

Original Article

Valorization of Used Banana Plants into Useful Compost

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Abstract - Waste management is a significant concern that impacts our ecosystems and societal frameworks. Annually, more than 2 billion metric tons of unsustainable waste produced by human activities are discarded globally. In India, nearly 7000 million metric tons of organic materials are produced yearly. The study focuses on banana tree waste, a major contributor due to the extensive cultivation of bananas in southern states. Utilizing waste nutrients for crop production holds great significance in composting. The potential of composting as a sustainable solution is emphasized in the study, which discusses its microbiological principles, benefits, and various methods with a particular focus on windrow composting. The significance of the study is found in its potential to improve soil fertility, alleviate environmental pollution, and contribute to sustainable waste management practices in India. In the laboratory, compost piles were created using distinct proportions of banana tree waste, food waste, cow dung, and brown materials—the significance of composting lies in its ability to utilize waste nutrients for crop production. The paper particularly highlights the potential of banana waste as an organic fertilizer. The study indicates that increasing awareness among farmers about the benefits of using banana tree waste for enhancing soil fertility could aid in promoting sustainable waste management practices.

Keywords - Banana residue, Cow-dung, Food waste, Heavy metals, Pile composting.

1. Introduction

Solid waste management poses a significant challenge to society, particularly in India, where large amounts of organic waste are generated annually. A substantial proportion of this organic waste is deposited in landfills, incinerated, or pollutes aquatic ecosystems, resulting in ecological deterioration [1]. Effective disposal of this waste is crucial for maintaining a healthy biosphere. Composting has emerged as a popular method for stabilising organic waste, transforming it through biodegradation into water, carbon dioxide, energy, and compost [2]. The resulting compost can partially substitute artificial fertilisers [3].

Bananas, second only to mangoes in significance, are widely appreciated for their year-round availability, affordability, taste, nutritional benefits, and health advantages. Cultivated in around 120 countries, they produce approximately 86 tons of crop waste per hectare [4]. In India, particularly in the southern regions, bananas are a key fruit crop, contributing significantly to postharvest residue. Southern states such as Tamil Nadu, Andhra Pradesh, and Karnataka enjoy year-round production in India. In contrast, production persists throughout the year in northern and eastern states such as Maharashtra, Manipur, Assam, and Tripura. On the other hand, Gujarat, Bihar, Uttar Pradesh, and Jharkhand experience a harvesting season from September to November [5]. This consistent availability has established bananas as a

vital commodity for the processing and retail markets. The *Musa* species, part of the Musaceae family, is referred to by several names, including Banana, Bananier Nain, Canbur, Curro, and plantain. The most prevalent cultivars include *Musa acuminata* colla and the hybrid *M. paradisiaca*. Additionally, related species encompass the Abyssinian Banana (*Ensete ventricosum* cheesman), *Musa balbisiana* colla, *M. ornata* Roxb, and *M. textilis* Nee [6-9]. The banana plant is the largest herbaceous flowering plant [10]. They look like trees and can grow between 3.5 and 12 meters tall. They have strong, fibrous pseudo-stems created from the overlapping bases of large, spiral leaves, usually numbering 8 to 20 per plant. These leaves can reach 2.4 to 3.7 meters long and a width of about half a meter [11]. The primary stem produces a large terminal inflorescence that resembles a spike featuring female flowers at the base and male flowers at the top. Once matured, this spike develops into a cluster of bananas, typically 6 to 9 clusters, each containing 10 to 25 bananas. After flowering, the main stem dies, but a new stem sprouts from the underground rhizome or corn [12].

A commercial banana orchard or farm can produce a lot of banana waste, including leaves, pseudo-stems, inflorescence, trimmed suckers, bunch stalks, and fruits that are thrown away right away in the field and from the processing house. After harvest, about 70% of the plant parts remain as agricultural residue [13]. Presently, these wastes are disposed of in rivers, un-engineered landfills, lakes, and other



uncontrolled disposal sites, resulting in significant environmental risks when decomposing. Despite being the most popular disposal alternative, sanitary landfills are growing increasingly unsustainable because of the lack of available space and the potential for pollution, particularly in metropolitan and peri-urban areas. [14]. In addition, it contributes to the reduction of essential micronutrients present initially in the plant biomass [15]. Discarding banana residue in improper places may lead to the rapid circulation of wilt diseases, and burning may lead to air pollution. When immature or non-stable organic solid waste, like banana residue, is added to soil, certain substances or unsuitable growing conditions may affect plant growth. These circumstances could include the development of phytotoxic effects, heavy metal contamination, the presence of pathogenic microbes, the buildup of inorganic salts, and the immobilisation or imbalance of vital nutrients needed for plant growth [16-18].

Many methods are being used to eliminate organic waste, but to preserve nutrients, they need to be sustainable and safe for the environment. The quick decomposition of organic materials by humus-producing organisms is known as composting technology [16]. Composting banana crop waste boosts crop yields, increases organic matter, enhances soil microbial diversity, and provides an affordable source of nutrients. [19, 20]. Producing compost from various agro-industrial wastes minimises the probability of erosion and runoff, as well as the permanent wilting point in the soil. The application of compost enhances the pH of the soil, and it also increases its carbon and nitrogen content. Moreover, the utilization of compost improves the soil characteristics, such as cation exchange capacity, which helps in retaining nutrients and water, and holding capacity, which enhances the moisture retention by the soil

[21]. This approach facilitates the efficient management of organic waste through the regulated microbial degradation of biosolids. The final product is nutrient-dense and rich in organic content, rendering it highly suitable for agricultural and horticultural practices [22]. Compost acts as an effective soil conditioner, helping to restore vital soil conditions for sustainable agriculture [23]. Implementing composting practices in waste management provides flexibility and promotes efficient recycling (EPA). It offers an environmentally friendly alternative to traditional disposal methods and requires relatively low capital and operating costs, making it a cost-effective solution [24].

The advantages of compost extend beyond waste reduction and agriculture. It significantly decreases the need for landfill space and reduces surface and groundwater contamination. Given its many benefits, composting stands out as a sustainable and efficient approach to waste management [25]. Unlike other crop stalks, banana plants are an effective carbon-rich composting material due to their high

moisture content and abundance of essential nutrients [12]. On a dry weight basis, the plant contains a high amount of potassium (K), which ranges from 5.73 to 17.51 %, 2.33 % of calcium (Ca) and 0.39 % of magnesium [13]. The high lignocellulosic content and abundant plant nutrients found in banana leaves can be recovered through anaerobic digestion, composting, vermicomposting, etc. [15]. Many researchers have analysed the composting of banana residue with different inocula and its effect on various crops. However, the use of food waste, considering its high generation in residential institutes and restaurants and the banana residue, has not been studied. This paper, therefore, studies the feasibility and the nutrient analysis of banana compost, discussing the various physico-chemical characteristics of the different piles of composting.

2. Materials and Methods

2.1. Materials

The experiment was conducted in the Field Engineering Laboratory, Department of Civil Engineering, NERIST, Arunachal Pradesh, India. Composting was done using windrow composting. Banana tree parts like leaves, stems, and pseudo stems were collected from type-1 NERIST staff quarters. Food waste was collected from the NERIST hostel. Brown materials consisting of a mix of dry leaves, cardboard, and newspaper were collected from the NERIST campus, and cow dungs were collected from Doimukh, a nearby town, from the campus. After collecting the materials, they were chopped down into small pieces around 2-3 cm and let dry for 24 hours. After drying the materials, 10 piles were made with different proportions of banana leaves, stems, banana and food waste, and cow dung. Some brown materials were also added to promote aeration and moisture control-Table 1 lists different compost piles with varying proportions of garbage.

The ratios of green and brown waste materials were deliberately altered across different compost piles to assess the impact on composting and final product quality. A balance of the carbon and nitrogen ratios is crucial for efficient composting. By adjusting the proportions of banana tree waste, food waste, dry leaves, newspaper, and cardboard, the study examined how different C: N ratios influenced decomposition rates, temperature changes, moisture regulation, pH, electrical conductivity variation, and variation of heavy metals.

The goal was to pinpoint the most effective mixture for producing mature, nutrient-rich compost from banana tree residues by comparing different combinations. Each pile received a constant 1 kg of cow dung as a microbial inoculum, ensuring that observed differences were due to the varying ratios of other materials. Cow dung played a dual role - supplying microorganisms that accelerated decomposition and acted as a natural fertilizer. It was added equally to all piles, enabling a fair comparison of how other materials and their ratios affected the composting process.

Table 1. Different proportions of various pile composting

Pile (P)	Leaves (kg)	Stem (kg)	Banana (kg)	Food Waste (kg)	Cow Dung (kg)
P-1	1.50	1.25	0.50	1.75	1.0
P-2	1.25	1.75	0.75	1.25	1.0
P-3	1.75	1.50	1.0	0.75	1.0
P-4	2.00	1.00	0.5	1.50	1.0
P-5	1.00	0.75	1.5	1.75	1.0
P-6	1.00	2.00	2.0	2.0	1.0
P-7	2.00	1.00	2.0	2.0	1.0
P-8	1.00	3.00	2.0	1.0	1.0
P-9	1.00	1.00	2.0	3.0	1.0
P-10	3.00	2.00	1.0	1.0	1.0

2.2. Methods

Throughout the 120-day composting time frame, the temperature was continuously monitored using a digital thermometer. Using a digital shaker, a dried and pulverised sample of about 10 mg was mixed with 100 mL of distilled water, and the resulting solution was agitated for two hours. A digital pH meter was used to monitor the pH, and Whatman No. 42 filter paper filtered the solution. After that, a digital conductivity meter (Systonic) was used to determine the filtrate's electrical conductivity. Gravimetric analysis was used to determine the moisture content in accordance with IS: 10158-1982 guidelines. Kjeldahl's device was used to measure the total nitrogen. After the compost sample was digested, the ammonia was distilled and titrated. The Walkley and Black method was used to titrate the percentage of Total Organic Carbon (TOC). The Atomic Absorption Spectrometer (AAS) was employed to test for zinc (Zn), cadmium (Cd), lead (Pb), copper (Cu), and chromium (Cr).

3. Results and Discussion

The composting process started at the end of November 2023 and continued until March 2024. During winter, the

banana tree waste took nearly five months to mature into compost. Specific necessary experiments were conducted to see the quality of the compost.

3.1. Temperature

A digital thermometer measured the compost temperature at every 5-day interval. The composting process was done at peak winter time, with frequent rainfall. Due to the climate conditions, the pile temperature increased slowly. During composting, the initial temperature of the piles ranged from 17°C to 20.5°C, and increased to 20°C to 24°C after five days. By 55 to 70 days, temperatures peaked at 45.5°C to 58.7°C, though the rise was slow due to climate conditions. After 70 days, temperatures began to decline. Harada et al. (1981) noted a correlation between temperature and biochemical activity in compost, while [26] described a typical temperature pattern: a rapid initial increase to 55°C to 60°C, sustained for weeks, followed by a gradual decrease to 30°C to 22°C, and finally levelling off at ambient temperature. These temperature fluctuations reflect the decomposition and stabilization processes in composting. The graph represents the temperature changes in Figure 1.

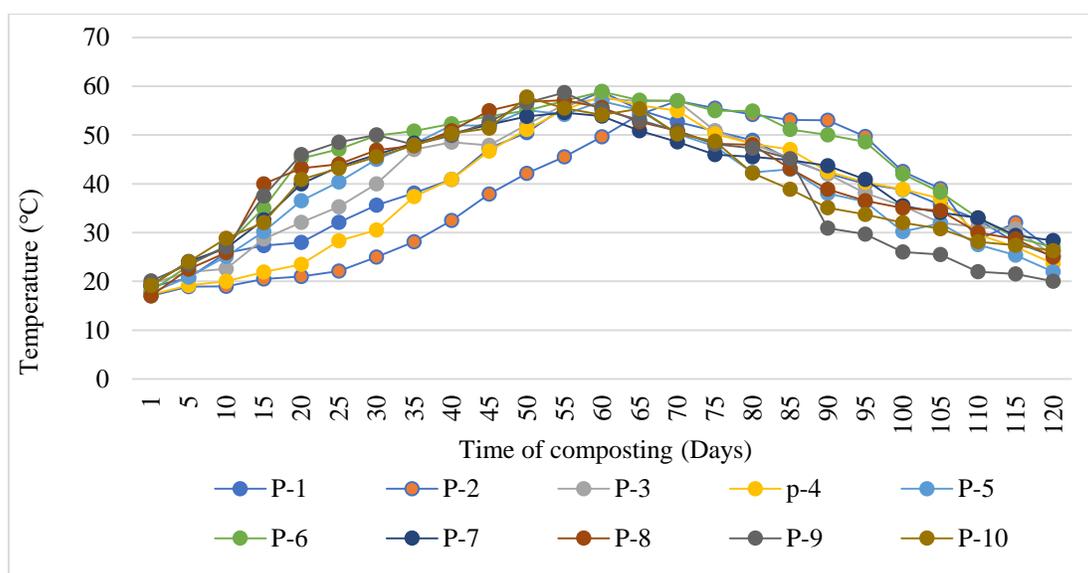


Fig. 1 Change in temperature during composting

3.2. pH

The piles' pH was observed every 5-day interval by a digital pH meter. [27] indicate that composting is most effective at a pH of around 8. [28] noted that initial composting stages see a drop in pH due to acid-forming bacteria, followed by a rise in alkalinity as ammonia accumulates, stabilizing near neutral or slightly alkaline by the end. According to the Municipal Solid Waste (Management & Handling Rules, 2000), compost should have a pH between 5.5 (slightly acidic) and 8.5 (alkaline). While low pH levels might impede the decomposition of organic waste, increased

alkalinity is reflected in the composting process when the mesophilic phase gives way to the thermophilic phase. Various heaps' pH changed from acidic to alkaline [29]. A graph in Figure 2 illustrates the pH variations. All compost piles had starting pH values between 3.00 and 4.52. After 100 days, pH values peaked before gradually decreasing to near neutral. Variations in the pH transition from acidic to alkaline and back to neutral among the piles can be linked to differing ratios of composting materials. Specifically, the ratios of banana leaf stems and other ingredients significantly influenced the pH changes.

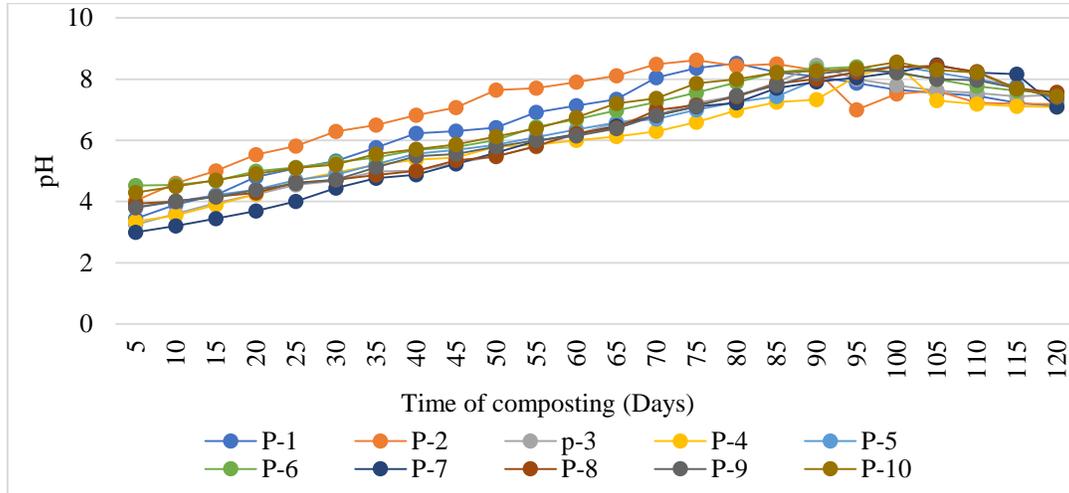


Fig. 2 Change in pH during composting

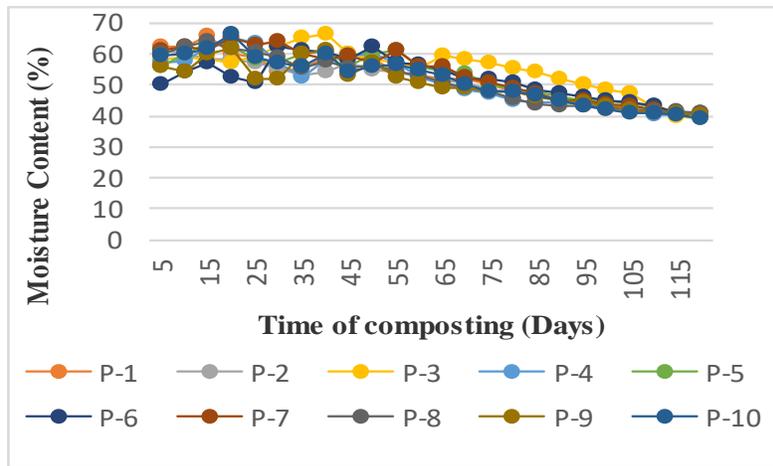


Fig. 3 Variation in moisture content during composting

3.3. Moisture Content

Optimal moisture content is essential for boosting microbial activity and enhancing metabolic rates. Mature compost typically has a moisture content between 35% and 45% (Composting Handbook, 2000). Moisture levels below this range can hinder microbial growth and result in poor decomposition. If compost becomes too dry, adding water can help stimulate microbial activity (Cornell, 2003). Insufficient moisture (<30%) restricts bacterial activity, while excessive moisture (>65%) can slow decomposition, create odours from

anaerobic pockets, and cause nutrient leaching. A decrease in moisture content towards the end of composting signifies successful decomposition and the production of mature compost [29]. Figure 3 shows the correlation graph between moisture content and time. Moisture content was much higher at the beginning of the composting process. Also, there were considerable fluctuations in moisture content up to 55 to 65 days. After 65 days, the moisture content decreased gradually until the end of the compost.

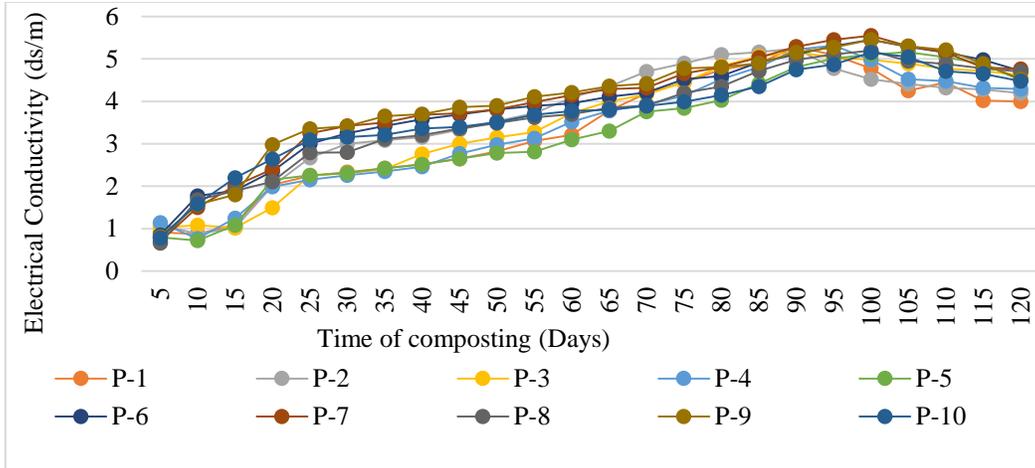


Fig. 4 Variation in EC during composting

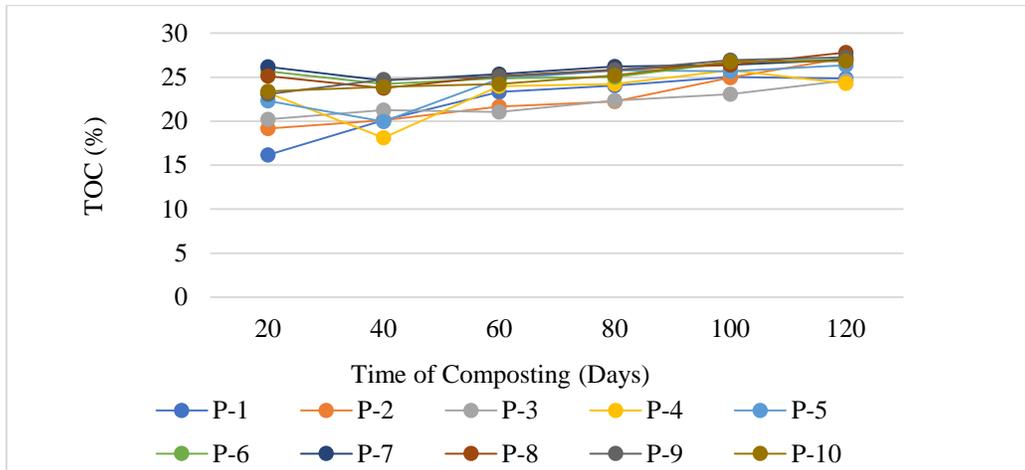


Fig. 5 Changes in TOC during composting phases

3.4. Electrical Conductivity

Electrical conductivity is a measurement used to assess the salinity of soil. In the compost industry, there has been hesitation regarding the use of finished compost due to high electrical conductivity reading, which indicates elevated levels of soluble salt. Higher electrical conductivity readings signify a saltier compost product.

In composting, the electrical conductivity typically ranges from 2.67 ds/m to 4.53 ds/m. Also, a plotted graph between electrical conductivity changes and time during the composting process is shown in Figure 4. The electrical conductivity increased gradually from the start to about 100 days in this process. After 100 days, the electrical conductivity slowly decreases. Here, electrical conductivity was much higher than its ideal range. The reason for higher electrical conductivity may be the acidic quality of the banana and stem. The variations observed towards the end of the composting process may also be due to the release or fixation of nutrient ions resulting from changes in the growth of aerobic microbial populations.

3.5. Total Organic Carbon

Figure 5 depicts the variations in total organic carbon during the composting process. According to this test, it varied between 16.17% and 26.18% for various piles in the first several days and between 24.29% and 27.79% at the conclusion of the composting process. The total organic carbon value in P-1, P-3, P-4, P-5, P-6, P-7, and P-8 varies greatly. The inability of the microbes to generate sufficient heat for microbial activity due to the low temperature and rainfall during the composting period could be the reason for the inappropriate total organic carbon in compost. The graph in Figure 5 also explains the correlation between TOC and composting time.

3.6. Total Nitrogen

In this research, all the piles' total nitrogen concentration demonstrates an increased value with composting time. Compared to findings from other studies, the total nitrogen content in this compost is relatively low, which may be attributed to ammonia volatilization and variations in temperature throughout the composting process [30]. In this

research work, it has been observed that nitrogen content increases with the increasing amount of banana stem, banana, and food waste. The graph, as shown in Figure 6, shows that, except for 20-day and 40-day intervals, nitrogen content increases with increasing amounts of stem, banana, and food waste. Therefore, this observation indicates that adding banana stems, bananas, and food waste increases the nitrogen content.

3.7. C/N Ratio

Several elements are essential for microbial decomposition in the composting process. Nevertheless, carbon and nitrogen are of paramount importance. Carbon is a vital energy substrate and constitutes the fundamental architecture, comprising approximately 50% of microbial

biomass. Conversely, for development and function, nitrogen is essential for proteins, nucleic acids, amino acids, enzymes, and co-enzymes. The C/N ratio of various heaps was measured every 20 days. The acceptable range of the C/N ratio is between 20 and 40, as per the Municipal Solid Waste (Management and Handling) Rules, 2000. Numerous studies have found that when the number of composting days increases, the C/N ratio drops. In these experiments, it has been observed that with increasing time, the C/N ratio decreased, but there were significant fluctuations of the C/N ratio in P-1, P-2, P-3, P-4, P-5, and P-9. However, the C/N ratios of P-, P-7, P-8, and P-10 have decreased gradually. The graph showing the comparison ratio of carbon and nitrogen is presented in Figure 6.

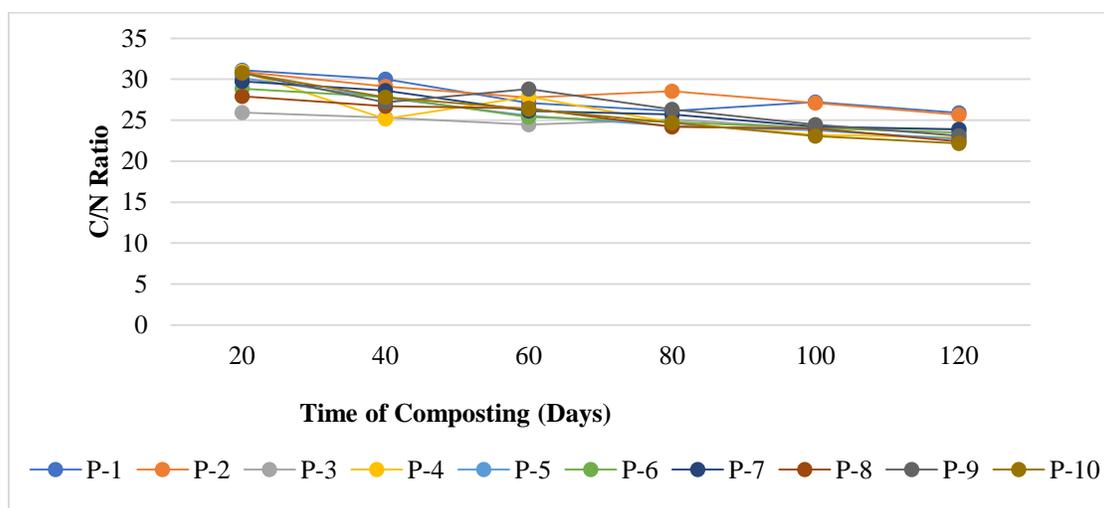


Fig. 6 Variation in C/N ratio during composting

Table 2. Heavy metals content in different piles (in ppm)

Pile	Cu	Zn	Pb	Cd	Cr
1	1.0751	1.003	0.9831	0.8013	0.9201
2	0.0412	0.9310	0.4205	0.0213	0.1194
3	0.8375	0.0721	0.1201	0.1750	0.0135
4	0.0275	0.0154	0.0012	0.0314	0.0112
5	0.0175	0.6210	0.0811	0.7206	0.0921
6	0.1570	0.8105	0.1975	0.0761	0.0685
7	0.1260	0.0621	0.0065	0.1975	0.1347
8	0.2007	0.0092	0.0912	0.1172	0.1237
9	0.0314	0.0274	0.0452	0.0156	0.0013
10	0.0974	0.1202	0.0604	0.1203	0.0513

3.8. Heavy Metals

Heavy metal contamination harms biological systems due to its resistance to biodegradation, resulting in accumulation within plant tissues [31]. The implications of utilizing compost with elevated concentrations of heavy metals reveal

a corresponding increase in the accumulation of non-essential heavy metals within both plant tissues and soil matrices [32]. The presence of these heavy metals poses significant risks to human and animal health when concentrations exceed established thresholds. Consequently, it is imperative to ascertain the heavy metal composition of compost, as their presence may impede plant development, and sustained application has the potential to compromise soil integrity [33]. In this experiment, heavy metals are tested for all the piles by Atomic Absorption Spectrometry (AAS), as shown in Table 2. The table shows that when the amount of banana trees and food waste increased, the heavy metals also increased. Negative readings in AAS can arise from several factors. Contamination or spectral interference in the blank solution is a common cause. Additionally, if the concentration of heavy metal being analysed falls below the instrument's detection limit, it may not produce any signal, resulting in negative or zero output. Other potential reasons for negative AAS values include instrument noise and calibration problems. The table shows that adding more banana trees and food waste increases heavy metal content.

4. Conclusion

Higher amounts of banana tree waste and lower amounts of food waste give higher values of temperature and pH. The samples P-3, P-6, P-7, P-8, and P-10 contain more banana tree waste and less food waste. At the end of the process, the temperatures recorded were 31.1 °C for P-3, 27.0 °C for P-6, 28.4 °C for P-7, 25 °C for P-8, and 26.3 °C for P-10. Regarding pH, the values at the end of composting were 7.09 for P-3, 7.55 for P-6, 7.09 for P-7, 7.57 for P-8, and 7.45 for P-10. Moisture content levels were initially relatively high during the early days of composting. Significant fluctuations occurred from days 55 to 65, after which moisture content gradually decreased until the composting process ended. A higher amount of banana tree waste mixed with a lower amount of food waste piles showed higher electrical conductivity. However, it is out of its ideal range. A more significant proportion of banana tree waste and a lower proportion of food waste led to a steady rise in carbon content. In contrast, nitrogen content rises as the amount of banana stems, bananas, and food waste increases. The composting process revealed a decreasing C/N ratio over time. Significant fluctuations in the C/N ratio were noted in samples P-1, P-2, P-3, P-4, P-5, and P-9. However, P-6, P-7, P-8, and P-10 steadily declined their C/N ratios. This indicates that an increase in banana tree waste and a decrease in food waste contribute to the gradual reduction of the C/N ratio. This study focused on testing five heavy metals: Cu, Zn, Cr, Pb, and Cd. Data analysis revealed that as the amounts of banana trees and food waste increased, so did the levels of heavy metals. Lowering the amount of banana tree waste is essential to reducing heavy metal content in compost. The research

findings indicate that P-4 demonstrates the best composting performance. All parameters of the composting process fall within the ideal range for this pile. Improved aeration, microbial inoculation from cow manure, balanced feedstock ratios, and efficient heat regulation were the main factors that contributed to the success. In general, pile composting proves to be an affordable, environmentally friendly, and expandable method of managing banana waste, particularly in areas with limited resources.

4.1. Future Scope

Considering the massive generation of banana residue, composting it with different inoculums and bulking materials can be studied. The application of the compost to various crops can be further analyzed in detail. The use of a specific part of the banana residue may be discussed, considering the nutrient and quality assessment of the compost. Smart composting, where the composting process may be precisely monitored and optimized by applying IoT sensors that track temperature, moisture, and oxygen. Compost can be prepared all year round, as the plantation and harvest of the banana plant lack seasonality. Hence, the compost prepared from banana residue would be cheaper economically. At the same time, easily prepared compost can also be sold in the market, helping the farmers. However, care should be taken when choosing the banana residue, as bananas growing in exposed soil may present contaminants like heavy metals. Widespread adoption of innovative composting techniques is essential to reaching the zero-waste target, but this shift requires resolving socio-ecological obstacles, including low public awareness, policy gaps, and possible ecological issues related to large-scale implementation.

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