2020). The process of composting is a natural process of recycling nutrients and the obtained final product is "compost" which is rich of humus. Compost is a soil amendment which fertilizes soil and enhances its physicochemical properties, enhances soil carbon and nitrogen restoration (Sanchez et al., 2017; Zhong et al., 2021; Ayilara et al., 2020). It also reduces the use of chemical fertilizers and pesticides, therefore, ultimately reduce the contamination of surface and ground water from the leachate and runoff of these compounds. Additionally, the high temperature during the thermophilic stage of composting is also known to degrade complex organic compounds like tetracycline (Chia et al., 2020; Sayara et al., 2020) and microplastics (Sun et al., 2021). Currently, phasing out landfills in favour of "zero waste" and "circular economy" is the aim of European Union (EU) that support sustainable

development. In order to achieve the aforementioned objectives, policy pressure will therefore be increased to enhance and optimise current bio-waste composting procedures (Stegenta et al., 2019). Due to sufficient ventilation and thorough mixing, rotary drum composters are among the several decentralised composting systems that are believed to be energy-neutral and effective for quickly turning various forms of organic waste into compost (Manu et al., 2021). Several feedstocks have been used for composting such as palm mill oil waste (Singh et al., 2010), waste activated sludge (Yamada and Kawase, 2006), pistachio waste (Jalili et al., 2019), food waste (Ravindran et al., 2022), fruit and vegetable waste (Ghinea and Leahu, 2020), rose waste in combination with green yard waste (Nijs et al., 2019) and many more.

One of the most destructive environmental issues, species invasion is causing a significant issue in the natural ecological system due to their altering nature to the ecosystem. Because of their harsh nature, invasive species have posed a threat to the environment (Kausar et al., 2020). Therefore, management of these utmost problematic weeds and their conversion into a highly nutritious soil conditioner via composting is the most effective way to reduce their harmful impacts on agriculture and economy. Previously some weeds have also been investigated as feed stock of composting like *Ageratum conyzoides* or goat weed (Maturi et al., 2021), *Mikana micrantha Kunth* or mile-a-minute (Kausar and Khwairakpam, 2022), *Eichhornia crassipes* or water hyacinth (Singh and Kalamdhad, 2016). In line with this idea, the aim of the present research work is to evaluate the decomposition of *Parthenium* weed in three different composition ratios with inoculum and bulking agent through rotatory drum composting technique. The study further encompasses the comparison of physico-chemical parameters and nutrient concentration in the three compositions, as well as the morphological and structural properties of final product were studied.

2. Materials and methods

2.1. Materials

The raw material for composting i.e. *Parthenium* weed was collected from nearby areas of Babasaheb Bhimrao Ambedkar University, Lucknow. Cow dung was selected as the source of microorganism for the composting which was collected from a nearby village Jagat Kheda and the bulking agent, sawdust was purchased from a saw mill. Chemical reagents were used in research work including ferrous ammonium sulphate, potassium dichromate, hydrochloric acid, sulphuric acid, sodium hydroxide and other chemicals and reagents were purchased from Thermo Fisher (India).

2.2. Physico-chemical characterization of weed biomass, sawdust and cow dung

Prior to the composting, the collected weed biomass, sawdust and cow dung were analysed for different parameters because the properties of compost chiefly depends on the initial characters of raw materials. The pH and EC were analysed using portable Water Analyser (Model no. 371, Systronics, India); however, MC, VS and ash content were determined as described in (ASTM D29s74; EPA 1964). The sCOD was estimated by closed reflux dichromate method given by APHA (2012). The values of different parameters of *Parthenium*, sawdust and cow dung are shown in Table 1.

Table 1 Initial analysis of *Parthenium*, Cow dung and Sawdust

Parameters	pH	EC (µS/cm)	Moisture Content	Volatile Solids	Ash Content
<i>Parthenium biomass</i>	7.89	9.2	52.86 %	32.22 %	67.78 %
Cow dung	7.74	13.4	81 %	82.39 %	17.61%
Sawdust	6.5	19.85	36 %	46.5 %	53.5 %

2.3. Design of rotatory drum

The main rotating part of the reactor is a plastic barrel that has been used for storing engine oil in the transport industry. The capacity of the barrel is 250 litres. The motive behind using plastic container is that the reactor can be washed with water easily and can be ready for next composting in only 2-3 hours. Plastic based reactor is corrosion-free, therefore no anti-corrosion paint is required to preserve its life. The rotating axle of the reactor is made up of a galvanized iron rod (GRD), which was purchased from a scrap vendor. The purpose behind using GRD was that it does not corrode and hence can be washed along with the barrel part. To facilitate the joints of the axle and the reactor, two flench plates of steel have been used. The light weight steel plates were used for fabrication of reactor, hence it prevents additional weight on the reactor after the loading of substrate. The rotation of the reactor was brought about by the bearings mounted on steel stands. The stands are roughly triangular in shape to give maximum stability. The stands are highly mobile and can be dissembled in a few minutes and it can be carried to any place. Moreover, the axle, reactor barrel, bearings, etc. all can be kept as separate parts and assembling them takes only 10-15 minutes.

Teeth like structures were present inside the reactor to homogenise the lumps formed during the process of composting and they were tilted at an angle for proper distribution of waste inside the drum. The opening was kept open to let escape the generated heat and gases during the composting process. However, opening was tightly closed with special design locks during rotation of the reactor. The reactor was provided with marine handle which reduces ones effort while rotating it. A cross ventilation inside the reactor was maintained by holes made on the both sides above the flench plate. At bottom of the reactor there were minute openings for passing of leachate, which was collected at the bottom through a plate. A schematic diagram of the rotary drum compost reactor is shown in Fig. 1

2.4. Composting and sampling process

Collected *Parthenium* weed was first cut into small pieces below 1 cm size and mixed with cow dung and sawdust with different ratios in three different runs A, B and C as shown in Table 2.

Table 2 Waste composition in different runs

Run	<i>Parthenium</i> (Kg)	Cow Dung (Kg)	Saw Dust (Kg)	Ratios
A	32	4	4	8:1:1
B	28	8	4	7:2:1
C	24	12	4	6:3:1

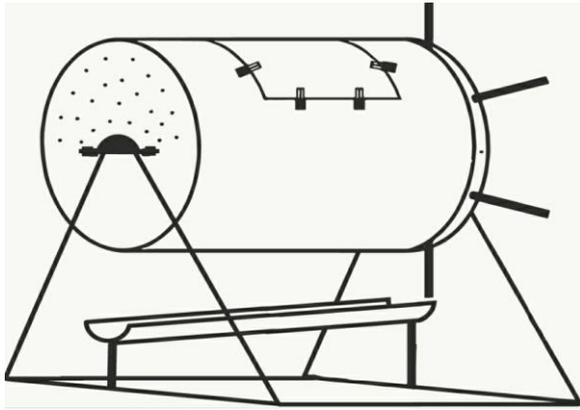


Fig. 1 Schematic diagram of the rotary drum compost reactor

A total amount of 40 Kg was filled in one run and remaining volume of drum was left unfilled for proper aeration. The run was carried out for a period of 20 days during which the drum was rotated manually two times on daily basis. During the complete composting process temperature was recorded every day and three times a day which was averaged. On the interval of every fifth day sample was collected from three different places in the drum after rotating the drum. After collection, the sample was dried, grounded and sieved through 250 microns pore size mesh and stored in air tight container for physico-chemical analysis. A flow diagram of the present study has been shown in Fig. 2



Fig. 2 Flow diagram of the composting process

2.5. Analysis of composting sample

The sample collected was extracted in water with 1:10 w/v ratio of sample and water and the supernatant was analysed for pH, EC and sCOD. Whereas, MC, VS and ash content were determined using solid sample. Analysis of different nutrients in the compost was analysed by the use of flame photometer (model no. 6478, Systronics, India).

2.6. Morphological and structural analysis of end product

After completion of 20 days composting period the final obtained product was analysed using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) (Model JSM 4490, JEOL, Japan), Fourier transform infrared spectroscopy (FTIR, Model NICOLET 6700, Thermo Fischer Scientific, USA) and powder X-ray diffraction (PXRD, Model D8 Advance Eco, Make: Bruker, Germany) to confirm the decomposition of weed.

3. Results and discussion

3.1. Study of physico-chemical variations

Temperature profiling is one of the major aspects of composting, it gives information about degradation kinetics and dominance of different microbial populations at different time intervals (Maturi et al., 2021). Fig. 3a shows the variations in composting temperature in the duration of 20 days. Initial temperatures were found 26.3°C, 24.6°C and 27.5°C in run A, B and C, respectively. The temperature was increased and it found maximum about 56.5 °C in run C on 5th day. In run A and B, the maximum temperatures were observed 56°C and 55°C, respectively on day 4, and it is representing higher microbial degradation at initial stage (Varma and Kalamdhad, 2014). According to Mohee and Mudhoo (2005) a temperature range of 52 to 60°C is best for maximum activity of thermophilic microorganisms, which was achieved in all the three runs of the present study. This increased temperature represents thermophilic stage of composting that comprises maximum degradation of organic matter due to the activity of thermophilic microorganisms. After that the temperature continues to go down to mesophilic stage.

Fig. 3b shows the variations in pH during the composting period. An increase in pH was recorded in all the three runs

which were again decreased at the end. The increased in pH during composting, results from the degradation of protein which generates ammonia. Furthermore, the proper aeration by the rotation of drum causes decrease in CO₂ level inside which is also responsible for the increase in pH (Kalamdhad et al., 2009). Upon degradation of most of the organic matter production of ammonia decreases, and process of nitrification starts by nitrifying bacteria that eventually reduces the pH to 8, 7.6 and 7.3 in run A, B and C, respectively. EC is representative of salinity in the composting process Fig. 3c shows the variations in EC values. All the three runs shows decrease in EC. Initially, the organic matter decomposition may release some salts and ammonium ions that can increase the value of EC as shown in Run A on 5th day, but as the composting period

increase these salts and ions may get precipitated that decreases the EC. The sCOD content of the material was found to decrease continuously in all the three runs (Fig. 3d). The decrease in sCOD represents reduction in the degradable organic content. The rapid changes in the physicochemical condition are the probable reason for the selection of various microbial communities successively, in the process of composting, however, temperature and substrate availability are the most influencing factors (Bhatia et al., 2013). The quickly changing physicochemical conditions in composting processes are likely to select for a succession of different microbial communities and it could be expected that temperature and the available substrates, are the main factors.

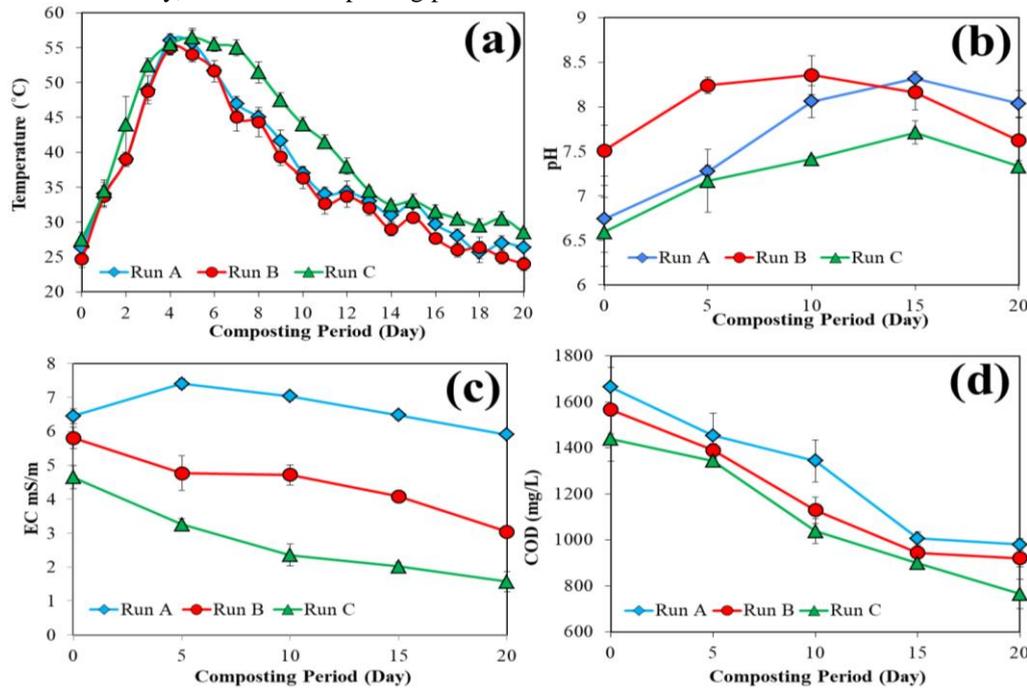


Fig. 3 Variations in a) temperature, b) pH, c) EC and d) sCOD during the process of composting.

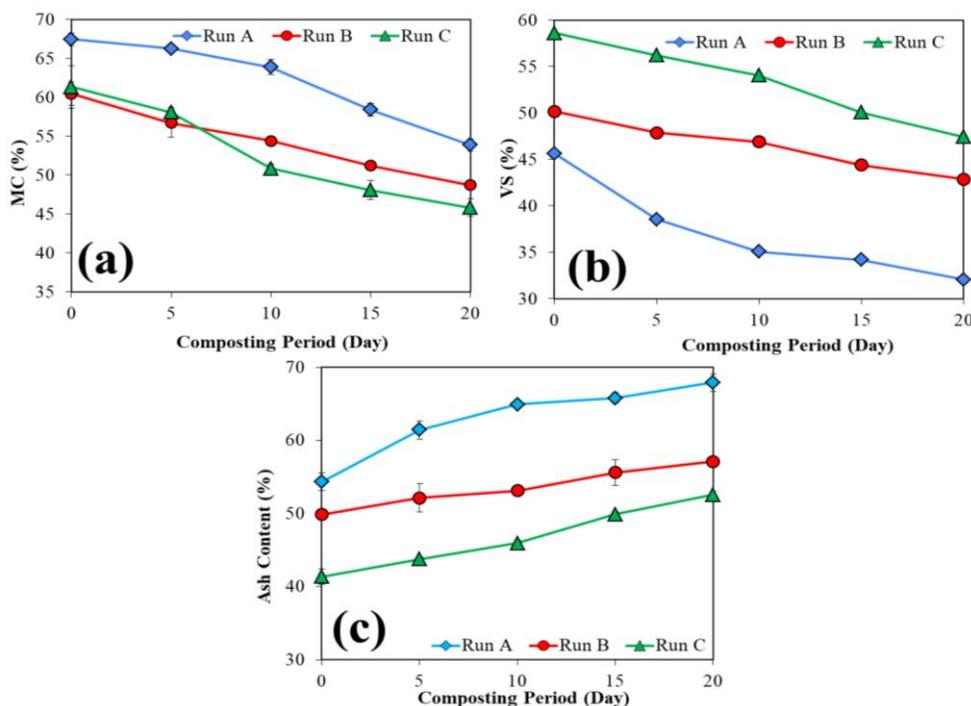


Fig. 4 Variations in a) moisture content, b) volatile solids and c) ash content during the composting period

All the runs showed a gradual decrease in MC upto day 20 as depicted in Fig. 4a. The MC was decreased from 67.47% to 53.86% in run A, from 60.45% to 48.7% in run B and from 61.32% to 45.8% in run C, maximum MC was reduced in run C. However, no leachate was observed during the whole composting process in any of the run. MC about 15-20 % is essential in the final product as per the Solid Waste Management (SWM) rule (2016) which is lesser than the values obtained in this study. Therefore, further curing of the final product for around 2 weeks is required for stabilization of waste (Manu et al., 2019). Fig. 4b and 4c shows that VS was also decreased with an increasing composting period while the ash content showed an opposite trend. VS depicts amount of organic matter; hence, a decrease in VS content is result of decrease in organic matter due to active decomposition. Whereas the organic matter decreases, the amount of mineralized inorganic content increases, therefore, the ash content was increased with an increasing composting period. Fig. 4b and 4c shows maximum amount of VS and minimum

amount of ash content at initial in run C that was due to high decomposition of organic matter in the run C.

3.2. Analysis of macronutrients

Macronutrients are essential for the growth of plants K is the third essential mineral after nitrogen and phosphorous, required for plants. Fig. 5a, b and c shows the profiling of Na, Ca and K in the composting process. An increase in concentration of all the three elements in each run was observed. Increase in nutrients concentration resulted due the degradation of organic matter and its mineralization (Kausar et al., 2020). The maximum concentration of Na was found 5.61, 8.31 and 10.16 g/Kg, maximum concentration of Ca was found 14.93, 23.13 and 27.68 g/Kg, and maximum concentration of K was found 9.78, 10.85 and 11.72 g/Kg in run A, B and C, respectively. Maximum concentration of all the three nutrients was found in run C.

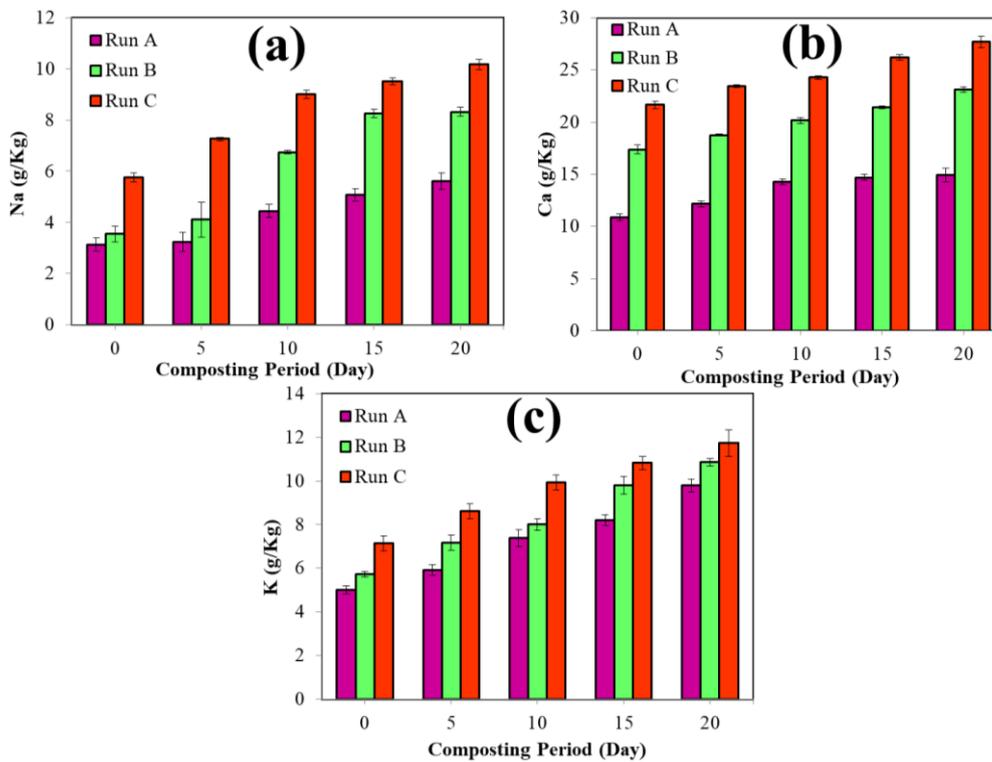


Fig. 5 Profiling of a) Na, b) Ca and c) K during the process of composting

3.3. Advanced Analysis of Compost samples

The weed sample was analysed initially and after composting in run C (as it gave best results in comparison with run A and B) through different techniques, SEM, EDS, FTIR and XRD to evaluate the deformations occurred to the weed in the process of composting. Fig. 6a, b, c and d shows the SEM analysis of composting mixture prior to composting and after composting. The analysis revealed that prior to composting process, the surface morphology was clear, fragmented with clear and sharp boundaries can be seen and they can be identified separately. Whereas, after composting process, the SEM analysis shows clumping of material, the outer surface has been disintegrated and appearing rough, no separate fragments are visible they have been merged with clumped degraded material. During the composting process, activity of various microorganisms

releases several enzymes that degraded the organic matter resulting in the disintegration of the substrate in 20 days of composting period (Biyada et al., 2021)

EDS analysis showed different elements in both substrates i.e., before and after composting (Fig. 7a and b). FTIR analysis results of substrate mixture have been shown in Fig. 7c. Several peaks were observed in the FTIR analysis that corresponds to the presence of different functional groups. Most of the peaks were presents in both, before and after composting samples, but the absorption intensity of the peaks was more after composting. A major adsorption band at around 3376 cm⁻¹ corresponds to the -OH bonds in alcohols, phenols and water molecules. Peak at 2921 cm⁻¹ corresponds to the C-H bond, peak at 1650 cm⁻¹ corresponds to N-H/NH₂ deformation in primary amides/amines. Peaks at 1512 and 1236 cm⁻¹

corresponds to N-H deformation in secondary amides and C-O-C stretch, respectively. Peaks at 1049, and 1029 cm^{-1} corresponds to the C-O stretch in primary/cyclic alcohols or anti-symmetric stretch of P-O-C bond in organophosphorous. The XRD pattern (Fig 7d) show about similar diffraction pattern of substrate before and after composting, except for the peaks that appeared at $2\theta = 50.25^\circ$ and 68.05° before

composting. These sharp peaks at $2\theta = 50.25^\circ$ and 68.05° are representative of CaCO_3 and P_2O_5 and after composting there intensities were reduced greatly. However, other peaks representative of CaCO_3 at $2\theta = 22.6^\circ, 26.8^\circ$, and peaks for P_2O_5 at $2\theta = 20.8^\circ$ were still present in substrate after composting.

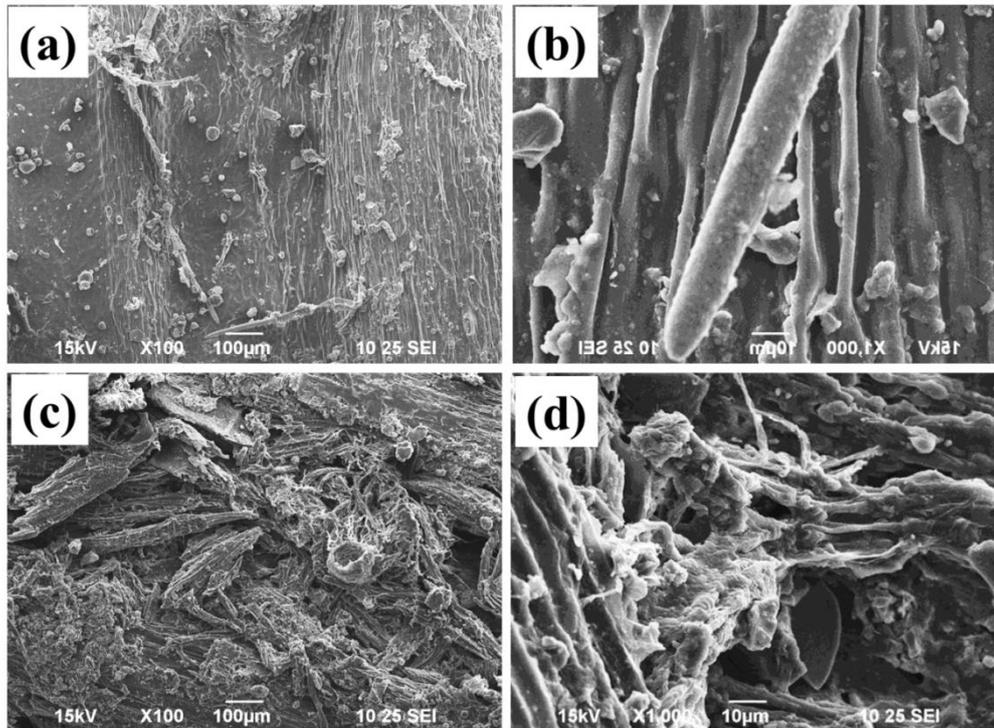


Fig. 6 a) and b) SEM analysis of the composting mixture on 0 day, and c) and d) SEM analysis of composting mixture on 20th day (Run C)

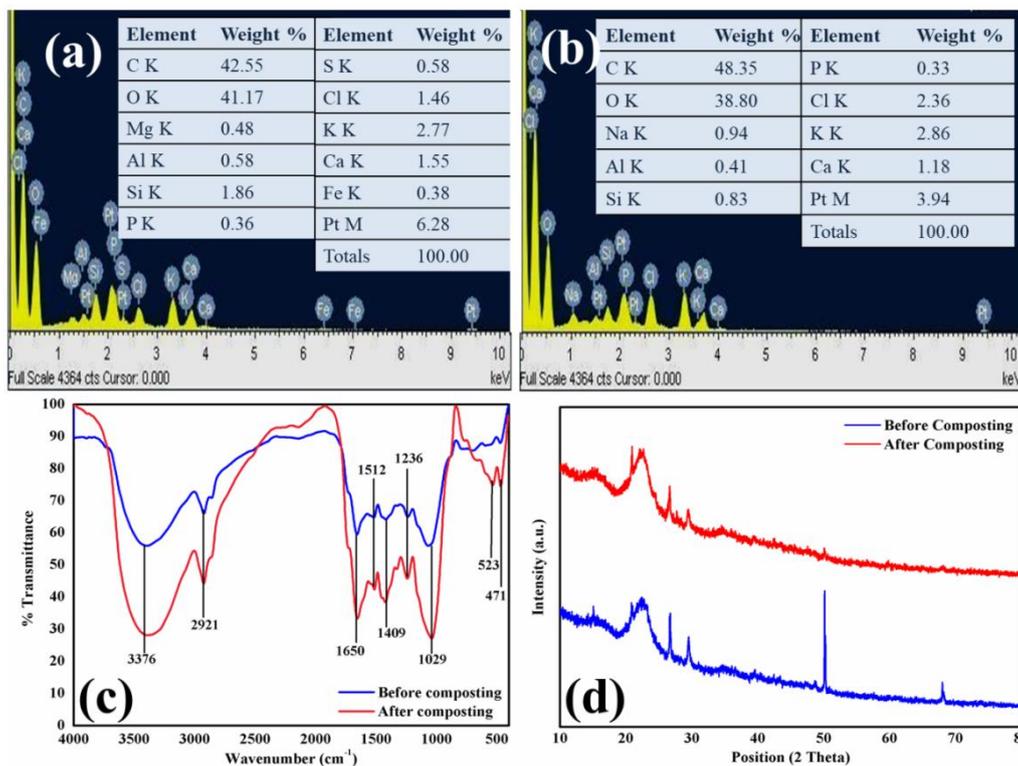


Fig. 7 a) and b) EDS analysis of the substrate mixture before and after composting, respectively, c) FTIR analysis and d) XRD analysis of the substrate in the process of composting.

4. Conclusion

An effective and sustainable management of *Parthenium* weed through rotatory drum composting has been done in this work. Three different ratios of weed, cow dung and saw dust were evaluated in run A, B and C, best results were obtained in run C. The thermophilic stage was achieved within initial 5 days of the composting set up and maximum ~56°C temperature was recorded in run C. A continuous decrease in soluble COD and volatile solid shows a decomposition of organic matter and increased mineralization that also increased ash content. Profiling of macronutrients revealed increasing concentration with an increasing composting time and maximum concentration of Na, Ca, and K was found in run C 10.16 g/Kg, 27.68 g/Kg and 11.72 g/Kg, respectively. The decomposition of the weed was also analysed by the usage of different instrumental techniques such as SEM, FTIR, XRD that represented changes in morphological and structural properties of final product in comparison with initial feed stock that resulted due to decomposition of organic matter. Therefore, the rotatory drum composting of *Parthenium* weed with the ratio of weed, cow dung and saw dust 6:3:1 was most effective, due to proper aeration by rotation of drum and optimized amount of weed, inoculum and bulking agent.

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Author contribution

Shalu Rawat: Drafted manuscript, **Mr. Danish Kaleem:** Performed the experiments and collected all data, **Mr. Prakhar Bajpayi and Mr. Sumit Kumar Swarnkar:** Designed rotatory drum composting reactor, **Dr. Jiwani Singh:** supervised the research work, reviewed and edited manuscript.

Conflict of interest

Authors declare no conflict of interest.

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