Journal of
Materials in Life Sciences

Vol. 2 No. 2 (2023)

Full Paper

Study of Green Biosynthesized Silver Nanoparticles using Banana Peels on Organic Waste Composting

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Article history
Received
19 September 2023
Revised
1 November 2023
Accepted
5 November 2023
Published online
25 November 2023

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Abstract

Composting is a sustainable method of organic waste management with significant environmental advantages. The utilization of nanoparticles, namely silver nanoparticles (AgNPs), has garnered interest due to its potential impact on crop productivity. Nevertheless, there is limited knowledge regarding the effects of AgNPs on waste decomposition. This study reports on synthesized green AgNPs using banana peel extract (BPE) as a reducing and capping agent. The impact of these BPE-AgNPs on the organic waste composting process was studied in treatment groups consisting of various concentrations of AgNPs and Ag^+ in comparison to a control group without any Ag treatment. The compost samples were analyzed for temperature, pH, moisture, electrical conductivity, and mineral content throughout the composting period. The results indicated successful synthesis of BPE-AgNP showed by its surface plasmon resonance (SPR) peak at 430 nm and Fourier transform infrared (FTIR) spectroscopy results that showed functional groups involved for reducing Ag^+ to Ag^0. The presence of the AgNPs was observed not to influence the performance of the composting process and humification. Nonetheless, mineral analysis revealed that the content of magnesium was sufficient for supporting plant growth. The findings of this study indicate the functionality of organic waste compost may not be affected by the presence of AgNPs, even in relatively low quantities. The utilization of BPE-AgNPs in solid form may offer valuable insights into the impact of composting on soil microbial communities, warranting further study in the future.

Keywords Composting, silver nanoparticles, green synthesis, humic substances, banana peels, nitrogen

1.0 INTRODUCTION

Organic waste generation poses significant environmental challenges, with an estimated 360 million tons produced annually, of which more than 60% remain untreated, contributing to the release of noxious gases and the spread of infectious diseases (Lu et al., 2022). The increasing demand for fruits and vegetables due to economic and dietary changes has resulted in significant amounts of organic waste, which includes agricultural waste, industrial wastewater, municipal waste, animal manure, green waste, and food scraps (Patra et al., 2022). Composting appears as the best approach for recycling such large amounts of organic waste, as it involves the breakdown of agricultural waste into organic matter while eliminating harmful pathogens. This produces sustainable remediation tools, natural fertilizers and soil conditioners (Zhang et al., 2015). Composting is more affordable and risk-free compared to other methods of garbage disposal, and it can reduce waste volume by 40–50% (Zhao et al., 2023).

As part of modern agricultural advancements, nanotechnology shows promise in improving crop productivity while preserving the environment (Kale et al., 2021). Agricultural nano-fertilizers, such as titanium oxide nanoparticles, zinc nanoparticles, and others, offer greater penetration and effectiveness in controlling nutrient runoff, and reducing soil residues (Morales-Díaz et al., 2017; Elsayed et al., 2022). According to Zhang et al. (2019), the presence of iron oxide nanoparticles has shown beneficial outcomes in composting such as improvements in composting efficiency, enzyme activity, and overall quality of the compost (Lou et al. 2019).

Nowadays, silver nanoparticles (AgNPs) have gained significant attention for their size-dependent properties applicable to agriculture (Soto et al., 2019). However, there remains a lack of literature on the effects AgNPs in composting, despite their extensive use in biological systems and potential role in improving crop productivity (Kale et al., 2021). Synthesizing AgNPs through physical and chemical methods can be costly and potentially harmful, leading to toxic chemical residues on particle surfaces with negative implications for biomedical applications (Soto et al., 2019). As an alternative, green synthesis utilizing plant extracts has emerged as a promising technique to generate AgNPs.

In this study, banana peel extract was utilized as a reducing and stabilizing agent for AgNPs. The green BPE-AgNPs were synthesized and characterized before applying it into organic waste compost. The objectives were to analyze the effect of BPE-AgNP addition on the macroscopic composting dynamics of vegetable and fruit wastes. It is also to evaluate whether the physicochemical attributes of the compost are suitable for future agricultural use. The study included regular monitoring of temperature, pH, soil conductivity, total nitrogen, phosphorus, potassium and trace elements such as magnesium (Mg) and silver (Ag).

2.0 MATERIALS AND METHODS

2.1 Synthesis of green AgNPs using banana peel extract (BPE)

In the preparation of BPE-AgNPs, extracts from banana peels were first obtained using a method adapted from Sarah (2021) with minor modifications. The banana peels were washed thoroughly using ultrapure water to remove the dust particles adhering to the surface of the fruit peels. Subsequently, the banana peels were cut into smaller pieces and subjected to a drying process in an oven set at a temperature of 55°C for 24 hours. After 24 hours, the dried residues were ground to form fine powder using a mixer grinder. Approximately 2 g of powdered banana peel residues were added to 100 mL of ultrapure water, which was then heated at 90°C for 20 minutes. The extract was then cooled down to room temperature. The banana peel extract (BPE) was filtered using the Whatman filter (Sigma-Aldrich) and stored at 4°C for further use.

To synthesize BPE-AgNP, the source of silver (precursor) was silver nitrate ($AgNO_3$). Approximately 25 ml of 2.5mM $AgNO_3$ was mixed with 3 ml of BPE. The mixture was heated up to 70°C for 72 hours. During this time, color changes were observed and recorded. Other methods to validate the successful formation of BPE-AgNPs include UV-Vis and FTIR spectroscopies.

2.2 Composting conditions

Composting was performed outdoors at the Department of Biosciences building, Faculty of Science, Universiti Teknologi Malaysia located at Johor Bahru, Johor, Malaysia. The procedure was carried out in a kitchen plastic filter basket with a plastic basin as the outer compartment to collect the leachate. The source of organic waste used was a mix of fruit and vegetable wastes that were collected from household debris. The organic waste was chopped into smaller pieces and ground using a food processor to accelerate the composting process. The compost was prepared by using the layering technique (Copyright LY2019007508), where the first layer was landscape waste (dry leaves) followed by organic waste and organic soil. The compost was filled into kitchen filter baskets in 1:1:1 ratio with a total mass of 1 kg in each filter basket. The compost was mixed after 1 day of composting to give better aeration, and oxygen and get rid of any gaseous produced during the decomposition process.

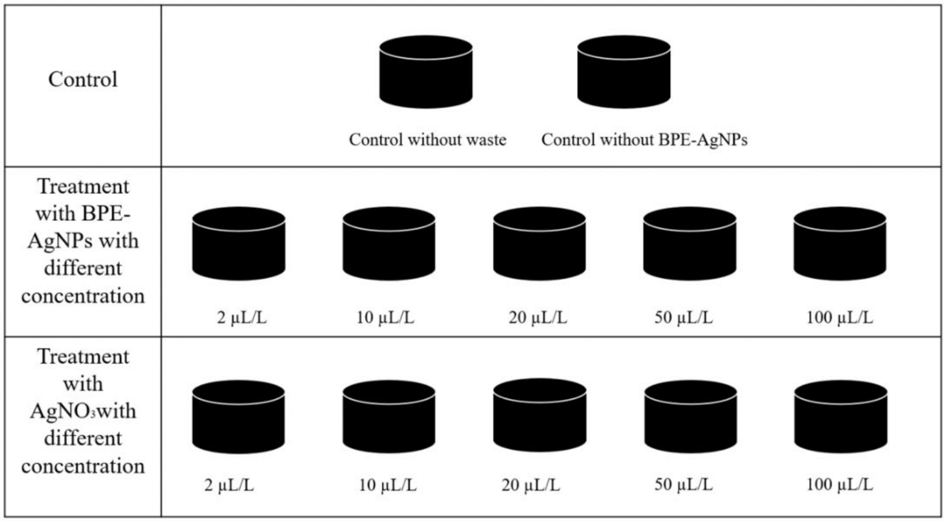
In this study, three compost groups were prepared (Figure 1), which is treatment groups with (i) BPE-AgNP and (ii) Ag^+ application at various range of concentrations (2-100 uL), including control groups that consist of compost without organic waste and without BPE-AgNPs. The experimental set-up for each group was conducted in duplicate. The composting process was terminated after 17 days of treatment.

2.3 Treatment of BPE-AgNP on organic compost

The BPE-AgNPs employed for this study were able to resist aggregation as they can form a stable solution when kept in water (Sarah, 2021). The BPE-AgNPs solution was prepared in deionized water at 2, 10, 20, 50 and 100 μl/L, and added to the compost after it was set up as in Figure 1b. Following treatment, a net was placed over the compost filter baskets to prevent insects or precipitation (rain) from damaging the compost. To ensure adequate aeration and absorption, the compost was manually mixed once per day until it took the appearance of soil. Similar procedures were performed for other treatment groups of Ag^+ and control groups.

2.4 Analytical procedures

The temperature, pH and soil conductivity of the compost were monitored on a daily basis using 2 in 1 soil pH and moisture meter (TAKEMURA, Japan) and a direct soil EC tester (HANNA GroLine, UK). The readings were taken at three different positions of the compost for each experimental group. These data were plotted into a graph and analyzed against Ag^+ treatment and control groups.



(a)

Sample	Types of Treatment	Composting material
C1	Control without waste	Dried leaves and organic soil
C2	Control without BPE-AgNPs	Dried leaves, organic soil and organic waste
A1	2µl/L BPE-AgNPs	Dried leaves, organic soil, organic waste and 2 µl/L BPE-AgNPs
A2	10µl/L BPE-AgNPs	Dried leaves, organic soil, organic waste and 10 µl/L BPE-AgNPs
A3	20µl/L BPE-AgNPs	Dried leaves, organic soil, organic waste and 20 µl/L BPE-AgNPs
A4	50µl/L BPE-AgNPs	Dried leaves, organic soil, organic waste and 50 µl/L BPE-AgNPs
A5	100µl/L BPE-AgNPs	Dried leaves, organic soil, organic waste and 100 µl/L BPE-AgNPs
B1	2µl/L BPE-$AgNO_3$	Dried leaves, organic soil, organic waste and 2 µl/L BPE- $AgNO_3$
B2	10µl/L BPE- $AgNO_3$	Dried leaves, organic soil, organic waste and 10 µl/L BPE- $AgNO_3$
B3	20µl/L BPE- $AgNO_3$	Dried leaves, organic soil, organic waste and 20 µl/L BPE- $AgNO_3$
B4	50µl/L BPE- $AgNO_3$	Dried leaves, organic soil, organic waste and 50 µl/L BPE- $AgNO_3$
B5	100µl/L BPE- $AgNO_3$	Dried leaves, organic soil, organic waste and 100 µl/L BPE- $AgNO_3$

(b)

Figure 1 Experimental layouts of organic waste compost in three different groups treated with BPE-AgNP, Ag^+ ($AgNO_3$ solution) and without waste/AgNP (b).

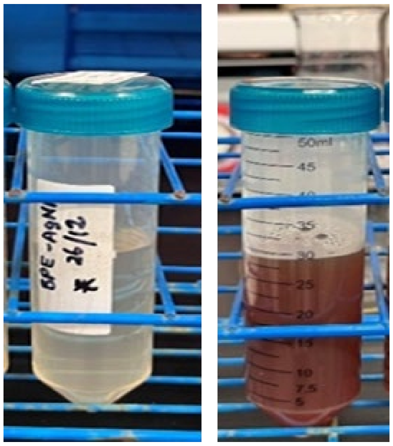
2.4.1 Analysis of mineral element and trace metals

In addition to physical parameters, mineral elements namely nitrogen (N), phosphorus (P), and potassium (K) were also analysed using an NPK soil sensor (VBESTLIFE, China). The final compost was treated with BPE-AgNP and control groups were subjected to trace metal determination after the composting process was terminated on day 17. The compost samples were oven-dried at 100°C, and analyzed for Ag and Mg elemental composition, including humic (HA) and fulvic acid (FA) concentration. The data obtained for total N, P and K were plotted into the graph and analyzed against Ag^+ treatment and control groups.

3.0 RESULTS AND DISCUSSION

3.1 BPE-AgNP characterization

The successful formation of AgNPs using banana peel extract was observed through a noticeable color change from colorless to brownish within 72 hours of incubation (Figure 2). This distinct colour change in the reaction mixture indicates that BPE-AgNPs have been successfully formed. The change may be due to the reduction of Ag^+ ions to AgNP (Ag^0) by the active compounds present in the BPE extracts (Mouriya et al., 2023). The presence of many secondary metabolites such as flavonoids, tannins, phlorotannins, alkaloids, glycosides, and terpenoids in banana peel extract served as reducing agent that aided in the reduction of silver ions (Alharbi et al., 2022). The UV-vis spectroscopy employed in this study provides additional evidence for the formation of AgNPs. Figure 3 shows the reduction of Ag^+ to metallic Ag (Ag^0), which was indicated by the UV-Vis absorbance spectrum value at 430nm.



(a) (b)

Figure 2 Color changes of the BPE solution before (a) and after (b) the addition of 2.5 mM of $AgNO_3$ after 72 hours of incubation.

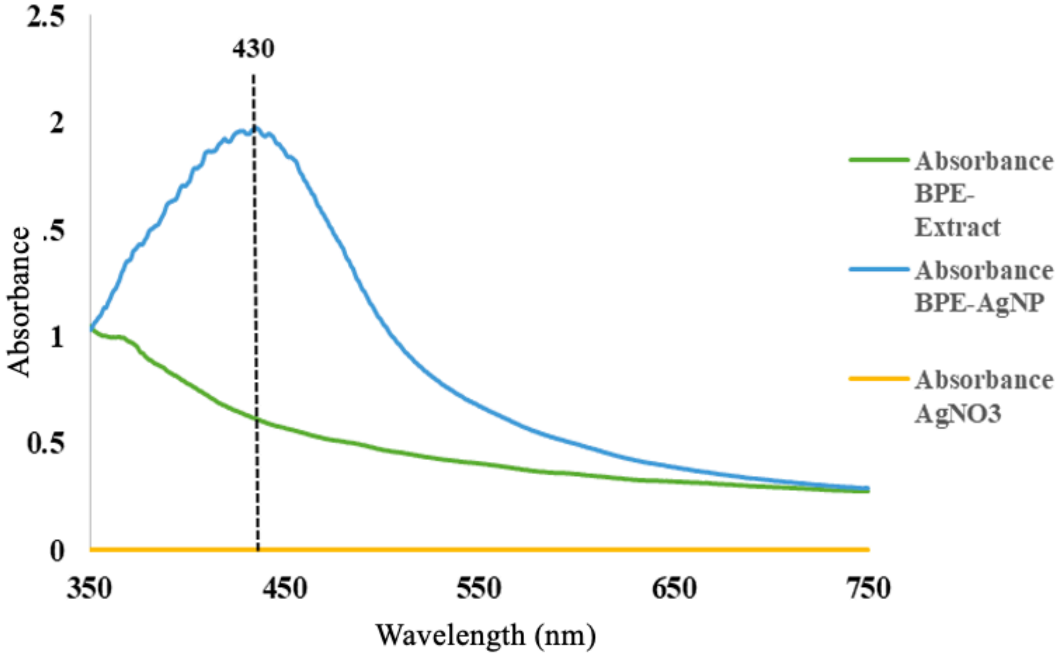


Figure 3 Visible absorption spectra of BPE extract, synthesized BPE-AgNPs2.5 mM $AgNO_3$.

The finding in Figure 3 agrees with a study conducted by Ibrahim (2015) who reported the surface plasmon resonance (SPR) peak at the same wavelength for its synthesis using banana peel extract. The absorption bands observed in the SPR analysis are a result of the resonance between the vibrating free electrons in the silver nanoparticles and the incident light waves (Chafidz et al., 2020). $AgNO_3$ and BPE extract did not display any characteristic peak at 430 nm.

For the FTIR characterization, both BPE and BPE-AgNPs samples showed the same characteristic peaks at around 3273, 2920, 2949, 1603, 1360 and 1042 cm^{-1} (Figure 4). There are prominent shifts in the functional groups' region of the FTIR spectrum from 3270-3275, 2920-2922, 2949-2950, 1603-1604, 1354-1375 and 1053-1031 cm^{-1} in BPE-AgNP sample. These peaks are associated with O-H stretching vibrations of alcohol or phenols, C-H vibrations of alkanes, N-H and C-N vibrations of aliphatic amines, or C-O vibrations of alcohol, carboxylic acids, esters, and ethers. The various functional groups can be linked to their presence in polymers of banana peel such as lignin, cellulose and hemicellulose, including the phenolic groups that help in the reduction of silver ions into AgNPs as well as for capping and stabilizing the nanoparticles (Ibrahim, 2015). The observed shifts in the functional groups of the banana extract confirm its dual role as a reducing agent and a capping agent in the synthesis of AgNPs. The FTIR spectra analysis reveals that the carboxyl group, the hydroxyl group, and the amide group are primarily responsible for reducing Ag^+ ions to Ag^0 and stabilizing the BPE-AgNPs.

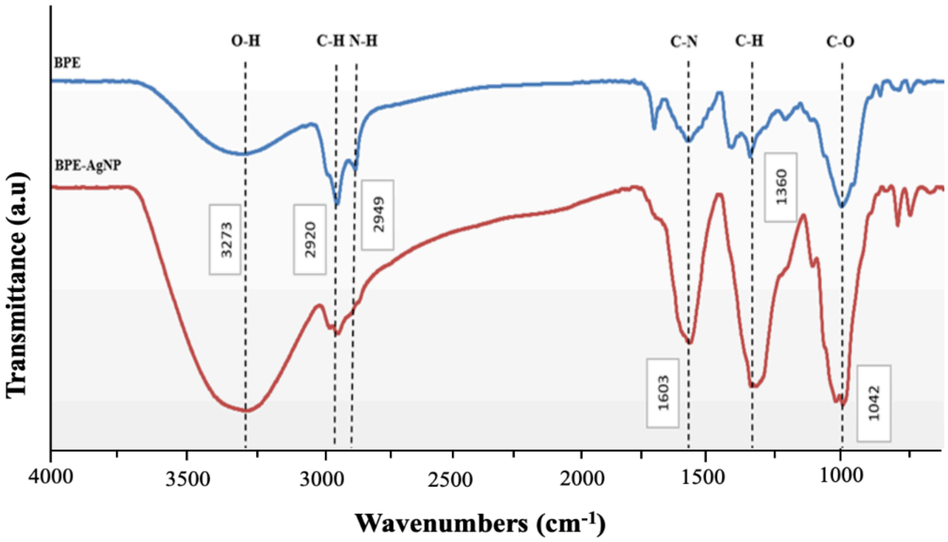


Figure 4 Fourier-transform infrared spectroscopy (FTIR) spectra of BPE and BPE-AgNP.

These functional groups demonstrate their ability to bind to Ag^0, acting as both reducing agents and stabilizers, which is consistent with previous research highlighting the utilization of biological molecules in nanoparticle synthesis (Swargiary et al., 2018).

3.2 Physical characteristics of compost

Several physical changes that occurred during the composting process before and after treatment of BPE-AgNP and Ag$^+$ from day 1 to day 17 were recorded and analyzed. This analysis includes the physical examination of the compost, changes of pH, temperature and soil electrical conductivity.


(a) (b)

Figure 5 The appearance of the initial (a) and final (b) compost.

Figure 5 depicts the compost's appearance on day 1 (a) and day 17 (b). The final compost on day 17 did not possess a fine powdery texture. Remnants of vegetable and fruit wastes, including dried leaves, were still present at approximately 30-40%. These observations indicate that the composting process had not reached its completion. In composting, the final mature compost should resemble a regular soil or topsoil and crumbly texture with no recognizable organic materials (Amery et al., 2020). The appearance of compost on day 17 concluded that the compost was in its immature state, which was due to the time and site constraints. Ideally, composting should be prolonged for a longer period until all recognizable organic materials have completely decomposed, resulting in a darker and cooler compost. Other than that, the presence of larger branches and leaves can also impede the degradation process, and rainy days to lower the compost temperature. The immature compost, however, still can be utilized to impede seed germination and the growth of plants (Jain et al., 2019).

3.3 pH variations

From Figure 6a, all compost samples showed an average pH value below 7 from day-1 to day-4, which was around 3.4 to 6.8, except for control group C1 without organic waste. In the control group, the pH value is slightly near neutral which is 7 from day-1 to day 17. The lower pH observed in compost C2 and all treatment groups that drop below neutral pH at the beginning days might be due to the formation of organic acids. The initial acidity is also due to the presence of acidic citrus waste from the fruits and vegetables waste in the compost. The acidic conditions promote the growth of fungi and the breakdown of lignin and cellulose (Kiyohiko Nakasaki et al., 1993; Sundberg et al., 2004). The pH that continued to rise was due to the release of ammonia caused by the induction of the proteolytic process (Pathak et al., 2012). Chefetz et al. (1998) and Jamaludin et al. (2017) shared the same findings that during the maturation and cooling phases, the pH drops to a neutral level. In this work however, treatment of BPE-AgNPs (A1-A5) did not show any pH differences to the groups treated with Ag^+, as well as C2 control groups 17 days. All pH readings exhibited similar trends throughout the entire process of organic waste decomposition (Figure 5a).

3.4 Temperature and soil conductivity

Figure 6b displays the monitored temperature of compost samples from day 1 to 17. All compost with different types of treatments (A1-A5; BPE-AgNP treatment and B1-B5; Ag^+ treatment) showed similar trends of temperature. The initial temperature of all composts showed a slight increment on day 1 to 3, between 29.0°C and 30.5°C. The temperature decreased in all compost treatments from day 4 to 7 (between 26 and 29°C) before it rose from 29 to 33°C afterwards until day-13. The temperature was observed to cool down after day 13 onwards in overall compost samples.

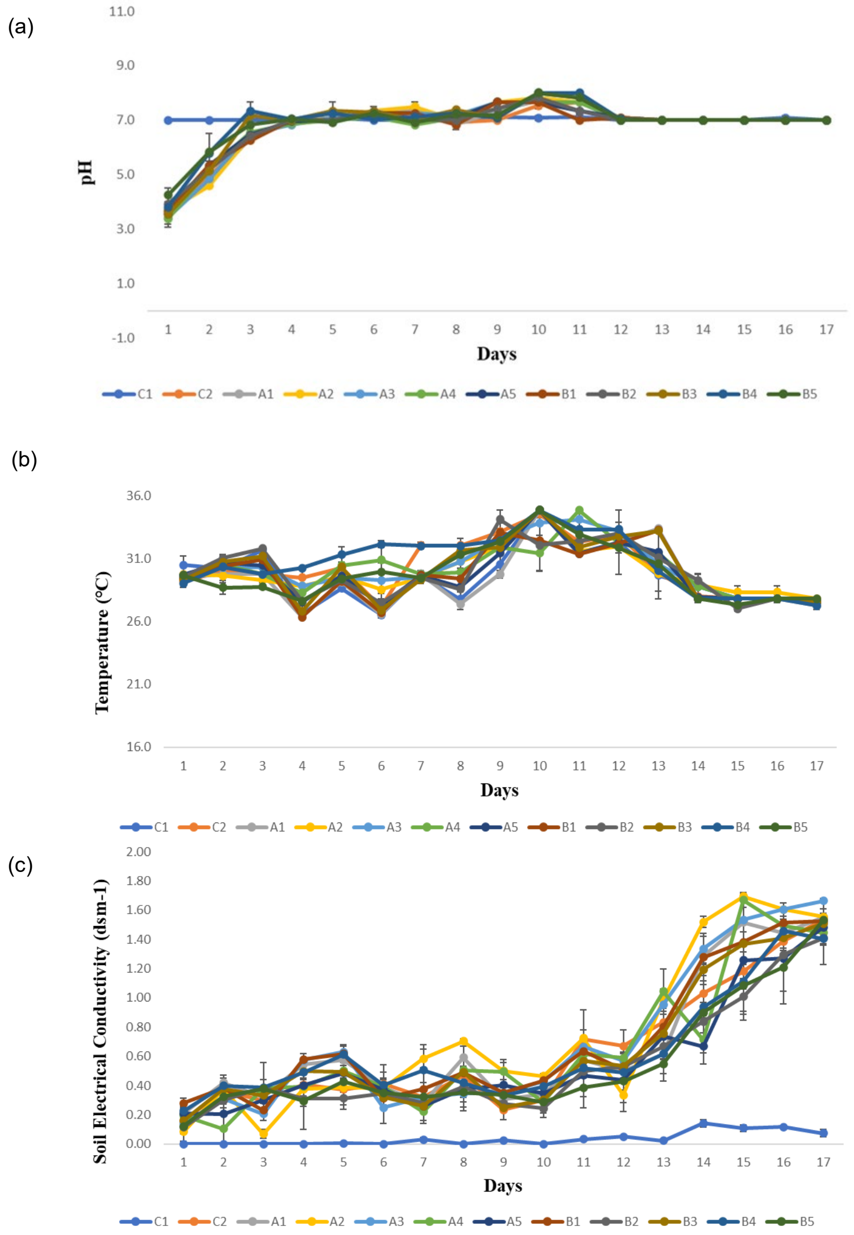


Figure 6 Average changes in (a) pH value (b) temperature and (c) soil conductivity in compost treated with BPE-AgNP (A1-A5), Ag^+ ions (B1-B5), and controls groups composed of compost without organic waste (C1) and without BPE-AgNPs (C2) from day 1-17.

The increasing trend of temperature over the time of the decomposition process showed that the composting is nearly reaching the thermophilic phase. As the composting process is in its active phase, the highest temperature observed within the majority of compost treatments is 34.9°C, which is mainly on day 10. In the final stages of composting, the results indicate that all compost types have the same constant temperature of 27.3-27.8°C.

During decomposition, temperatures of compost will usually change through three stages, which are mesophilic, thermophilic, and cooling stages. As the compost progresses through the thermophilic stage, microbes are active until it reaches a certain stage of decomposition. The rise of temperature afterwards which occurred around day 7 to 13 was nearly a thermophilic stage that caused microorganisms to respire and decompose the organic matter (Sundberg et al., 2004, Jamaludin et al., 2017). In the terminal phase of decomposition, fewer organic compounds are available for microbial degradation (Pathak et al., 2012), hence the temperature returns to its original level known as cooling.

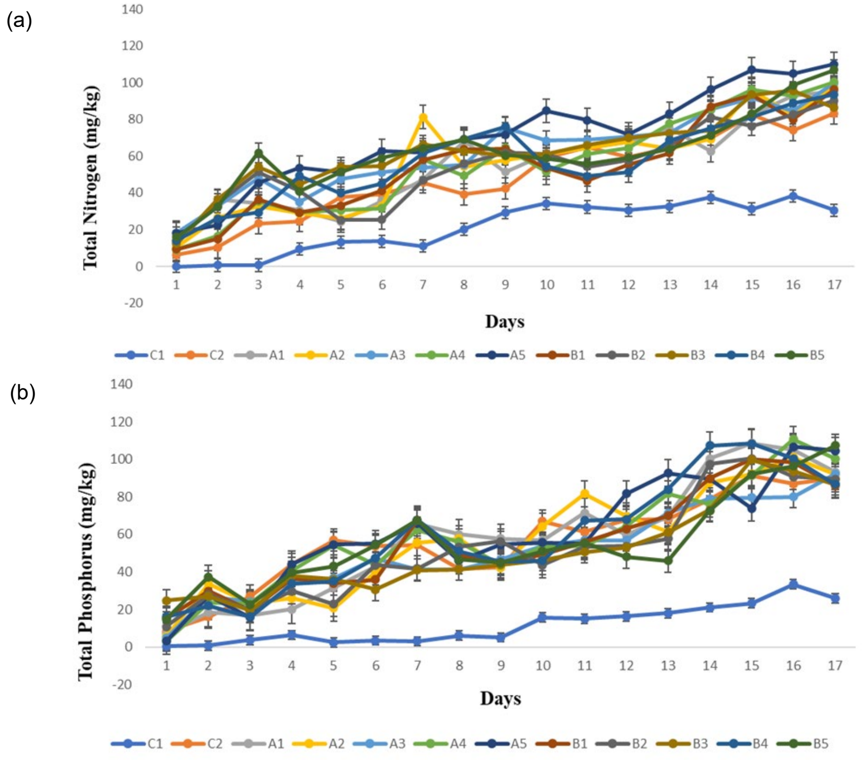
Another parameter measured in this study was soil electrical conductivity (EC), which measures the salinity in compost products, and also indicates whether the compost has phytotoxic or phytoinhibitory effects. From Figure 6c, the EC measurement of compost samples with BPE-AgNP (A1-A5) and Ag$^+$ (B1-B5) treatment, including the group without AgNP/Ag$^+$ treatment showed an increased trend from day 1 to day 17. The average value of EC was between 0.16 dS.m^{-1} on day 1 dan went up to 1.48 dS.m^{-1} by day 17. The control group without organic waste (C1) had a very low EC value, which is below 0.14 dS.m^{-1} during 0-17 days of composting. The upward trend of EC can be attributed to the release of mineral salts such as phosphate and ammonia ions during the decomposition of organic matter in the environment (Irvan et al., 2018). The similar trendline of compost treated with BPE-AgNP and $AgNO_3$ compared to control C2 showed that both applications did not impact EC condition.

3.5 Total nitrogen, phosphate and potassium analysis

Several elements studied for this experiment include nitrogen (N), phosphorus (P) and potassium (K). Figure 7a-c displays the results of total nitrogen (TN), Phosphorus (TP) and Potassium (TK) of compost samples treated with BPE-AgNP, Ag$^+$ and control groups (without organic waste, C and without AgNP/Ag$^+$ treatment, C2).

Compost treated with BPE-AgNPs at 100μL/L was found to record the highest TN of all compost samples. The TN value was prominently increased than any other groups from day 10 (85 mg/kg) to day 17 (110 mg/kg). Other compost samples as such those treated with BPE-AgNPs (2-50 μL/L), Ag$^+$ (2-100 μL/L) and control groups showed a similar trend of TN increment over time. Control group C1 recorded the lowest TN value due to the absence of nitrogen-rich waste from organic waste, added into the soil mixture during composting.

The increment of TN in all organic waste compost samples (C2, A1-A5 and B1-B5) is highly associated with the temperature as observed in Figure 6b. When the temperature drops and the maturing stage begins, TN increases due to acceleration in the nitrification process, enhancing NO_3^- and lowering NH_4^+ concentrations in the final compost product. Both nitrification and denitrification processes contribute to the high-value N_2O production and surface emission (Hao & Benke, 2008). The BPE-AgNP treatment (100 uL/L) on compost that recorded the highest TN value from day 10 onwards indicates that the green NP may influence the composting process. However, there is currently little knowledge of how AgNP affects the TN value of organic compost.



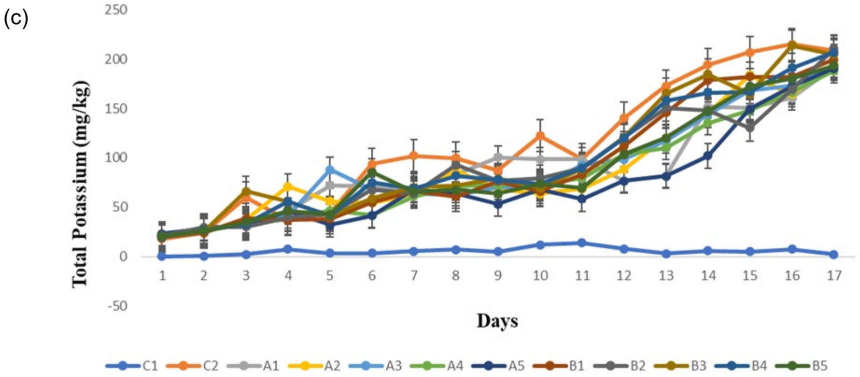


Figure 7 Average changes in total (a) nitrogen (b) phosphorus and (c) potassium in compost treated with BPE-AgNPs (A1-A5), Ag^+ ions (B1-B5), and control groups composed of compost without organic waste (C1) and without BPE-AgNPs (C2) from day 1-17.

For total phosphate (TP) and total potassium (TK) results, treatment of compost with BPE-AgNP and Ag^+ showed data fluctuations from day 1 to day 17 (Figure 7b and 7c). However, both elements were observed to exhibit an upward trend as the days passed. Control group C1 did not show any increment due to absence of phosphate and potassium-rich waste in the compost. It showed TP value below 33 mg/kg during day 1 to 17 of composting process. The highest TP concentration achieved was in final compost treated with 40 μl/L BPE-AgNP with value of 120 mg/kg (day 16). For TK, the highest reading was in final compost treated with control C2 (without BPE-AgNP treated) with reading of 215 mg/kg (day 16).

Several studies have indicated that organic matter from compost or biowaste is a valuable source of phosphorus (Khan et al., 2009). It is possible that the increase in TP (Figure 7b) during composting was a result from the higher rate of carbon loss during the decomposition of organic matter (Lin, 2008). The TK values that are not constantly increasing (Figure 7c) in this study was due to interruption of microorganisms in the compost. Jamaluddin et al. (2017) reported that microorganisms require nutrients such as potassium for their activity and growth. Hence, this could be the reason why the TP trend is fluctuating in the experiment. Overall, the phosphate and potassium elements in the organic waste compost were not affected by the addition of BPE-AgNP.

3.6 Trace elements and humic acid analysis

Trace elements analysed in the final composts include Mg and Ag content. Table 1 shows the comparison of both elements in the final compost of treatment samples (100 μl/L of BPE-AgNPs) and control samples C2 (without cBPE-AgNPs). From the results, the Ag content was found undetectable in treatment compost samples, whereas the amount of Mg was recorded at the highest value (1728 mg/kg) compared to a control group with a value of 1729 mg/kg.

Table 1: Trace elements of final compost with and without BPE-AgNP treatment.

Mineral	Control (without BPE-AgNPs) (mg/kg)	Treatment with 100 ul/L BPE-AgNPs (mg/kg)
Magnesium (Mg)	1439.00	1728.00
Silver (Ag)	1.56	ND

*ND-not detected within limit of ICP-OES

In the study, the Mg content in both treatment and control compost groups showed a sufficient amount that can ensure optimal growth of the plant. The amount of Mg required by plants for optimal growth ranges between 1500-3000 mg/kg. (Guo et al., 2016). Its absence will typically exhibit the plant's interveinal chlorosis, which significantly reduces growth and affects crop yield (Gransee & Führs, 2013). The organic waste used in the experiment mainly composed of orange peels is high in Mg like in banana, kiwi and papaya which contributed to the mentioned amount above.

The absence of Ag in the final compost treated with 100 μg/L compost and its substantially low concentration in the control samples indicate that the use of BPE-AgNP as an enhancer did not leave any trace on the compost. Although Stamou & Antizar-Ladislao (2016) optimized treatment protocol has been followed, the insufficient quantity of compost for each ratio may contribute to these outcomes. There is also the possibility that Ag could be released in the leachate. This study, however, did not measure the total Ag content of the compost leachate.

A study by Gitipour et al. (2013) mentioned that there is a possibility that total Ag can be released through the leachate. AgNP may endure surface transformations when introduced in a system or environment with high enrichment of chlorides and sulphides, for instance, in wastewater, landfills or composter leachate. The released AgNP may transform into silver chlorides

(AgCl) or silver sulphides (Ag_2S), which are less toxic than metallic AgNP prepared by chemical or physical means. Although the green synthesis method was opted for the AgNP preparation to overcome issues with toxicity and stability, there are still possibilities that it will go through surface functionalization when introduced to the environment. Research conducted by Abdelmigid et al. (2021) reported that biologically synthesized AgNPs can be less stable than that of chemically synthesized AgNPs.

3.7 Humic acid and fulvic acid quality

Humic substances (HSs) are essential for enhancing crop nutrition, stress resistance and crop quality (Gerzabek et al., 2022). The comparison of humic substances between two final composts treated with 100 μl/L BPE-AgNPs and the control are presented in Table 2. In control compost without BPE-AgNPs and in the treatment with 100 μl/L BPE-AgNPs, the percentages of fulvic acid (FA) are significantly higher than the percentages of humic acid (HA).

Table 2 HA and FA content of final compost with and without BPE-AgNP treatment.

Humic substances	Control (without BPE-AgNPs) (%)	Treatment with 100 μl/L BPE-AgNPs (%)
Humic acid (HA)	3.61	4.07
Fulvic acid (FA)	28.62	28.02
Ratio HA/FA	1:10 (0.10)	1:10 (0.10)

In any compost condition, FAs are commonly synthesized first followed by the formation of HAs. In this regard, a high level of HAs in the compost achieved indicates its high level of maturity, low level of HAs indicates a low level of maturity (Gerzabek et al., 2022). The HA/FA for both treatments in ratios of 1:10 (0.1) showed no significant differences in terms of humic substance formation (Table 2).

Both compost samples are considered immature since they consist of low levels of HAs in comparison to FAs. Higher HA/FA ratios are associated with faster organic matter humification (Lanno et al., 2022), which was not observed in this study. A HA/FA ratio less than 1 indicates immature compost that has been influenced by the organic material used. Cellulose and lignin are two examples of organic compounds that have a considerable influence on the humification process (Lanno et al., 2022). The final compost in this study is believed to require a longer decomposition process to ensure that the compost is mature.

In addition to improving compost conditions in future experiments, the analysis of microbial community structure in compost in response to green AgNP treatment is also regarded to be worthwhile. Microbes serve an important role in the composting process by quickly breaking down the organic matter, resulting in richer soil that boosts plant growth and health. There is currently very little knowledge on the effects of AgNPs on the microbial community in composted samples. The AgNP was reported to influence the enzymatic activity of degrading bacteria and fungi as a result of its anaerobic toxicity (Jain et al. 2019).

Gitipori et al. (2013) and Das et al. (2012) discovered that the dynamics of toxicity may differ when analyzing microbial communities in composted materials, as compared to doing experiments using pure cultures. The study found that Ag-based treatment has changed the overall bacteria communities to be highly diverse, with Clostridia (49.5%), Bacilli (27.9%) and beta-Proteobactera (13.4%) pre-dominating. In contrast to that investigation, Ahmed & Dutta (2020) discovered that soil samples treated with AgNPs synthesized using green methods exhibited a reduced microbial count. The study, however, was unable to definitively determine whether the change was attributed to beneficial or harmful microbes. Additional research conducted to view this aspect is highly suggested to further investigate the potential benefits of using stabilized green AgNPs for enhancing soil quality.

4.0 CONCLUSION

Green synthesis of AgNPs has recently emerged as an alternative pathway to eliminate or minimize energy and chemical usage. Banana fruit peels were successfully used as a reducing agent and stabilizer for the green synthesis of BPE-AgNPs. The treatment of BPE-AgNPs on the compost was found to influence the compost nitrogen content, but not in other physicochemical attributes. The undetectable Ag element in the final compost suggests that the amount of treatment that is too little may cause an insignificant impact to the compost conditions. Although stable, green AgNPs were applied to resist aggregation under various environmental conditions, there are possibilities that surface transformation occurred to form complexes with organic matter in the compost. The results herein suggest that at relatively low concentrations, the organic waste enrichment compost may not be influenced by the presence of green AgNP.

Acknowledgment

The authors would like to acknowledge Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (Q.J130000.2645.15J81 and R.J130000.7754.4J391) for financial support.

References

Ahmed, A. A., Dutta, P. (2020). Effect of green synthesized silver nanoparticles on soil properties. *Jourmal of Medicinal Plants Studies*, 8(1), 34-37.

Alharbi, N. S., Alsubhi, N. S., Felimban, A. I. (2022). Green synthesis of silver nanoparticles using medicinal plants: Characterization and application. *Journal of Radiation Research and Applied Sciences*, 15(3), 109–124.

Appiah-Effah, E., Nyarko, K. B., Antwi, E. O., Awuah, E. (2016). Effect of bulking materials and mixing ratios on concentration of nutrients during composting of raw faecal sludge from peri-urban areas. *Water Practice and Technology*, 11(1), 234–242.

Chafidz, A., Afandi, A. R., Rosa, B. M., Suhartono, J., Hidayat, P., Junaedi, H. (2020). Production of silver nanoparticles via green method using banana raja peel extract as a reducing agent. *Communications in Science and Technology*, 5(2), 112-118.

Chefetz, B., Chen, Y., Hadar, Y. (1997). Water-extractable components released during composting of municipal solid waste. In International Symposium on Composting & Use of Composted Material in Horticulture 469 (pp. 111-118).

Das, P., Williams, C. J., Fulthorpe, R. R., Hoque, M. E., Metcalfe, C. D., Xenopoulos, M. A. (2012). Changes in bacterial community structure after exposure to silver nanoparticles in natural waters. *Environmental Science and Technology*, 46(16), 9120-9128.

Gitipour, A., el Badawy, A., Arambewela, M., Miller, B., Scheckel, K., Elk, M., Ryu, H., Gomez-Alvarez, V., Santo Domingo, J., Thiel, S., Tolaymat, T. (2013). The impact of silver nanoparticles on the composting of municipal solid waste. *Environmental Science and Technology*, 47(24), 14385–14393.

Gitipour, A., Thiel, S. W., Scheckel, K. G., Tolaymat, T. (2016). Anaerobic toxicity of cationic silver nanoparticles. *Science of the Total Environment*, *557–558*, 363–368.

Guo, W., Nazim, H., Liang, Z., Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. *The Crop Journal*, 4(2), 83-91.

Hao, X., Benke, M. B. (2008). Nitrogen transformation and losses during composting and mitigation strategies. *Dynamic Soil, Dynamic Plant*, 2(1), 10-18.

Huszalina Hussin, 2021. Modul Prihatin Denai Sungai Malaysia - Teknik Tanaman dan Pengkomposan Lestari. UNESCO IHP Malaysia and Universiti Teknologi Malaysia. ISBN 978-967-19987-7-9.

Ibrahim, H. M. M. (2015). Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. *Journal of Radiation Research and Applied Sciences*, 8(3), 265–275.

Jain, M. S., Daga, M., Kalamdhad, A. S. (2019). Variation in the key indicators during composting of municipal solid organic wastes. *Sustainable Environment Research*, *29(1), 1-8.*

Jamaludin, S. N., Kadir, A. A., Azhari, N. W. (2017). Study on NPK performance in food waste composting by using agricultural fermentation. *MATEC Web of Conferences*, 103, 05015.

Kadir, A. A., Azhari, N. W., Jamaludin, S. N. (2016). An overview of organic waste in composting. *MATEC Web of Conferences*, *47*.

Kale, S. K., Parishwad, G. V., Patil, A. S. H. A. S. (2021). Emerging agriculture applications of silver nanoparticles. *ES Food and Agroforestry*, 3, 17-22.

Khan, K. S., Joergensen, R. G. (2009). Changes in microbial biomass and P fractions in biogenic household waste compost amended with inorganic P fertilizers. *Bioresource Technology*, 100(1), 303-309.

Kiyohiko Nakasaki, Hideki Yaguchi, Yasushi Sasaki, Hiroshi Kubota. (1993). Effects of pH control on composting of garbage. *Waste Management & Research*, 11(2), 117–125.

Kumar, R., Shweta. (2011). Enhancement of wood waste decomposition by microbial inoculation prior to vermicomposting. *Bioresource Technology*, 102(2), 1475–1480.

Lanno, M., Klavins, M., Purmalis, O., Shanskiy, M., Kisand, A., Kriipsalu, M. (2022). Properties of humic substances in composts comprised of different organic source material. *Agriculture*, 12(11), 1797.

Lin, C. (2008). A negative-pressure aeration system for composting food wastes. *Bioresource Technology*, *99*(16), 7651–7656.

Mouriya, G. K., Mohammed, M., Azmi, A. A., Khairul, W. M., Karunakaran, T., Amirul, A. A. A., Ramakrishna, S., Santhanam, R., Vigneswari, S. (2023). Green synthesis of *Cicer arietinum* waste derived silver nanoparticle for antimicrobial and cytotoxicity properties. *Biocatalysis and Agricultural Biotechnology*, *47*, 102573.

Pathak, A. K., Singh, M. M., Kumara, V., Arya, S., Trivedi, A. K. (2012). Assessment of physico-chemical properties and microbial community during composting of municipal solid waste (Viz. KItchen waste) at Jhansi City, UP (India). *Recent Research in Science and Technology*, 4(4), 10-14.

Patra, R. K., Behera, D., Mohapatra, K. K., Sethi, D., Mandal, M., Patra, A. K., Ravindran, B. (2022). Juxtaposing the quality of compost and vermicompost produced from organic wastes amended with cow dung. *Environmental Research*, *214*, 114119.

Phongtongpasuk, S., Poadang, S., Yongvanich, N. (2016). Environmental-friendly method for synthesis of silver nanoparticles from dragon fruit peel extract and their antibacterial activities. *Energy Procedia*, 89, 239-247.

Sarah Syafiqah Jajul. (2021). Fruit waste mediated synthesis of silver nanoparticles and its decolorization capability on dyes. Degree thesis, Universiti Teknologi Malaysia (UTM)

Soto, K. M., Quezada-Cervantes, C. T., Hernández-Iturriaga, M., Luna-Bárcenas, G., Vazquez-Duhalt, R., Mendoza, S. (2019). Fruit peels waste for the green synthesis of silver nanoparticles with antimicrobial activity against foodborne pathogens. *LWT*, 103, 293–300.

Stamou, I., Antizar-Ladislao, B. (2016). The impact of silver and titanium dioxide nanoparticles on the in-vessel composting of municipal solid waste. *Waste Management*, 56, 71–78.

Sundberg, C., Smårs, S., Jönsson, H. (2004). Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. *Bioresource Technology*, 95(2), 145–150.

Yee, K.J., Nik Malek, N.A.N., Ahmad Zawawi, N. (2022). Antibacterial properties of green silver nanoparticles using banana peels extract loaded on zeolite clinoptilolite. *Proceedings of Science and Mathematics*, 12: 135-146.

Zhang, L., Hu, Y., Huang, H., Ren, L., Zhang, J., Yan, B., Luo, L., Liu, J., Gu, S. (2022). Response of bacterial community to iron oxide nanoparticles during agricultural waste composting and driving factors analysis. *Bioresource Technology*, 345, 126530.

Zhang, L., Zeng, G., Dong, H., Chen, Y., Zhang, J., Yan, M., Zhu, Y., Yuan, Y., Xie, Y., Huang, Z. (2017). The impact of silver nanoparticles on the co-composting of sewage sludge and agricultural waste: Evolutions of organic matter and nitrogen. *Bioresource Technology*, 230, 132–139.

Zhang, L., Zhu, Y., Zhang, J., Zeng, G., Dong, H., Cao, W., Fang, W., Cheng, Y., Wang, Y., Ning, Q. (2019). Impacts of iron oxide nanoparticles on organic matter degradation and microbial enzyme activities during agricultural waste composting. *Waste Management*, 95, 289–297.

Zhang, W., Zhao, Y., Lu, Q., Feng, W., Wang, L., Wei, Z. (2022). Evaluating differences in humic substances formation based on the shikimic acid pathway during different materials composting. *Bioresource Technology*, 364, 128060.

Zhao, X., Dang, Q., Zhang, C., Yang, T., Gong, T., Xi, B. (2023). Revisiting organic waste-source-dependent molecular-weight governing the characterization within humic acids liking to humic-reducing microorganisms in composting process. *Journal of Hazardous Materials*, 442, 130049.