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Evaluation of Chemical Profile of Organic Waste Compost Accelerated Via Microbial and Nanocomposite Amendments

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Abstract

Microbial activities are capable of accelerating some biological processes such as biodegradation of materials in the environment. This study was carried out to evaluate the chemical profile of organic waste compost accelerated via microbial and nanocomposite amendments. The beneficial microbes ((*Bacillus* species, *Candida* species, and *Enterobacter* species) that were used to accelerate composting of the selected substrates were isolated from soil, roots of soy bean, and ripe pineapple using microbiological standard techniques. The ability of the beneficial microorganisms to degrade complex organic and inorganic matter in compost was evaluated using substrates from leftover food, fruit and vegetable, and papers. The required conditions for optimum conversion of the substrates such as moisture and aeration were provided throughout the duration of 56 days. Key physicochemical parameters, including pH, carbon-to-nitrogen (C/N) ratio, phosphorus, potassium, ammonium-nitrate ratio, and trace metals (zinc and copper), were monitored throughout the composting period. Initial characterization revealed significant variation in substrate quality, with paper waste exhibiting a high C/N ratio (173:1) and food waste showing a lower ratio (24:1), indicating differing biodegradability potentials. During composting, pH increased across all treatments, approaching near-neutral conditions by week eight. A substantial reduction in C/N ratio was observed, with the consortium treatment achieving the lowest value (13:1), indicating advanced compost maturity. Nutrient enrichment was evident, particularly in phosphorus and potassium, with the consortium and magnesium nanocomposite treatments showing superior performance. The ammonium-nitrate ratio declined significantly across treatments, reflecting enhanced nitrogen stabilization. Trace metal dynamics indicated reduced zinc and copper concentrations in treated setups compared to control. Overall, microbial consortium and magnesium nanocomposite amendments significantly improved compost quality and maturity compared to control conditions. These findings highlight the potential of combined biological and nanotechnological approaches in optimizing composting processes for sustainable waste management.

Keywords: Composting; Compost maturity; Effective microorganisms; Magnesium nanocomposite; Nutrient dynamics; Waste management

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1. Introduction

Microorganisms comprise of tiny living organisms which could either be beneficial to man or incur harm. Man possesses a strong association with microorganisms in the environment due to their ubiquitous nature (Pushpa *et al*., 2016; Uba, 2019a; 2019b; Egurefa *et al*. 2020a; 2020b; Okolo *et al.*, 2025). Beneficial microorganisms such as *Escherichia coli, Bacillus* species, *Enterobacter* species, *Saccharomyces* species etc. have a wide range of applications in the industries for production of essential commodities while some are used in agriculture sector for improving crop production via biotechnology and other processes (Ogbo and Okonkwo, 2012; Limaye *et al*., 2017; Okpalaunegbu *et al.*, 2025; Obiefuna *et al.* 2025; 2026).

Research has shown that certain microorganisms are capable of playing vital role in wastes management (Abu-Zahra *et al*., 2014; Uba, 2019c; Uba *et al*., 2019a; 2019b; 2019c). Some microorganisms are capable breaking down bulk organic and inorganic substrates to release smaller substances such as carbon. When these complex substances are degraded, the product of the degradation provides carbon and energy for metabolic processes in the microbes. The ability of the microbes to degrade the complex organic matter had attributed to their ability to synthesize enzymes such as amylases, lipases, protreinases, ligninases, and cellulases (Ab muttalib *et al*., 2016; Uba *et al*. 2016; Uba *et al.*, 2017; Nkamigbo *et al*. 2020a; 2020b; Njoku *et al*. 2019a; 2019b; Okoye *et al*., 2026).

Several researchers have documented that the ability of certain microbes to degrade complex organic matter to simpler ones confer them with high potentials in solid waste management (Uba *et al*. 2020c; 2020d; 2020e; Uba e*t al.*, 2021a; 2021b; Dokubo *et al*., 2022a; 2022b; Anidu *et al*., 2023; Obiefoka *et al*., 2023; Dokubo *et al*., 2024; Ubajekwe *et al*., 2025; Uba *et al*., 2025). One of the methods of solid wastes management is composting. In composting, decomposition occurs which enable microorganisms to degrade the organic matter in the solid wastes. But it is worthy to note that the rate decomposition can be affected when the autochtonous microorganisms are unable to degrade complex organic compounds. In regard to this, it is highly imperative to introduce known microorganisms to compost to accelerate composting (Ali *et al.*, 2013; Anichebe *et al*., 2019; Okoye *et al*. 2020a; 2020b; 2020c).

It is worthy to note that during composting, there several changes that occur such as chemical changes which had been attributed to the chemical reaction that occurs when complex molecules are broken down. Some of the chemicals that have been observed are carbon, nitrogen, phosphorus, pH etc. (Awasthi *et al*., 2015; Uba *et al*. 2024; Mere *et al.* 2025; Enemchukwu *et al*. 2026a; 2026b).

Recent advancements in composting technology have focused on enhancing decomposition rates and compost quality through the use of microbial inoculants and nanomaterials. Effective microorganisms (EM) and microbial consortia are known to accelerate organic matter degradation by introducing beneficial microbial communities that enhance enzymatic activities and nutrient cycling. Similarly, nanomaterials such as magnesium-based nanocomposites have gained attention for their ability to improve microbial metabolism, adsorb toxic compounds, and enhance nutrient availability during composting (Dokubo and Uba, 2023; Uba and Obiefuna, 2023; Ofunwa et al., 2024; Ubani *et al*., 2024a; 2024b; 2025; Ekwenze *et al*., 2025).

Despite these advancements, there is limited information on the combined effects of microbial inoculants and nanocomposites on compost maturity and nutrient dynamics. Several researchers (Ajmal *et al*.. 2020a; Alisa *et al*., 2020; Anukam *et al.* 2020a; 2020b; Uba *et al.*, 2020a; 2020b; Umeh *et al.*, 2020; 2021; Dokubo *et al*., 2024) have worked on the chemical compositions of compost but few studies are available on the chemical profile of a compost prepared using microbial and metal nanocomposites additives. Hence, the aim of this study is to eevaluate the chemical profile of organic waste compost accelerated via microbial and nanocomposite amendments. By monitoring key parameters such as pH, C/N ratio, nutrient content, and trace metals, this study provides insights into optimizing composting processes for improved efficiency and environmental sustainability.

2. Materials and Methods

2.1 Sample Collection

Pure magnesium nitrate (MgNO3) reagents and other chemicals of analytical grade that were used in this study were obtained from Loba Chemie, Mumbai India.Rhizospheric soil samples and roots of soy beans were aseptically collected with sterile hand trowel and knife from the school garden (Coordinates describe using hand held GPS) within premises of Chukwuemeka Odumegwu Ojukwu, Uli Campus, Ihiala Local Government Area, Anambra State while ripe queen pineapple (*Ananas comosus*) specimens were bought from Nkwo Ogbe Market Ihiala Anambra State. All the samples were placed into sterile polyethylene bags and transported on ice to the Microbiology Laboratory of Chukwuemeka Odumegwu Ojukwu University Uli Campus, Nigeria for further analysis (Uba *et al.*, 2026a; 2026b; 2026c).

2.2 Isolation of Rhizospheric Bacterial (RB) Species

According to the method of Ogbo and Okonkwo *et al*. (2012), the washed roots of soy beans plants were cut into 3 cm segments and disinfected by soaking in 70 %ethanol for 5 min, in 6.25 % sodium hypochlorite for 10 min, followed by several rinses in sterile distilled water. Intact root pieces (0.5 to 1.0 cm) were then placed into tubes of semisolid (0.05%) nitrogen free biotin medium (NFb) and incubated without shaking for 5 days at 30℃. This medium was composed (g/L) of: DL-malic acid 5; KOH 4; K_2HPO_4 0.5; $MgSO_4·7H_2O$ 0.2; $CaCl_2$ 0.02;NaCl 0.1; $FeSO_4·7H_2O$ 0.5; Agar 5 g and (mg/L) of: $NaMoO_4·2H_2O$ 2; $MnSO_4·H_2O$ 10. The medium also contained 2 mL of 0.5 % solution of bromothymol blue in95% ethanol and had a final pH of 6.8. After incubation, the white pellicles from tubes which showed this characteristic feature, were subcultured onto solid semi selective, Congo red-NFb medium. The appearance of red to scarlet colony suggestive of rhizospheric bacterium was selected and purified by repeated streaking on same medium (Alfred *et al*. 2023; 2025).

2.3 Isolation of Yeast

The fruits were washed with sterile water containing disinfectant, drained, peeled and sliced into smaller pieces. The juices were aseptically extracted using a hand juice extractor, filtered with muslin cloth and the filtrates collected in a sterile plastic container as described by Umeh *et al.* (2019). For the isolation of the yeasts, 100 mL of Yeast Extract Dextrose Peptone broth (40 g of peptone water, 10 g of yeast extract and 20 g of dextrose sugar (sucrose) in 1 L of distilled water) was added into a 250 mL conical flask containing with 100 g of the 48 h fermenting crushed pineapple, respectively and were incubated for 2 - 5 days at 30 °C to enhance microbial growth. An aliquot of 0.1 mL of the YEDP broth containing the pineapple juice was inoculated onto Potato Dextrose Agar (PDA) medium (Fifty (50) mg/L of tetracycline and 0.05 mg/L of gentamycin were added to the PDA medium to inhibit bacterial growth) in duplicates using a glass spreader. The plates were incubated at 30 °C for 72 h. The colonies that appeared on the plates were further sub - cultured and incubated for another 48 h at 30 °C in order to obtain pure cultures. The selected yeast isolates were obtained and the pure cultures of the isolates were stored in 10 % glycerol at 4 °C in Bijou bottles (Alabere *et al.* 2020; Okafor *et al.*, 2023; Ele *et al*. 2025).

2.4 Composting

2.4.1 Seed culture

The modified methods of Limaye *et al.* (2017), Uba aand Okonkwo *et al*. (2025) and Okwonkwo *et al.* (2026) were adopted for the composting method. Three strains selected for the formation of consortium were designated as: Rhizospheric bacterium (RB), Phosphate solubilizing bacterium (PSB) and Yeast strain (YS). These strains were used as the seed culture for composting.

2.4.2 Inoculum build up and formulating the consortium of selected strain

The three selected strains were grown at room temperature for 36 h on nutrient broth medium until maximal exponential growth was reached. For each strain, bacterial and yeast suspensions were prepared in saline with 0.01 % Tween – 80. Pooled bacterial and yeast suspensions were prepared by adding 100 mL suspension of each strains (Ibo *et al*. 2020; Dokubo and Uba, 2026).

2.4.3 Magnesium Nanoparticle and Nanocomposite Biosynthesis

The modified method of Ofunwa *et al*. (2024) and Saied *et al.* (2021) was adopted in the biosynthesis of magnesium nanoparticles and nanocomposites using mixture of bacterial and fungal filtrates under magnetic stirrer for 120 min, 70 °C and 80 rpm

2.5 Substrate Collection and Preparation

The food waste consisting of leftover food, fruit and vegetable were collected from the eatery centres, restaurants, local markets and vendors in Uli town (Uba *et al*. 2020c; 2020d). Saw dusts were collected from timber sheds and local carpentry workshops at Ihiala town (Uba *et al*. 2020e; 2020f). The grass straws were collected within Chukwuemeka Odumegwu Ojukwu University, dried and chopped into pieces (Uba *et al.*, 2020g). The paper waste consisting mostly of unused office paper and tissue paper were gathered from within the Chukwuemeka Odumegwu Ojukwu University Uli campus. All safety measures when handling these wastes such as wearing rubber gloves and face masks are observed. All the non - compostable materials contained in the waste were sorted out and not included in the compost preparation. The food waste samples were then rinsed with the tap water for removing the oil and impurities. The organic wastes were air - dried for a couple of days to remove the excessive moisture. The sorted organic materials were crushed to fine particles and then transferred to a rectangular composter as a raw material for composting (Ali *et al.* 2013; Limaye *et al.* 2017; Saleh *et al.* 2020; Uba and Udaba *et al.* 2026). All sample collection centers were located in Ihiala Local Government Area, Anambra State, Nigeria.

2.6 Composting Unit

The passive aeration composting experiment was carried out in 13 L laboratory made plastic bin composter with dimensions 43 cm x 32 cm x 25 cm (length x width x height) and aeration holes (0.6 cm diameter) at the sides of the bin ((Plate 3.2). Each experiment contained5.5 kg shredded and dried final waste mixture of approximately 55% food waste, 15% saw dust waste, grass chopping waste 22 % and 8% paper with or without inoculation as described by Aslanzadeh *et al.* (2019). The first set up was added the bacterial and yeast suspension labeled effective microorganisms, the second set up was magnesium nanoparticles labeled Mg nanocomposite, the third set up was added a combination of both microbial suspension and magnesium nanocomposite labeled consortium while the fourth set up labeled uninoculated control was maintained with saline of 0.01 % Tween -80, respectively (Zhao *et al.* 2017; Saleh *et al.* 2020; Idu *et al*., 2026a; 2026b; Ibe *et al*. 2023).

2.7 Maintaining the Moisture and Aeration Level

Composting units were kept in the laboratory shade. Composting was allowed to take place for 8 weeks. Moisture level was maintained by addition of 20 mL sterile water to the pile every day. All the samples were aerated by turning the pile using sterile plastic rod every day in the first two weeks and after that only once a week for the rest of the experimental period. The experiment was carried out in triplicates (Chukwura *et al*. 2025).

2.8 Analysis of the Composted Material

During the 56 days composting period (Ofunwa *et al*. 2024), the following parameters for the experiments were measured as follow:

2.8.1 Carbon Nitrogen Ratio

2.8.1.1 Total organic carbon determination

The total organic carbon (TOC) in the different compost treatment and control samples were determined by partial oxidation method (20) through titration against 1N $(NH_4)_2Fe(SO_4)_2.6H_2O$ using diphenylamine indicator as described by Ataikiru *et al*. (2019); Uba and Chukwura, (2016); Okafor *et al*. (2021a) and (2021b). In this test,10.0 mL of 1N potassium dichromate was added to 1 g of soil sample in a 250 mL Erlenmeyer flask, and the mixture was gently shaken to disperse soil. Thereafter, 20 mL concentrated tetraoxosulphate (iv) acid was added, swirled and allowed to stand for 30 min. A 100 mL distilled water was added, followed by the addition of 10 mL O - phosphoric acid. Three to four drops of the indicator was added and titrated with 0.5N ferrous ammonium sulphate till colour changed from green to blue and finally to red (end point).

2.8.1.2 Total nitrogen determination

The Kjeldahl spectrophotometric method was adopted according to the modified methods of Okalebo *et al*. (2002) and FAO (2008). One gram of sediment samples was weighed and placed in a Kjeldahl flask. Kjeldahl catalyst was added with composition: 0.358 g of sodium sulphate, 0.358 g of potassium sulphate, 0.1415 g of titanium oxide, 0.1415 g of copper sulphate with 10 mL of H_2SO_4, 2 mL silicon oil and 3 - 5 glass beads to reduce frothing. The mixture was heated gently until frothing ceases. It was later boiled briskly until the solution is clear and then the digestion continued for at least 30 min. Dilute all the digested sample, standards and the blanks to 1 + 9 (v/v) with distilled water to match the standards. With the aid of a pipette, take 0.2 mL of the digested sample, standard and the blank into clearly labelled test tube and add 5.0 mL of the reagents N1 and N2 and vortexed simultaneously. Allow standing for 2 h to observe blue colouration and measure the absorbency at 650 nm. Plot a calibration curve and read off the concentration of N in the solution.

The nitrogen concentration in the sample material expressed in %N is calculated as follows:

$$N (\%) = \frac{(a - b) \times v \times 100}{1{,}000 \times w \times al \times 1{,}000} \quad \text{Equation (1)}$$

where a = concentration of N in the solution, b = concentration of N in the blank, v = total volume at the end of analysis procedure, w = weight of the dried sample and al = aliquot of the solution taken.

2.8.1.3 Total phosphorus determination

The spectrophotometric ascorbic acid method was adopted according to the modified methods of Okalebo *et al*. (2002) and Uba *et al*. (2018a), (2018b). In this study, 5 mL of the supernatant clear wet-ashed digest solution was added into a 50 mL volumetric flask containing 20 mL of distilled water. Then, 10 mL of the ascorbic acid reducing agent was added to each flask, beginning with the standards and made up to 50 mL with water, stoppered and shaken well and allowed to stand for 1 h until full colour development. The standards, samples as well as the blank absorbances (blue colour) were then measured at 880_{nm} wavelength with UV-VIS Spectrophotometer (752 N SpectrumLab). A graph of absorbency against standard concentrations was plotted. The solution concentrations for each unknown and the blank was determined by subtracting the mean blank value from the unknown sample values after extrapolating from the standard curve to have a value for corrected concentration (= c in subsequent calculations). The concentration of phosphorus in the sample is given by:

$$P \text{ in sample } (\%) = \frac{c \times 0.05}{w} \quad \text{Equation (2)}$$

where c = the corrected concentration of P in the sample; 0.05 = equivalent value of the volume of the digest and dilution factor; w = weight of the sample.

2.8.1.4 Water- soluble potassium determination

Thepotassium content of the samples were determined according to the method of AOAC (2012) as described by Okeke *et al*. (2025a) and (2025b), respectively. Exactly 2 g of 2 mm sieved dried sediment samples were weighed into an extraction cup and 20 ml of ammonium acetate added at a pH of 7 and was agitated using a mechanical shaker for about 20 min and filtered using a 9 mm filter papers. The filtrates obtained were read using atomic absorption spectrophotometer (FS240AA - Agilent, USA).

2.8.1.5 Ammonium nitrate ratio

2.8.1.5.1 Ammonium determination

The exchangeable ammonium was determined using iodophenol blue method of FAO (2008) as as described by Uba *et al*. (2018c) and (2019d). Ten grams of compost samples was weighed and placed in a 250-mL wide-mouth Erlenmeyer flask and mixed with 100 mLof 2 M KCl. The solution was placed and shaken on a mechanical shaker for 1 hr. The soil – KCl suspension was allowed to settle for about 30 min. until the supernatant is clear and then filtered using filter paper. One millilitres EDTA reagent was added to 3 mL of filtrate, mixed and allowed to stand for 1 min. Then, 2 mL of the phenol nitroprusside reagent was added followed by 4 mL of the buffered hypochlorite reagent and the flask was immediately diluted to volume 25 mL with NH_4^- free water, and thoroughly mixed. The flask was placed in a water-bath maintained at 40 °C for 30 min. The flask was removed from the bath, cooled to room temperature, and the absorbance of the coloured complex was determined at a wavelength of 636 nm against a reagent blank solution. The NH_4^-N concentration of the sample was determined by reference to a calibration curve plotted from the results obtained with 25 mL standard samples containing 0, 2, 4, 6, 8, 10, and 12 µg of NH_4^-N/mL.

The calculation is ($NH4^-N$ in the sample as noted from the standard curve =
A(µg/mL):

µg of NH_4 N in 1 g soil x =

$$\frac{A \text{ x } 100 \text{ (total vol. of extract) x}}{5 \text{ (vol. of extract estimated) x}} \frac{1}{10 \text{ (wt. of soil)}}$$

$$= 2A \qquad \text{Equation 3}$$

Where: weight of the soil taken for estimation = 10 g; total volume of extract = 100 mL; volume of extract taken for estimation = 5 mL

2.8.1.5.2 Nitrate determination

The exchangeable nitrate was determined using Brucine method by adopting the modified method of USEPA (1971) as described by Uba *et al*. (2019e). The pH of the samples was adjusted to approximately 7 with acetic acid (6.7) or sodium hydroxide (6.8) after filteration. Ten millilitres aliquot of standards and samples were pipetted into the sample tubes. Ten millilitres of sulfuric acid solution was pipetted into each tube and mixed by swirling. The tubes were allowed to come to thermal equilibrium in the cold-water bath. After the temperatures of the tubes have equilibrated, 0.5 mL Brucine-sulfanilic acid reagent was added to each tube (except the control tubes) and carefully mixed by swirling. The test rack was placed in the 100 °C water bath for exactly 25 minutes. The rack was removed after incubation and allowed to cool to room temperature. The absorbance against the reagent blank was read at 410 nm using a 1 cm cell.

Calculation: The standard curve was obtained by plotting the absorbance of standards run by the above procedure against µg NO_3^-N /mL. The absorbance of the sample without the brucine-sulfanilic reagent was subtracted from the absorbance of the sample containing brucine-sulfanilic acid and determine µg NO_3^-N /mL.

2.9 Data Analysis

Data analysis was done using a two-way analysis of variance (ANOVA) was adopted in comparing the decomposition and removal efficiencies of the consortium, effective microorganisms and magnesium oxide nanocomposite with respect to their controls at 95 % confidence interval. Values less than 0.05 were considered significant at 95 % confidence intervals (Uba *et al.*, 2020h; Afulukwe *et al.*, 2025; 2026).

3. Results

Table 1 represents the chemical parameters of the wastes used in composting. From the results, paper waste had the highest carbon nitrogen ratio value of 173:1 while food scrap waste had the lowest carbon nitrogen ratio value of 24:1, respectively.

Figure 1 represents the changes in C/N ratio of composted materials during composting period. At the startup, the magnesium nanocomposite setup had the highest C/N ratio value of 198:1 followed by the control setup with 181:1, effective micro-organisms setup with 149:1 and consortium setup with 139:1. After the eighth week, the effective micro-organisms setup had the C/N ratio value of 16:1followed by magnesium nanocomposite setup with 14:1, the consortium set up with 13:1 and control set up with 11:1, respectively.

Figure 2 represents the changes in pH of composted materials during composting period. At the startup, the control setup had the highest pH value of 5.95 followed by the magnesium n-anocomposite setup with 5.94, consortium setup with 5.94 and effective micro-organisms setup with 5.92. After the eighth week, the effective micro-organisms and magnesium nanocomposite setups had the highest pH value of 6.98followed by control setup with 6.97, and consortium set up with 6.96, respectively.

Figure 3 represents the changes in phosphorus content of composted materials during composting period. At the startup, the effective micro-organisms setup had the highest phosphorus content value of 2.23mg/kg followed by the consortiumsetup with 1.70 mg/kg, magnesium nanocomposite setup with 1.38 mg/kg and control setup with 1.18 mg/kg. After the eighth week, the consortium setup had the phosphorus content value of 28.43 mg/kgfollowed by magnesium nanocomposite setup with 27.30 mg/kg, the effective micro-organisms set up with 22.08 mg/kg and controlset up with 12.58 mg/kg, respectively.

Figure 4.represents the changes in potassium content of composted materials during composting period. At the startup, the consortium setup had the highest potassium content value of 6.02mg/kg followed by the effective micro-organisms setup with 5.07 mg/kg, magnesium nanocomposite setup with 5.02 mg/kg and control setup with 3.02 mg/kg. After the eighth week, the consortium setup had the potassium content value of 9.32 mg/kg followed by magnesium nanocomposite setup with 9.05 mg/kg, the effective micro-organisms set up with 8.22 mg/kg and control set up with 6.08 mg/kg, respectively.

Figure 5 represents the changes in ammonium nitrate ratio of composted materials during composting period. At the startup, the consortium setup had the highest ammonium nitrate ratio value of 26.21followed by the effective micro-organisms setup with 11.89, magnesium nanocomposite setup with 6.75 and control setup with 5.16. After the eighth week, the control setup had the ammonium nitrate ratio value of 1.12followed by magnesium nanocomposite setup with 0.26, the effective micro-organisms set up with 0.22 and consortium set up with 0.05, respectively.

Figure 6 represents the changes in zinc content of composted materials during composting period. At the startup, the effective micro-organisms setup had the highest zinc content value of 1.32 mg/kg followed by the magnesium nanocomposite setup with 1.21 mg/kg, consortium setup with 1.20mg/kg and control setup with 0.49 mg/kg. After the eighth week, the consortium setup had the highest zinc content value of 0.59 mg/kg followed by magnesium nanocomposite setup with 0.41 mg/kg, the effective micro-organisms set up with 0.32mg/kg and control set up with 2.88 mg/kg, respectively.

Figure 7 represents the changes in copper content of composted materials during composting period. At the startup, the magnesium nanocomposite setup had the highest copper content value of 1.46 mg/kg followed by the effective micro-organisms setup with 1.46 mg/kg, consortium setup with 1.29mg/kg and control setup with 0.44 mg/kg. After the eighth week, the effective micro-organisms setup had the highest copper content value of 0.64 mg/kg followed by consortium setup with 0.58 mg/kg, the magnesium nanocomposite set up with 0.49mg/kg and control set up with 0.18 mg/kg, respectively.

Table 1: Chemical parameters of the wastes used in composting

Parameter	Food scrap waste	Saw dust waste	Grass chopping waste	Paper waste
Total carbon (%)	33.00	170.00	154.00	249.00
Total nitrogen (%)	1.40	2.50	3.12	1.44
C:N	24:1	68:1	49:1	173:1

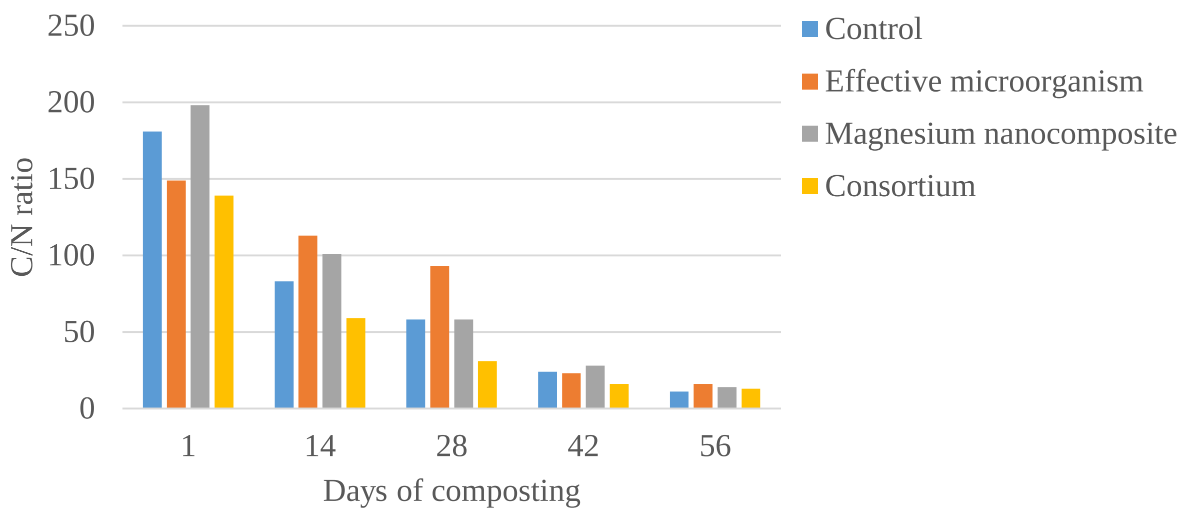

Figure 1: Changes in C/N ratio of composted materials during composting period

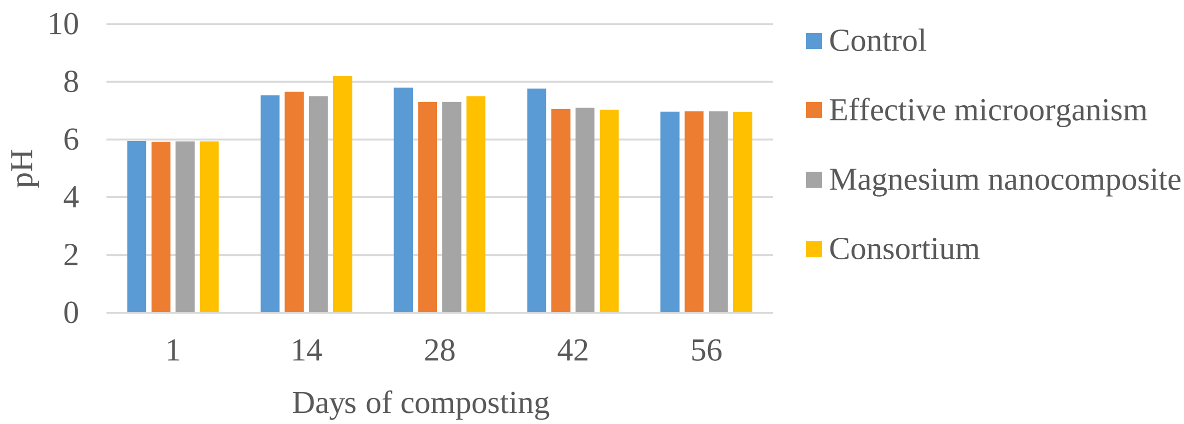

Figure 2: Changes in pH of composted materials during composting period

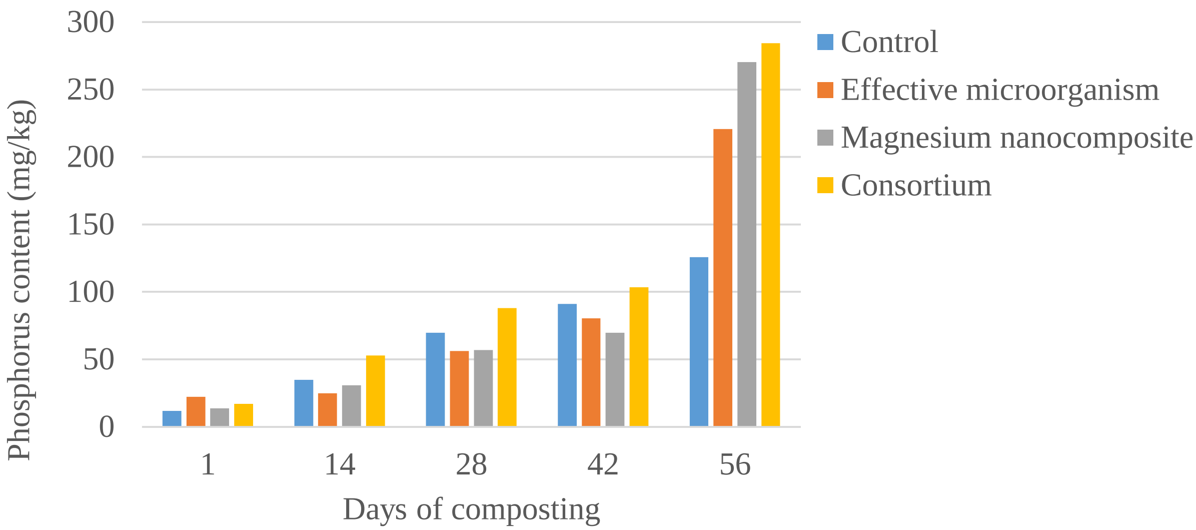

Figure 3: Changes in phosphorus content of composted materials during composting period

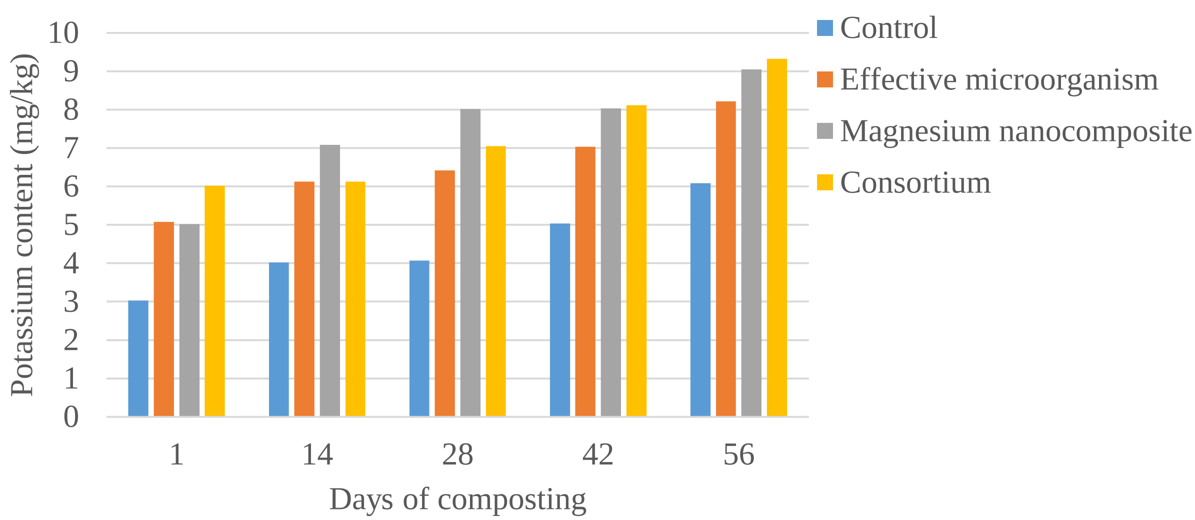

Figure 4: Changes in potassium content of composted materials during composting period

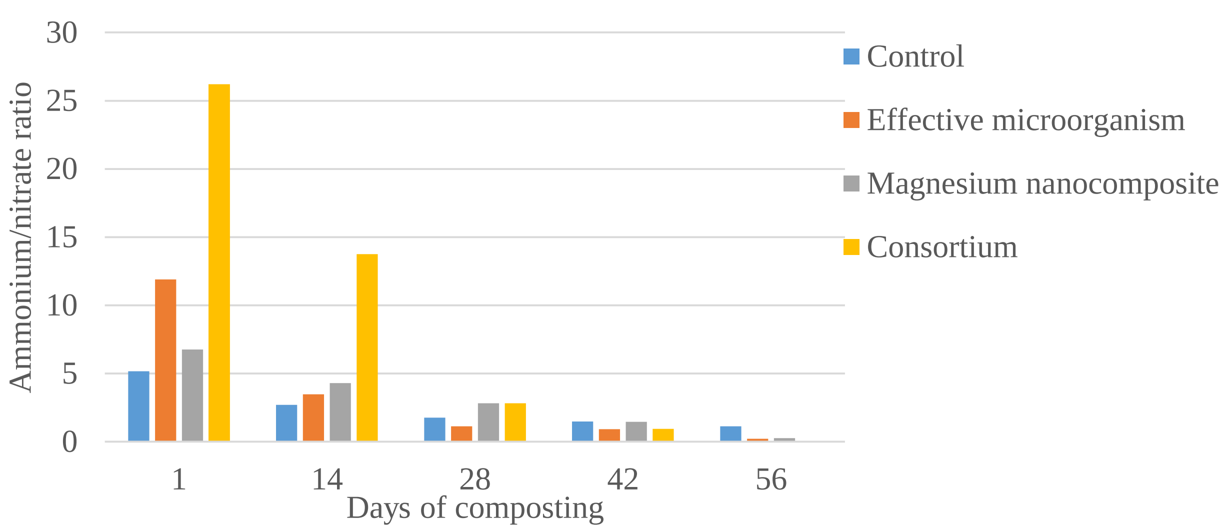

Figure 5: Changes in ammonium nitrate ratio of composted materials during composting period

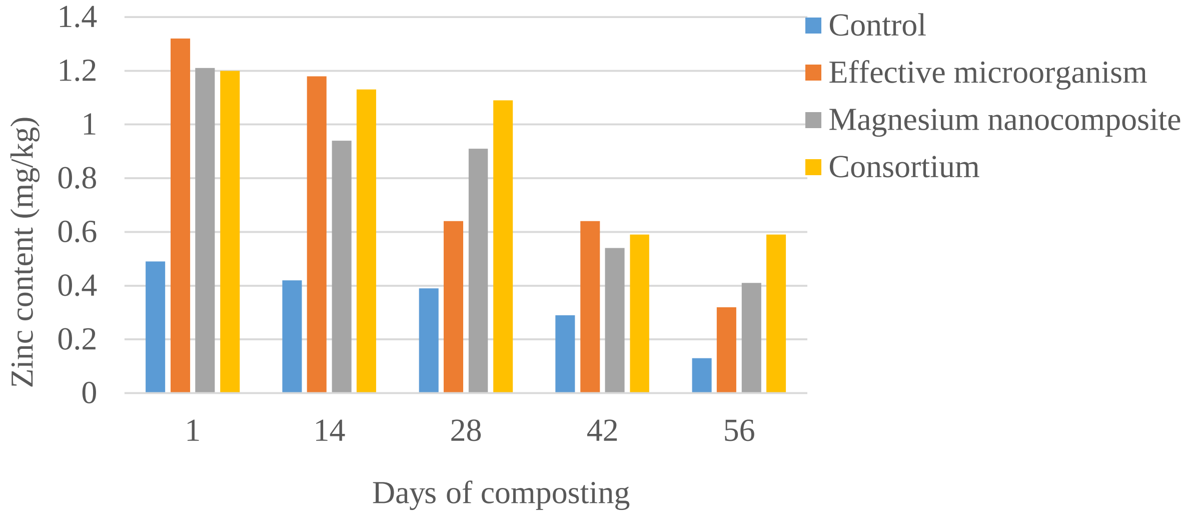

Figure 6: Changes in zinc content of composted materials during composting period

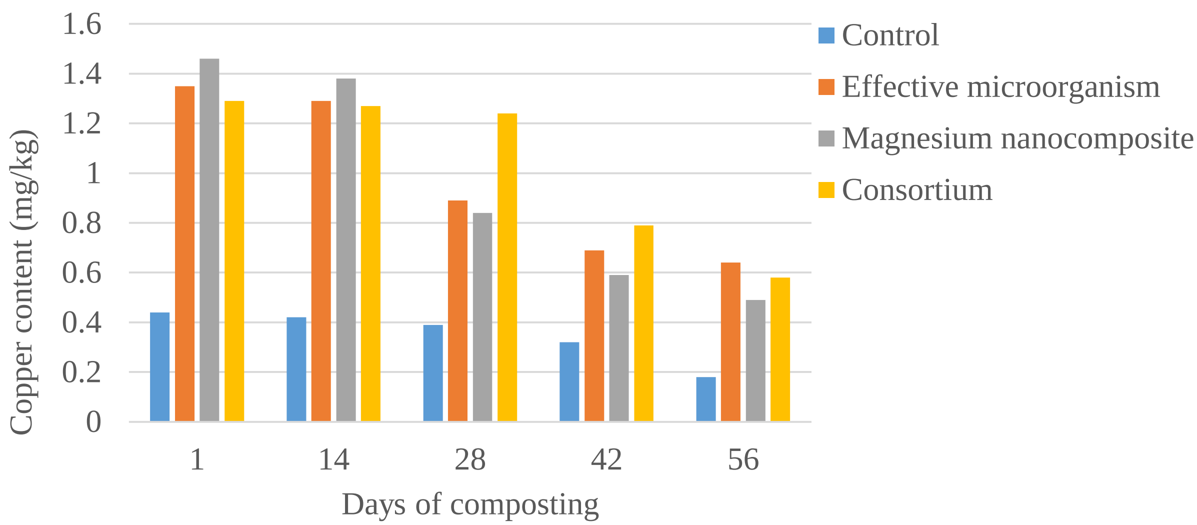

Figure 7: Changes in copper content of composted materials during composting period.

4. Discussion

The composting process is a dynamic biochemical system driven by microbial activity and strongly influenced by substrate composition and treatment conditions. In this study, variations observed in physicochemical parameters across the different setups reflect the impact of microbial inoculants and magnesium nanocomposite on organic matter degradation and nutrient transformation. A nutritional balance in form of an optimum C/N ratio is essential to formulate an efficient compost mix. As composting proceeds with time, variations in C/N projected the rate of organic degradation as governed by the extent of carbon transformed to CO_2 (Ralstogi *et al*., 2020; Ezeamama *et al*., 2025a; 2025b). Researchers have suggested various ideal or recommended range of C/N ratios ranging from 12 to 25 but the optimal value is often dependent on the initial feedstock (Iheukwumere *et al*., 2012a; 2012b; Pushpa *et al*., 2016; Mamo *et al*., 2021). In this study, the results in Table 1 and Figure 1 revealed that the C:N ratio values of the final composts in the treatment set ups were lower than those in the feedstock or raw composting materials. However, there were continuous lowering of C:N ratio values of the compost treatment set ups in this study and were all found within the recommended or ideal range of between 12 and 25 except in the control set up; thus, the compost products were determined to be in their mature phases. Enhanced organic matter decomposition in the presence of Effective Microorganisms resulted in lowering the C/N ratio (Pushpa *et al*., 2016). In general, higher C:N ratio in compost signifies the existence of non-metabolized complex carbon and nitrogen while thorough decomposition of these materials is demonstrated by the lower C:N ratios (Mundi *et al*., 2013; 2014; Karanja *et al*., 2019).

The pH of the growing medium plays a major role in the availability of plant nutrients. The best value of pH is between 6 and 7, which is common for most of the plants (Shilev *et al*., 2014). In this study, the result in Figure 2 demonstrated that composting process generally started at slightly low pH in all the treatments units of the study which could be due to the presence acidic materials such as food wastes. The pH then increase progressively as decomposition of composted materials set in which could due to protein decomposition and gradual disappearance of CO_2. Initiation of active decomposition of materials led to a slight decrease in the pH to almost neutral pH conditions at the end of the composting period. Random variations from acidic, neutral and alkaline pH at different composting periods among the treatments were also observed. Also, non - significant ($P > 0.05$) differences was detected among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA). Zhang and Sun (2016) reported that ideal values for pH generally range from 5.5 - 8.0 during compositing and in this study, the composting pH in all treatment set ups and control were within this range.

Primary nutrients required by microorganisms for proper composting are carbon (C), nitrogen (N), phosphorus (P), and potassium (K) (Okoye *et al*. 2014; Pushpa *et al*., 2016; Umezulora *et al.,* 2026). The results in Figures 3 and 4 revealed remarkable and substantial increase in the phosphorus (Figure 3) and potassium (Figure 4) content levels of all the compost units through the 56 composting periods. The reasons for these positive changes could be due to the complete breakdown of organic matter contents and precipitation of phosphorus and potassium ions in solid form thereby making these ions not readily available to dissolve and undergo leaching process. Phosphorus and potassium content levels of resultant composted materials in this study have shown that the composts have approached maturation phase.

Ammonium- Nitrate ratio (NH_4^+/NO_3^-) has been described as an important maturity index as the values decrease as composting advanced due to aerobic nitrification process. Generally, decrease in NH_4^+ concentration and increase in NO_3^- concentration in a composted material during composting is regarded that the final compost pile had mature or approaching maturation phase (Selim *et al*. 2012). Researchers have suggested various ideal or recommended limit of < 1.00 for NH_4^+/NO_3^- ratio and at this limit considered the final compost mature (Gao *et al*., 2010; Okoye *et al*., 2016a; 2016b; Alisa*et al*., 2020b) while higher values showed the presence of unstabilized, partially decomposedand metabolized materials during the process. In this investigation, the result in Figure 5 showed that there were drastic decline in the NH_4^+/NO_3^- ratio in all the treatment set ups and control. The possible reason for these changes could be attributed to the complete breakdown of organic matter contents release as CO_2 and subsequent increase in the nitrification process.

Heavy metal concentration in compost is one of the main factors that restrict marketing and use due to bioaccumulation potential of these metals. Zinc (Zn)and Cu were reported as the most abundant heavy metals in the source-separated municipal solid waste as observed in other studies (Selim *et al*., 2012; Tibu *et al*., 2019). In this research work, the results in Figures 6 and 7 demonstrated the continuous decrease in zinc (Figure 6) and copper (Figure 7) content levels in all the composting units throughout the 56 days of composting. The possible reason for this decline could be attributed to the feedstock or waste source separation at the point of waste collection point and subsequently during sample processing thereby prevent chances of metal pollution. Another possible for this decreasing trends in Zn and Cu levels could be due to formation metal complexes with the accumulated compost humic substances rendering them non – available for biological processes and not water extractable. Statistically, extreme significant differences ($P < 0.05$) were detected in zinc and copper (content levels among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA) and hence could be applied agricultural purpose of soil amendment and plant growth. These compost metal observations in the present study was confirmed by published works of Selim *et al*. (2012), Ofori (2013), Tibu *et al*. (2019), Alisa*et al*. (2020) and Anameze *et al*., (2023) who reported low concentration of heavy metals in their composted piles.

5. Conclusion

The findings of this study demonstrate that composting efficiency and nutrient quality are significantly improved through the application of microbial inoculants and magnesium nanocomposite. The reduction in C/N ratio, stabilization of pH, and enhancement of essential nutrients such as phosphorus and potassium indicate effective organic matter decomposition and compost maturity. Among the treatments, the microbial consortium showed superior performance in nutrient enrichment, while all amended setups outperformed the control. Overall, the integration of biological and nanotechnological approaches presents a promising strategy for producing high-quality compost and promoting sustainable organic waste management.

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