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# Monitoring Compost Maturity Using Enzymatic Indicators in Microbial and Nanocomposite-Treated Systems

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**Abstract**

This study evaluated the influence of microbial inoculants and magnesium nanocomposite on enzymatic activities during the composting of organic materials. Key enzymes, including dehydrogenase, catalase, invertase, urease, and alkaline phosphatase, were monitored as indicators of microbial activity and compost maturity. At the onset of composting, dehydrogenase activity was highest in the effective microorganisms and magnesium nanocomposite treatments (1.02 mg TPF/g/hr), compared to the control (0.36 mg TPF/g/hr). However, by the end of the composting period, the control recorded the highest value (1.96 mg TPF/g/hr), while the consortium treatment showed the lowest (0.54 mg TPF/g/hr). Catalase activity initially peaked in the control (2.03 M/L $KMnO_4$/g) but increased significantly in the magnesium nanocomposite treatment to 3.65 M/L $KMnO_4$/g at maturity, compared to 2.70 M/L $KMnO_4$/g in the control. Invertase activity was highest at the start in the magnesium nanocomposite setup (0.35 mg glucose/g) and lowest in the effective microorganisms treatment (0.26 mg glucose/g), while at the end, the control recorded the highest value (0.45 mg glucose/g) and the consortium the lowest (0.36 mg glucose/g). Urease activity showed a marked decline across treatments, decreasing from 31.20 mg $NH_3$/g in the magnesium nanocomposite setup and 25.20 mg $NH_3$/g in the control at the beginning to 8.20 mg $NH_3$/g and 1.00 mg $NH_3$/g, respectively, at the end of composting. Alkaline phosphatase activity increased substantially, with the effective micro - organisms treatment rising from 4.60 mg phenol/g at the start to 28.00 mg phenol/g at the end, while the control recorded the lowest final value (16.40 mg phenol/g). Overall, the results indicate that microbial and nanocomposite amendments significantly influence enzymatic dynamics, enhancing early-stage microbial activity and accelerating compost stabilization. These findings underscore the importance of enzyme-based monitoring and highlight the potential of integrated amendments in improving composting efficiency and quality.

***Keywords:*** *Composting; Compost maturity; Enzyme activity; Magnesium nanocomposite; Microbial inoculants.*

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## Introduction

The rapid increase in the generation of organic wastes from domestic, agricultural, and agro-industrial activities has become a major environmental concern, particularly in developing countries (Alisa *et al*., 2020a; Anukam *et al.* 2020a; 2020b). Improper disposal of these wastes contributes to environmental pollution, greenhouse gas emissions, and public health risks. Composting has emerged as an environmentally sustainable and cost-effective strategy for the management and valorization of organic waste (Uba *et al*., 2020a; 2020b). This biological process involves the aerobic decomposition of organic materials by diverse microbial communities, resulting in the formation of a stable, nutrient-rich product that can be applied as an organic fertilizer to improve soil health and agricultural productivity (Umeh *et al.*, 2020; 2021; Dokubo *et al*., 2024; Uba *et al*. 2020c; 2020d).

The efficiency of the composting process is largely governed by microbial activity, which drives the breakdown of complex organic compounds such as cellulose, hemicellulose, proteins, and lipids into simpler forms (Uba *et al*. 2016; Uba *et al.*, 2017). Monitoring microbial activity during composting is therefore essential for understanding the progression of decomposition and determining compost maturity (Nkamigbo *et al*. 2020a; 2020b). Among the various indicators available, enzymatic activities are considered highly sensitive and reliable biochemical markers because they directly reflect microbial metabolism and functional diversity within the composting system (Njoku *et al*. 2019a; 2019b; Egurefa *et al*. 2020a; 2020b; Okolo *et al.*, 2025; Okoye *et al*., 2026).

Key enzymes such as dehydrogenase, catalase, invertase, urease, and alkaline phosphatase play crucial roles in organic matter transformation and nutrient cycling (Dokubo and Uba, 2023; Uba, 2019a; 2019b; Okpalaunegbu *et al.*, 2025; Obiefuna *et al.* 2025; 2026). Dehydrogenase activity is widely recognized as an indicator of total microbial oxidative activity and reflects the intensity of biological oxidation processes occurring within compost (Uba and Obiefuna, 2023). Catalase activity is associated with the breakdown of hydrogen peroxide, thereby protecting microbial cells from oxidative damage and indicating aerobic microbial activity (Ofunwa *et al*., 2024; Uba *et al*., 2025). Invertase catalyzes the hydrolysis of sucrose into glucose and fructose, thus facilitating carbon utilization by microorganisms (Ubani *et al*., 2024a; 2025). Urease is responsible for the hydrolysis of urea into ammonia, playing a critical role in nitrogen mineralization, while alkaline phosphatase is involved in the release of inorganic phosphate from organic phosphorus compounds, thereby contributing to phosphorus availability (Uba e*t al.*, 2021a; 2021b; Ubani *et al*., 2024b; Ekwenze *et al*., 2025).

In recent years, efforts to enhance composting efficiency have focused on the use of microbial inoculants and advanced materials (Uba *et al*., 2024; Anichebe *et al*., 2019). Effective microorganisms (EM) and microbial consortia have been widely applied to accelerate the composting process by introducing beneficial microbial populations that enhance enzymatic activity and organic matter degradation (Mere *et al.*, 2025; Uba *et al*., 2019c; 2019d). These inoculants improve the rate of decomposition, reduce composting time, and enhance the quality of the final compost product (Okoye *et al*., 2020a). In addition, the application of nanomaterials, particularly magnesium-based nanocomposites, has gained increasing attention due to their potential to improve microbial metabolism, enhance enzyme activity, and facilitate nutrient transformation (Enemchukwu *et al*., 2026a; Uba, 2019c). Magnesium plays a vital role in enzymatic reactions as a cofactor, and its nano-form may further enhance bioavailability and reactivity within compost systems (Enemchukwu *et al*., 2026b; Okoye *et al*., 2020b; 2020c).

Despite these advancements, there is still limited understanding of how microbial inoculants and nanocomposite materials interact to influence enzymatic activity patterns throughout the composting process. Most studies have focused on physicochemical parameters, with less emphasis on the biochemical processes that underpin compost stability and maturity (Dokubo *et al*., 2022a; 2022b; Anidu *et al*., 2023; Obiefoka *et al*., 2023; Dokubo *et al*., 2024; Ubajekwe *et al*., 2025). A detailed investigation of enzyme dynamics can provide deeper insights into microbial functionality and the effectiveness of different composting amendments.

Therefore, this study aims to evaluate the changes in key enzymatic activities—dehydrogenase, catalase, invertase, urease, and alkaline phosphatase—during the composting of organic materials amended with effective microorganisms, microbial consortium, and magnesium nanocomposite. By comparing these treatments with a control setup, this research seeks to elucidate the role of biological and nanotechnological interventions in enhancing composting efficiency and accelerating compost maturity. The findings of this study will contribute to the development of improved composting strategies for sustainable organic waste management and agricultural applications.

## Materials and Methods

### Sourcing and Collection of Samples

All reagents used in this study, including pure magnesium nitrate ($MgNO_3)_2$, were of analytical grade and sourced from Loba Chemie, Mumbai, India. Rhizospheric soil samples and soybean roots were aseptically collected using a sterile hand trowel and knife from the school garden, with coordinates recorded using a handheld GPS, within the premises of Chukwuemeka Odumegwu Ojukwu University, Uli Campus, Ihiala Local Government Area, Anambra State. Fresh ripe queen pineapple (*Ananas comosus*) samples were purchased from Nkwo Ogbe Market in Ihiala, Anambra State. All collected samples were transferred 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).

### Enrichment and Isolation of Effective Microbial Species

The methods of Ofunwa *et al*. (2024), Alfred *et al*. (2023) and Alfred *et al*. (2025) were adopted in the isolation of rhizospheric bacterial (RB) species, phosphate solubilizing bacteria (PSB) and yeast using nitrogen free biotin medium (NFb), Pikovaskaya (PVK) agar medium and Yeast Extract Dextrose Peptone broth, respectively. After incubation, discrete colonies were selected and purified cultures were preserved in 20 % glycerol contained in Bjou bottle and stored at - 70 °C.

### Magnesium Nanoparticle and Nanocomposite Biosynthesis

The modified methods of Saied *et al.* (2021), Okafor *et al.*, (2023) and Ele *et al*. (2025) were 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.

### 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*. 2020e). Saw dusts were collected from timber sheds and local carpentry workshops at Ihiala town (Uba *et al*., 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 were 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 (Saleh *et al.* 2020; Uba and Udaba *et al*. 2026). All sample collection centers were located in Ihiala Local Government Area, Anambra State, Nigeria.

**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. Each experiment contained 5.5 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*. (2020). 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 (Saleh *et al.* 2020; Idu *et al*., 2026a; 2026b; Ibe *et al*., 2023).

**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).

**Analysis of the Composted Material**

During the 56 days composting period, compost samples were collected and the following parameters for the experiments were measured following the methods of Ofunwa *et al*. (2024); Oghonim *et al*. (2020a) and (2026b) as follow:

**Biochemical Analysis of the Composted Material**

**Dehydrogenase activity (DHA) assay**

DHA was determined according to the methods of Njoku *et al*. (2019); Uba and Chukwura, (2016); Okafor *et al*. (2021a) and (2021b). One gram of compost, 30 mg glucose, 1 mL of 3 % 2, 3, 5 triphenyltetrazolium chloride (TTC) solution and 5 mL pure water were added. The samples were incubated for 24 h at 37 °C. The formation of 1, 3, 5 triphenylformazan (TPF) was determined spectrophotometrically at 485 nm and results were expressed as mg TPF $g^{-1}$ dry sample. All dehydrogenase activity results reported with the mean value of three replicates determinations calculated on an oven-dry basis; moisture was determined from loss in weight after drying the compost at 105 °C for 48 h.

**Catalase activity assay**

By adopting the methods of Wu *et al*. (2016) and Uba *et al*. (2018a), (2018b), the activity of hydrogen peroxidase oxidoreductase (catalase) in compost was determined by back-titrating residual $H_2O_2$ with $KMnO_4$. Two grams air-dried compost samples into 100 mL beakers followed by 40 mL distilled water and 5 mL 0.3 % $H_2O_2$. The compost samples were incubated in the dark at 25 °C for 20 min in incubator shaker. Then, 5 mL 6 $ML^{-1}$ sulfuric acid was added to stabilize the unbroken $H_2O_2$. The suspension was filtered with slow-filter paper. Thereafter, 25 mL filtrate solution was taken and titrated against 0.3 $ML^{-1}$ $KMnO_4$ till light pink (record volume of $KMnO_4$ used as B). Meantime, 25 mLof 0.3% $H_2O_2$ was titrated against 0.3 $ML^{-1}$ $KMnO_4$ till light pink (record volume of $KMnO_4$ used as A). Here, (A-B)×actual concentration of KMnO4 was the compost catalase activity. The compost catalase activity was calculated as milliliter of 0.3 $ML^{-1}$ $KMnO_4$per gram of soil after 20 min.

**Invertase activity assay**

By adopting the methods of Wu *et al*. (2016), Okeke *et al*. (2025a) and (2025b), the invertase activity (sucrase) (substrate, 5 % sucrose) ,also was measured by reducing sugars release in the incubation period of 24h at 37 °C and colorimetrically. In this test, 5 g air - dried compost samples was placed into 50 mL conical flask and 15 mL of 18 % sucrose solution, 5 mL pH5.5 phosphate buffer and 5 drops of toluene were added. The mixture solution was shaken and incubated in the incubator at 37 ºC for 24h. After filtration, 1 mL filtrate was taken and placed into 50 mL volumetric flask containing 3 mL 3,5- dinitrosalicylic acid. The mixture was heated for 5 min in a boiling water bath and cooled in a running water for 3 min. Thereafter, distilled water was added to dilute the yellowish mixture to 50 mL mark. Three millilitres of the yellow solution was taken to detect the colorimetry at 508 nm wavelength. The sucrase activity was milligram of glucose produced from sucrose hydrolyzed by invertase after 24h per gram of compost

**Urease activity assay**

By adopting the methods of Wu *et al*. (2016), Uba *et al*. (2018c) and (2019d), the compost urea amidohydrolase (urease) (substrate, 10% urea) was determined colorimetrically by the liberated $NH_4^+$ after 24h of incubation at 30 °C. In this test, 5 g air - dried compost samples was placed into 100 mL conical containing 1 mL toluene and left for 15 min. To this solution, was added 10 mL 10 % urea solution and 20 mL citrate buffer (pH 6.7) and mixed carefully, and the contents allowed to stand for approximately 15 minutes until the toluene had completely penetrated the composted sample. A control, in which 10 mL distilled water was substituted for the urea, was run simultaneously for each soil sample. The mixture was incubated at 37 °C for 24 h, diluted with 38 °C hot water to 100 mL mark, carefully shaken and filtered into the conical flask. Thereafter, 3 mL of the filtrate was taken and placed into 50 mL volumetric flask containing 10 mL distilled water and thoroughly shaken. To this was added 4 mL of sodium phenol solution, 3 mL sodium hypochlorite solution, shaken thoroughly and left for 20 min and finally diluted to 50 mL mark with distilled water. The blue mixture was determined spectrophotometrically at 578 nm wavelength within 1 h. The compost urease activity was expressed as $NH_3$-N milligram per gram soil after 24 h.

**Phosphatase activity assay**

By adopting the methods of Wu *et al*. (2016) and Uba *et al*. (2019e), the phosphomonoesterase (phosphatase) was determined spectrophotometrically by the liberated phenolphthalein after the substrate 1 % sodium phenolphthalein phosphate, was incubated 1 hr at 30 °C. In this test, 5 g air - dried compost samples was placed into 100 mL conical flask containing 1 mL toluene and left for 15 min. To this solution, 5 mL disodium phenol phosphate and 5 mL of the borate buffer (pH 10.0 borate buffer for alkali phosphatase) were mixed, respectively. Also, disodium phenolphosphate was replaced by 5 mL distilled water which serves as control for each compost sample. The mixture system was diluted with 38 °C hot water to 50 mL mark after incubation at 37 °C for 24 hr and filtered. Thereafter, 1 mL of the filtrate was added into 100 mL conical flask containing 5 mL borate buffer, 3 mL of 2.5 % potassium ferricyanide, 3 mL of 0.5 % 4 -amino-antipyridine, mixed thoroughly and make to100 mL volume with distilled water. The optical density of the stable pink liquid after

30 min was measured at 570 nm and phosphatase activity was calculated as phenol milligram per gram soil.

**Data Analysis**

Data were analyzed using GraphPad Prism Version 8.0.2. Descriptive statistics were performed to summarize the data in the form of mean and standard deviation. The two tailed paired T-Test and Two Factor Analysis of Variance (ANOVA) followed by Dunnett's multiple comparison test 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 and P values below 0.05 were considered significant (Uba *et al.*, 2020h; Afulukwe *et al.*, 2025; 2026).

## Results

Figure 1 represents the changes in dehydrogenase activity of composted materials during composting period. At the beginning of the composting, the effective micro-organisms and magnesium nanocomposite setups had the highest dehydrogenase activity value of 1.02 mg TPF/g/hr while control setup had the lowest dehydrogenase activity value of 0.36 mg TPF/g/hr. At the end of the composting, the control setup had the highest dehydrogenase activity value of 1.96 mg TPF/g/hr while the consortium setup had the lowest dehydrogenase activity value of 0.54 mg TPF/g/hr.

Figure 2 represents the changes in catalase activity of composted materials during composting period. At the beginning of the composting, the control setup had the highest catalase activity value of 2.03 M/L $KMnO_4$/g while consortium setup had the lowest catalase activity value of 1.45 M/L $KMnO_4$/g. At the end of the composting, the magnesium nanocomposite setup had the highest catalase activity value of 3.65 M/L $KMnO_4$/g while control set up had the lowest catalase activity value of 2.70 M/L $KMnO_4$/g.

Figure 3 represents the changes in invertase activity of composted materials during composting period. At the beginning of the composting, the magnesium nanocomposite setup had the highest invertase activity value of 0.35 mg glucose/g while effective micro-organisms setup had the lowest invertase activity value of 0.26 mg glucose/g. At the end of the composting, the control setup had the highest invertase activity value of 0.45 mg glucose/g while consortium set up had the lowest invertase activity value of 0.36 mg glucose/g.

Figure 4 represents the changes in urease activity of composted materials during composting period. At the beginning of the composting, the magnesium nanocomposite setup had the highest urease activity value of 31.20 mg $NH_3$/g while control setup had the lowest urease activity value of 25.20 mg $NH_3$/g. At the end of the composting, the magnesium nanocomposite setup had the highest urease activity value of 8.20 mg $NH_3$/g while control consortium set up had the lowest urease activity value of 1.00 mg $NH_3$/g.

Figure 5 represents the changes in alkaline phosphatase activity of composted materials during composting period. At the beginning of the composting, the effective micro-organisms setup had the highest alkaline phosphatase activity value of 4.60 mg phenol/g while consortium setup had the lowest alkaline phosphatase activity value of 0.80 mg phenol/g. At the end of the composting, the effective micro-organisms setup had the highest alkaline phosphatase activity value of 28.00 mg phenol/g while control set up had the lowest alkaline phosphatase activity value of 16.40 mg phenol/g.

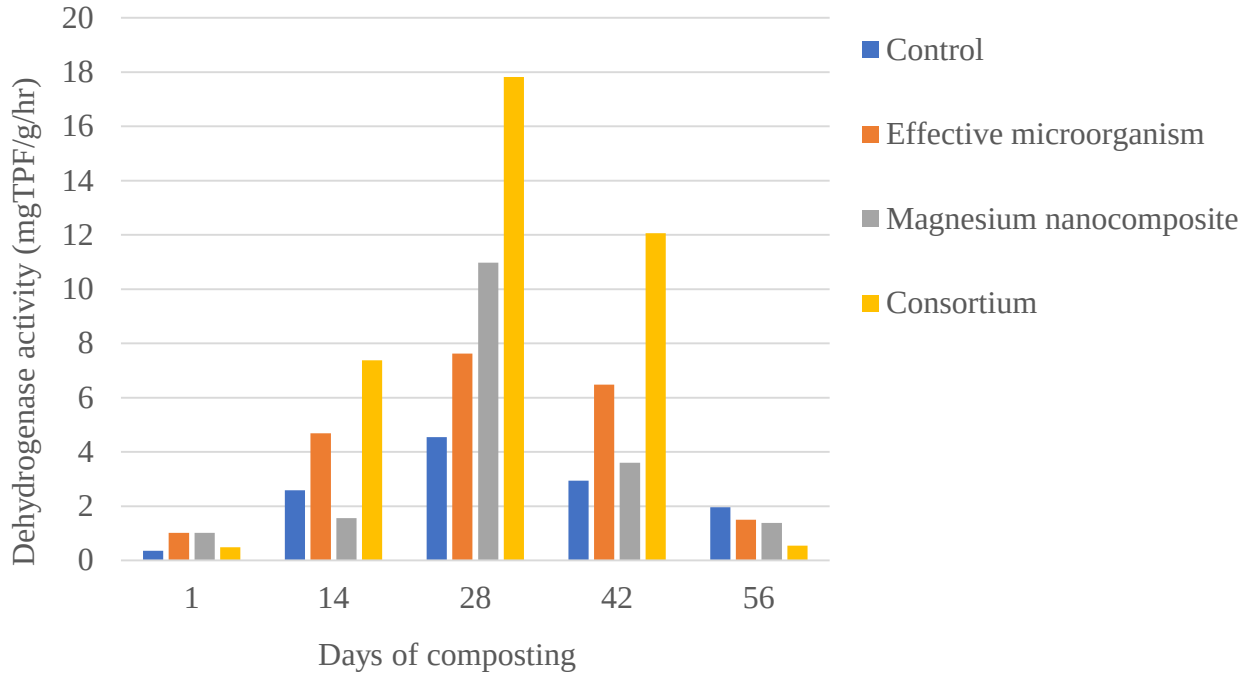


**Figure 1:** Changes in dehydrogenase activity of composted materials during composting period
**Key:** mg = Milligram; TPF/g/hr = Triphenyl formazan per gram of compost per hour

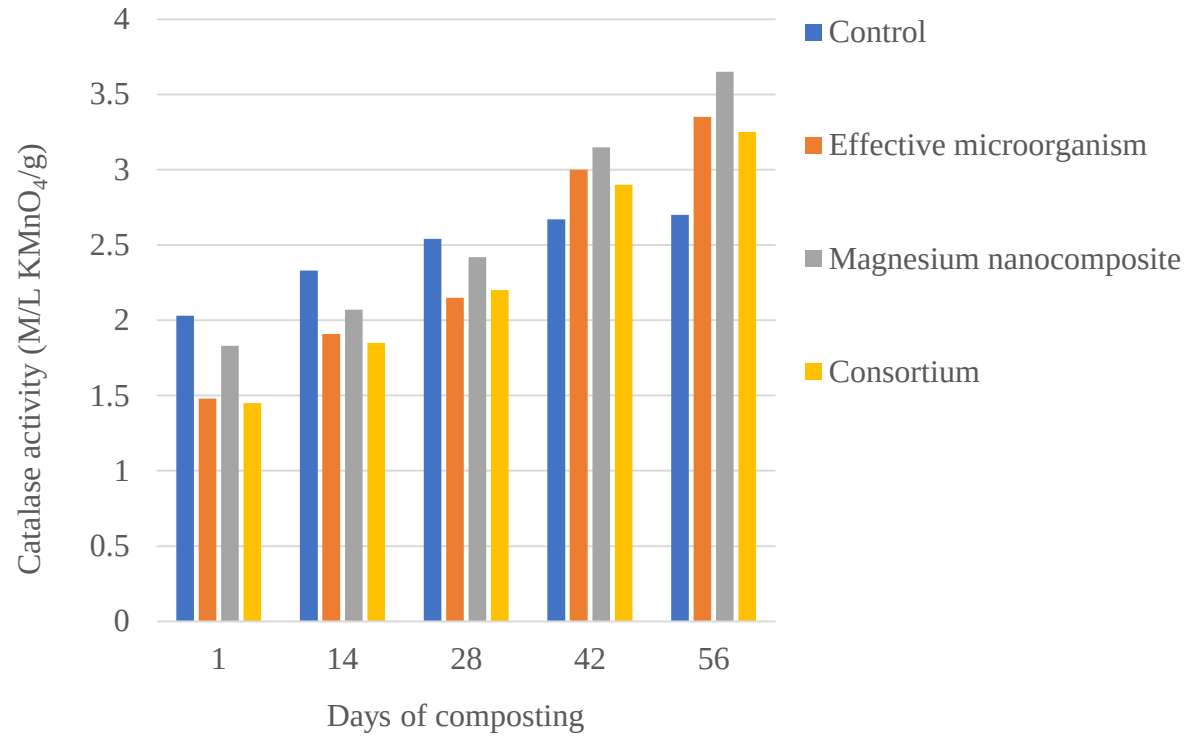


**Figure 2:** Changes in catalase activity of composted materials during composting period
**Key:** M/L $KMnO_4$ /g = Moles per litre potassium per manganate per gram of compost

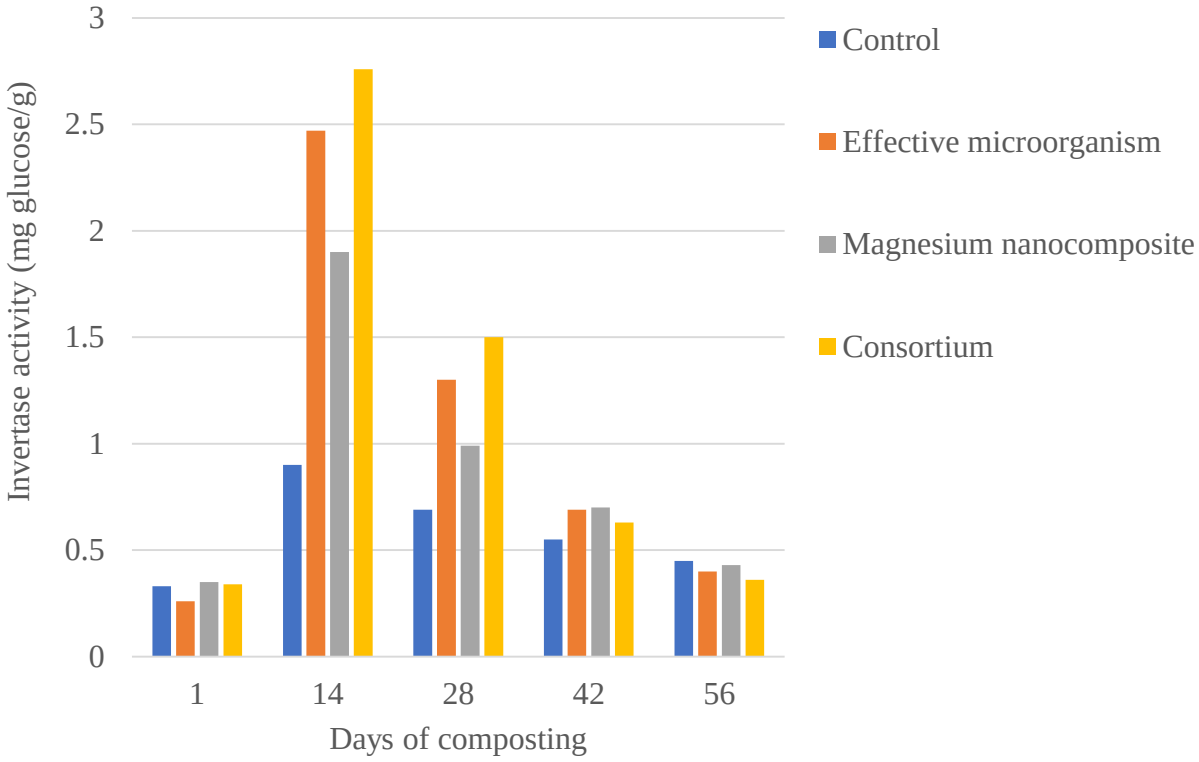


**Figure** 3: Changes in invertase activity of composted materials during composting period
**Key:** mg glucose/g = Milligram glucose per gram of compost

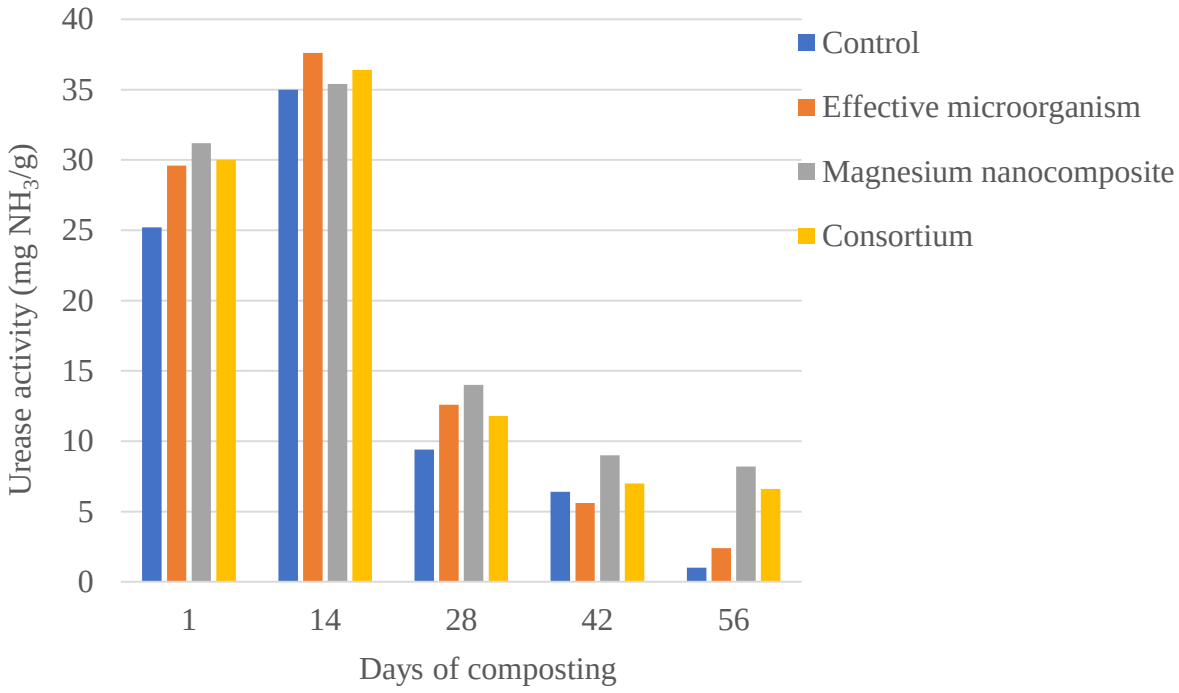


**Figure 4:** Changes in urease activity of composted materials during composting period.
**Key:** mg $NH_3$ /g = Milligram ammonia per gram of compost.

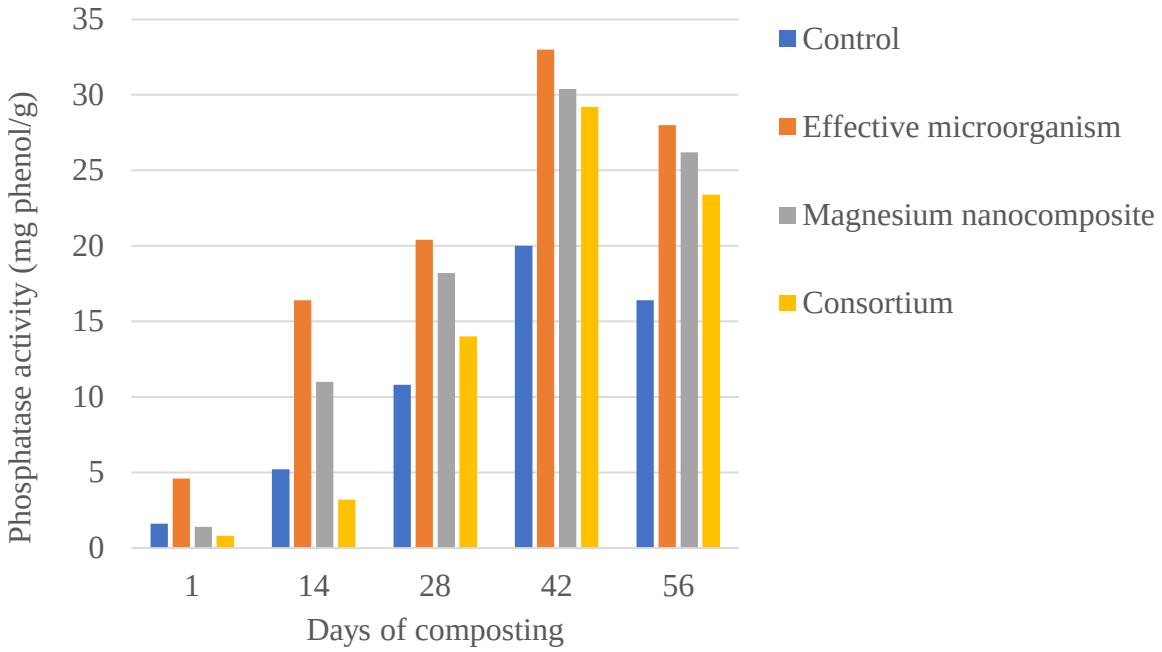


**Figure 5:** Changes in alkaline phosphatase activity of composted materials during composting period.
**Key:** mg phenol /g = Milligram phenol per gram.

## Discussion

The monitoring of enzyme activities throughout the compost process is informative with respect to understanding transformations that occurred during composting (He et al., 2013). Enzyme activities in the compost depends on the available biodegradable matter and microbial activity at different stages of composting (Kazemi et al., 2017a). Dehydrogenase activity is a measure of the intensity of microbial metabolism in compost and thus of microbial activity in compost (Kazemi et al., 2017a). The result in Figure 1 showed that dehydrogenase activity increased steadily from the initial stage of the composting in all the set ups and 28 days had the highest dehydrogenase activity. Oxidation of simple carbon substrates catalyzed by enzymes led to rapid increase in dehydrogenase activity in the initial period of composting (Kazemi et al., 2017b). High intensity of dehydrogenase has

been attributed to the thermophilic phase of the composting process (Bernardi et al., 2018). After 28 days, a dramatic decline was observed in dehydrogenase activity, which signifies the reduction in pH and available organic matter for microbes and the subsequent completion of the active composting phase and mineralizationprocess (Ratogi *et al*., 2019). Statistically, no significant change ($P < 0.05$) was detected in dehydrogenase activity among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA). The profile of dehydrogenase activity recorded in this studywas very similar to the studies reported by Kazemi et al. (2017a) on (2019b) on agro –industrial waste compost, respectively.

Catalase demonstrates the intensity of the degree of composting oxidation, because catalase can decompose hydrogen peroxide produced in the composting process and thus decrease its poisoning effect to microorganism (Ukalska-Jaruga *et al*., 2018). The result in Figure 2 showed that there was gradual rise in catalase activity in all the composting units throughout the 56 days composting period. The possible reason for the gradual increase in catalase activity during the composting process could be due to the increase in biochemical metabolism activity enhanced by the thermophiles (active microbial flora) as possible replacement for the mesophiles alongside the increase in the composting temperature. Statistically, no significant change ($P < 0.05$) was detected in catalase activity among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA).The catalase activity profile recorded in this study was also very similar to the previous study reported by Feng *et al.* (2019) on different livestock compost.

Invertase catalyzes the hydrolysis of sucrose into subunits like glucose, which can be assimilated by microorganisms or plants for their metabolic activities and hence drives carbon cycling (Wu *et al*., 2016).Urease catalyzes the transformation and decomposition of urea to ammonia and $CO_2$ as well as promote the transformation, decomposition and mineralization of nitrogenous organic matter (Kazemi *et al*., 2017a). Thus, it was the key index to evaluate the transformation velocity of nitrogen in the composting process (Feng *et al.*, 2019). The results in Figures 3 and 4 revealed similar changing trends in both invertase (Figure 3) and urease (Figure 4) activities in all the composting units during 56 days composting period. It was observed there were sharp rise in both activities in the first 14 days of composting indicating higher microbial metabolic activities secreting higher invertase and urease concentrations for the decomposition and transformation susceptible carbon and nitrogenous organic matters (Li *et al*., 2016; Kazemi *et al*., 2016). As the composting processes proceed after 14 days to 56 days, the invertase and urease activities in the composted pile reduced gradually, which could be attributed to the reduction in the mesophilic microbial counts. Thereafter, a reduction in invertase and urease activities and the partial breakdown and mineralization rate of carbon and nitrogenous organic matters also resulted as the reactions proceed into the thermophilic phase of the composting. Thus, lower concentration of urease activity towards the last stage of composting process results in lower $NH_3$volatilization, that is, lesser losses of N during the 56 days composting process (Bernardi *et al*., 2018). Statistically, no significant ($P > 0.05$) changes was detected in the invertase activities while significant changes ($P < 0.05$) was detected in the urease activities among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA). The invertase and urease activities profiles recorded in this study were supported and upheld with the previous studies reported by Hannum *et al*. (2017), Jain *et al*. (2018), Feng *et al.* (2019) and Rastogi *et al.*, 2019) on straw, biochar, MSW and different livestock composts.

Phosphatase activity is involved in the hydrolysis of organic phosphorus or sulfur to different inorganic forms that plants can metabolize (Awasthi *et al*., 2015). Phosphatase is considered as a general microbial indicator because of the critical role it plays in P cycles. Information about the evolution and behaviour of phosphatases also gives information about the hydrolytic enzymes as a whole in composting, since they are considered to be good representatives of overall hydrolytic activity, at least in organic soils (Kazemi *et al*., 2017b). The result in Figure 5 revealed that the initial concentration of alkaline phosphatase in all the composting units was high and significantly increase in the positive trends till day 42 of the composting period. The higher intensity of alkaline phosphatase activity could possibly be due to the continual influx of available forms of phosphorus during the composting process which agreed with Figure 5 result above, since stronger growth of microorganisms results into higher activity of phosphatase and eventually higher quantity of orthophosphate (inorganic form of P) (Kazemi *et al*., 2017b; Bernardi *et al*., 2018). After 42 days of composting, alkaline phosphatase activity slightly decrease. The decline in the level of alkaline phosphatase activity during the maturation phase could be due to variations in the enzymes - humic substances complex formation during the late stage of composting process (Bernardi *et al*., 2018). Statistically, significant changes ($P < 0.05$) was detected in the phosphatase activities among the means of treatment set ups relative to control set up using two factor Analysis of Variance (ANOVA).

Generally, the highest levels of the enzymatic activities evaluated in this study happened during the thermophilic active phase of the composting process in all the composting units. Several researchers who worked and evaluated the enzymatic activities in different composting feed stocks and systems reported similar enzymatic trends and concluded that thermophilic phase of composting stimulated enzymatic activities while the healing or cooling phase of composting inhibited enzymatic activities (Jurado *et al*., 2014).

## Conclusion

The study demonstrates that enzymatic activities are effective indicators of microbial dynamics and compost maturity during the composting process. The application of microbial inoculants and magnesium nanocomposite significantly influenced enzyme activity patterns, enhancing early-stage microbial metabolism and accelerating biochemical transformations. Increased catalase and alkaline phosphatase activities in treated setups indicate improved oxidative processes and phosphorus mineralization, while the decline in urease activity reflects stabilization of nitrogen compounds in mature compost. Although the control setup exhibited higher dehydrogenase and invertase activities at later stages, this

suggests delayed decomposition compared to amended treatments. Overall, the results confirm that the integration of microbial and nanocomposite amendments can optimize enzymatic processes, shorten composting duration, and improve compost quality. These findings support the use of enzyme-based assessments as reliable tools for monitoring composting efficiency and maturity in sustainable waste management systems.

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