The University of Tehran Press

Pollution

https://jpoll.ut.ac.ir/

Print ISSN: 2383-451X
Online ISSN: 2383-4501

Exploring Sustainable Waste Solutions: Evaluating Mixing Ratios in Agitated Pile Composting with Sugarcane Agro-Industrial Waste

Suraj Asava[1] | Dayanand Sharma[2]✉ | Chandrashekhar Parab[1] | Anudeep Nema[3] | Ousmane Lass Donzo[2] | Amit Kumar[2] | Kunwar D Yadav[1]

1. Department of Civil Engineering, SV National Institute of Technology, Surat, Gujarat, India 395007.
2. Civil Engineering Department, Sharda University, Greater Noida, U.P., India 201310.
3. Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India 462021.

Article Info

Article type:
Research Article

Article history:
Received: 15 May 2024
Revised: 1 September 2024
Accepted: 09 January 2025

Keywords:
In-vessel
Windrow
Agriculture waste
Bagasse
Food waste

ABSTRACT

This study focused deeply on sustainable solid waste management practices, specifically focusing on the co-composting of various organic materials such as sugarcane leaves/ trash, sugarcane bagasse, food waste, cow dung, and press mud (generated from the sugarcane industry). Five trapezoidal shape agitated piles (heap) were prepared with various combinations (Trials 1 to 5). This study investigates the dynamic changes in critical parameters while composting and their implications for compost quality and maturity. The results showed that the percentage increase in total nitrogen (1.76-2.24%, 1.93-2.23%), phosphorus (1.35-3.52%, 1.18-2.62%), and potassium content (4.5-8.7%, 4.7-8.9%) in trial 3 and 5, which underscore their roles in enhancing soil fertility and crop productivity. The decline in carbon-to-nitrogen ratios in trial 3 (45.5-26.3) and trial 5 (46.6-24.3) correlates with the growth of lignocellulose-degrading bacteria, facilitating humic substance formation critical for compost stability. Lignocellulosic degradation, evidenced by cellulose, hemicellulose, and lignin content changes, further emphasises its importance in compost maturation. Additionally, reductions in CO2 evolution rate (20.9-3.8%, 22.1-3.9%) and volatile solids (81.9-43.8%, 83.8-43.8%) content in trials 3 and 5, reflect microbial activity and compost stabilisation. Trial 3 and 5 were the suitable combinations for the sugarcane agro-industrial waste composting. These findings highlight that effective waste management enhances agricultural productivity and reduces environmental impact by improving soil health using of composted sugarcane waste.

Cite this article: Asava, S., Sharma, D., Parab, Ch., Nema, A., Lass Donzo, O., Kumar, A., & Yadav, K. D. (2025). Exploring Sustainable Waste Solutions: Evaluating Mixing Ratios in Agitated Pile Composting with Sugarcane Agro-Industrial Waste. *Pollution*, 11(1), 117-133.
https://doi.org/10.22059/poll.2024.376557.2373

Publisher: The University of Tehran Press.
DOI: https://doi.org/10.22059/poll.2024.376557.2373

INTRODUCTION

The relentless growth in population has led to a surging demand for sugars, resulting in an impressive annual production of 181 million tonnes of sugarcane (Byakodi & Babu, 2022). The sugarcane industry produces significant volumes of solid waste, including ash and filter cake. Nowadays, approximately 30 kg of cake filter is generated per tonne of processed sugarcane (Sharma et al., 2022). During the 2014/15 harvest season in Brazil, which saw the processing of 634.77 million tonnes of sugarcane, roughly 19.04 million tonnes of filter cake were produced (Zainudin et al., 2022). Improper disposal of this organic waste can lead to environmental pollution and potential public health risks. Hence, composting emerges as a crucial waste management approach within the sugarcane industry. When administered to soil, the resultant compost bolsters its physical attributes, augmenting both its permeability and ability to retain

---

*Corresponding Author Email: *dayanandsvnit@gmail.com*

moisture. Moreover, it alters the soil's chemical and microbial composition, imbuing it with humic compounds alongside essential macro- and micronutrients.

The global cattle industry, boasting a staggering population of nearly 1.5 billion bovines (Mukesh et al., 2022), significantly exacerbates the waste dilemma. The ever-growing demand for bovine-derived products, particularly milk, has led to a notable surge in cow dung production. Cow dung, a substantial contributor to greenhouse gas emissions, releases significant amounts of methane and carbon dioxide into the atmosphere (Johnson & Johnson, 1995). As a result, the environmental impact of the cattle industry extends beyond its primary functions, affecting climate change and air quality. Efforts to mitigate these effects through innovative waste management strategies are imperative to reduce the industry's environmental foot print and promote sustainable practices in livestock farming.

Some researchers have studied composting and co-composting of sugarcane waste using various combinations and methods. The study by (Ansari et al. 2021) states that chemically pretreated bagasse significantly reduced its lignocellulosic content and transformed into a humic substance and have higher percentages of germination index. The waste crushed using a trash mulcher and spray of TNAU Biominerlizer had a positive influence on soil fertility and yield of cane (Dhanushkodi et al., 2019). Lignocellulolytic bacteria consortia have enormous potential for development as a novel type of decomposing for sugarcane waste processing (Rahayu et al., 2022). Soto-Paz et al. (2021), finds that processing time directly impacts product quality by the shortest processing time by varying the mixing ratio and turning frequency. But here it's difficult for the farmer to go through pretreatments due to a lack of technological awareness, poor purchasing power, etc. (Dhanushkodi et al., 2019; Powar et al., 2022). Therefore, a simple methodology is required to be investigated which can handle sugarcane waste effectively.

Composting which required less sophisticated equipment is a biodegradation method that has potential to convert sugarcane waste into a nutrient rich compost. Utilizing compost has been recognized as an effective method to enhance the physical, chemical, and biological attributes of soil. Oazana et al, (2020) and Calcino et al., (2010) observed that Bedminster compost led to increased sugarcane yield and elevated levels of soil nutrients such as calcium (Ca), copper (Cu), potassium (K), magnesium (Mg), and nitrogen (N). Stoffella and Graetz (2000) similarly noted that compost containing sugarcane filter cake, a by-product of sugarcane juice filtration, enhanced soil humic content and enriched it with macro- and micronutrients like nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca) (Stoffella & Graetz, 2000). Moreover, Hernández et al., (2016) proposed that applying compost incorporating cow manure could boost both crop yield and soil fertility. The process of composting is an aerobic biological one wherein complex biological waste substances undergo degradation by bacterial action into stable compounds such as nitrates, phosphates, cellulose, and proteases (Poornima et al., 2024). These compounds are highly nutritious for soil and conducive to agricultural productivity (Lim et al., 2016). As a natural and eco-friendly process, composting does not generate harmful effluents or air pollutants (Oazana et al., 2020) rendering it a sustainable and cost-effective alternative while reducing reliance on synthetic fertilizers (Srinivasan et al., 2016). Furthermore, it does not necessitate specialized equipment or chemical additives, making it an accessible solution (Rastogi et al., 2020). Therefore, biotransformation of sugarcane waste such as bagasse and leaves into organic fertilizer by incorporating press mud, food waste and cow dung can be a effective solution for the ever-growing sugarcane waste.

The aim and novelty of this study is to experimentally evaluate the efficiency of the co-composting of sugarcane bagasse, leaves, food waste, cow dung, and press mud and address the issue of sugarcane waste management by converting sugarcane waste into nutrient-rich compost. By transforming sugarcane waste from into a valuable resource, this study seeks to promote environmental sustainability and enhance agricultural productivity in sugarcane-growing regions.

MATERIALS AND METHODS

Raw Materials

The current investigation examines the decomposition process of sugarcane leaves and bagasse waste from the sugarcane industry in conjunction with sugarcane press mud, food waste, and cow dung. Sugarcane leaves and bagasse served as the primary materials for decomposition. The experiment took place between April to July 2021 at the designated composting site at Asava farma at. Hanumantgaon, tehsil- rahata district- Ahmednagar state- Maharashtra (India). 1.5 metric tons of bagasse and press mud were gathered from Padmashree Dr. Vithalrao Vikhe Patil Sahakari Sakar Karkhana in Pravaranagar, Ahmednagar, Maharashtra, India, utilizing local transport equipment consisting of a tractor and trailer. Sugarcane leaves were sourced from a farm adjacent to the composting facility. The bagasse comprised of various sugarcane varieties, while the sugarcane leaves were of the CO-265 variety. Sugarcane trash/ leaves were mechanically shredded to achieve a particle size ranging from 1 to 5 cm using a chaff cutter and shredder. The sugarcane bagasse, being already in the appropriate size, was not subjected to further shredding.

Food waste collected from the girl's hostel of Pravara Medical Trust in Loni. Collection of this waste was facilitated utilizing drums made of plastic. Subsequently, the food waste that is fresh underwent grinding utilizing a churner at the mess to get the particle size down to 0.5–1.0 mm from 1.5–3.0 cm, thereby enhancing decomposition efficiency. Manual segregation was conducted to remove polyethylene, plastic glasses, spoons, and other undesired materials.

Fresh cow dung was procured from a nearby cow farm as per requirement. Water addition was implemented to facilitate proper mixing and maintain moisture levels, thereby augmenting degradation efficiency. This facilitated the interaction of meal leftovers, cow dung, press mud, and marital materials with the surface area of bagasse and sugarcane trash waste, thereby enhancing degradation effectiveness. Initial characteristics of raw materials are given in Table 1.

Reactor configuration and design

A trapezoidal pile structure was constructed with dimensions $L\times B\times H=1.5\,\text{m}\times 1\,\text{m}\times 1.10$

Table 1. Characteristics of raw materials used during the experiment.

Parameters ⇩	Press mud	Bagasse	Sugarcane Leaves	Cow dung Slurry	Food Waste
Moisture Content (%)	76.19±3.05	46.38±4.01	38.96±2.93	85.10±4.14	87.46±3.89
pH	6.54±0.32	7.9±0.21	6.73±0.23	8.1±0.18	5.8±0.21
EC (mS/cm)	1.25±0.22	0.472±0.11	1.50±0.11	4.5±0.21	2.13±0.20
Volatile Solids (%)	79.80±2.72	84.60±3.89	82.54±1.84	65.66±2.92	76.28±2.98
Total Organic Carbon (%)	43.60±1.54	47.00±1.26	45.85±1.12	36.48±1.36	42.37±1.76
Nitrogen (%)	1.6±0.02	0.37±0.02	0.52±0.15	1.22±0.1	1.98±0.1
Phosphorous (%)	0.96±0.3	0.035±0.01	0.07±0.01	0.9±0.1	0.25±0.2
Potassium (%)	0.42±0.2	0.12±0.1	0.57±0.2	1.14±0.2	0.54±0.23
Lignin (%)	9.3±1.72	10.4±3.68	13.56±2.38	-	-
Cellulose (%)	10.4±1.23	42.4±2.43	39.28±1.08	-	-
Hemicellulose (%)	10.0±1.12	14.5±1.89	27.62±1.46	-	-

All values are mean of triplicates±standard deviation
ST= sugarcane trash, AJ= amritjal, CD= cow dung, FW= food waste, EC= electrical conductivity

Table 2. Treatments and combination of raw materials

Treatment	Combination	Weight of raw materials
T1	Bagasse + Press Mud	150 kg + 90 kg
T2	Bagasse + Food Waste	150 kg + 90 kg
T3	Bagasse + Cow Dung	150 kg + 90 kg
T4	Sugarcane Leaves/ Trash + Press Mud	150 kg + 90 kg
T5	Sugarcane leaves/ Trash + Food Waste	150 kg + 90 kg

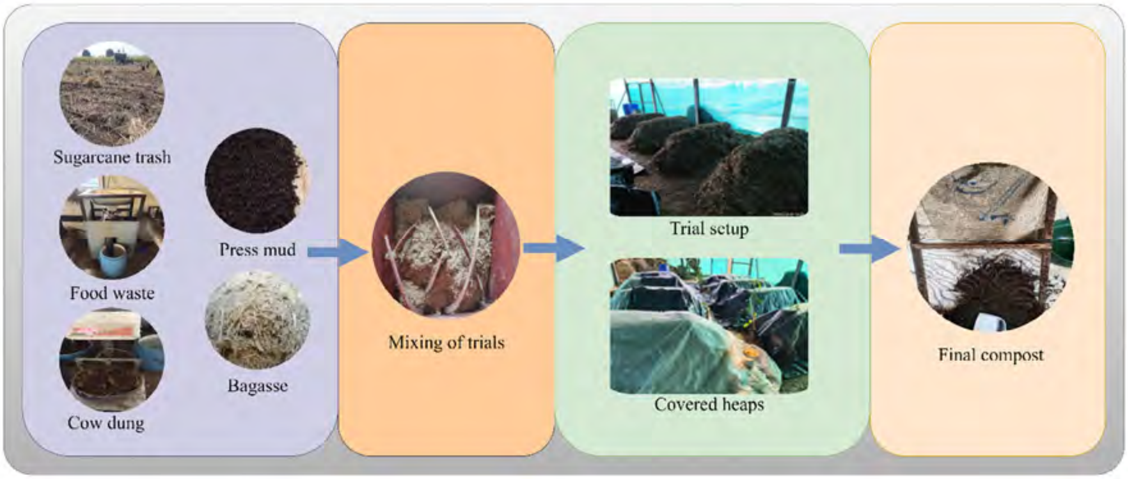

Fig. 1. Experimental setup for the present research work

m. Prior to heap formation, the ground surface was marked with the necessary dimensions. Ground markings were delineated to facilitate heap formation within specified dimensions, ensuring geometric integrity. Five heaps were constructed and named as T1 to T5. Each trial heap was filled with 150 kg of bagasse and sugarcane trash as given in Table 2. Heap formation proceeded in layers, starting with a base layer of 0.25 m, onto which 25% of the compostable waste was placed, followed by layer-by-layer heap construction. Water was administered to sustain moisture levels, with a garden sprayer utilized to prevent flooding and ensure uniform moisture distribution.

During the initial seven days, plastic sheets were employed to cover the heaps, minimizing heat loss, and inhibiting fungal and bacterial proliferation. Heap rotation every seven days commenced from the 7th day to facilitate thorough mixing and agitation. Temperature monitoring was conducted daily until reaching equilibrium with ambient temperature using a Mextech ST9283B multi-stem thermometer. Temperature readings were obtained at three locations within each heap: top, middle, and bottom, to ascertain average trial temperatures. Additional characteristics were noted at seven-day periods over the subsequent 91 days. Table 1 shows the initial characterization of raw waste and table 2 indicates the ratio of mixed waste which was used for the study. Figure 1 shows the flow chart of working methodology of the current research work.

Samples were extracted by collecting 150 grams from the top, bottom, and sides of each heap. These samples were then subjected to oven-drying at temperatures ranging from 70 ± 2 °C for a duration of 24 to 72 hours, followed by sieving via a 0.2 mm sieve. The evaluation included the determination regarding the reduction of total volatile solids, total Kjeldahl nitrogen, and CO_2 rate of evolution, Index of Germination, degradation of lignin, and other relevant specifications. Samples were either analyzed immediately following acquisition or kept in air-tight containers for future examination.

Analysis of physicochemical parameter

A hot air oven was used to dry the sample which was maintained at 70 ± 2 ºC for 24 to 72 hours to determine the moisture content. To assess pH and electrical conductivity, a 10-gram sample dried in the oven was combined with distilled water at a 1:10 w/v ratio. This mixture was then placed on a rotary shaker for two hours and left to settle for one hour before filtration through Whatman filter paper no. 42. The Kjeldahl method was employed to quantify the total nitrogen content. The determination of nitrogen in the form of ammonia utilised the potassium chloride extraction technique in conjunction with the phenate method. To calculate total volatile solids, a 20-gram sample undergoing oven drying was introduced into a muffle furnace set at 550 ± 5 ºC for 2 hours. To determine the aggregate quantity of carbon derived from organic compounds, the total volatile solids were divided by a factor of 1.83 (Adhikari et al., 2009). The soda lime method was adopted to calculate the CO_2 evolution rate. (Sarika et al., 2014). The stannous chloride method was employed to quantify phosphorus content, involving the digestion of a 0.2 g sample with a mixture of $H2SO_4$ and $HClO_4$ at a 5:1 ratio for 2 hours at 300 °C. To determine the potassium content, a flame emission spectrophotometer was utilised (Jain et al., 2019). To compute the germination index, a sample weighing 50 grams was combined with 100 ml of distilled water and agitated for 6 hours. Subsequently, centrifugation was conducted at 8000 rpm for 20 minutes. The resulting mixture was then placed into a petri dish, and following an incubation period of 72 hours at 25ºC, ten radish seeds were sown. The germination index was calculated using the equation (1).

$$\text{Germination index} = \left\{\left(\frac{\text{Number of seeds germinated in compost}}{\text{Number of seeds germinated in control}}\right) \times \left(\frac{\text{Average root length of germinated seeds from compost}}{\text{Average root length of germinated seeds from control}}\right)\right\} \times 100 \quad (1)$$

To ascertain the lignin concentration, a powdered sample weighing 3 grams underwent digestion utilising 72% H_2SO_4. The resulting extract was later filtered, and its absorbance at 205 nm was gauged, facilitating the evaluation of acid-soluble lignin content. Subsequently, the sample was filtered again, and the filtrate was dried at 105 °C, which aligned with the National Renewable Energy Laboratory procedure. The acetic/nitric reagent extraction method was employed to assess cellulose content. (Updegraff, 1969), and to determine hemicellulose content, the method involved utilising the variance between natural detergent fibre (NDF) and acid detergent fibre (ADF) was adopted as per Goering and Van Soest (Goering & Van Soest, 1970).

Statistical Analysis

Significance of divergence among all physicochemical and biological parameters, was calculated using one-way Analysis of Variance (ANOVA) at level of significance less than 0.05 ($p < 0.05$). For the computation of variance, SPSS 13.0 software was utilized.

RESULT AND DISCUSSION

Temperature, moisture content (MC), pH, and electrical conductivity (EC) variations

In the composting process of sugarcane leaves and bagasse, temperature variations occur as a result of microbial activity. Initially, temperatures rise as microorganisms metabolize readily available sugars and organic matter, generating heat. This phase, known as the thermophilic phase, sees temperatures peaking between 50-58°C (refer figure 2A), ideal for the decomposition of intricate organic compound. Subsequently, as the readily available organic

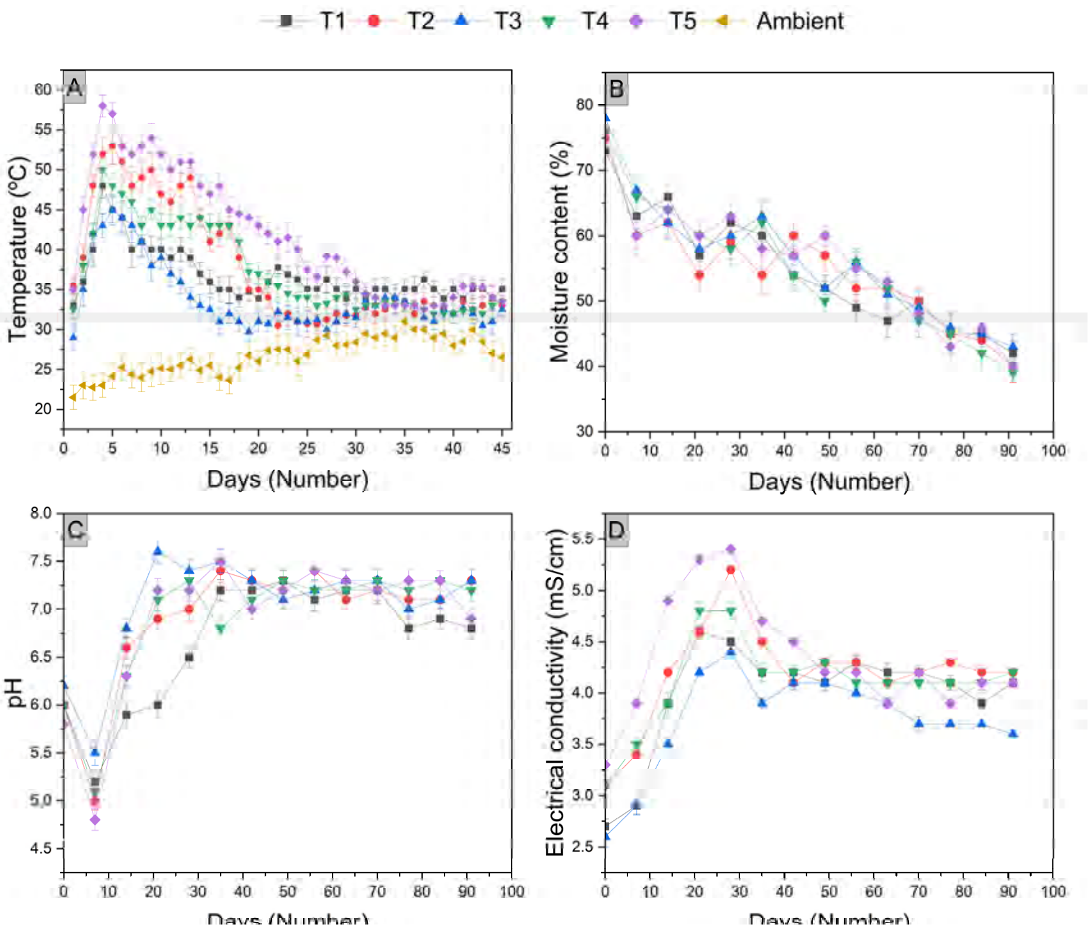

Fig. 2. Temporal variation of temperature (A), moisture content (B), pH (C), and electrical conductivity (D) over 91 days of composting.

matter is consumed, temperatures gradually decline during the maturation phase. Throughout composting, monitoring and managing temperature fluctuations are essential for ensuring peak /optimal conditions for microbial action and efficient decomposition of sugarcane residues into nutrient-rich compost.

Moisture content (MC) influences the composting process, affecting temperature, carbon-to-nitrogen ratio, and nutrient dynamics. It is essential for maintaining the thermophilic stage and achieving pathogen-free end products (Ghanney et al., 2021). During this study, MC of T1, T2, T3, T4 and T5 was maintained initially at 73.1±3%, 75.2±2%, 78.03±1.5%, 76.2±3.5%, and 76.12±3.5% respectively. As composting progressed, the MC of all compost treatments was reduced and the variation between the treatments was not significant ($p > 0.05$) (Table S1). After 91 days, MC of T1, T2, T3, T4 and T5 was 42.21±2%, 40.1±2.5%, 43.2±2%, 39.1±1.3% and 40.15±1.3% respectively (Figure 2B). The reduction of moisture content was due to evaporation during aeration and utilisation by microbes to carry out their metabolic processes.

pH is one of the key elements that greatly influences the composting process. For the growth of bacteria, the pH range of 6.0 to 7.5 was ideal, while the pH range of 5.5 to 8.0 was ideal for the growth of fungi (Ho et al., 2022). Initially, the pH was acidic, but it became alkaline as the degradation progressed (Raza et al., 2017). Low pH during early composting phases is responsible for ammonia emission (Li & Li, 2015). Initial pH of T1, T2, T3, T4 and T5 was 6±0.12, 6.1±0.1, 6.2±0.1, 6±0.1, and 5.8±0.1 respectively. pH was dropped in all Interventions implemented on the 7th day of composting (Figure 2C) with T2 showed lowest pH of 4.8±0.11. The pH drop during the later stages of composting might have been caused by the volatilization of ammoniacal nitrogen and the release of H^+ ions as a result of the microbial nitrification process by nitrifying bacteria (Cáceres et al., 2018). After 91 days, pH of T1, T2, T3, T4 and T5 was 6.8±0.1, 7.3±0.11, 7.3±0.12, 7.2±0.11, and 6.9±0.1 respectively.

Electrical conductivity (EC) measures the concentration of soluble salts in compost, which can affect soil fertility and plant growth. High EC in compost can harm plants due to the accumulation of ions like Na^+ and Cl^-, which interfere with root water uptake (Gondek et al., 2020). Initial EC of T1, T2, T3, T4 and T5 was 2.7±0.07 mS/cm, 3.1±0.09 mS/cm, 2.6±0.1 mS/cm, 3.1±0.02 mS/cm, and 3.3±0.02 mS/cm respectively. A peak was observed on the 28th day of composting, in which T5 shows the highest EC of 5.4 mS/cm. Every treatment exhibited notable variation ($p<0.05$) in means of EC (Figure 2D). Tukey's Honest Significant Difference (HSD) test resulted in significant differences observed in T3 and T5 treatments (Figure 6C). After 91 days, EC of T1, T2, T3, T4 and T5 was 4.1±0.04 mS/cm, 4.2±0.03 mS/cm, 3.6±0.04 mS/cm, 4.2±0.04 mS/cm, and 4.1±0.03 mS/cm respectively. During thermophilic phases, high organic matter degradation and conversion to nutrients led the EC value to increase. The increase in the rate of EC towards composting, was related to a rise in mineral cation concentration (Fornes et al., 2012).

Variations of CO_2 evolution rate, total volatile solids (TVS), total organic carbon (TOC) and ash content

Microorganisms are major players in the biological process of composting, when organic matter is broken down and converted into mineralized materials that resemble soil in certain ways. Biological aerobic respiration rates throughout the composting process are directly shown by the CO_2 evolution rates (Gea et al., 2004). Therefore, measuring the CO_2 evolution rate is essential for understanding microbial activity as well as reducing the effects on the environment of composting (Stegenta-Dabrowska et al., 2020). Also, evaluation of microbial activity and composting efficiency requires determining the carbon dioxide (CO_2) evolution rate and oxygen (O_2) uptake rate (Zhou et al., 2015). Significant variation in CO_2 evolution rate ($p < 0.05$) was noted among all treatments (Figure 3A), where maximum change was observed between T3 and T5. On the 7th day, the T1, T2, T3, T4, and T5 CO_2 evolution rates was 20.3±0.7 mg/g-VS/day, 20.3±0.6mg/g-VS/day, 18±0.9 mg/g-VS/day, 20.9±0.9 mg/g-VS/day, and 22.1±0.9 mg/g-VS/day respectively. Gradually, CO_2 evolution was reduced, showing microbial activity became limited due to the limited availability of food. After 91 days, the CO_2 evolution rate of T1, T2, T3, T4 and T5 was 2.3±0.4 mg/g-VS/day, 3.8±0.5 mg/g-VS/day, 1.6±0.4 mg/g-VS/day, 3.8±0.7 mg/g-VS/day, and 3.9±0.7 mg/g-VS/day respectively.

Total solids (TS) and total volatile solids (TVS) are common control metrics used in biological interventions, and their determination using standard methods is crucial for evaluating compost stability and maturity (Peces et al., 2014). Initial TVS of T1, T2, T3, T4 and T5 was 85.2±1.8%, 83.8±1.2%, 82.4±2.1%, 81.9±1.2%, and 86.4±1.4%, respectively. Significant reduction ($p < 0.05$) in organic matter was observed in all treatments where maximum variation was between T3 and T5. The reduction in volatile matter was gradual, and no reduction was observed after the 80th day of composting (Figure 3B). The microbial activity disintegrates the complex organic compound to simpler units and subsequently TVS being reduced massively (Chatterjee & Mazumder, 2016). T5 showed the maximum reduction in volatile matter by 56.01%. After 91 days, TVS of T1, T2, T3, T4 and T5 was 51.3±1.2%, 43.8±1.2%,53.4±1.7%, 47.4±1.2%, and 42.8±1.4%, respectively.

Total organic carbon is used as a sign of assessing the maturity of compost. It is suggested that the transition of organic carbon into different fractions during composting is able to be employed as a marker for compost maturity. (Hou et al., 2024). Initial TOC of T1, T2, T3, T4 and T5 was 46.55±1.00%, 45.8±0.67%, 45.02±1.16%, 44.75±0.67%, and 47.21±0.77% respectively. After 91 days, TOC of T1, T2, T3, T4 and T5 was 28.03±0.67%, 23.49±0.66%,

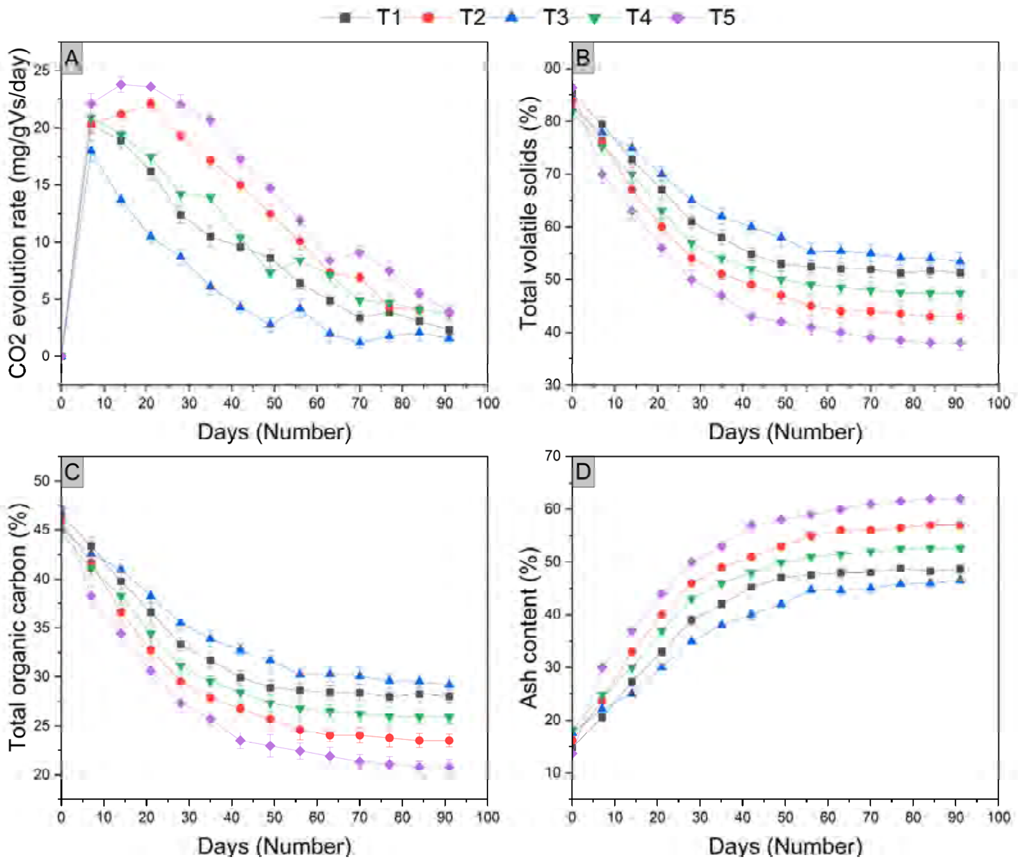

Fig. 3. Temporal variation of CO2 evolution rate (A), total volatile solids (B), total organic carbon (C) and ash content (D) over 91 days of composting.

29.18±0.94%, 25.90±0.67%, and 20.76±0.77% respectively. Ash content is another indication of the increased rate of degradation and is inversely proportional to the TOC (R= -1) (Sharma et al., 2022). Initial ash content of T1, T2, T3, T4 and T5 was 14.8±0.65%, 16.2±0.74%, 17.6±0.9%, 18.1±0.74%, and 13.6±0.12%, respectively. After 91 days, ash content of T1, T2, T3, T4 and T5 was 48.7±0.88%, 56.9±0.77% 46.6±0.81%, 52.6±0.77%, and 62.1±0.76%, respectively (Figure 3C and D). The decrease in total organic carbon (TOC) during composting is attributed to microbial consumption of organic matter for energy and growth. Complex organic substances are broken down into simpler forms by microorganisms releasing carbon dioxide as a by-product. This process reduces the overall carbon content in the compost pile. Conversely, the increase in total volatile solids (TVS) is the result of organic stuff being converted into volatile compounds such as carbon dioxide, water vapour, and organic acids during microbial decomposition. These volatile compounds contribute to the total mass of solids in the compost, leading to an elevation in TVS throughout the composting process.

Variations of ammoniacal nitrogen, total nitrogen (TN), phosphorus (P) and potassium (K)

Ammoniacal nitrogen is a significant source of nitrogen loss during composting, and its measurement helps understand and control this loss. It is involved in transforming nitrogen compounds and significantly impacts the standard and maturity of the compost. (Qiu et al., 2021). Initial ammoniacal nitrogen of T1, T2, T3, T4 and T5 was 161±0.7mg/kg, 147±0.4 mg/kg, 159±1.1 mg/kg,152±1.1 mg/kg, and 152±0.4 mg/kg, respectively. After 91 days, ammoniacal nitrogen of T1, T2, T3, T4 and T5 was 137±0.8 mg/kg, 140±0.3 mg/kg, 139±0.4 mg/kg, 136±0.9

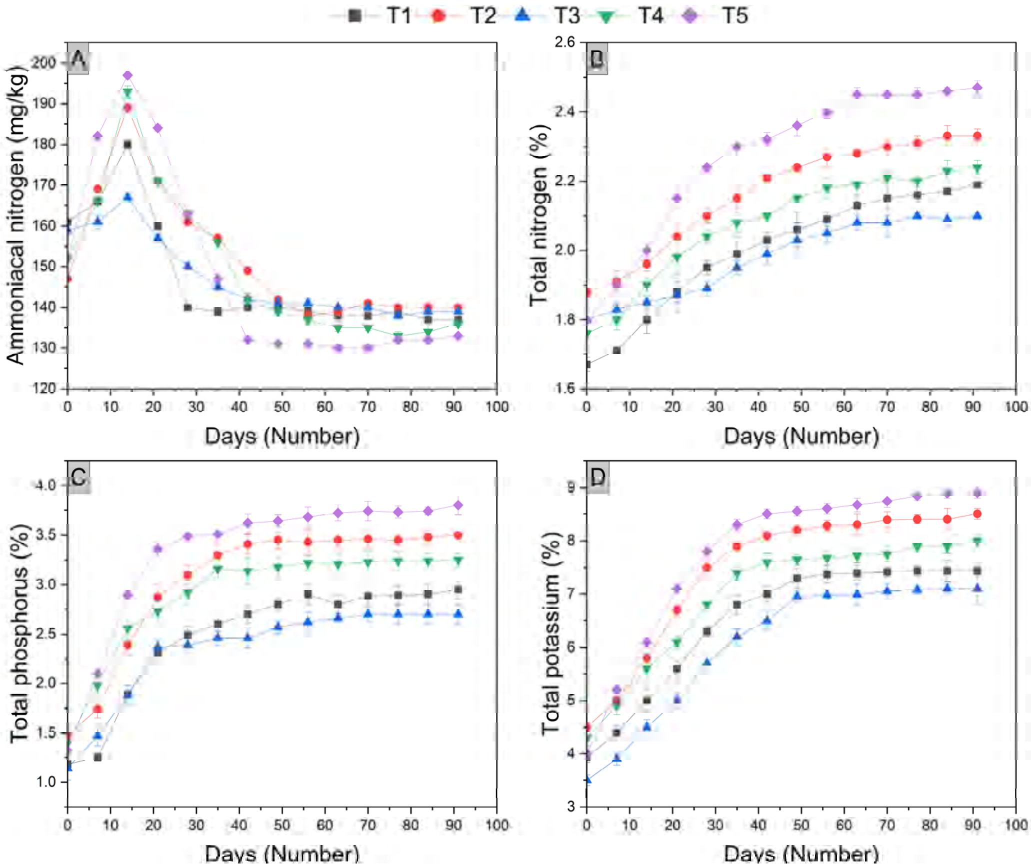

Fig. 4. Temporal variation of ammoniacal nitrogen (A), total nitrogen (B), phosphorus (C) and potassium content (D) over 91 days of composting.

mg/kg, and 133±0.3 mg/kg, respectively. The decrease in ammoniacal nitrogen (NH_4-N) levels observed across T1, T2, T3, T4, and T5 after 91 days can be attributed to several factors (Figure 4A). Initially, high NH_4-N levels are common due to the decomposition of nitrogen-rich organic materials present in the composting feedstock. Microbial activity during composting leads to the conversion of ammonium nitrogen into gaseous forms such as ammonia (NH_3) and nitrogen gas (N_2), which are lost to the atmosphere through volatilization (Hoang et al., 2022). Additionally, some NH_4-N is utilized by microorganisms as a nitrogen source for growth and metabolism, contributing to its decrease over time. The variations in NH_4-N levels among T1 to T5 could be influenced by differences in initial feedstock composition, C:N ratio, moisture content, aeration, and temperature, which affect microbial activity and nitrogen dynamics during composting. Despite these variations, the overall trend of decreasing NH_4-N levels indicates effective nitrogen transformation and stabilization during the composting process.

Nitrogen is an essential constituent of compost. Optimal use of organic composts, rich in nitrogen, can lead to sustainable crop production and soil quality (Sung et al., 2023). Initial TN of T1, T2, T3, T4 and T5 was 1.67±0.02%, 1.88±0.01%, 1.8±0.01%, 1.76±0.01%, and 1.81±0.05% respectively. After 91 days, TN of T1, T2, T3, T4 and T5 was 2.19±0.01%, 2.33±0.02%, 2.1±0.01%, 2.24±0.02%, and 2.47±0.02% respectively. A significant difference in means of T1-T5 and T3-T5 was observed (Figure 7C). Total nitrogen levels increased across all treatments, reflecting microbial decomposition and transformation of organic nitrogen into mineral forms (Figure 4B). Factors such as initial feedstock composition, carbon-to-nitrogen (C: N) ratio, moisture, aeration, and temperature influenced nitrogen dynamics during composting

(Azim et al., 2018).

Phosphorus is essential for plant growth, development, and metabolism, and its availability to plants is crucial for improved production yields. (Paez et al., 2022). Initial total phosphorus content in T1, T2, T3, T4 and T5 was 1.18±0.02%, 1.48±0.09%, 1.14±0.12%, 1.4±0.09% and 1.32±0.02%, respectively. After 91 days, total phosphorus content inT1, T2, T3, T4 and T5 was 2.95±0.1%, 3.5±0.03%, 2.7±0.1%, 3.25±0.07% and 3.8±0.1% respectively (Figure 4C). Initially, the phosphorus present in the organic materials used for composting undergoes mineralization and transformation during microbial decomposition. Microorganisms break down organic phosphorus compounds into inorganic forms, making phosphorus more available for plant uptake. Additionally, the composting process may lead to the concentration of phosphorus due to the loss of volatile organic matter and water content, resulting in a higher phosphorus content in the remaining compost (Azim et al., 2018). The variations in TP levels between T1 and T5 may stem from differences in initial feedstock characteristics and composting conditions.

Potassium is the nutrient that plants need third most after nitrogen and phosphorus, playing an essential function in osmotic adjustments, enzyme activation, and charge balancing in plant cells (Wakeel et al., 2016). Initial total potassium content in T1, T2, T3, T4 and T5 was 3.93±0.1%, 4.5±0.09%, 3.5±0.1%, 4.3±0.15%, and 4±0.09% respectively. After 91 days, total potassium content in T1, T2, T3, T4 and T5 was 7.44±0.12%, 8.5±0.1%, 7.1±0.3%, 8±0.1%, and 8.9±0.1% respectively (Figure 4D). The elevated level of total nitrogen measured, phosphorous and potassium suggests effective stabilization, which can contribute to the fertility and productivity of soils when these composts are applied to agricultural lands.

Variations of C/N ratio, lignin, cellulose and hemicellulose

Higher C/N ratios promote the growth of lignocellulose degrading bacteria, which improves the development of humic materials, thus affecting the quality of compost (Zhang et al., 2021). Initial C/N ratio of T1, T2, T3, T4 and T5 was 27.87±0.7, 24.35±1.3, 28.14±0.12, 25.42±1.3 and 26.22±0.58 respectively. After 91 days, C/N ratio of T1, T2, T3, T4 and T5 was 12.8±0.1, 10.08±0.8, 13.89±0.2, 11.56±0.8 and 8.61±0.7respectively. The significant decrease in the carbon-to-nitrogen (C: N) ratio observed across T1 to T5 after 91 days of composting show the utilization of carbon-rich organic matter by microorganisms for growth and metabolism (Figure 5A). Initially, high C:N ratios suggest an abundance of carbon relative to nitrogen in the composting feedstock. Microbial decomposition of carbon substances, which causes the release of carbon dioxide and the incorporation of nitrogen into microbial biomass, lowering the C:N ratio (Fog, 1988).

A three-dimensional polymeric composite material is lignocellulosic biomass synthesised by plants, primarily cellulose, hemicelluloses, and lignin (Erdocia et al., 2021). Lignocellulosic degradation is crucial for the formation of humic substances, which contribute to compost stability and maturation (Ghanney et al., 2023). Initial cellulose content in T1, T2, T3, T4 and T5 was 38.6±0.24%, 38.02 ±0.14%, 42.4±0.18%, 41.7±0.14%and 40.1±0.21%respectively. After 91 days, cellulose content in T1, T2, T3, T4 and T5 was 32.1±0.13%, 33.1±0.08%, 26.3±0.11%, 28.2±0.05%, and 30.3±0.05%respectively (Figure 5B). Significant difference in means of T1 T5, T2 T3, T3 T5 was observed by Tukey's Honest Significant Difference (HSD) test at $p < 0.05$ (Figure 8C).

Hemicellulose and lignin is the integral components of plant cell walls, all undergo decomposition during the composting process. Hemicellulose, a complex polysaccharide composed of various sugar units like xylose, glucose, mannose, and arabinose, experiences degradation facilitated by microbial activity, temperature, aeration, moisture content, and the carbon-to-nitrogen (C: N) ratio. Microbial activity, particularly by bacteria and fungi, leads the charge in hemicellulose and lignin breakdown, producing enzymes like hemicelluloses that cleave bonds between sugar units, yielding simpler sugars for microbial consumption (Houfani

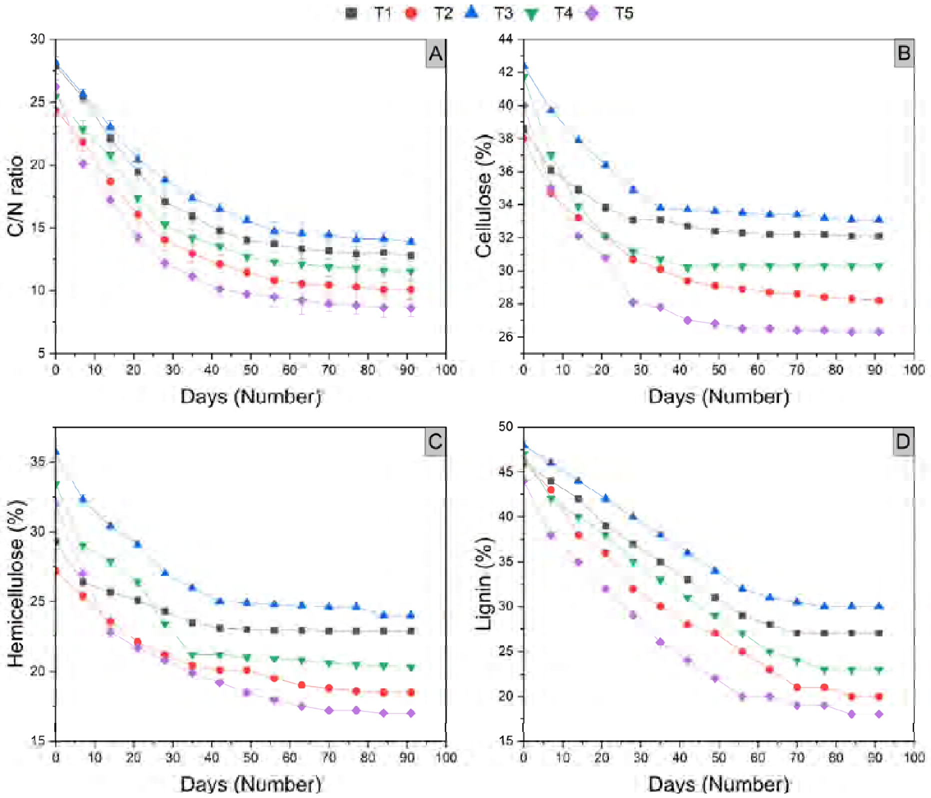

Fig. 5. Temporal variation of C/N ratio (A), cellulose (B), hemicellulose (C) and lignin content (D) over 91 days of composting

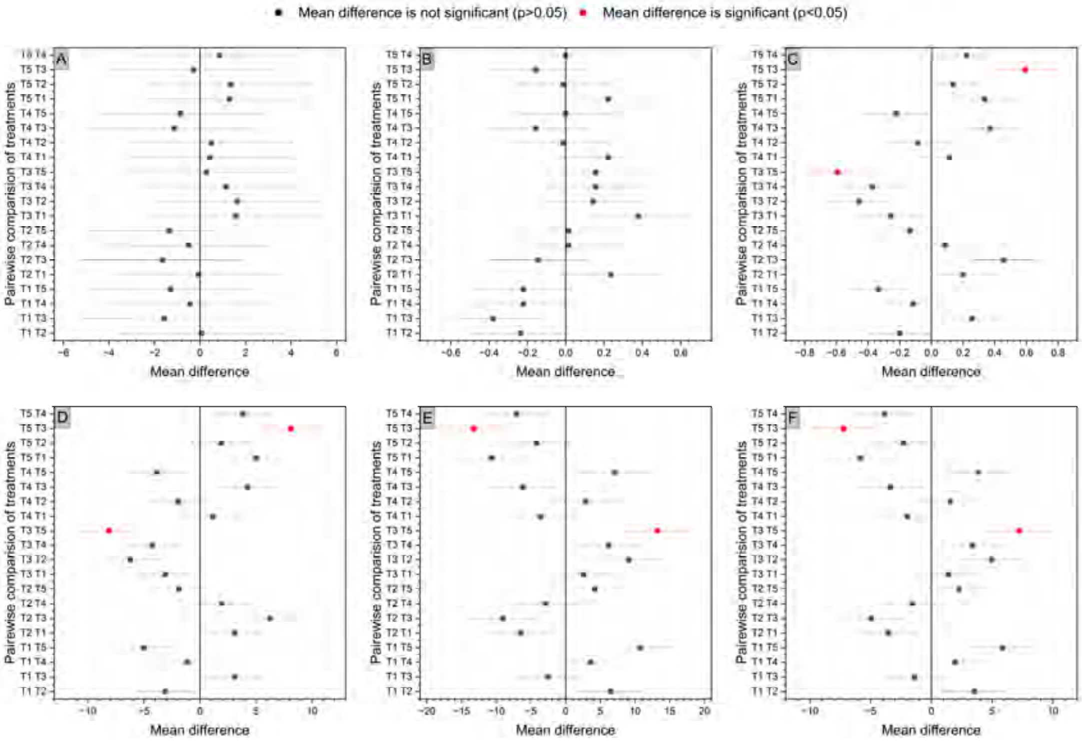

Fig. 6. Tukey's Honest Significant Difference (HSD) test at a significance level, $p < 0.05$ to find significant and non-significant differences between means of different pairwise comparison of treatments of moisture content (A), pH (B), electrical conductivity (C), CO_2 evolution rate (D), total volatile solids (E) and total organic carbon (F).

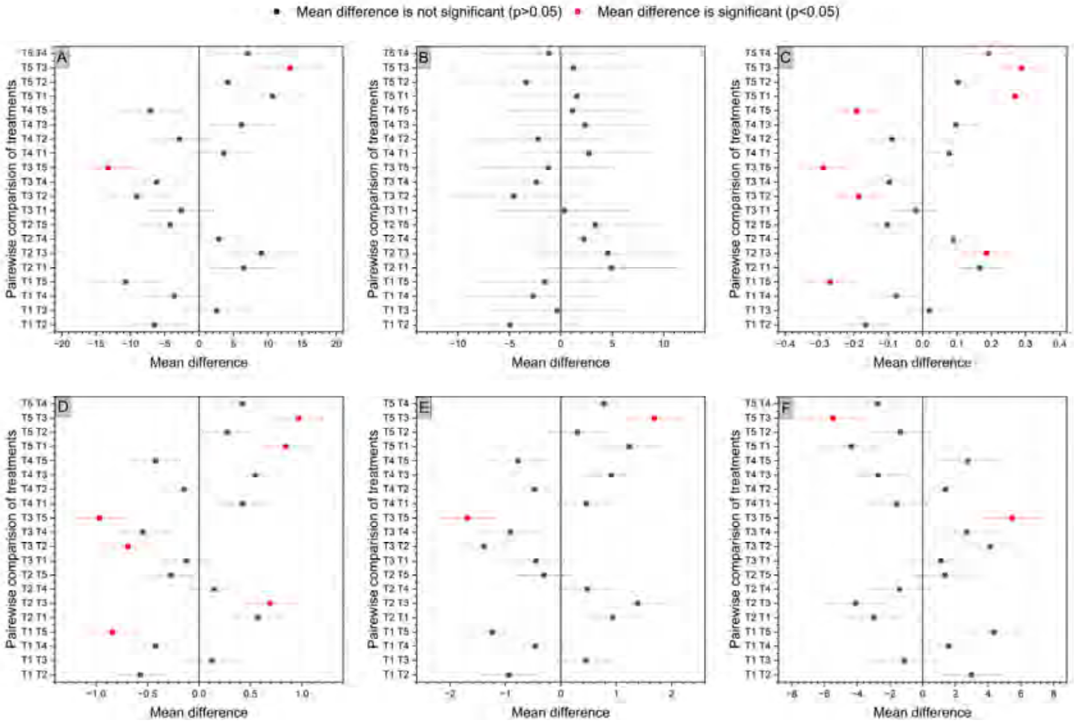

Fig. 7. Tukey's Honest Significant Difference (HSD) test at a significance level, $p < 0.05$, to find significant and non-significant differences between means of different pairwise comparisons of treatments of ash content (A), ammoniacal nitrogen (B), total nitrogen (C), total phosphorus (D), total potassium (E) and/N ratio (F)

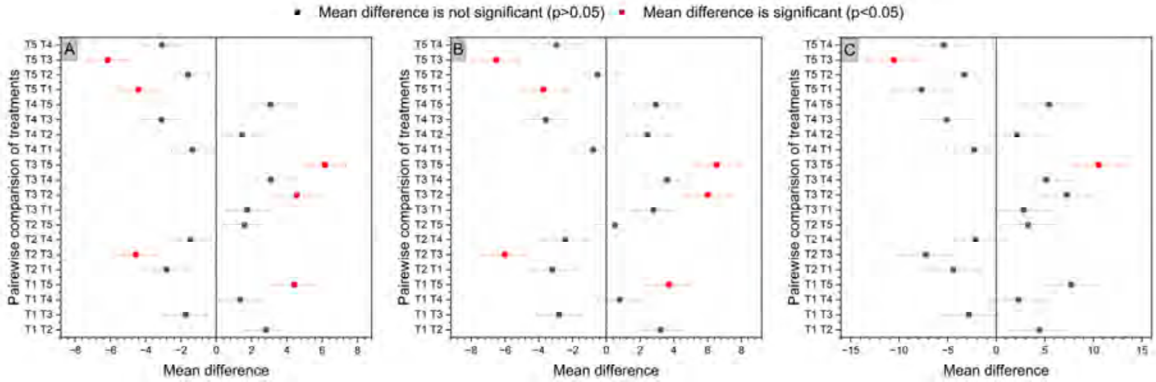

Fig. 8. Tukey's Honest Significant Difference (HSD) test at significance level, $p < 0.05$, to find significant and non-significant differences between means of different pairwise comparison of treatments of cellulose (A), hemicellulose (B) and lignin content (C).

et al., 2020). Elevated temperatures within compost piles foster the activity of thermophilic bacteria adept at breaking down hemicellulose, while also aiding in the denaturation of hemicellulose, making it more accessible to microbial enzymes. Initial hemicellulose content in T1, T2, T3, T4 and T5 was 29.3±0.54%, 27.2±0.25%, 35.7±0.42%, 33.4±0.25% and 27.9±0.45%respectively. After 91 days, hemicellulose content in T1, T2, T3, T4 and T5 was 22.9±0.14%, 18.5±0.12%, 24.1±0.11%, 20.3±0.12% and 18.7±0.15% respectively (Figure 5C). Adequate aeration is crucial for hemicellulose degradation as it ensures oxygen availability, essential for aerobic microbial decomposition. Proper oxygen levels support the growth and activity of hemicellulose-degrading microorganisms, preventing the onset of anaerobic conditions that could impede decomposition. Similarly, initial lignin content in T1, T2, T3, T4 and T5 was 46.1±0.25, 45.8±0.45, 48.13±0.45, 47.2±0.28 and 44.21±0.54 respectively. After 91 days, acid insoluble lignin content in T1, T2, T3, T4 and T5 was 27.31±0.12%, 20.11±0.15%, 29.8±0.15%, 23.25±0.12%, and 18.2±0.14% respectively (Figure 5D). Moreover, maintaining optimal moisture levels is imperative for microbial activity and hemicellulose degradation, as water is essential for the activity of hemicellulolytic enzymes and the growth of hemicellulose-degrading microorganisms. However, excessive moisture can lead to waterlogging and anaerobic conditions, hindering microbial activity. Additionally, the carbon-to-nitrogen (C:N) ratio of composting materials influences hemicellulose decomposition, with materials rich in carbon requiring nitrogen for microbial decomposition. Balancing the C:N ratio by adding nitrogen-rich materials enhances microbial activity and facilitates hemicellulose and lignin degradation throughout the composting process.

Correlation between physicochemical parameters and comparison with global standards

Pearson's correlation between 16 variables was calculated and shown as a heat map (Figure 9) further to explore the significant correlation between the physicochemical parameters. Temperature was directly correlated with CO_2 evolution rate (R=0.66) and ammoniacal nitrogen content (R=0.69) due to microbial activity degrading organic matter and generating heat and CO_2. A positive relation was also observed between EC and TN (R=0.46), TP (R=0.68), TK (R=0.57) and ash content (R=0.74), suggesting an increase in nutrients and ash content is responsible

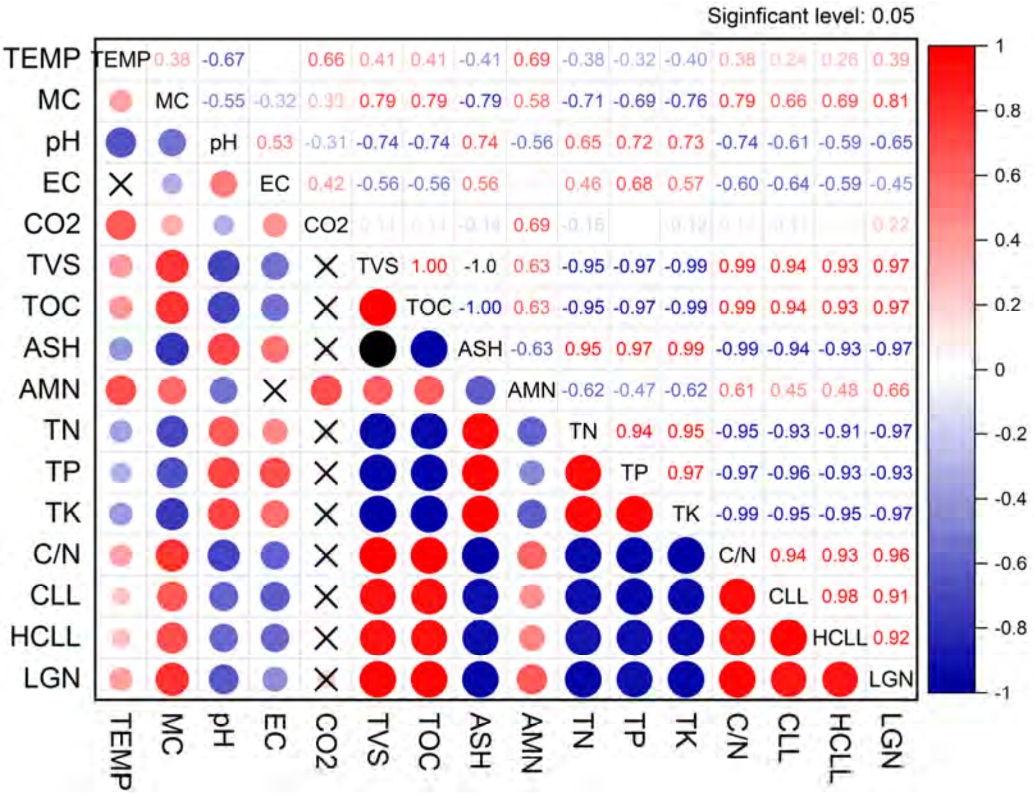

Fig. 9. Correlation plot of Pearson's correlation coefficients of all parameters at significance level $p<0.05$ in which the size of the circle is proportional to the strength of the correlation. TEMP: temperature, MC: moisture content, EC: electrical conductivity, CO2: CO2 evolution rate, TVS: total volatile solids, TOC: total organic carbon, ASH: ash content, AMN: ammoniacal nitrogen, TN: total nitrogen, TP: total phosphorus, TK: total potassium, C/N: C/N ratio, CLL: cellulose, HCLL: hemicellulose, LGN: Lignin

Table 3. Comparison of the physicochemical parameters' values of final composts from all treatments with various international compost standards. (Rao and Parsai 2023; Zhou et al., 2020)

Parameter	**Final Compost**					**Compost standards**				
	T1	T2	T3	T4	T5	a	b	c	d	e
MC (%)	42	40	43	39	40	15-25	-	-	-	-
pH	6.8	7.3	7.3	7.2	6.9	6.5-7.5	5.5-8.5	5.5–8.5	5.5–8.5	5.5-8.5
EC (mS/cm)	4.1	4.2	3.6	4.2	4.1	<4	<2.5	<3	<3	<4
TVS (%)	51.3	43	53.4	47.4	38	-	-	-	-	-
TOC (%)	28.03	23.5	29.18	25.9	20.76	≥12	-	-	-	-
TN (%)	2.19	2.33	2.1	2.24	2.47	≥0.8	≥0.2	≥1.5	>1	-
TP (%)	2.95	3.5	2.7	3.25	3.8	≥0.4	≥0.4	≥1.5	-	-
TK (%)	7.44	8.5	7.1	8	8.9	≥0.4	≥0.8	≥1	-	-
C/N	12.8	10.08	13.89	11.56	8.61	<20	-	-	-	-
GI (%)	85	95	85	89	97	>80	>80	>80	>80	>80

a: Indian fertiliser order control (1985)
b: China's standard of organic fertiliser (GB, 18877-2009)
c: Japanese ministry of agriculture, forestry and fisheries (2008)
d: US Compost Quality Council (2001)
e: Canadian council of the ministers of the environment (2005)

for increased ion content. Nutrient availability was negatively correlated with organic matter degradation, such as TVS and TOC content (R>-0.95). Lignocellulose degradation in compost significantly improves nutrient content (R>-0.9) because the main structural component of plant cell walls, contains bound nutrients such as nitrogen, phosphorus, and potassium. Microorganisms break down the complex lignocellulosic structure during degradation, releasing these bound nutrients into the compost.

The final compost parameters were compared with global compost standards such as Indian fertiliser order control (1985), China's standard of organic fertiliser (GB, 18877-2009), Japanese ministry of agriculture, forestry and fisheries (2008), US Compost Quality Council (2001) and Canadian council of the ministers of the environment (2005) to evaluate its suitability to use in agriculture (Table 3). Moisture content in all trials exceeded the limit given by Indian fertiliser order control (1985). High moisture content will lead to an increase in the weight of compost; therefore, measures need to be identified to reduce the moisture for better handling. pH of the compost was within the range for all trials. EC of all trials except T3 was slightly high due to an increase in nutrient content such as N, P and K in which T5 showed the highest concentration among other trials. The C/N ratio was within the range of the Indian fertiliser order control standard, and the highest C/N reduction was seen in T5, indicating that composting of sugarcane leaves/trash along with food waste resulted in the highest organic matter degradation and nutrient availability. The germination index more than 80% indicate that the compost is free from any phytotoxic substance. All trials showed a germination index of more than 80%, with T5 being the highest at 97%.

CONCLUSION

The present research examined the changes in crucial parameters during agitated pile composting of sugarcane agro-industrial waste and their influence on the quality and maturity of the compost. In trial 3 to 5, ammoniacal nitrogen emerged as a significant contributor to nitrogen loss, with implications for compost quality and stabilization. The rise in total nitrogen content over time indicates the efficient conversion of organic nitrogen into plant-available forms, promoting sustainable agriculture practices. Moreover, the levels of phosphorus and potassium also showed notable increases, highlighting their importance in enhancing soil fertility and crop productivity. Interestingly, the decline in carbon-to-nitrogen ratios was correlated with the growth of lignocellulose-degrading bacteria, facilitating the formation of humic substances critical for compost stability. The degradation of lignocellulose, as evidenced by changes in cellulose, hemicellulose, and lignin content, further emphasized its role in compost maturation. Additionally, the observed reduction in CO_2 evolution rate and volatile solids content reflected microbial activity and compost stabilization. Trial 3 and 5 was the suitable combinations for the sugarcane agro-industrial waste composting. However, further studies are required to optimize treatment combinations by adjusting the mixing ratios. Microbial assays are not performed in this study which can be a future scope to understand biodegradation process in detail. Studies are required to assess the feasibility of implementing this study on a larger scale. Also, cost economics needs to be studied.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCE

Adhikari, B. K., Barrington, S., Martinez, J., & King, S. (2009). Effectiveness of three bulking agents for food waste composting. Waste Manag., 29(1); 197–203.

Ansari, M., Zafar, U., Ejaz, U., Sohail, M., Pirzada, A., & Aman, A. (2021). Comparison of composting of chemically pretreated and fermented sugarcane bagasse for zero-waste biorefinery. J. Mater. Cycles Waste Manag., 23(3); 911–921.

Azim, K., Soudi, B., Boukhari, S., Perissol, C., Roussos, S., & Thami Alami, I. (2018). Composting parameters and compost quality: a literature review. Org. Agric., 8(2); 141–158.

Byakodi, A. S., & Babu, B. T. S. (2022). Aerobic Composting of Sugar Pressmud with Stabilized Spentwash and selected Microbial Consortium. Eurobiotech J., 6(1); 32–39.

Cáceres, R., Malińska, K., & Marfà, O. (2018). Nitrification within composting: A review. Waste Manag., 72; 119–137.

Calcino, D. V, Schroeder, B. L., & Hurney, A. P. (2010). Extension and adoption of the’SIX EASY STEPS’nutrient management program in sugarcane production in north Queensland. Proc. Int. Soc. Sugar Cane Technol., 27; 1-10.

Chatterjee, B., & Mazumder, D. (2016). Anaerobic digestion for the stabilization of the organic fraction of municipal solid waste: A review. Environ. Rev., 24 (4); 426-459

Dhanushkodi, V., Hanif, N. A., Amuthaselvi, G., & Easwaran, S. (2019). In-situ sugarcane trash composting: A boon for soil fertility and cane yield (Saccum officiharnarum). J. Pharmacogn. Phytochem., 8(2S); 207–209.

Erdocia, X., Hernández-Ramos, F., Morales, A., Izaguirre, N., de Hoyos-Martínez, P. L., & Labidi, J. (2021). Lignin extraction and isolation methods. In Lignin-based Materials for Biomedical Applications: Preparation, Characterization and Implementation. Elsev., 61–104.

Fog, K. (1988). The effect of added nitrogen on the rate of decomposition of organic matter. Biol. Rev., 63(3); 433–462.

Fornes, F., Mendoza-Hernández, D., García-de-la-Fuente, R., Abad, M., & Belda, R. M. (2012). Composting versus vermicomposting: A comparative study of organic matter evolution through straight and combined processes. Bioresour. Technol., 118; 296–305.

Gea, T., Barrena, R., Artola, A., & Sánchez, A. (2004). Monitoring the biological activity of the composting process: Oxygen uptake rate (OUR), respirometric index (RI) and respiratory quotient (RQ). Biotechnol. Bioeng., 88(4); 520–527.

Ghanney, P., Qiu, H., Anning, D. K., Yang, H., Wang, Y., & Kugbe, J. X. (2021). Moisture-induced pattern of gases and physicochemical indices in corn straw and cow manure composting. Appl. Sci., 11(18); 8493.

Ghanney, P., Yeboah, S., Anning, D. K., Yang, H., Wang, Y., & Qiu, H. (2023). Moisture-Induced Effects on Lignocellulosic and Humification Fractions in Aerobically Composted Straw and Manure. Fermentation, 9(6); 551.

Goering, H. K., & Van Soest, P. J. (1970). Forage fiber analyses (apparatus, reagents, procedures and some applications). Agric. Handb., US Agricultural Research Service., 379

Gondek, M., Weindorf, D. C., Thiel, C., & Kleinheinz, G. (2020). Soluble Salts in Compost and Their Effects on Soil and Plants: A Review. Compost Sci. Util., 28(2); 59–75.

Hernández, T., Chocano, C., Moreno, J.-L., & García, C. (2016). Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (Lactuca sativa L.) crops—Effects on soil and plant. Soil Tillage Res., 160; 14–22.

Ho, T. T. K., Tra, V. T., Le, T. H., Nguyen, N. K. Q., Tran, C. S., Nguyen, P. T., Vo, T. D. H., Thai, V. N., & Bui, X. T. (2022). Compost to improve sustainable soil cultivation and crop productivity. Case Stud. Chem. Environ. Eng., 6; 100211.

Hoang, H. G., Thuy, B. T. P., Lin, C., Vo, D. V. N., Tran, H. T., Bahari, M. B., Le, V. G., & Vu, C. T. (2022). The nitrogen cycle and mitigation strategies for nitrogen loss during organic waste composting: A review. Chemosphere, 300; 134514.

Hou, J.-Y., Liu, H.-T., Wang, L.-X., & Zhang, Z.-L. (2024). Novel perspective on qualitative assessment of swine manure compost maturity using organic carbon density fractions. Bioresour. Techno., 395.

Houfani, A. A., Anders, N., Spiess, A. C., Baldrian, P., & Benallaoua, S. (2020). Insights from enzymatic degradation of cellulose and hemicellulose to fermentable sugars– a review. Biomass Bioenergy, 134, 105481.

Jain, M. S., Daga, M., & Kalamdhad, A. S. (2019). Variation in the key indicators during composting of municipal solid organic wastes. Sustain. Environ. Res., 1(1); 1–8.

Johnson, K. A., & Johnson, D. E. (1995). Methane emissions from cattle. J. Anim. Sci.
, 73(8); 2483–2492.

Li, Y., & Li, W. (2015). Nitrogen transformations and losses during composting of sewage sludge with acidified sawdust in a laboratory reactor. Waste Manag. Res., 33(2); 139–145.

Lim, T. J., Spokas, K. A., Feyereisen, G., & Novak, J. M. (2016). Predicting the impact of biochar additions on soil hydraulic properties. Chemosphere, 142; 136–144.

Mukesh, M., Gujar, G., & Sodhi, M. (2022). Livestock sector: an integral component for country's food and social security. Adv. Anim. Experiment. Model.., 341–351.

Oazana, S., Varma, V. S., Saadi, I., Sharma, D., Hanan, A., Medina, S., Avidov, R., Grinshpon, Y., Rosenfeld, L., & Gross, A. (2020). High-rate stabilization and associated air emissions prospected during on-site in-vessel sewage sludge composting. Bioresour. Technol. Rep., 11; 100543.

Paez, L. A., Garcia, J. F., Parra, J. D., & Jacome, L. L. (2022). Effect of phosphoric rock on the chemical, microbiological and enzymatic quality of poultry, equine and cattle manure compost mix. Int. J. Recycl. Org. Waste Agric., 11(3); 385–398.

Peces, M., Astals, S., & Mata-Alvarez, J. (2014). Assessing total and volatile solids in municipal solid waste samples. Environ. Technol., 35(24); 3041–3046.

Poornima, S., Dadi, M., Subash, S., Manikandan, S., Karthik, V., Deena, S. R., Balachandar, R., Kumaran, S. K. N., & Subbaiya, R. (2024). Review on Advances in Toxic Pollutants Remediation by Solid Waste Composting and Vermicomposting. Sci. Afr., 23; e02100.

Powar, R. V., Mehetre, S. A., Powar, T. R., & Patil, S. B. (2022). End-Use Applications of Sugarcane Trash: A Comprehensive Review. Sugar Tech., 24(3); 699–714.

Qiu, Z., Li, M., Song, L., Wang, C., Yang, S., Yan, Z., & Wang, Y. (2021). Study on nitrogen-retaining microbial agent to reduce nitrogen loss during chicken manure composting and nitrogen transformation mechanism. J. Clean. Prod., 285; 124813.

Rahayu, F., Nugraheni, S. D., Diana, N. E., Santoso, B., Wijanarko, A., & Hariyono, B. (2022). The potential of new bio-decomposers for composting sugarcane waste. IOP Conference Series: Earth Environ. Sci., 974(1).

Rastogi, M., Nandal, M., & Khosla, B. (2020). Microbes as vital additives for solid waste composting. Heliyon., 6(2).

Raza, S., Munir, N., Naz, S., Ahmed, J., & Ameen, A. (2017). Effect of pH during composting of municipal solid waste. Pakistan Journal of Scientific and Industrial Research Series A: Phys. Sci., 60(2); 114–116.

Rao, J. N., & Parsai, T. (2023). A comprehensive review on the decentralized composting systems for household biodegradable waste management. J. Environ. Manage., *345*, 118824.

Sarika, D., Singh, J., Prasad, R., Vishan, I., Varma, V. S., & Kalamdhad, A. S. (2014). Study of physico-chemical and biochemical parameters during rotary drum composting of water hyacinth. Int. J. Recycl. Org. Waste Agric., 3(3); 1–10.

Sharma, D., Prasad, R., Patel, B., & Parashar, C. K. (2022). Biotransformation of sludges from dairy and sugarcane industries through vermicomposting using the epigeic earthworm Eisenia fetida. Int. J. Recycl. Org. Waste Agric., 11(2); 165–175.

Soto-Paz, J., Gea, T., Alfonso-Morales, W., Caicedo-Bravo, E., Oviedo-Ocaña, E. R., Manyoma-Velásquez, P. C., & Torres-Lozada, P. (2021). Co-composting of Biowaste: Simultaneous Optimization of the Process and Final Product Quality Using Simulation and Optimisation Tools. Waste Biomass Valor., 12(8); 4489–4502.

Srinivasan, R., Rao, K. J., Reza, S. K., Padua, S., Dinesh, D., & Dharumarajan, S. (2016). Influence of inorganic fertilizers and organic amendments on plant nutrients and soil enzyme activities under incubation. Int. J. Bio-Resour. Stress Manage., 7; 924–932.

Stegenta-Dabrowska, S., Sobieraj, K., Koziel, J. A., Bieniek, J., & Bialowiec, A. (2020). Kinetics of biotic and abiotic CO production during the initial phase of biowaste composting. Energies., 13(20); 1-22.

Stoffella, P. J., & Graetz, D. A. (2000). Utilization of sugarcane compost as a soil amendment in a tomato production system. Compost Sci. Util., 8(3); 210–214.

Sung, J., Kim, W., Oh, T.-K., & So, Y.-S. (2023). Nitrogen (N) use efficiency and yield in rice under varying types and rates of N source: chemical fertilizer, livestock manure compost and food waste-livestock manure compost. Appl. Biol. Chem., 66(1).

Updegraff, D. M. (1969). Semimicro determination of cellulose inbiological materials. Anal. Biochem., 32(3); 420–424.

Wakeel, A., Gul, M., & Zörb, C. (2016). Potassium for sustainable agriculture. In Soil Science: Agric. Environ. Perspect., 159–182.

Zainudin, M. H. M., Zulkarnain, A., Azmi, A. S., Muniandy, S., Sakai, K., Shirai, Y., & Hassan, M. A. (2022). Enhancement of agro-industrial waste composting process via the microbial inoculation: a brief review. Agronomy., 12(1); 198.

Zhang, W.-M., Wang, X.-J., Yin, S.-Q., Chang, X.-Y., & Hai, L. (2021). C/N ratio-induced changes in predominant bacteria affected carbon / nitrogen losses and humus synthesis in composting. Chin. J. Appl. Ecol., 32(11); 4119–4128.

Zhou, C., Liu, Z., Huang, Z. L., Dong, M., Yu, X. L., & Ning, P. (2015). A new strategy for co-composting dairy manure with rice straw: Addition of different inocula at three stages of composting. Waste Manag., 40; 38–43.

Zhou, X., Yang, J., Xu, S., Wang, J., Zhou, Q., Li, Y., and Xinyi. (2020). Rapid in-situ composting of household food waste. Process Saf. Environ. Prot., 141, 259–266.