EFFECT OF BULKING AGENT ON COMPOSTING AND GREENHOUSE GAS (GHG) EMISSIONS OF ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

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Dedication

I dedicate this research to my parents, whose hard work and sacrifices made my dream of getting this degree come true.

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List of Abbreviations

BA	Bulking agent
CH_4	Methane
CS	Corn stalks
CO_2	Carbon dioxide
CO_2 eq	Carbon dioxide equivalent
C/N	Carbon to nitrogen
DL	Dry leaves
GHG	Greenhouse gas emission
MC	Moisture content
MSW	Municipal solid waste
N_2O	Nitrous oxide
OFMSW	Organic fraction of municipal solid waste
TS	Total solids
TKN	Total Kjeldahl nitrogen
TC	Total carbon
TP	Total phosphorus
VS	Volatile Solids
WS	Wood shaving

Abstract

Solid waste generation is increasing day by day globally. Similarly, in Pakistan more than 50% of the municipal solid waste is biodegradable and contributes to greenhouse gas (GHG) emissions if not managed properly. To address this issue there's a need to use a waste management technique that is economically feasible, environmentally friendly, and practically possible. Composting of organic fraction of municipal solid waste is one of the promising techniques for converting waste into a resource. This study was aimed to convert waste (organic fraction of municipal solid waste) into a resource (compost) using three different bulking agents (wood shavings, dry leaves, and corn stalks) in three different reactors. The composting mixture was monitored for its characteristics like temperature, moisture content, TS, VS, TOC, TKN, C/N ratio, TP, and pH. Secondly, the GHG emission potential of compost was determined at different stages of compost formation. The final compost using three different bulking agents had C/N ratio of 20.6, 15 and 12.4 for wood shavings, dry leaves, and corn stalks respectively that is considered an ideal value for mature and stable compost. The results of GHG emission potential showed that raw waste had maximum GHG potential of 3114, 2926 and 2833 g CO_2eq/kg compost for wood shavings, dry leaves and corn stalks respectively as compared to final compost having GHG emission potential of 934, 832 and 736 g CO_2eq/kg compost for wood shavings, dry leaves and corn stalks respectively. Moreover, the net GHG emissions were found to be minimum and almost similar for all the three bulking agents in the final compost. Together, the results showed that composting of waste with bulking agents can produce a stable compost and can significantly reduce the GHG emissions.

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the critical issue of the management of solid waste, with a specific focus on the organic portion of municipal solid waste (MSW) in Pakistan. As the global population is growing at a continuous rate and, improvement in the standards of living, the solid waste generation is also increasing at a rate that is quite alarming. A significant portion of household waste is biodegradable in many Asian countries, including Pakistan, posing serious challenges for the management of waste.

1.1. Solid waste

Solid waste generation is increasing day by day globally, not only because the population is growing, but also due to improvement in our living standards. It is estimated that in Asian countries about 40 to 60 percent of the waste at household level is of biodegradable nature. Improper management and disposal of such a huge quantity of organic solid waste poses serious impacts on air, land, water and human health. It is estimated that landfills and dumps of solid waste are the contributor of greenhouse gas that is 2 %, consisting mainly of methane (Zeshan & Visvanathan, 2014). Asian countries are generating the municipal solid waste at the rate of 1 million tons per day and it is believed that this rate will increase to about 1.8 million tons per day by the year 2025 which is quite alarming. More than 50 % of the municipal solid waste is of organic nature in Asian countries. Municipal solid waste includes paper waste, yard waste, wood waste, food waste, bottle, textiles etc (Sohoo et al., 2021). Currently, municipal solid waste management practices that are environmentally sound are absent in Pakistan. About 60 to around 70% of municipal solid waste is collected but the collection rate is greater in bigger cities as compared to smaller cities. And after collection of this waste, about 50 % of the municipal solid waste is disposed of in the form of open dumping and 40 % of the municipal solid waste is sent to landfill sites that are not even specified in case of Pakistan (Khatri et al., 2021). The rate at which developing countries are generating the solid waste is 0.5 kg/ person/day and the average solid waste that is being generated per day in Pakistan is 71000 tons. Resource circulation of waste is mostly carried out through the process of recycling that is 8% and through composting that is just 2%. The figure given below shows the composition of municipal solid waste in Pakistan. And it can be seen from the figure that food waste and yard waste are the two major components of municipal solid waste in Pakistan. Out of the total composition of MSW, 30 % is food waste, 14 % is yard waste, 7% is cardboard and 6 % is paper waste, which is given below in **Figure 1.1.** Since organic fraction forms the major component of municipal solid waste in Pakistan, effective treatment of this fraction is very important for efficient management of waste (Devadoss et al., 2021).

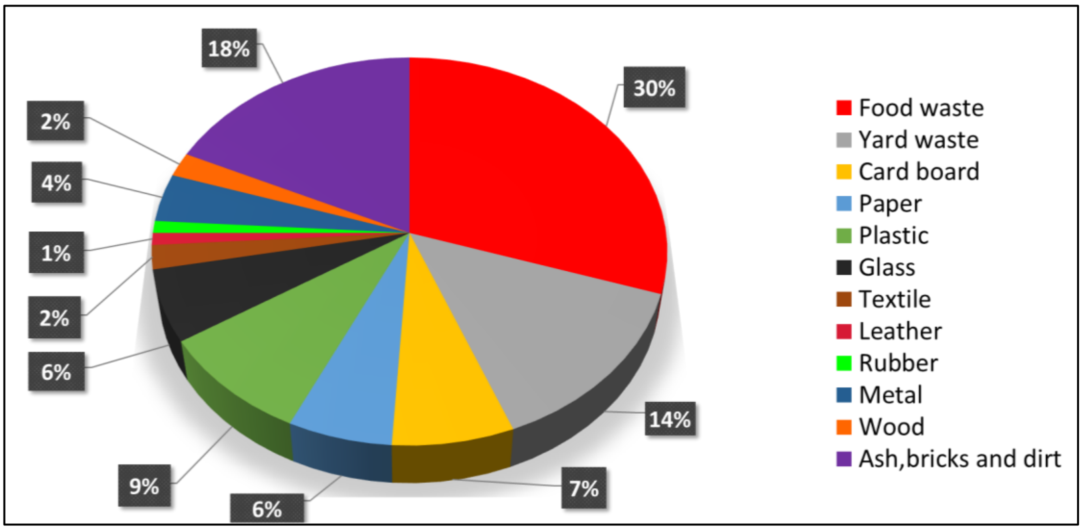

Figure 1. 1 Composition of MSW in Pakistan

Various technologies are available for management of organic waste and its reuse such as incineration and anaerobic digestion for the production of thermal energy, electricity and fuel. But these techniques are quite expensive, complicated and require technical expertise for their operations (Khalid et al., 2022). Traditionally, in both developed and developing nations, food waste is often disposed of inappropriately, either through open dumping, incineration, or as animal feed. As far incineration is concerned, the fly ash from incinerators has high levels of toxic chemicals, posing serious environmental and public health risks. Moreover, in 2013, the Food and Agriculture Organization reported that yearly greenhouse gas emissions resulting from food waste in landfills were nearly equivalent to the total emissions of Cuba i.e. approximately 3.3 billion tons of CO_2 annually. Furthermore, food waste was found to contribute significantly to global water loss, estimated at roughly 250 cubic kilometers each year. Consequently, food waste management has emerged as a significant environmental challenge, given its rich organic content and high biodegradability (Verma et al., 2023).

So, we need technology for the management of organic waste that is relatively simpler, cheap and has insignificant environmental impacts. Considering these factors, composting emerges as a promising technique that aligns with these criteria, providing an eco-friendly solution for managing organic waste and the end product can be used as a soil conditioner. Composting is a widely adopted method for the disposal of food waste. It involves the metabolic activities of microorganisms, harnessing their catabolic and anabolic processes to break down complex macromolecules like starch, fats, and proteins in the initial stage. Further, these components hydrolyze to form glucose, fatty acids, and peptides. Over time, these smaller compounds undergo further degradation and condensation, ultimately forming stable humic substances (Zhu et al., 2023). Amongst, aerobic composting is recognized as a more reliable method since it not only breaks down waste effectively but is also a good source for production of mature and stable compost, which widely employed as fertilizer or soil conditioner.

Various physicochemical parameters including pH, organic matter (OM), total nitrogen (TN), and total phosphorus (TP) affect the composting process by regulating microbial activities. These microbial activities, in turn, exert direct and indirect effects on the bioavailability of heavy metals (Guo et al., 2022). The moisture content within the composting mixture also holds significant importance since it serves as a medium that facilitates the movement of essential dissolved nutrients required to support the metabolic and physiological functions of microorganisms. Similarly, the carbon-to-nitrogen (C/N) ratio is also a crucial factor influencing both the composting process and the characteristics of the final product (Kumar et al., 2010).

Furthermore, the aeration rate also plays a vital role in the composting process, it is generally recommended to maintain 30% free air space when preparing the compost mixture. This percentage may fluctuate based on the particular substrate and composting system employed (Adhikari et al., 2008). Insufficient aeration, as well as excessive aeration, can lead to undesirable outcomes such as increased nitrogen loss and immature compost as an end product (Wang et al., 2021). (Zeng et al., 2018) reported that intermittent aeration can significantly reduce greenhouse gas emissions by 12.36% to 53.20% when compared to continuous aeration.

Studies indicate that the application of compost yields favorable outcomes and enhances soil fertility. Although composting is the most widely used technique globally for treatment of organic solid waste, but there are some issues in the process of composting such as low porosity of composting piles, longer time period required for degradation of waste, excessive moisture present in the food waste, generation of GHG emissions, which restricts the evolution of the composting process. So, we need to optimize the composting process in a practical and economic way. These issues are addressed through the introduction of bulking agents for optimizing the composting process (Zahra et al., 2023).

The composting process can be enhanced by incorporating bulking agents. These bulking agents help in improving aerobic conditions, managing gaseous emissions, accelerating biodegradation, and promoting product maturation by adjusting substrate physicochemical parameters such as C/N ratio and moisture content (Xu et al., 2021). The composition of bulking agents, including their C/N ratio and moisture content, varies depending on the specific materials used. For instance, wood chips typically have a high C/N ratio, and their moisture content depends on how dry they are; the high carbon content in wood chips is primarily in the form of lignin, which is resistant to biological degradation. On the other hand, materials like wheat straw and hay have a lower C/N ratio and their carbon content is more easily degradable (Adhikari et al., 2008). Moreover, adding vine shoot pruning as a bulking agent during the composting of food waste can accelerate the process, mitigate nitrogen losses, and enhance the overall stability of compost (Li et al., 2022). There are several bulking agents that can be used for the optimization of the composting process. The bulking agents used in this study were wood shavings, dry leaves, and corn stalks. The selection of these bulking agents was based on their excellent value both as a bulking agent and a carbon source.

Similarly, characteristics of food waste may also vary depending upon the component of waste such as Lettuce, onions, tomatoes, and cabbage contain more nitrogen (N) in their fresh weight (FW) when compared with potato tops, whole carrots, peppers, and bread. Before starting the composting process, it is crucial to thoroughly understand the characteristics of the food waste and the selected bulking agent. This knowledge allows for the formulation of a balanced recipe that considers moisture content to ensure proper aeration, pH levels for creating an optimal microbial environment, and the right balance of carbon and nitrogen to support microbial growth and development (Adhikari et al., 2008).

1.2. Significance of research

Significant distinctions exist between industrial-scale and laboratory-scale composting processes. In laboratory-scale composting, greater material uniformity is achieved, and process parameters are more effectively regulated. Conversely, industrial-scale composting encounters challenges arising from the expansion of reactor volumes, resulting in suboptimal material mixing and compaction issues. These factors, in turn, diminish the available porosity within the compost heap and hinder the complete decomposition of organic matter. Consequently, aeration efficiency and overall composting effectiveness are directly impacted (Peng et al., 2022). Therefore, In the present study, a lab-scale aerobic composting reactors were designed to investigate the effect of different types of bulking agents on the composting of food waste. The goal of the study is to identify a suitable bulking agent that offers significant advantages, including reduced nitrogen loss and enhanced compost quality. This information can be invaluable for making informed decisions regarding food waste composting operations. The findings from this study have the potential to make a substantial contribution to the advancement of composting practices in the future.

1.3. Scope of the study

The scope of the study includes:

- Construction of three lab-scale reactors to compost food waste
- The use of food waste is a mixture of fruit and vegetable waste as substrate
- Use of dry leaves, wood shavings, and corn stalks as bulking agents
- To evaluate the effect of bulking agents on the composting of food waste

- To analyze the performance of the composter by monitoring various physicochemical parameters such as total nitrogen, total phosphorus, and moisture content

1.4. Objective of the study

- To check the effect of bulking agents (wood shavings, corn stalks and dry leaves) on the stability and maturity of compost
- To mitigate GHG emissions associated with municipal solid waste by converting organic portion into stable and mature compost.

CHAPTER 2

LITERATURE REVIEW

With an emphasis on compost's nutrient content, possible environmental effects, and management techniques, the literature review chapter offers a thorough examination of the research that has already been done on the topic of employing it as an organic fertilizer. This chapter looks at sustainable management choices and highlights important discoveries about compost's greenhouse gas emissions in order to place the current work within a larger academic context.

2.1. Composting of organic fraction of municipal solid waste

2.1.1. Use of organic fraction of municipal solid and bulking agents

Awasthi and coworkers inspected the use of the organic portion of municipal solid and mixed with bulking agents. The analysis was directed in three open composting windrows which were led utilizing chopped OFMSW utilizing office, nursery, vegetables, and food waste. The examination lasted 35 days with uniform beginning material. A sum of 3 heaps was utilized in the examination.

2.1.2. Role of microbial inoculum

The heaps were immunized with the microbial consortium and turning of heaps on weekly basis for improving oxygen supply and enhancing the micobial activity

2.2. Physicochemical and enzymetic changes

The OM was kept somewhere in the range of 55 and 60 percent toward the beginning of the examination. The temperature of the heap was observed consistently. A microbial inoculum was arranged utilizing two lignocellulolytic contagious species. The Physicochemical properties of the fertilizer were broken down toward the beginning of the trial. To evaluate the microbial exercises, the temperature change was observed. The adjustment of temperature recommended that microbial exercises expanded since the temperature of the heaps expanded bit by bit. At first, the pH diminished quickly which was a result of microbial exercises, and microbial natural corruption which prompted the development of natural corrosive. The pH expanded in the later phases of the analysis and arrived at the most elevated worth of 7.38. TOC diminished as the trial advanced which was a significant boundary in proposing the development of the manure. TKN content diminished step by step toward the beginning and following 10 days in heap 1 and 3 it expanded fundamentally and in later stages it expanded progressively. The amylase and cellulase movement additionally expanded steadily in all heaps, this increment proposed that the utilization of BAs is liable for the change. BAs accessibility expanded microbial mass. The examination expressed that protease action is a significant mark of disintegration of OM on the grounds that they are significant chemicals during the treating the soil interaction which is the reason most extreme protease action was recorded toward the beginning of the cycle. A greatest phosphate movement was likewise recorded at the development time of the fertilizing the soil which is a basic microbial action marker. During the thermophilic stage the dehydrogenase movement was most extreme which is viewed as a solid sign of in general microbial action as it is straightforwardly engaged with the respiratory chain.

2.3. Germination index

The GI of heap 1 and heap 2 was more noteworthy than 90% which demonstrated the manure to be great and mature. The GI likewise affirmed that the compost was liberated from phytotoxins. The examination inferred that while the bulking agent was joined with OFMSW it was viewed as a helpful instrument to speed up microbial enzymatic movement during the composting process (Awasthi et al., 2015).

2.4. Home composting of organic waste using bulking agents

2.4.1. Study overview and methodology used

Guidoni and coworkers in 2018 used three different ratios of bulking agents to food waste to carry out the composting at home level. The trial was led in Southern Brazil in the mid-year season for 60 days and the reactors were shielded from sun and rain. The reactor was set haphazardly with confined admittance. The vegetables and raw fruit leftovers (LRFV) were gathered from an eatery which chiefly contained strips and extras of carrots, cabbage, apples, bananas, and lettuce. Five samples' worth of waste were weighed and placed in a two-liter beaker to measure the average density of LRFV (Guidoni et al., 2018).

2.4.2. Composting parameters and reactors setup

The trial utilized rice husk (RH) as the bulking agent since it was effectively accessible in the area. The physiochemical factors for RH chosen were MC 9%, pH 6.36, total nitrogen 0.64%, total organic carbon 44.36%, carbon to nitrogen (C/N) proportion 69.91 and mineral matter (MM) 16.24%. The examination was isolated into two phases. The examination starts with the day-to-day expansion of 4 L of every RH-LRFV blend for a time of 10 days. The later stage then, at that point, began the thirteenth day which included aerobic decomposition of waste followed by a period of stabilization phase in which no more waste was added to the reactors. The Reactor's temperature was estimated two times per week to ensure the reactor's temperature matched the room's temperature. To guarantee homogeneity the samples were taken from mixture of composting at three different points with size of the sample was 50 grams which was then examined in triplicate. The proposed strategy by Association of Official Analytical Chemists (1995) was utilized to examine MC, pH, MM, organic matter. Though the TOC was approximated utilizing proportion of change which depended on the "Van Bemmelen" transformation factor proposed by Jimenez and Garcia (1992). The Kjeldahl was utilized to examine the TN content. Germination index (GI) was estimated for cucumber and lettuce seeds. The all-out time taken for germination and root length when presented to a concentrate from the examples were contrasted with that acquired with distilled water (control) when brooded at 25 degrees Celsius for 48 hours in the incubator. For the trial T1 70:30, T2 50: and T3 30:70 was picked as the general proportion of RH and LRFV a measure of 4.0, 4.6, and 5.1 kg waste was added to the reactor week after week. The main arrangement of reactors was utilized for the portrayal of "Interaction Time" and the subsequent set was utilized got survey the impacts of utilizing different proportions of RH: LRFV. The noticed factors were separated in 2 sets. The primary set was examined exclusively according to the element "proportion" which included OM, MM dry matter (DM), TN, pH and TOC while the subsequent set was investigated previously and during the medicines which included C/N proportion, MC, and the GI of cucumber and lettuce seeds. Nine reactors were utilized in the review. During the examination there was a weight reduction on the grounds that reasonable circumstances were given to the microbiota which brought about debasement of degradable natural substances. During the analysis no adjustment of temperature was recorded. The dampness content in T1 decreased while in T2 and T3 it expanded in light of the fact that it might have surpassed the assimilation limit of RH. The aggregating fluid was eliminated by expanding turning recurrence and because of the presence of leachate gatherer. The MM, pH, OM, and TOC values were altogether unique somewhere in the range of T1 and T3. MM values were higher in T3 when contrasted with T1, however the TOC and OM values were lower. There was extraordinary decay in T3. The underlying pH esteem was 4 which later on expanded which was a result of degradation of natural mixtures which then, at that point, responded with basic components which brought about pH level ascent. The TN level expanded in every one of the examinations. At the point when the examination began an optimal C/N proportion was accommodated the treating the composting cycle which expanded in the later phases of the trial.

2.4.3. Plant growth and phytotoxicity

The GI at first showed that fertilizer expanded the plant development rate, however in later phases of the examination it decreased. The trial presumed that Treating the soil worked on the development of plant which is more impacted by the proportion of bulking agent. The outcomes likewise upheld the utilization of RH as bulking agent and when utilized in higher extents it additionally diminishes the phytotoxicity during fertilizing the soil cycle.

2.5. Decentralized composting of household wet biodegradable waste (HWBW)

Researchers in 2019 tried different things with a decentralized methodology for fertilizing the soil family wet biodegradable waste (HWBW) utilizing plastic drums. The HWBW contained uncooked and cooked waste. Garden waste (GW) was chosen as a bulking agent which generally comprised of leaves and grass clippings. A blended waste (MW) of HWBW and GW was ready at a proportion of 8:1. A microbial inoculum containing yeast, lactic corrosive microscopic organisms, and phototrophic microorganisms and 6.25 ml of inoculum was added to one kg of waste. A sum of six drums partook in the trial. In drums D1 to D4 six kgs of waste was added day to day from day 1 to day 12 while in D5 and D6 2.5 kg squander was added every day for fifteen days. During the taking care of stage the waste was blended every day. After fulfillment of the taking care of stage the application pace of blending the waste was diminished to week by week. During the dynamic decay time frame 100 grams tests were taken occasionally for examining.

2.5.1. Results and findings of composting using microbial inoculum

The examination kept guideline strategies to decide the substance, physical, and organic qualities of the waste. The control drum accomplished a limit of 43 degrees Celsius and temperature of the multitude of different drums accomplished more noteworthy than 55 degrees Celsius which is thought of as critical to kill microorganisms in the composting system. The control drum saw no progressions in its pH all through the trial while the wide range of various drums saw an expansion in pH which recommended quick corruption of the waste. The drum 4 experienced speedy change in pH because of expansion of inoculum which brought about a lot quicker debasement. The EC of the waste was 2.1-2.5 dS/m during the taking care of stage and at the later stages it arrived at a limit of 3.8 dS/m. In the event that the EC comes to or surpasses 4 dS/m or higher, it is then a potential inhibitor since then the solvent salts impede seed germination. The complete natural matter in the control drum diminished from 95% to 80% while in the wide range of various drums it decreased fundamentally. The C/N proportion of the control drum remained at 15.2 while for the wide range of various drums it ran somewhere in the range of 9.8 and 11.2. The phytotoxicity tests were directed and the outcomes recommend that the germination was 80 - 90% in every one of the pots with tests from D2 - D6 while for the post with test from D1 it was 8 - 21%. There was a significant change in squander mass and volume which likewise demonstrated biodegradation. The review showed that manure liberated from microorganisms can be delivered creating HWBW the outcomes were additionally upheld by the development tests followed by phytotoxicity tests which proposed that 20 % of the manure can be utilized for the development of cress plants as compost (Manu et al., 2019)

2.6. Evaluation of unconventional bulking agents for composting food waste

In 2020, Lee, J. H. and colleagues made an effort to determine how effective uncommon BAs were for composting food waste. In order to determine whether three unusual non-woody materials—insect brass, mushroom debris, and ginkgo leaves—are suitable for co-composting food waste, their respective efficacies were compared to those of sawdust. Styrofoam was utilized to construct the experiment's compost box in order to prevent heat loss throughout the composting process. 30% (w/w) of the bulking agents were added. The ideal water content, which is between 50% and 60%, was kept constant. To help the compost pile's temperature rise quickly, 90 grams of quicklime were added. 90 grams of livestock manure and 30 grams of efficient microorganisms were combined to introduce aerobic bacteria, which acted as inoculating materials for composting. Additionally, sugar that had been dissolved in water was added to the compost pile, providing the microorganisms with nutrition. The trial ran for fifty-six days. Three distinct procedures were used to determine the maturity of the compost waws: Solvita, CoMMe-101, and Germination index. The three stages of the composting process were the mesophilic stage, which was followed by the thermophilic stage, and the lengthy cooling and maturation stage, which was the last stage. When the second stage began, the high temperatures killed out dangerous microbes and weed seeds as a result of the first stage's low molecular compounds being broken down by the microorganisms. The mushroom waste had the greatest temperature of all, peaking at 68.9 degrees Celsius. The sawdust compost recorded the lowest temperature, 39.6 degrees Celsius. The temperature was high until the 21st day, at which point it began to drop and by the 28th day, it was at room temperature. The treatments using sawdust, ginkgo leaves, insect droppings, and mushroom debris continued to have the highest average temperature. All of the treatments' water contents stayed within the ideal ranges, with the exception of the insect feces treatment, which had a water content of 73% and was thrown out due to its deterioration. Because ammonia gas is produced during the breakdown of nitrogen, the pH in all treatments increased initially, reaching a maximum of 8.4, but then fell as organic acid broke down into organic matter. In every treatment, the amount of NaCl dropped. With the exception of sawdust, every treatment had a germination index greater than 70. The ginkgo leaf treatment matured first, then the deciduous leaves from mushroom waste. The longest to mature was the sawdust compost (Lee et al., 2020)

2.7. Maize stover as bulking agent in dairy manure composting

In an effort to support Japanese circular dairy farming, Maeda, M. (2020) looked into the use of maize stover as a bulking agent in the composting of dairy manure. In an experimental field, maize was planted specifically for the study. Two weeks after harvesting, the stover was gathered and arranged into five randomly selected squares. The stover was then dried for 48 hours at 60 degrees Celsius. The study's compost was primarily made up of corn stover or wheat straw, together with the dung of nursing cows. Four tons of dairy cow feces and 150 kg of CS and WS were utilized as bulking agents. They were combined and stacked on a concrete floor that was watertight. Every two weeks, the pile was rotated to allow for improved OM decomposition and the introduction of oxygen. An infrared photoacoustic detector and a dynamic chamber system were also used to measure gas emissions. An inverter was employed to maintain a steady airflow. After turning, 500-gram samples of the compost were taken, homogenized, and used to assess inorganic N, total solids, volatile solids, and electrical conductivity. After the compost was heaped, its warmth rose noticeably. Since the temperature of CS was found to be higher than that of WS, CS is a useful bulking agent for compost made from dairy manure. Active OM degradation led to a considerable drop in the weight of CS and WS. Methane emissions during the experiment varied between WS and CS. The GHG emissions of WS and CS were nearly identical. High temperatures may have benefited human diseases and plant pathogenic fungi during the experiment. The experiment showed that maintaining a high temperature is necessary to keep weeds out of the pile. According to the research, using CS and WS as bulking agents in the composting of manure lowers emissions of both CH_4 and N_2O. The study came to the conclusion that because CS with high NO3-N levels is hazardous to dairy cattle, it shouldn't be utilized as a bulking agent. The study backed up the use of CS since it aided in the breakdown of organic matter and reduced methane production during the composting of manure (Maeda et al ., 2020).

2.8. Food waste composting and GHG emissions

The study utilized sawdust and mature compost as bulking agents to optimize the composting of food waste digestate. Seven kilograms of carefully blended feedstock were added to each of the experiment's reactors. Throughout the experiment, atmospheric air with a composition of 78% nitrogen and 21% oxygen was kept at an aeration rate of 0.25 L/kg/hr. After thoroughly mixing the material on 0, 3, 7, 11, 15, 22, and 29, 200 grams of samples were taken from each reactor for biological examination and physiochemical characteristics. The experiment's temperature profile showed notable variations because the temperature of reactor 2 (which contained just mature compost) and reactor 1 (the control) initially rose to 65 degrees Celsius. The maximum temperature attained in Reactor 3, which employed sawdust as a bulking agent, was 55 degrees Celsius. Compared to all the other treatments, Reactor 4, which contained sawdust and mature compost, reached the cooling phase quicker because it degraded more quickly. Pathogen destruction was also guaranteed throughout the thermophilic phase. The compost's initial pH ranged from 8 to 9, and as the procedure went on, it varied from 7.5 to 9, indicating that the BAs had no effect on the compost's alkalinity. Reactors 3 and 4's electrical conductivity did not change considerably when sawdust and mature compost were introduced, whereas reactors 1 and 2's electrical conductivity decreased. Reactors 1 and 2 showed inadequate composting conditions with a C/N ratio of less than 10, but reactors 3 and 4 showed strong microbial decomposition with a C/N ratio of fewer than 20, indicating mature compost. As the experiment went on, the GI of every treatment increased to >50%, indicating that the phytotoxicity had decreased as a result of improved nutrification and increased aeration. Initially, all of the treatments had GI values of 0%, which indicated that the FWD was extremely poisonous. This demonstrated that the addition of mature compost and sawdust as co-compost helped the FWO become bio stabilized into high-quality compost. It was determined that the Hashimoto kinematic model and the first-first order kinematic model, which were employed in the experiment, were effective in forecasting the total CO_2 emission. The study found that in order to increase the rate of decomposition and create high-quality compost, FWD can be employed successfully with mature compost and sawdust as a bulking agent (Song et al., 2021).

2.9. Impact of bulking agents on bacterial dynamics and GHG emissions in kitchen waste composting

A group of researchers in 2021 investigated the dynamics and roles of bacteria driven by BAs to reduce gaseous emissions during the composting of kitchen garbage. Beijing Solid garbage Treatment Co. supplied the kitchen garbage for the experiment, which included meat, bones, vegetables, fruits, and other items in addition to staple foods. Commonly used bulking agents such as cornstalks, yard trash, and spent mushroom substrates were used. Multiple cylindrical composters linked to automated equipment were employed in the study to guarantee aeration. The kitchen trash was combined with all of the BAs at a wet mass ratio of 3:17. The heaps were turned twice a week to ensure biodegradation and maturation during the five-week experiment. 500 grams of samples were gathered using a multipoint sampling technique. Using a graph chromatograph and the syringe sampling method, the N_2O and CH_4 were found. Every composting pile had a comparable temperature profile. Within the first five days, the composting piles reached their greatest temperatures, indicating a fast breakdown. Following the initial five days, the temperature steadily dropped until day fifteen, at which point it started to rise once more before continuing to drop until the experiment's conclusion. Due to its soft texture, which decreased matric porosity for air diffusivity, cornstalk's temperature initially increased steadily among all the bulking agents, but it eventually surpassed the other two. Every treatment's pH profile was comparable; no notable alterations happened; initially, each treatment's pH increased, and after the first week, it stabilized. For both treatments, there was an increase in NH_4 content during the first week, most likely as a result of organic nitrogen mineralization and the nitrification process being impeded by the higher temperature. All of the treatments' GIs rose and eventually exceeded 130%, indicating the removal of inhibitory and phytotoxic compounds. All of the treatments' CH_4 emissions peaked during the first ten days, showing a similar profile that suggested the three BAs had comparable effects on the proliferation and activity of methanogens during the composting of kitchen trash. Every mound displayed enormous. The findings indicated that composting improves the bacterial community's richness and diversity. For bulking agents, the co-occurrence network of the bacterial community in composting differed considerably. With a total relative abundance of more than 85%, the network nodes in the composting piles belonged to the phyla Actinobacteria, Firmicutes, Bacteroidetes, and Proteobacteria. The SMS had the most number of bacterial linkages and nodes among the three BAs. It also held a large number of microorganisms, which enhanced the composting's biodiversity. The network structure in the CS was more complex and stable, and there were more constructive interactions within the network. According to the study's findings, using garden trash as a bulking agent to co-compost kitchen garbage reduces gaseous emissions. The primary conclusions were that the bulking agent-spent mushroom substrate led to Pseudomonas genus expansion, which in turn drove nitrate reduction and considerable N_2O emission. A healthy bacterial community in the compost made from cornstalks aided in the organic biodegradation process (Xu et al., 2021).

2.10. Composting and GHG emissions in Jordanian waste management

Al-Nawaiseh and his coworkers conducted organic waste composting in order to investigate viable substitutes for Jordan's solid waste management system. Composting input materials included a variety of inorganic and organic wastes, including manure, market waste, and garden waste. Three distinct compost pile types were created using various blending ratios and bulking agents, including sawdust, tree trimmings, and plant leftovers. Regular intervals were used to turn the piles. Water was supplied to maintain a moisture content of more than 50%. The piles' initial pH value fell beyond allowable bounds. The C/N was changed to the 25–35 w/w suggested values. To create mature compost, the procedure took a whole year. Because aerobic breakdown is exothermic in nature, the temperature of the compost rises as soon as microbial activity begins. All three piles' temperatures rose linearly, reaching a maximum in the second week that ranged from 65.3 to 68.1 degrees Celsius and satisfied the criteria for pathogen inactivation. After the second week, the temperature began to drop until the ninth week, at which point it sharply dropped—a temperature that is necessary for compost to dry out and stabilize. Initially, there was a low concentration of oxygen and a high concentration of carbon dioxide. However, as the process went on, the concentrations of O_2 and CO_2 rose and fell, respectively, indicating a decrease in biological deterioration. The moisture content was managed at or near 50% because the composting process will cause the pile to become dehydrated. Enough water was added to replace this reduction, allowing the substrate to continue biodegrading. Throughout the procedure, the C/N ratios showed a declining curve. Every pile had the same pH; at first, it increased, then it decreased, and finally, it was documented to have increased. All of the piles had pH values between 7.5 and 8, which is the ideal range, at the conclusion of the composting process. The macroelements that considerably enhance plant growth are the nutrient content, primarily phosphorus, potassium, and nitrogen. With the exception of P3, which comprised 1.36% sawdust, 49.32% chicken manure, and 4932% sheep manure, the nutrient level of all the piles increased. The analysis of the organic matter revealed that it ranged from 18 to 40%, meeting the criteria. Less than 6 mg/O_2/kg/DM/hour of O_2 was consumed during the study, and a stable compost is indicated when the consumption rate is less than 40 mg/O_2/kg/DM/hour. The rate of CO_2 production was below the compost stability cut-off value of 100 mg/CO_2/kg/hour. Overall study results indicated that the compost generated throughout the trial was a high-grade, pathogen-free, and product focused on the market (Al-Nawaiseh et al., 2021).

2.11. Composting agricultural waste and nutrient dynamics in Pakistan

In 2022, researchers evaluated the practice of composting agricultural waste items on farms in Pakistan in order to promote sustainable agriculture. A location close to the solid waste disposal facility was chosen for the experiment. Farm trash was gathered, including animal dung and agricultural waste like rice and wheat straw, fresh grass clippings, cotton and maize stalks, and tree prune leaves. Three piles in all were created. One layer of cotton stem and one layer of animal dung were present in P1. Animal dung and a layer of wheat and rice straw made up P2, while an animal layer and shredded maize stalk material made up P3. Every pile underwent manual aeration and was turned in accordance with normal procedures. Every pile's temperature was measured with a Certeza FT 707. To monitor pH, a multi-HACH pH meter was employed. The total nitrogen was measured using the Hach-Digesdahl instrument, and the moisture content was measured using the AOAC method. To find organic materials, dry combustion was done at 550 degrees Celsius. A water sieving device was employed in the study to evaluate the compost's particle size distribution. The nitrogen concentration increased in all reactors during the first four weeks of the composting process and continued to rise in all windrows until the fourteenth week. This increase in nitrogen concentration may have been caused by a net loss of dry mass and water evaporation from the rise in temperature throughout the organic carbon oxidation process. Bacteria that fix nitrogen may possibly be the cause of the increase in nitrogen. The experiment's phosphorus content increased gradually from the beginning to the end. From 1.65 to 13.98 ppm, it increased. Although there were fluctuations in the potassium, overall potassium content rose toward the end of the trial. All of the piles' C/N ratios started out between 20 and 30, but as the experiment went on, they decreased and, for P1, P2, and P3, respectively, they reached 17.0, 15.5, and 17.1, which was a sign of mature compost. All of the heaps' organic matter significantly deteriorated, which is a sign of an efficient degradation process. Because of the production of organic acid, the pile's pH was initially acidic during the composting process. As the organic acid was consumed, the pH rose during the thermophilic stage of the experiment and subsequently decreased to almost neutral as the compost reached maturity. One of the most important markers of the entire process is temperature, which also shows when infections and phytotoxicity have been eliminated. It is improbable that germs will be destroyed because the P2 reached a maximum temperature of 53 degrees Celsius while the P1 and P3 stayed below 50 degrees. To help destroy pathogens, add zeolite and lime to the compost. This will raise the temperature. The study found that different agricultural waste sources produce variable amounts of NPK, but that compost made from agricultural waste may still be utilized in agriculture (Hashim et al., 2022).

2.12. Greenhouse gas emission potential and management strategies

Digestate is a by-product of anaerobic digestion that contains organic materials that can benefit agricultural land. As a result, its use as an organic fertilizer has garnered a lot of interest since researchers discovered it in 2014. Nevertheless, there are a number of disadvantages to digestate, the most significant of which is that it tends to produce methane and raise greenhouse gas emissions. Therefore, careful management is needed to lessen these negative consequences on the ecosystem. Much research has been done recently to gain a better understanding of the characteristics of digestate from thermophilic dry anaerobic digesters and its implications on the environment. Therefore, to mitigate these detrimental effects on the ecosystem, attentive management is required. In recent times, extensive study has been conducted to gain a better understanding of the characteristics and environmental implications of the digestate from thermophilic dry anaerobic digesters. Total solids (TS), volatile solids (VS), carbon (C), and nitrogen (N) were continuously monitored in order to compute the C/N ratio, which is an essential factor in assessing whether digestate is appropriate for application on land. The digestate's C/N ratio often fluctuated between 15 and 20 across the trial, according to the results, suggesting that there is no need for further treatment and that it can be applied directly to agricultural land. The potential for digestate to release greenhouse gases is a significant component of the material's overall environmental impact. Depending on the kind of digestate being handled and managed—raw, stored, and stored-cured digestate, for example—this possibility changes. Raw digestate was shown to have the largest potential for greenhouse gas emissions, with 139 g CO_2-eq/kg of waste. On the other hand, it was discovered that the emission potentials of stored digestate and stored-cured digestate were, respectively, lower, at 125 and 80 g CO_2-eq/kg waste. Dictate discharged about 10% of its overall capacity for greenhouse gas emissions after two months in storage. In order to find tactics that reduce greenhouse gas emissions, the study also looked at different digestate management scenarios. The scenarios that involved applying digestate to land were found to have the lowest net greenhouse gas emissions out of the five that were suggested. This suggests that, while digestate has the potential to contribute to GHG emissions, its careful management, particularly through appropriate land application strategies, can mitigate these impacts and make it a viable option for sustainable agriculture (Zeshan & Visvanathan., 2014).

CHAPTER 3

MATERIALS AND METHODS

The purpose of this chapter, "Materials and Methods," is to give a thorough description of the materials and methodologies utilized in this investigation into the impact of bulking agents on the organic portion of municipal solid waste's composting and greenhouse gas emissions. Understanding the composition and the type of waste is a crucial step in the composting process since it has a significant impact on the effectiveness and quality of the compost that is produced.

3.1. Study area description

Before starting the composting process, it is very important to thoroughly understand the type and composition of waste. The compost feedstock was comprised of vegetables, fruit waste and inoculum which was ready made compost. Specifically, food waste including banana peels, apple peels, and potato peels was taken from Concordia -1 NUST, Islamabad. While rotten vegetables including spinach and pumpkin were acquired from Sabzi mandi, located in Itwar Bazar, Islamabad. The location map from where the samples were taken for this research

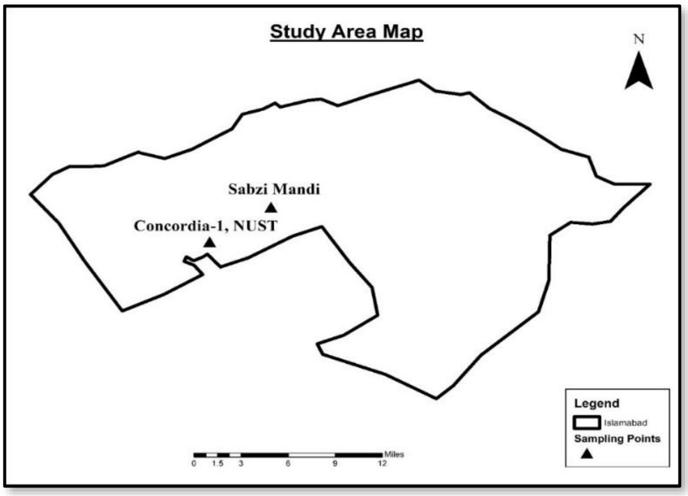

Figure 3. 1 Study area map

is shown below in **Figure 3.1.**

The composition of food waste, inoculum, and bulking agents in grams is shown below in **Table 3.1.** All the peels and vegetables were used in the same ratio which is given below in **Table 3.2.**

Table 3. 1 Composition of waste for composting process

Waste Composition (kg)	
Total waste	3
Food waste	1.8
Bulking agents (Wood shavings, Dry leaves, Corn stalks)	0.9
Inoculum (ready made compost)	0.3

Table 3. 2 Type of waste

Type of Waste (g)		
Sr. No.	Waste type	Weight
1	Potato peels	0.4
2	Apple peels	0.4
3	Banana peels	0.4
4	Spinach	0.4
5	Pumpkin	0.4
	Total	2.0

These conditions were established before starting the composting process given below in **Table 3.3.**

Table 3. 3 Composting conditions

Waste Composition (kg)	
Particle size of waste	1 to 2 cm
Aeration rate	0.1 L/kg/hr
Moisture content	40-60%
Number of days for composting	35 days
Thorough mixing of waste	Every 3rd day
Sampling of waste	Once a week

3.2. Design and working of reactors for composting process

The composting experiment was conducted in three stainless steel reactors with a volumetric capacity of 5 liters each. The reactors exhibited dimensions of 25 cm in height and 16 cm in diameter, providing an enclosed conducive to the composting process. The reactors were equipped with two ports i.e., one for leachate collection and the other for aeration purposes. The reactors were designed to have removable lids, allowing them to be opened during sample collection and facilitating manual mixing of the waste for homogeneity. Approximately 3 kg of thoroughly blended feedstock was introduced into each reactor. This composition included 0.9 kg of a bulking agent, 0.3 kg of inoculum and the remaining portion consisted of food waste that is 1.8 kg. In each reactor, a distinct bulking agent was employed as part of the composition. For the reactors, one was filled with corn stalks, another with dry leaves, and the third with wood shavings. These individual selections of bulking agents contributed to the diversity of the experimental setup. Additionally, temperature sensors were affixed to the reactor to ensure a controlled temperature environment throughout the experiment. The reactors were sealed using screws to prevent contact with air. To conduct the experiment systematically, a total of three reactors were employed having similar dimensions and specifications. All three reactors were connected with an aerator to facilitate aerobic composting. Aeration was provided from the bottom to all three reactors to maintain the aeration rate of 0.107 L/kg/hr throughout the entire process.

The whole composting process was carried out over the time frame of 35 days. Samples were methodically gathered on a weekly basis after thorough homogenization, and leachate extraction was also performed each week. The schematic representation of the compositing setup is shown in **Figure 3.2.**

Wood shavings, corn stalks, and dry leaves which are commonly used bulking agents in the process of composting were used for comparing the effect of these bulking agents on the overall stability and maturity of the compost. Wood shavings were collected from construction site H-13, Islamabad. Dry leaves were collected from a nearby park while corn stalks were taken from a local agriculture residue shop, located at 1-10, Islamabad. While preparing each pile for the three reactors, different raw organic materials such as vegetables (spinach, potato peels, and pumpkin) and fruit peels (apple and banana peels) were mixed thoroughly with a fixed ratio of bulking agents (Wood shavings, Dry leaves, and Cornstalk) These bulking agents were added to waste to improve aeration, achieve required C/N ratio for effective decomposition, enhance moisture management, and create spaces within the pile for better microbial activity. The characteristics of feedstock material are presented in **Table 3.4.** The total nitrogen concentration, C/N ratio, moisture content, volatile solids, and carbon percentage of the different organic components are compared in the table. Notably, wood shavings have the highest volatile solids content (98%), pumpkin has the highest moisture content (93%), dry leaves have the highest total solids (92%), and apple peels have the highest C/N ratio (112.50). Additionally, wood shavings have the highest carbon percentage (54.44%).

The composition of the waste mixture, inoculum and bulking agents in each of the three reactors is presented in **Table 3.5.**

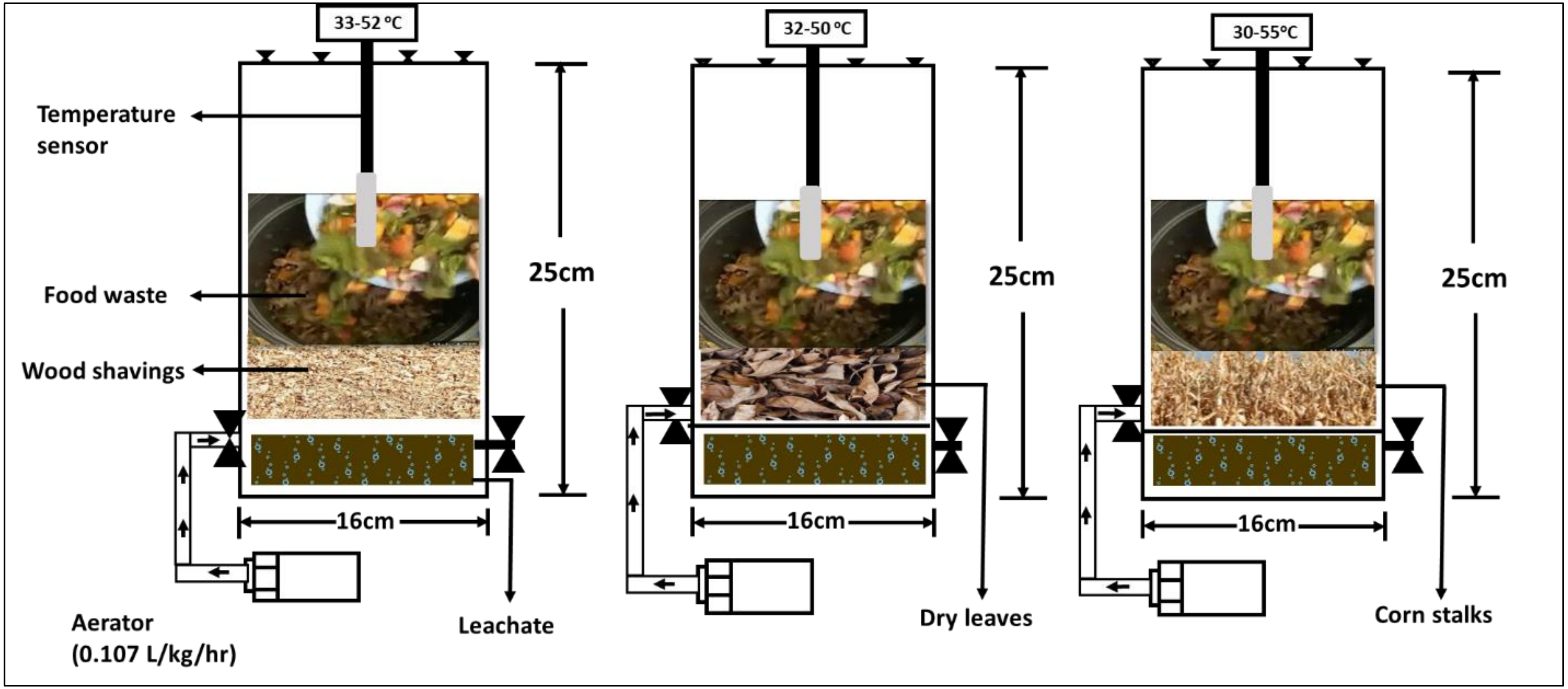

Figure 3. 2 Schematic representation of composting setup

Table 3. 4 Physicochemical characteristics of feedstock

Parameters	Potato peels	Apple peels	Banana peels	Spinach	Pumpkin	Dry leaves	Wood shavings	Corn stalk
Total nitrogen (%)	1.22	0.40	1.40	3.50	4.30	1.20	0.30	0.70
C/N ratio	36.88	112.50	32	12.85	10.46	37.50	150	64
Total solids (%)	18.70	21.30	12.20	17	7	92	91	84
Moisture content (%)	81.30	78.70	87.80	83	93	8	9	16
Volatile solids (%)	81.00	95	83.10	82	85	81	98	91
Carbon (%)	45.00	52.78	46.17	45.56	47.22	45.00	54.44	50.56

Table 3. 5 Reactors composition

Reactors	Reactor composition
Reactor-1	60wt% mixed fruit and vegetables+30wt% Wood shavings as a bulking agent+ 10% wt inoculum
Reactor-2	60 wt% mixed fruit and vegetables+30wt% Dry leaves as a bulking agent + 10% wt inoculum
Reactor-3	60 wt% mixed fruit and vegetables+30 wt% Cornstalks as a bulking agent + 10% wt inoculum

3.3. Physicochemical analysis

3.3.1. Method to determine pH

A digital pH meter was used to measure the pH of the compost. For that 1 gram of sample from all three reactors was taken and mixed with 10 ml of distilled water and mixed thoroughly for 30 minutes (Xiao et al., 2009) pH and electrical conductivity analyses were conducted utilizing a multimeter (in Lab pH/COD 720, Germany) to ensure precise readings.

3.3.2. Method to determine temperature

The temperature was measured using a thermocouple at the core of compost piles of all three reactors and was recorded using a digital meter attached at the top of all three reactors.

3.3.3. Method to measure total nitrogen, total solids, moisture content, and volatile solids

Parameters such as total Kjeldahl nitrogen, total solids and volatile solids were measured using the standardized procedure outlined in APHA (2017). Total solids were measured using an established method that involves drying the sample in an oven at 105° C for 24 hours. In this way, both total solids and moisture content were calculated. Volatile solids were determined on the basis of percentage of residue after heating in a muffle furnace for 30 minutes. Total Kjeldahl nitrogen was measured using the regular Kjeldahl process.

3.3.4. Method to measure total phosphorus (TP)

For the measurement of total phosphorus, the perchloric acid digestion method as detailed by Sommers et al. (1972) was used. For analysis of compost, 1 g of thoroughly mixed compost sample was placed in the digestion tube- Folin-Wu digestion tubes, and then 3 ml of the 70% of $HClO_4$ was added. After that, digestion tubes were put in the aluminum digestion block and digested for 75 min at a temperature of 203°C. When digestion was complete, the digest was allowed to cool and then diluted with 50 ml of distilled water. The tubes were then stoppered and inverted several times for a thorough mixing of the content present in the tubes. Then, the residue was removed from the extract by filtration for immediate P analysis. After that, 3 ml of extractant was pipette into test tubes, and then 3 ml of mixed reagent was added by a pipette. The mixed reagent comprises:

1. **Distilled water-200 ml**
2. **4M Sulphuric acid- 50 ml**
3. **Ammonium molybdate solution- 15ml**
4. **Ascorbic acid solution- 30 ml**
5. **Potassium antimony tartrate solution- 5ml**

The samples were then homogenized using a vortex meter for 30 min for the development of blue color. Then read the absorbance of samples in a spectrophotometer and set a wavelength of 400nm. Then the below-mentioned equation was used for measuring the total phosphorus present in the compost.

Calculation:

$$\text{mg P } kg^{-1} = (a - b) \times V \times 1L \times 1000\ g \times DF \times mcf\ W/1000\ mL \times 1kg$$

$$= (a - b) \times V \times DF \times mcf\ /W$$

Where:

a = concentration of P in sample extract, mg L^{-1}

b = concentration of P in blank, mg L^{-1}

V = volume of extractant, mL

W = weight of soil sample, g

DF = dilution factor = total volume of diluted sample solution/aliquot of extract, mL mL^{-1}

mcf = moisture correction factor

3.4. Estimation of GHG emissions from compost

This part of the study includes estimating the GHG emission potential at various stages of compost formation. The GHG (Methane and Nitrous oxide) emission potential before, during, and after the compost formation was calculated using the method given in section- below. The detailed methodology for estimating the GHG emissions potential is given in the following subsections.

3.4.1. Calculation methods

3.4.1.1. Methane emission potential of compost

Greenhouse gas emissions estimation was assessed using the mass balance method. This method computes methane formation potential based on the carbon content within the material (Zeshan & Visvanathan, 2014).

The detailed stepwise process is given below:

1. The characteristics of the compost, specifically the total solids (TS) and carbon (C) content, were determined through laboratory analysis. These values were then utilized in the calculation of methane formation potential.

2. The methane potential of the material (in grams per kilogram of waste) was transformed into greenhouse gas emissions (in grams of CO_2-equivalents per kilogram of waste) by applying a conversion factor of 25.

The equation used for CH_4 calculation:

CH_4 emission (grams of methane per kilogram of material)

= (M x TS x MCF x DOC x DOCf x F x (16/12)-R) x (1-OX) x 1000

gram of Carbon dioxide-equivalent/ kilogram = (gram of methane/ kilogram) x25

where M = Total mass of material (kg)

TS = Total solid content (fraction)

MCF = Moisture correction factor. That is 0.4

DOC = Degradable organic carbon (fraction) that is carbon value (VS/1.8 value)

DOCf = Fraction of DOC dissimilated. That is 0.77

F = Fraction of methane gas. That is 0.5

R = Recovered methane. That is 0

OX = Oxidation factor. That is also 0.

3.4.1.2. Calculation of nitrous oxide- N_2O emission from compost

The land-applied compost, biosolids, or digestate emits nitrous oxide that is equal to 0.01 of the applied nitrogen as specified by the IPCC. In this study, we have used the nitrous oxide emission factor which is 0.013 of applied nitrogen in the compost (Zeshan & Visvanathan, 2014).

The total amount of nitrogen that is provided by 1 kilogram of compost was calculated from the content of nitrogen of each type of compost (compost with wood shavings as a bulking agent, compost with dry leaves as a bulking agent, and compost with corn stalks as bulking agents). The amount of nitrous oxide that is to be emitted from 1 kilogram of the compost was then calculated by using a factor of 0.013 of the nitrogen applied. The amount of nitrous oxide emitted from the compost was then multiplied with the factor of 298, to convert it to the equivalent amount of carbon dioxide- CO_2.

3.4.1.3. Calculation of greenhouse gas (GHG) avoided by land application of compost

The utilization of compost for land application has the potential to serve as a substitute for synthetic fertilizers, thus contributing to a reduction in the emission of fossil carbon resulting from the energy-intensive production of chemical fertilizers. The total nitrogen (N) and phosphorus (P) content provided by 1 kilogram of compost was determined based on the respective N and P concentrations measured in each compost type. The quantification of greenhouse gas (GHG) emissions avoided or reduced through the land application of compost was subsequently computed using emission factors of 8.9 kilograms of CO_2-equivalents per kilogram of N and 1.8 kilograms of CO_2-equivalents per kilogram of P (Zeshan & Visvanathan, 2014).

CHAPTER 4

RESULTS AND DISCUSSION

The study examines the impact of various bulking agents, such as wood shavings, dry leaves, and corn stalks, together with food waste, such as apple, banana, potato, and pumpkin peels, and a ready-made compost inoculum, on the composting process in the Results and Discussion chapter. With an emphasis on reaching the ideal carbon-to-nitrogen ratio, it investigates how different ratios of these components affect the effectiveness of aerobic decomposition in three laboratory-scale reactors.

4.1. Characteristics of waste mixture at the start

In this study, three different types of bulking agents along with food waste (Apple peels, banana peels, potato peels, spinach, and pumpkin) and inoculum that was ready-made compost in this case, were used in three different laboratory scale reactors. Then a mixture of bulking agents, food waste, and inoculum was prepared in different proportions to ensure the appropriate conditions at the start of the composting process to achieve an efficient process of aerobic decomposition. The bulking agents that were used in this study were wood shavings, dry leaves, and corn stalks. The aim of using these bulking agents was to adjust the initial carbon-to-nitrogen ratio to be within the recommended value of 25-35 w/w (Al-Nawaiseh et al., 2021a)

Table 4. 1 The physicochemical properties of initial composting piles

Parameters	Compost with wood shavings	Compost with dry leaves	Compost with corn stalks
TKN (%)	1.5	1.84	1.6
C/N	33	25	29
TS (%)	40	40	38
MC (%)	60	60	62
VS (%)	89	83	85
TP (%)	0.037	0.067	0.09
pH	7.8	7.9	8
C (%)	49	46	47
Temp (^{o}C)	33	32	30

The results shown in **Table 4.1**. indicate that the initial C/N ratio for the three piles is within the recommended values for stimulating degradation and immobilization of nitrogen. The initial pH for all three reactors was slightly higher than the recommended value of 6 & 7.5 for the development of microbes (Al-Nawaiseh et al., 2021a). The moisture content for all three reactors was within the recommended value of 50-60% for efficient decomposition of organic substrate.

4.2. Temperature variation in compost for different bulking agents

The temperature profiles of the waste mixture were almost similar for all three reactors, which experienced the mesophilic, thermophilic, cooling, and mature stages. All three reactors accomplished their temperature summit within the first 3 - 5 days, given their sharp decomposition of organic substances to create heat. A persistent decline with a few slight fluctuations in temperature happened from that point, with the depletion of promptly biodegradable organic substances. Since microorganisms and organic matter could be redistributed to reactivate metabolic exercises by turning composting piles, the temperature profile showed an increase again on day 14 for all three reactors. From day 24 ahead, the temperature declined to an ambient level without any further increase after turning of waste manually on day 28 (Xu et al., 2021). The temperature variation in compost for different bulking agents has been shown below in **Figure 4.1.**

When cornstalks were used as bulking agents, a slower increase in temperature was observed in the beginning as compared to wood shavings and dry leaves as bulking agents. This might be linked with the softer texture of corn stalks which resultantly reduces the porosity of the matrix for diffusivity of air, slowing down the biodegradation of organic matter as compared to wood shavings and dry leaves as bulking agents. But, since the bulking agent corn stalks contain more bioavailable substances such as hemicellulose and carbohydrates. So, from day 7 onward temperature rapidly increased exceeding the other two treatments.

4.3. pH of compost for different bulking agents

The pH values at the initial stage of the composting process were recorded between 7 and 8 for each of the three reactors. After that, the process of ammonification

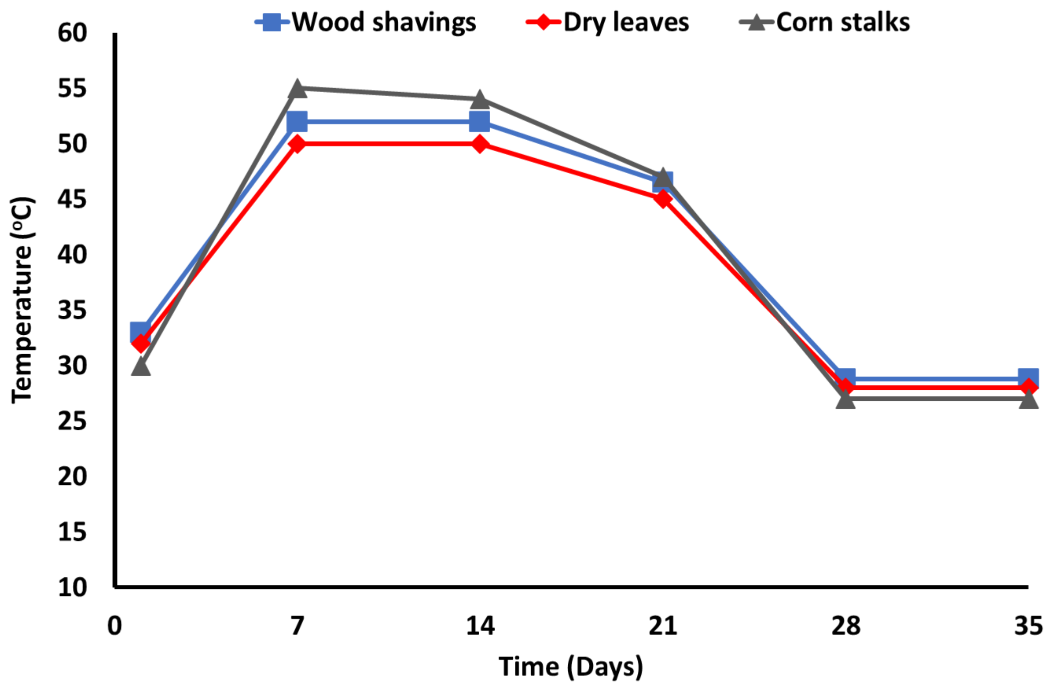

Figure 4. 1 Temperature variations in compost for different bulking agents

occurs, where the nitrogen that is organic in nature is transformed into amide and ammoniacal nitrogen, characteristic of its alkaline reaction in the development of NH_3, which likewise causes an increase in the pH in the medium. The final pH of the compost in the reactor with corn stalks as a bulking agent was 9.5, basic, as compared to bulking agents- wood shavings and dry leaves, which had pH values somewhere in the range of 8.5 and 9. This alkaline characteristic in all three reactors might be attributed to least formation of leachate and volatilization of ammonia (Guidoni et al., 2018). The final pH value for all the three reactors was above 8.0 . This higher pH value has an advantage for its in agriculture land with acidic soil. The final pH for all the three treatments is shown in **Figure 4.2.**

4.4. Volatile solids in compost for different bulking agents

Initially volatile solids may be high as organic matter starts to break down. The graphical representation of changes in volatile solids throughout the composting process is shown below in **Figure 4.3.**

As you can see in the graph below, the volatile solids are very high in the beginning of composting process. As the organic matter starts to breakdown, the volatile solids

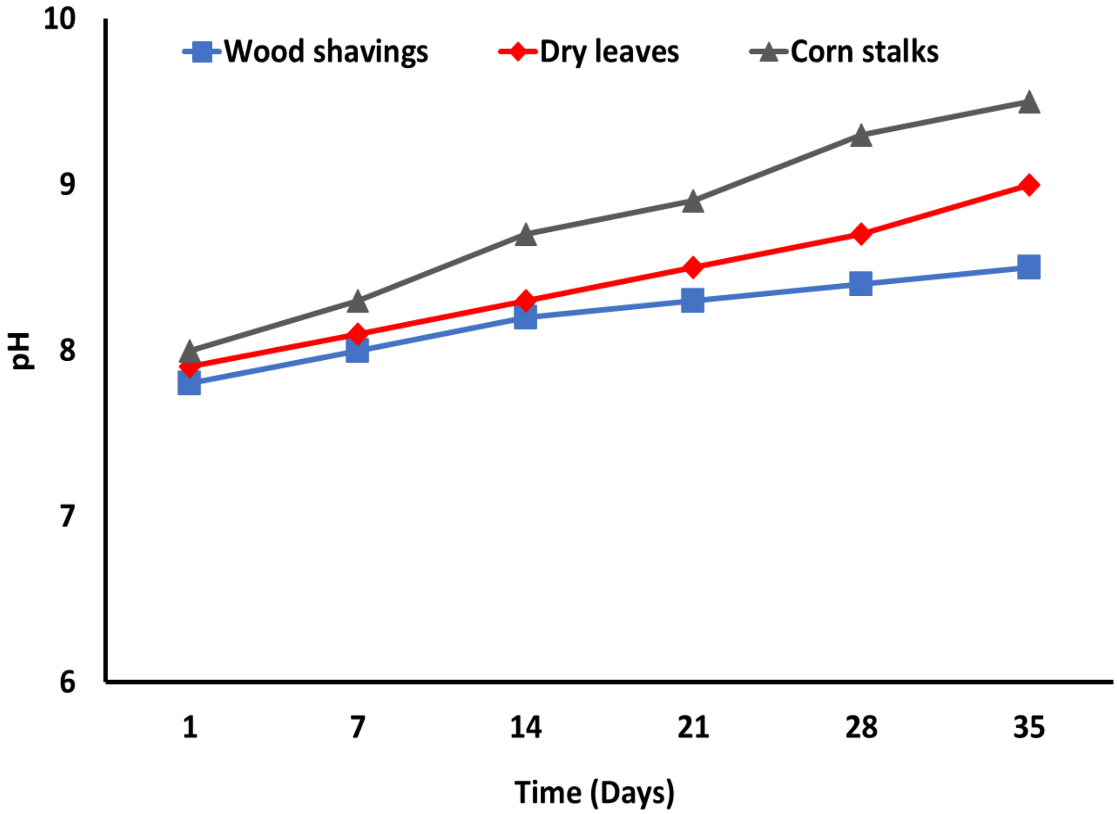

Figure 4. 2 Variation in pH of compost for different bulking agents

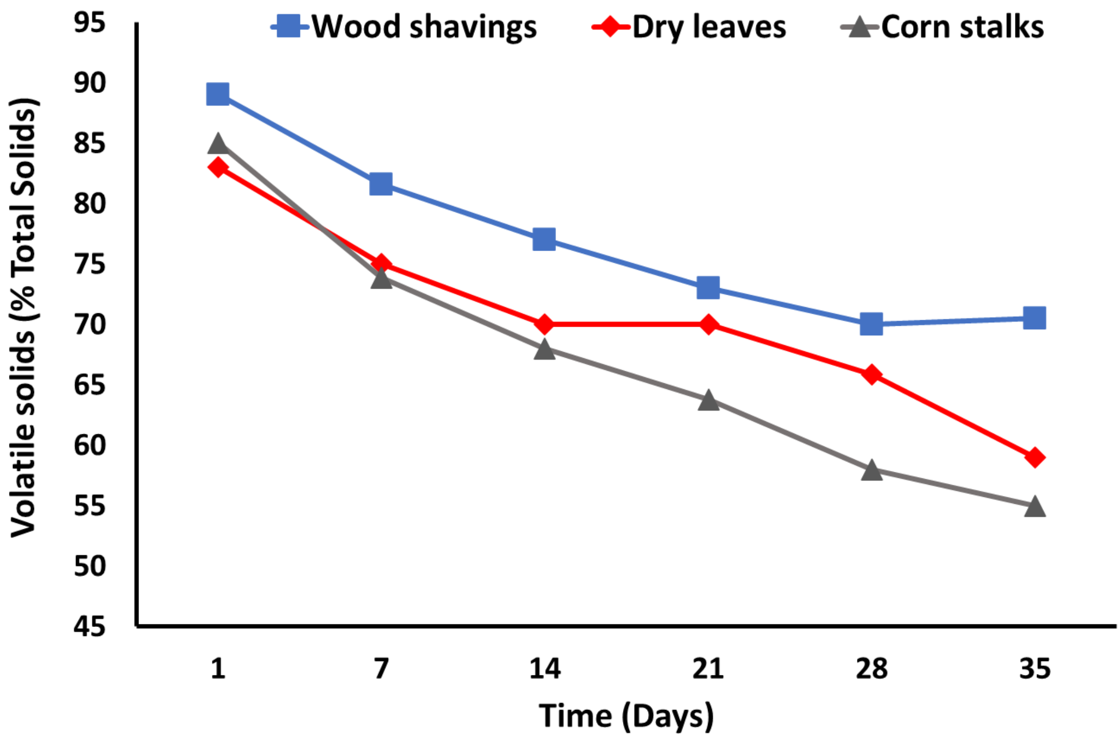

Figure 4. 3 Variation in volatile solids of compost for different bulking agents

show a significant reduction at the end of composting process (Al-Nawaiseh et al., 2021). This indicates that organic matter has undergone decomposition and stabilization. The volatile solids in the case of compost with wood shavings show low reduction as compared to the compost with dry leaves and corn stalks. The reason behind this is that wood shavings have high cellulose and lignin content which take greater time for degradation.

4.5. Total organic carbon in compost for different bulking agents

The variation in the total organic carbon in all three reactors is presented in the form of graphs. The TOC (Total organic carbon) for all three reactors at the initial stage of the composting process was in the range of 45-49%. Though there were variations in the trend of certain composting mixtures, it was also observed that the TOC content in all composting mixtures decreased during the composting period, with the thermophilic phase experiencing the highest reductions. This general decrease in TOC during the composting period might be attributed to the biodegradation of organic matter which is related to the rise in temperature and total loss of TOC which was in the form of carbon dioxide when the micro organisms utilize this carbon for energy (Ameen & Dohuki, 2022). In comparison to the other two reactors with dry leaves and corn stalks as bulking agents, delay in organic carbon reduction was observed in a reactor with wood shavings as a bulking agent. This delay in TOC reduction in a reactor with wood shavings as BA might be attributed to their initial C/N ratio (33), which is slightly more than the optimum range in comparison to other mixtures. The total carbon variations in compost for different bulking agents are shown below in **Figure 4.4.**

4.6. Moisture content (MC) and total solids in compost for different bulking agents

Moisture content and total solids are interrelated to each other. When the percentage concentration of moisture content is high, then the percentage concentration of total solids is low and when total solids are high then the moisture content is low, and vice versa. At the start of the composting process, the moisture content was high until the 4th week, and total solids were low in all three reactors. After the 4th week, MC was reduced and total solids were increased. The organic materials in the composting pile often absorb water at the start of the process which results in

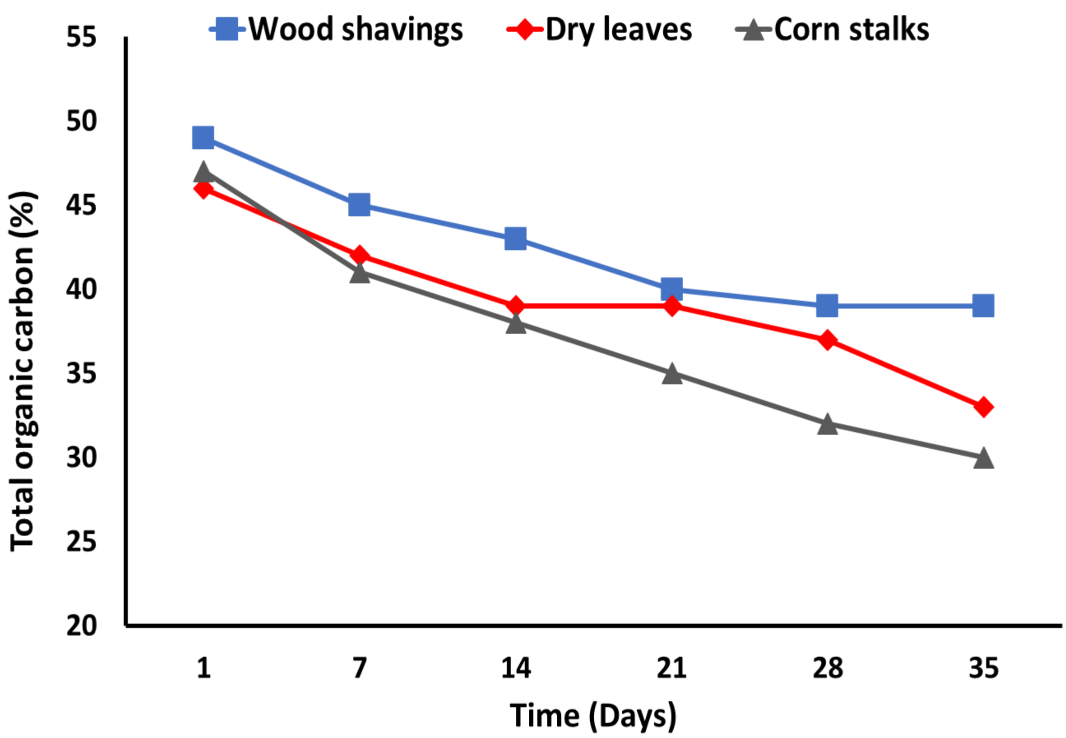

Figure 4. 4 Variation in total carbon in compost for different bulking agents

decreased total solids at the beginning of the composting process. This absorption could lead to an initial increase in moisture content and a reduction in the concentration of total solids temporarily. On the other hand, the microorganisms that are responsible for breakdown consume organic matter as a nutrient and an energy source. This microbial breakdown results in the decomposition of complex organic substances into simpler forms, such as water, carbon dioxide, and microbial biomass. This organic matter conversion into more simpler forms resultantly decreases the total solids.

Moisture content defines the composting fate and the content of nutrients of present in the compost. When moisture content is high it causes the leaching of nutrients and also does not allow the rise of temperature in the compost piles. At the start of the composting process, MC should be in the range of 50–65% from stoping the loss of nutrients from leaching (Zahra et al., 2023). Moisture content at the initial stage of composting was within the recommended range of 50-65 % in all three reactors. But during weeks 3 and 4 moisture content increased in all the reactors. The reason behind this increase was that the experiment was conducted in the months of July and August and there was a lot of humidity in the lab which increased moisture content. But after week 4 the compost from all three reactors was taken out and put in the sunlight to adjust the moisture content and achieve the level of optimal range. The MC of the final compost for compost with wood shavings, for compost with dry leaves, and for compost with corn stalks as bulking agents is shown below in **Figure 4.5 and Figure 4.6**

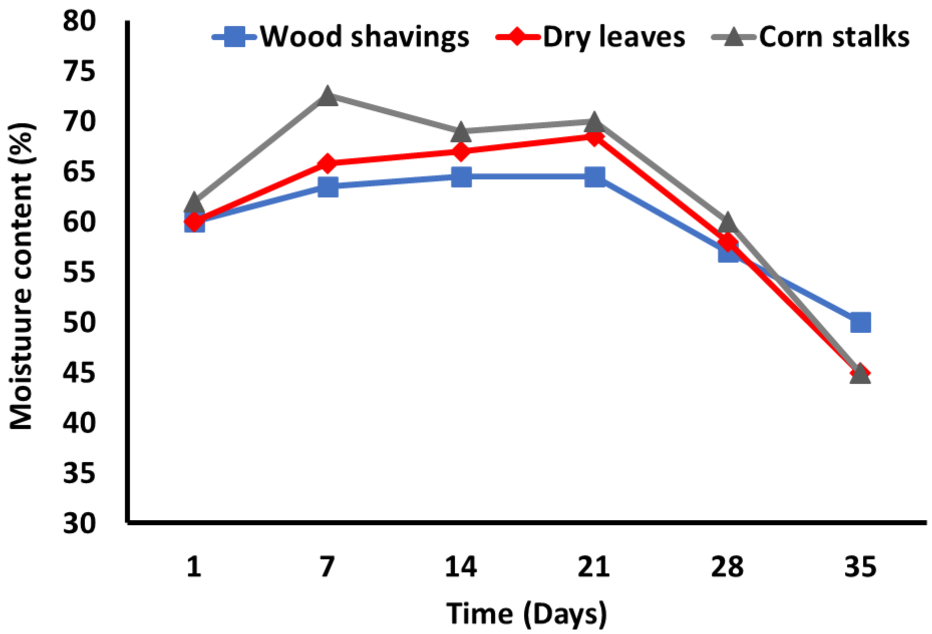

Figure 4. 5 Variation in moisture content in compost for different bulking agents

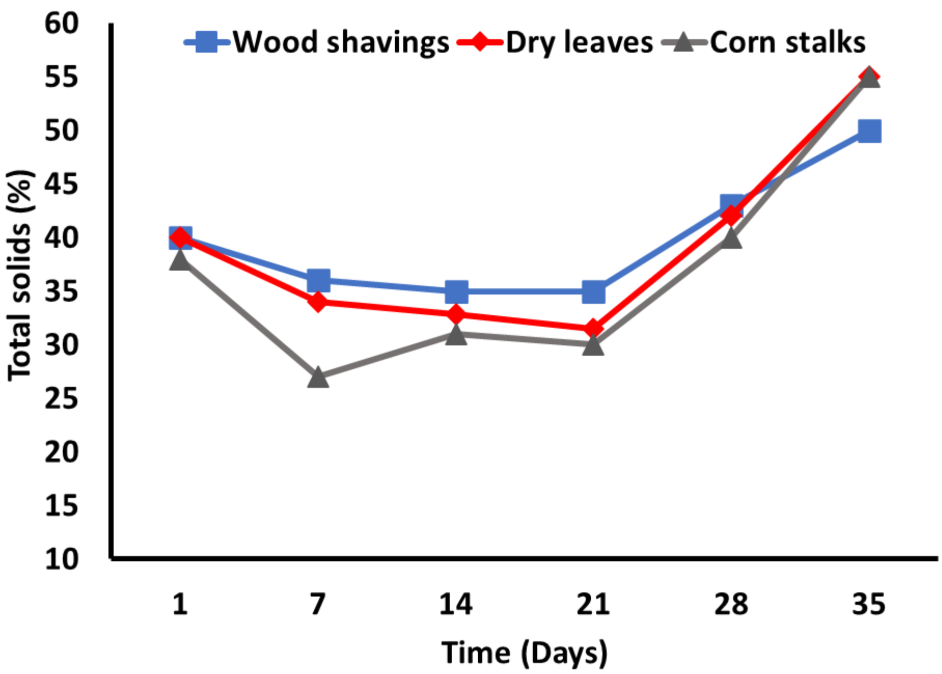

Figure 4. 6 Variation in total solids in compost for different bulking agents

4.7. Evaluation of maturity of compost

4.7.1. C/N ratio of compost for different bulking agents

The C/N (Carbon to Nitrogen) ratio is considered one of the most important parameters and indicators for the assessment of the composting process. The reduction in the C/N ratio defines the efficiency of the composting process, reflecting the immediate utilization of nitrogenous and carbonaceous organic substrate (Song et al., 2021). Adjusting the ratio of waste to bulking agent is necessary to assess the carbon and nitrogen content of the compost. When the C/N ratio is high, it increases the maturation phase, and when it is lower it results in rapid loss of nitrogen through runoff and volatilization. The optimum C/N ratio for the final and stable compost is 14–18, indicating a gradual nitrogen mineralization when being applied to the soil (Zahra et al., 2023).

The ratio of waste and bulking agents was adjusted to assess the carbon-to-nitrogen content of the compost before starting the composting process. The C/N ratio in this study was within the value of 25-35 w/w to start an effective composting process as recommended by studies conducted in the past. The C/N ratio for compost with wood shavings at the start of composting was 33, for compost with dry leaves was 25, and for compost with corn stalks was 29. The final C/N ratio for all three reactors was less than and equal to 20, which is considered an ideal value and indicator of stable and final compost (Song et al., 2021). The graphical

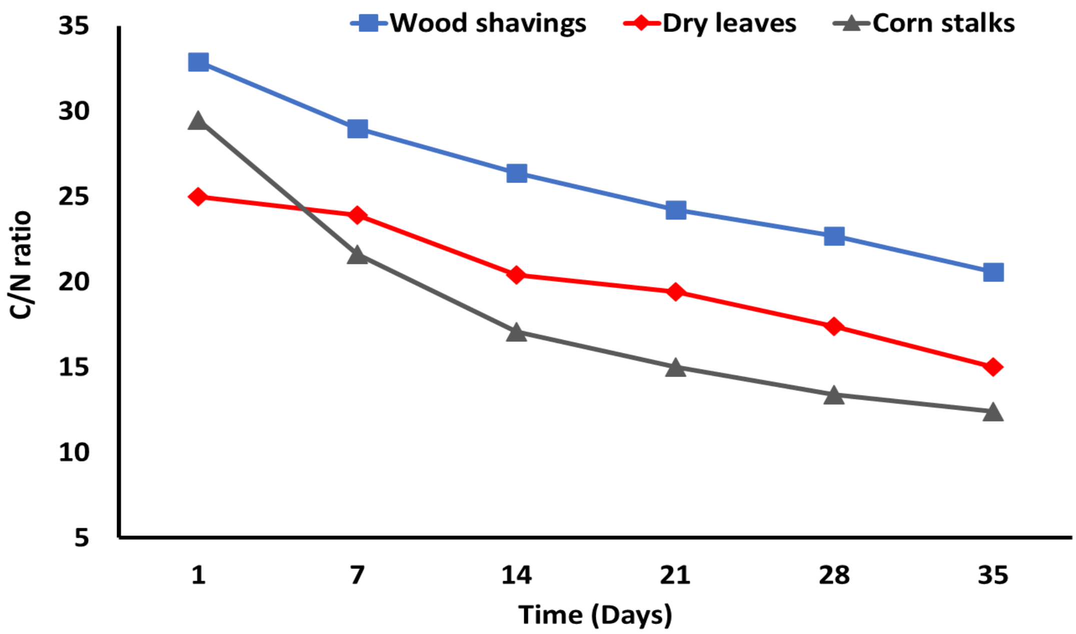

Figure 4. 7 Variation in C/N ratio of compost for different bulking agents

rrepresentation of the C/N ratio of compost with three bulking agents in three different reactors is given below in **Figure 4.7.**

4.8. Total Kjeldahl nitrogen (TKN) of compost for different bulking agents

Total nitrogen showed an initial rise in all reactors during the initial four weeks and continued to increase til week 6. As per past studies, the elevation in total nitrogen levels may be due to the dry mass loss from emissions associated with CO_2, water loss through evaporation, and the activity of nitrogen-fixing bacteria (Hashim et al., 2022). Other studies also indicate that the increase in the TKN values throughout the composting process might be due to the concentration effect resulting from the degradation of organic matter, which results in weight loss. Additionally, the nitrogen-fixing bacteria's involvement could also contribute to a rise in the concentration of nitrogen (Ameen & Dohuki, 2022).

The graph presented below in **Figure 4.8** shows the weekly increase in the overall nitrogen content, attaining its peak at week 6 in all three reactors. Maximum concentrations of the TKN values were observed in the last week of composting, indicating a potential contribution of the nitrogen-fixing bacteria during the advanced stages of the composting process. It was also observed that compost with dry leaves and corn stalks as bulking agents have higher TKN values throughout the composting process than the compost with wood shavings. The reason behind this is that wood shavings have a higher amount of lignin and cellulose content which degrade comparatively slowly than the other 2 bulking agents that were used in this study (Ameen & Dohuki, 2022).

4.9. Total phosphorus in compost for different bulking agents

The collective phosphorus concentration in the compost pile experiences a gradual increase week by week. As shown in the graphs given below, the total phosphorus content in each of the three reactors—compost with wood shavings (WS), compost with dry leaves (DL), and compost with corn stalks (CS)—gradually increases throughout the composting process. The highest concentration was observed in the final week, as compared to the lowest levels were observed in the initial phases. The Concentrations of phosphorus fluctuate between 0.03% and 0.24%.

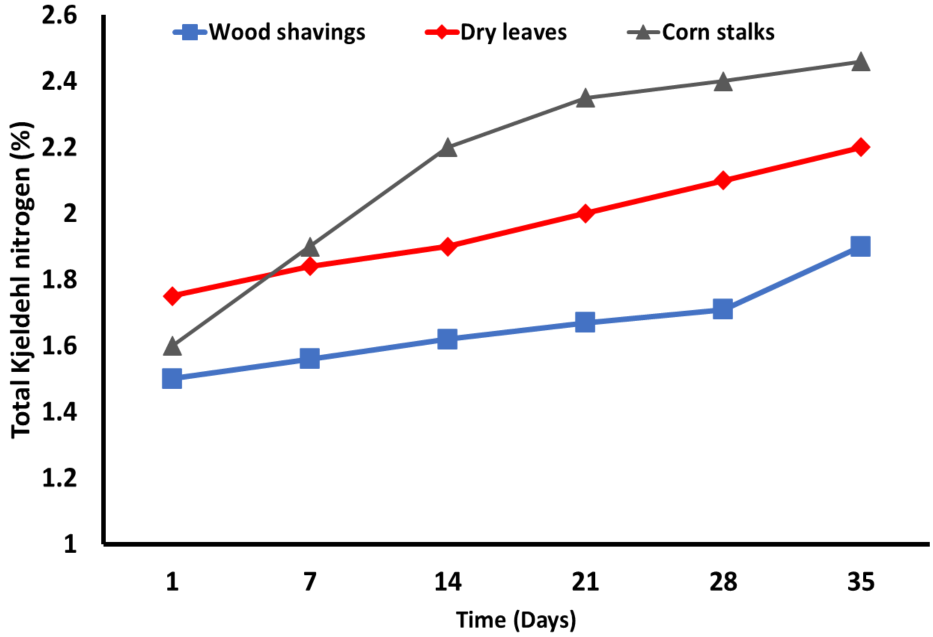

Figure 4. 8 Variation in Total Kjeldahl nitrogen in compost for different bulking agents

The variation in total phosphorus present in compost for different bulking agents over the period of six weeks is shown below in **Figure 4.9.**

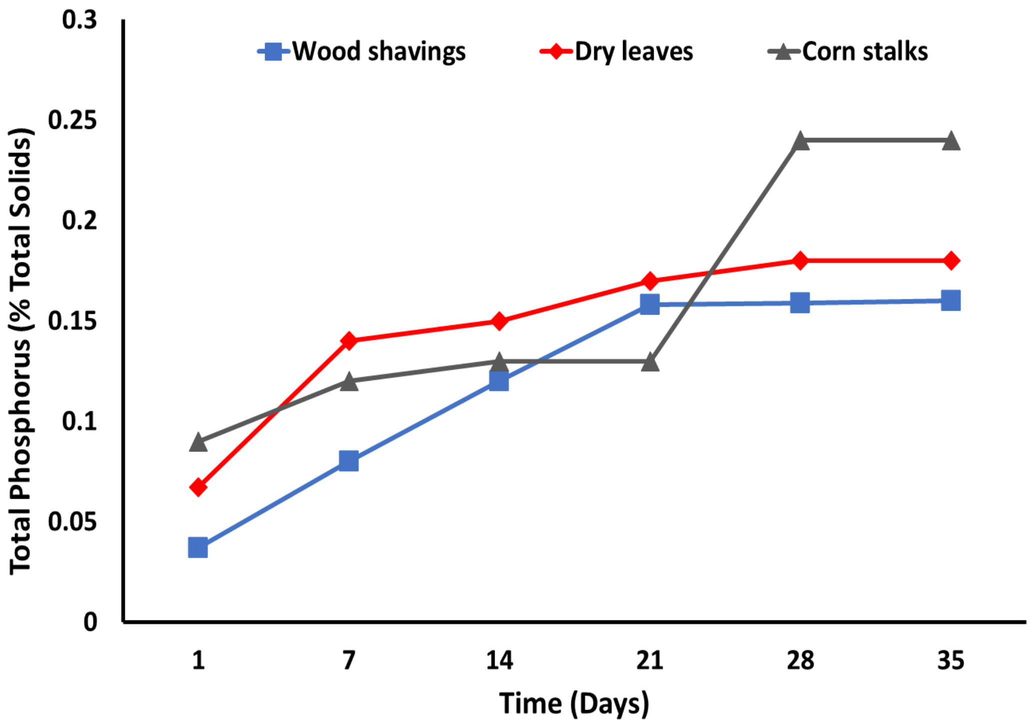

Figure 4. 9 Variation in total phosphorus in compost for different bulking agents

The elevation in total phosphorus content during composting may be attributed to a concentration effect induced by the accelerated rate of carbon loss associated with the decomposition of organic materials (Hashim et al., 2022). Other studies also suggested that the rise in the concentration of phosphorus is linked to the reduction in compost volume and the concurrent increase in pile bulk density (Al-Nawaiseh et al., 2021b).

4.10. Compost management from GHG emissions perspective

The second objective of this study was to mitigate the GHG emissions that are linked with MSW (municipal solid waste) by converting organic part of the municipal waste into a mature and stable compost. GHG emission potential of compost was calculated at different stages of compost formation using different bulking agents. A comparison was made, of the different compost formation options such as compost with wood shaving, dry leaves, and cornstalks as bulking agents with regards to GHG emission was then made possible. The results regarding this have been presented and discussed in this section.

4.10.1. Methane emission potential of compost mixture for different bulking agents

The GHG emissions potential of final and mature compost was estimated by using the equation that is given in section 3.4.1.1. and compared with the organic fraction of municipal solid waste before starting the composting process (Gunamantha & Sarto., 2012). When we compare the GHG emissions potential of mature compost that is 901 CH_4 gCO_2 eq in case of compost with wood shavings 791 CH_4 gCO_2 eq in case of compost with dry leaves and 690 CH_4 gCO_2 eq in case of compost with corn stalks with that of OFMSW before starting the composting process, it was very high, that is 3045 CH_4 gCO_2 eq in case OFMSW with wood shavings 2840 CH_4 g CO_2 eq in case of OFMSW with dry leaves and 2763 CH_4 gCO_2 eq in case of OFMSW with corn stalks. Thus, with composting under aerobic conditions by using different bulking agents, the GHG emission potential of OFMSW decreases by about 70% in the case of compost with wood shavings, 72% in the case of compost with dry leaves, and 75 % in the case of compost with corn stalks. GHG emissions potential of OFMSW at the initial stage of compost VS matured compost in the case of Methane (CH_4) is shown below in **Figure 4.10.**

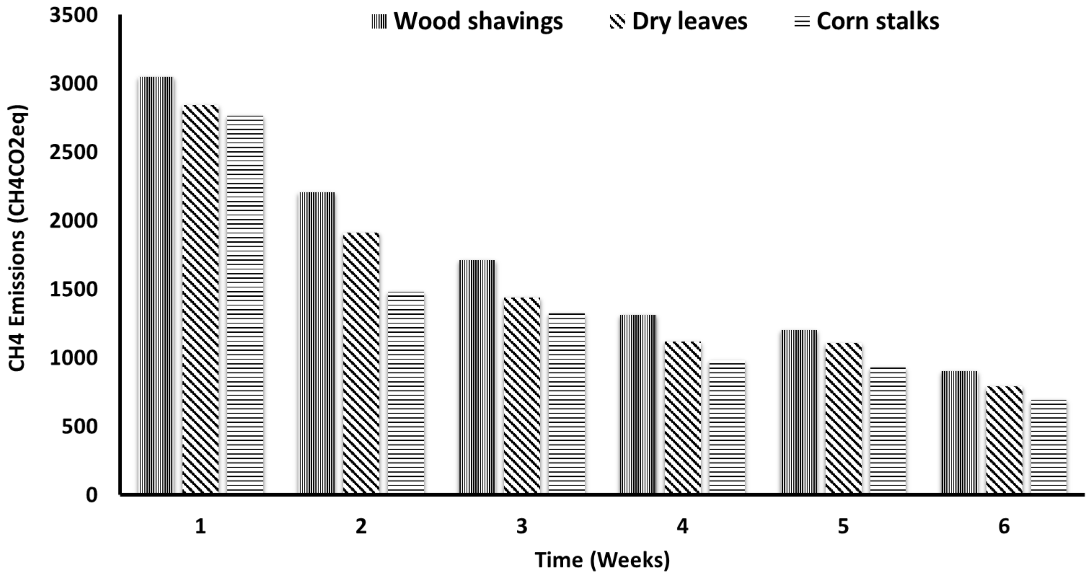

Figure 4. 10 Methane emission potential of compost mixture for different bulking agents

4.10.2. Nitrous oxide emission potential of compost mixture for different bulking agents

The amount of nitrous oxide that is to be emitted from three different types of compost using different bulking agents was calculated, the details of which are given in section 3.4.1.2. of chapter 3. After that these emission potentials were compared with the organic fraction of municipal solid waste before starting the composting process. When we compare the N_2O emission potentials of mature compost, they were 33, 41 and 46 gCO_2 eq/kg compost for wood shavings, dry leaves, and corn stalks respectively with that of OFMSW before starting the composting process, they were very high, 70, 86, 70 gCO_2 eq/kg compost for OFMSW with wood shavings, dry leaves and corn stalks respectively. Thus, with composting under aerobic conditions by using different bulking agents, the N_2O emissions were reduced by about 53%, 52 %, 34 % for wood shavings, dry leaves, and corn stalks respectively (Zeshan & Visvanathan, 2014). GHG emissions potential of OFMSW at the initial stage of compost VS matured compost in the case of N_2O is shown below in **Figure 4.11.**

4.10.3. Cumulative GHG emission potential of compost mixture for different bulking agents

The cumulative GHG emissions at different stages of compost formation were calculated. If we look at the cumulative GHG potential of compost in **Table 4.2**, it is observed that in GHG Emissions potential of OFMSW decreases by 70% in the case of composting with wood shavings, 71% in case of dry leaves and 74% in case of cornstalks (Møller et al., 2009).

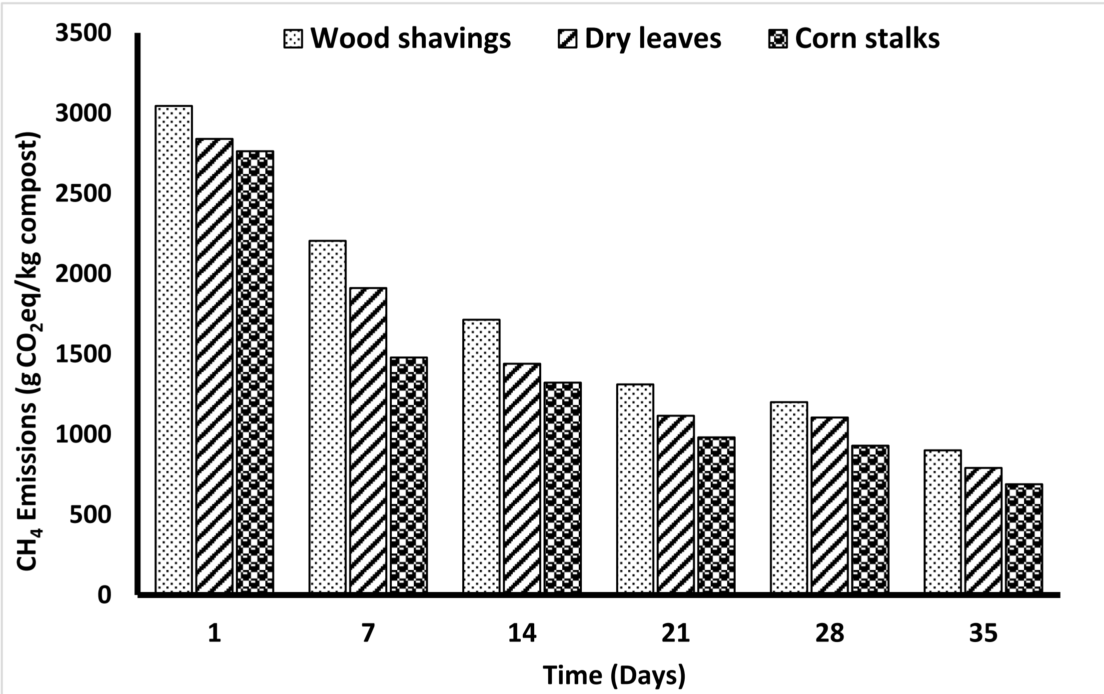

Figure 4. 11 Nitrous oxide emission potential of compost mixture for different bulking agents

Table 4. 2 Loss of GHG emission potential of compost mixture over time

Days	Wood shavings	Dry leaves	Corn stalks
	(gCO_2eq/kg compost)		
1	3114.7	2926	2833
7	2261	1971	1530
14	1762	1491	1380
21	1351	1163	1034

28	1240	1149	979
35	934	832	736

4.10.4. Emissions avoided by land application of compost (Nitrogen & Phosphorus)

The second part of second objective was how GHG will be avoided by land application of compost. That means by applying compost to soil we can avoid the GHG emissions of fossil carbon by energy use for production of chemical fertilizer. In this study the N and P act as nutrients provided by the land applied compost is the most important factor, which replaces the use of chemical fertilizer and hence the GHG from fertilizer manufacturing is avoided (Brown et al., 2010). The **Figures 4.12 & 4.13** presented below shows the GHG emissions avoided by land application of compost.

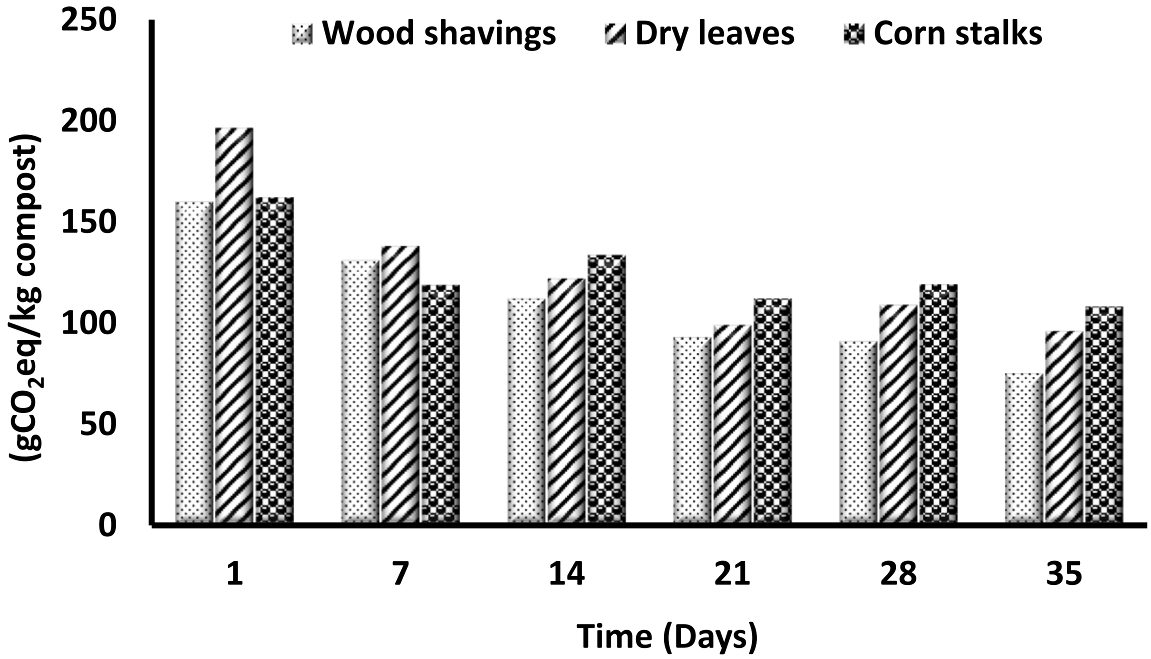

Figure 4. 12 Emissions avoided by land application of compost (Nitrogen)

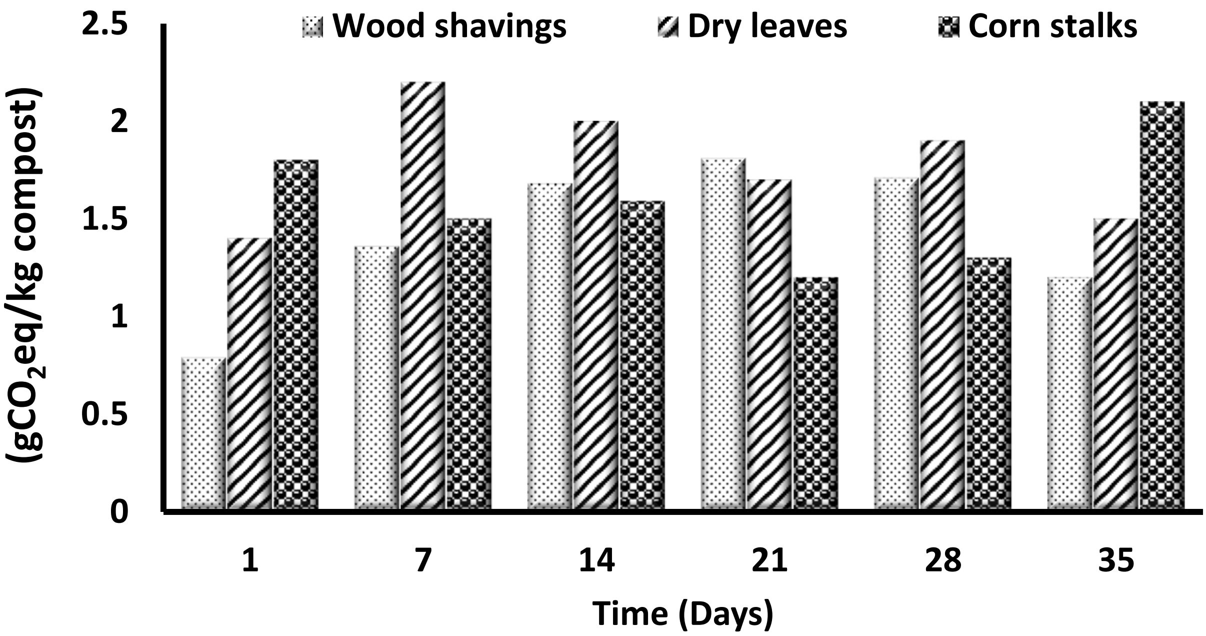

Figure 4. 13 Emissions avoided by land application of compost (Phosphorus)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of the research findings together with specific recommendations. The objective is to offer useful advice for enhancing composting procedures and raising the general efficacy of waste management systems

5.1. Conclusions

The C/N ratio results indicate that composting organic fraction of municipal solid waste with three bulking agents has produced mature and stable compost. Results of GHG emissions from compost show that raw waste has the maximum GHG potential and should not be dumped and landfilled as its dumping contributes the most `to GHG emissions. Results also indicate that the results were almost similar for all the three bulking agents. The C/N ratio was 20, 15, and 12.4 for compost with wood shavings, dry leaves, and corn stalks respectively, which shows that dry leaves and corn stalks formed more stable compost than wood shavings as bulking agents. As far as GHG potential is concerned, all three bulking agents showed maximum reduction as compared to raw waste that had maximum Greenhous potential. Composting waste has the potential to significantly reduce GHG emissions, with reductions of 70%, 71%, and 74% observed for wood shavings, dry leaves, and corn stalks, respectively. So, all the three bulking agents proved beneficial for composting,

5.2. Recommendations

The organic fraction of municipal solid waste has the maximum GHG emission potential and should not be dumped or landfilled as its dumping contributes the most to GHG emissions. The co-composting of waste with sludge and manure could be investigated for future studies. The effect of macronutrients other than (nitrogen, and phosphorus) and micronutrients should also be investigated for future studies.

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