








Banana plant waste composting through microbial inoculation and its performance in spinach

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Original Research

Abstract:

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Purpose: After harvesting bananas, the entire biomass of the plant, which contains nutrients as well as large amounts of organic carbon, is removed from the field. Therefore, the main purpose of the present study is to utilize this potential waste as a source of macro and micronutrients for plant growth and development.

Method: Banana plant waste and vegetable waste composting were evaluated through microbial inoculation with bacteria *Pseudomonas aeruginosa* AMBCD-1 and yeast (*Saccharomyces cerevisiae*) for about 45 days. Further the assessments of physicochemical properties of biodegraded compost were analyzed. A polybag experiment was also carried out to study the effect of biodegraded waste on the growth performance of spinach (*Spinacia oleracea*) using completely randomized design (CRD).

Results: The results revealed an increasing concentration of nitrogen (1.73%), phosphorus (0.369%) and potassium (2.621%) in treatment T3 (banana plant waste + *P. aeruginosa*) which were significantly higher as compared to other treatments. Further, compost obtained after the degradation of banana plant waste was evaluated for the performance of spinach. The treatment T3 (banana plant waste + *P. aeruginosa*) exhibited significantly maximum plant height about 20.7 cm and increased concentrations of nitrogen (2.87%), phosphorus (0.3%) and chlorophyll (0.54 mg/g) in comparison to other treatments. Maximum root length was recorded in treatment T6 (banana plant waste + *P. aeruginosa* + vegetable waste).

Conclusion: Moreover, microbial inoculation of bacteria *P. aeruginosa* AMBCD-1 represented an effective strain for fast degradation of banana plant waste which enhanced the growth parameters of spinach.

Keywords: *Pseudomonas aeruginosa*; Spinach; Composting; Banana plant waste

1. Introduction

The production of organic wastes has surged in tandem with the rapid growth of the agricultural sector, urbanization, and population (Zhang et al., 2013; Shah et al., 2015). By releasing pollutants and harmful gases into the atmosphere, these wastes are endangering the environment (Zhang et al., 2013). Banana growers typically rely on fertilizers high in phosphate and nitrogen, as well as sporadic applications of farmyard manure. After bananas are harvested, the entire biomass of the plant, which contains all the nutrients lost through fruit harvest as well as large amounts of organic carbon, is removed from the field. Two tons of banana wastes are thought to be left behind for every tone of harvested

bananas. Thus, the banana waste is one of the potential plant residues available to be utilized as a source of NPK and micronutrients for plant growth and development. A cheap, environmentally friendly method for treating a variety of organic wastes is composting (Aslam, 2008). Large amounts of leftover material, such as banana stalks, pseudo stems, leaves, and trashes, are left over after fruit is plucked and contain just as much nutrition as the fruit itself. Traditionally, large amounts of organic carbon and nutrients are disposed of either incinerating or dumping in soil in landfills (Memon et al., 2012; Khokhar, 2019). One ton of banana residue contains 15 kg N, 7 kg P and 23 kg K (Doran and Kaya, 2005). Composting has been recognized P and 23 kg K (Doran and Kaya, 2005). Composting has gained

popularity recently due to concerns about land degradation, the harm that excessive and improper use of inorganic fertilizers can do to ecosystems, air pollution, soil health, soil biodiversity, and sanitation (Mishra and Roy, 2007). Composting has several advantages, such as better soil fertility and health, which raises agricultural output, better soil biodiversity, and fewer environmental hazards (Bernal-Vicente et al., 2012). Composting banana crop waste improves soil microbial life, increases organic matter, increases crop yields, and is an inexpensive source of nutrients (Phirke and Kothari, 2005; Mawahib et al., 2015). Composting of banana plant waste may provide a sustainable solution by converting waste into a stable, humus-like material that enriches soil structure, enhances water retention, and improves nutrient availability. Abro et al. (2019) concluded that higher organic matter, total N, P, K were observed for banana crop residues enriched with sugar cane press mud. Microbial inoculation is one useful method for accelerating the biotransformation of organic materials during the composting process. Adding microorganisms could accelerate the decomposition of organic matter, mineralization, microbial enzyme activity, and the quality of the final products throughout the composting process. Producing compost from various agro-industrial wastes minimizes the probability of erosion and runoff, as well as the permanent wilting point in the soil. It also increases the pH, organic carbon and nitrogen, cation exchange, and water-holding capacity of the soil.

According to Xu et al. (2020), the inoculation of effective microorganisms may improve the composting process's organic matter and the metabolism of readily available organic components. Furthermore, Wei et al. (2019) found that the inclusion of actinomycetes increased 8.3 enzyme activity and 34.3 lignocellulose breakdown in the composting of wheat, rice, maize and soybean straw. Also Zeng et al. (2010), who reported that adding *Phanerochaete chrysosporium* to agricultural waste compost (a mixture of rice straw, vegetables, rice bran, and soil) during the mesophilic cooling phase increased the activity of xylanase, manganese peroxidase, and lignin peroxidase, which in turn increased the lignocellulose degradation ratio by 40%.

Zeng et al. (2010) study revealed that, in contrast to the inoculation during the first phase of the agricultural waste (rice straw + bran + vegetable) composting process, the addition of *Phanerochaete chrysosporium* during the second phase promotes a considerable shift in compost maturity. By significantly enhancing the breakdown of lignocellulose, bacterial inoculation at different stages of composting rice straw, (Zhou et al., 2015) maize straw (Zhao et al., 2016) and citrus peel (Wang et al., 2019) reduced the C/N ratio and composting period. According to a review by Fan et al. (2017) the microbial inoculation on lignocellulosic waste composting showed nearly 100% positive effect on temperature, inoculation rate, microbial population, C/N ratio, humification, and more than 50% on degradation of organic matter, germination index (GI), and N, P, and K. Our study focuses on preparation of banana plant waste compost by utilizing microbial inoculation through bacteria *P. aeruginosa* (AMB-CD-1) and fungus *S. cerevisiae*. Fi-

nally the prepared compost was used to determine its impact on spinach growth, nutrition and soil properties.

2. Materials and method

Collection of selected isolates

The bacteria *P. aeruginosa* AMBCD-1 and yeast *S. cerevisiae* were collected from Department of Agricultural Microbiology, College of Agriculture, IGKV, Raipur (C.G.). The bacteria *P. aeruginosa* AMBCD-1 was originally isolated from cow dung by Raj et al. (2023) whereas yeast (*S. cerevisiae*) was purchased from Microbial Type Culture Collection (MTCC), Chandigarh (India).

Revival of cultures

The selected bacterial isolates *P. aeruginosa* AMBCD-1 and yeast *S. cerevisiae* were streaked on nutrient agar medium and yeast extract peptone dextrose (YEPD) medium respectively for reviving the cultures. The individual colonies of bacterial and yeast isolates were inoculated in nutrient agar slants and YEPD slants respectively and incubated for 24 hours in a BOD incubator at 37 °C. The agar slants and YPD slant representing required growth were stored in a refrigerator at 6 – 8 °C till further use. The sub-culturing was done at a regular interval period of 15 days.

Preparation of compost pit

Banana plant wastes were obtained from the banana field at College of Agriculture, IGKV Raipur (C.G.). The banana plant wastes were cut into pieces of about 3 to 4 cm in length with the help of a cutting knife. The chopped banana plant wastes were washed with tap water before use.

The composting of banana plant waste was observed for 45 days with bacteria and yeast in a wooden box (50 × 21 × 36 cm). The bottom of the box was filled with a sand layer (2.5 cm), then filled with a black soil layer (5 cm), before adding chopped banana plant waste (28.5 cm) in 4 boxes, and the other 3 boxes were filled with a sand layer (2.5 cm), then filled with a black soil layer (5 cm), before adding chopped banana plant waste co-composted with vegetable waste (28.5 cm).

Microbial degradation

For the microbial degradation process 7 treatments and 3 replications were taken. The treatment details are summarized in Table 1. Bacterial and fungal broth containing *P. aeruginosa* AMBCD-1 and *S. cerevisiae* were at regular intervals (one week) and allowed to compost in open environmental conditions for about 45 days. During composting the moisture content was between 60 – 70% and temperature about 30 – 35 °C (depends on local weather).

Nitrogen, phosphorus and potassium analysis of microbial degraded banana plant waste

The nitrogen content of banana plant waste samples was determined by taking 0.25 g of uniformly prepared sample in a digestion tube and adding 1 g of a salt mixture (K_2SO_4 and $CuSO_4 \cdot 5H_2O$ mixed in 10:1 ratio) in the tube, 10 mL of concentrated sulphuric acid (H_2SO_4) was added and this mixture was digested at 350 °C in the digestion unit

Table 1. Treatment details of microbial degradation of banana plant waste.

S. No.	Treatment	Details
1	T1	Banana plant waste (leaf, stem)
2	T2	Banana plant waste + <i>S. cerevisiae</i>
3	T3	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1
4	T4	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + <i>S. cerevisiae</i>
5	T5	Banana plant waste + <i>S. cerevisiae</i> + Vegetable waste
6	T6	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + Vegetable waste
7	T7	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + <i>S. cerevisiae</i> + Vegetable waste

till the digested material became colorless, then allowed to cool. The digested clear material was transferred and filtered into a 100 mL volumetric flask by repeated washing with distilled water, and the volume was made up to the mark. This digested material is used for the estimation of P and K content analysis, as given below.

Phosphorus content was determined by the vanadomolybdophosphoric acid yellow color complex method as described by Jackson (1973). An aliquot of 10 mL was taken, and 10 mL of vanadomolybdate yellow reagent was added in a 50 mL volumetric flask, and the volume was made up to the mark. After half an hour, color intensity was measured by a spectrophotometer at 540 nm. Potassium content was determined by a flame photometer, as described by Chapman and Pratt (1961). An aliquot of 10 mL was taken in a 25 mL volumetric flask, and the volume was made up to the mark. Then the potassium content was determined by a flame photometer.

Organic carbon content in degraded banana plant waste

Walkley - Black method was used to determine organic carbon (Walkley and Black, 1934). One gram of air-dried banana plant waste compost sieved at 0.15 mm was taken into a 500 mL beaker. Ten (10) mL of 1N potassium dichromate solution and 20 mL of concentrated H₂SO₄ were added using a pipette and a dispenser, respectively. The beaker was swirled to mix the suspension. After 30 minutes, 200 mL of distilled water was added, followed by the addition of 10 mL of concentrated H₃PO₄ using a dispenser, and the mixture was allowed to cool. Then, 10 – 15 drops of diphenylamine indicator were added. The content is stirred with a Teflon-coated magnetic stirring bar in a beaker and placed on a magnetic stirrer. The mixture was then titrated with a 0.5 M ferrous ammonium sulfate solution until the color changed from violet-blue to green. Also, two blanks were tested, containing all reagents but no compost.

Calculation:

$$\text{Oxidizable organic carbon(\%)} = \frac{(V_{\text{blank}} - V_{\text{sample}}) \times 0.3 \times M}{W_t}$$

where:

M = Molarity of (NH₄)₂SO₄.FeSO₄.6H₂O solution (about 0.5 M)

V blank = Volume of (NH₄)₂SO₄.FeSO₄.6H₂O solution required to titrate the blank (mL) Vsample = Volume of (NH₄)₂SO₄.FeSO₄.6H₂O solution required to titrate the

sample (mL) Wt = Weight of air-dry soil (g)

$0.3 = 3 \times 10^{-3} \times 100$, where 3 is the equivalent weight of C.

pH content in degraded banana plant waste

Fifty grams of air-dry compost were placed into a 100 mL glass beaker, and 50 mL of distilled water was added, which was mixed well with a glass rod. The suspension was allowed to stand for 30 minutes, during which stirring was done every 10 minutes. After 1 hour, the suspension was stirred, and the pH meter was calibrated. The combined electrode was put in suspension (about 3 cm deep). The reading was taken after 30 seconds with one decimal. The combined electrode was removed from the suspension and thoroughly rinsed with distilled water, followed by carefully drying the excess water with a tissue.

Moisture content in degraded banana plant waste

About 10 grams of air-dried compost was placed into a previously dried (105 °C) and a weighted metal can with a lid and weight was taken. After that, it was placed in the oven with the lid unfitted to dry at 105 °C overnight (i.e., for 24 h). The next day, after the compost had dried, the container was removed from the oven using tongs. The lid was fitted and allowed to cool in a desiccator for at least 30 minutes and the weight was taken (Sparks et al., 1996).

Calculation:

$$\text{Moisture(\%)} = \frac{\text{wet sample(g)} - \text{dry sample(g)}}{\text{Dry sample(g)}}$$

Electrical conductivity (EC) of degraded banana plant waste

Fifty grams of air-dry compost was taken into a 100 mL glass beaker. 50 mL distilled water was added and mixed well with a glass rod. The suspension was allowed to stand for 30 minutes during which it was stirred after every 10 minutes. After an hour, the suspension was stirred and filtered using suction. This was done by first putting a round of Whatman No. 42 filter paper in the Buchner funnel. Secondly, the filter paper was moistened with distilled water making sure that it was tightly attached to the bottom of the funnel and all holes were covered. The vacuum pump was stood, and the suction and the suspension were poured into the Buchner funnel. The filtration continued until the compost sample on the Buchner funnel started cracking. The procedure was repeated till the filtrate was clear. The conductivity meter was calibrated according to the maker's

instructions. The clear filtrate was transferred into a 50 mL bottle. The reading was taken by immersing the conductivity cell in the solution. Then, the conductivity cell was removed, rinsed thoroughly with distilled water, and dried excess water with a tissue.

Effect of prepared banana plant waste compost on growth and development of Spinach

Polybag Experiment

A polybag experiment was conducted utilizing the microbial-degraded banana plant waste compost to evaluate the growth performance of spinach grown under controlled conditions. This experiment was conducted in the Department of Agricultural Microbiology, IGKV, Raipur (C.G.). The experiment and treatment details of the experiment are presented in Tables 2 and 3.

Determination of plant growth parameters

The growth parameters of spinach (*Spinacia oleracea*) were determined using appropriate methods 45 days after sowing (DAS) for plant height, and root length. With the use of a measuring scale of 30 cm, the height and root length of randomly selected spinach plants was measured from the ground level to the top of the middle leaves 45 days after sowing (DAS).

Chemical analysis of plant sample at 45 DAS

Nitrogen content in dried plant sample

The nitrogen content of samples was done by taking 0.25 g uniformly prepared sample in a digestion tube adding 1 g salt mixture (K_2SO_4 and $CuSO_4 \cdot 5H_2O$ mixed in 10:1 ratio) in the tube, 10 mL of concentrated sulphuric acid (H_2SO_4) was added and this mixture was digested at 350 °C in digestion unit till the material becomes colorless. Then the nitrogen in digested material was distilled by an automatic KEL plus system (Pelican). For phosphorus and potassium

analysis about one gram of banana plant waste samples were taken in a digestion tube and 10 mL of triacid mixture (Concentrated HNO_3 , $HClO_4$ and H_2SO_4 in a ratio of 9:4:1) were added to it. This mixture was digested at 150 °C in a digestion unit till the digested material became colorless and then allowed to cool. The digested clear material was transferred and filtered into a 100 mL volumetric flask by repeated washing with distilled water and made up the volume to the mark. This digested material is used for the estimation of P and K content analysis as given below.

Phosphorus and potassium content in dried plant sample

Phosphorus content was determined by the vanadomolybdo-phosphoric acid yellow color complex method as described by Jackson (1973). An Aliquot of 10 mL was taken and 10 mL of vanadomolybdate yellow reagent was added to a 50 mL volumetric flask and volume was made up to the mark. After half an hour color intensity was measured by Spectrophotometer at 540 nm. Potassium content was determined by a flame photometer as described by Chapman and Pratt (1961). Aliquot 10 mL was taken in a 25 mL volumetric flask and the volume was made up to the mark. Then potassium content was determined by a flame photometer.

Chlorophyll content of spinach leaves at 45 DAS

Estimation of chlorophyll (By Acetone Method): The chlorophyll content of leaves at flowering time was determined at 45 DAS. The representative fresh leaf samples were taken. These were washed with distilled water and dried with blotting paper. Chlorophyll is soluble in acetone. When the sample is macerated in acetone, chlorophyll gets dissolved in it.

The optical density of the extract is measured at 663 and 645 nm wavelengths using a spectrophotometer because at these wavelengths, maximum absorption of chlorophyll "a" and "b" takes place respectively. Using the absorption

Table 2. Details of the experiment setup to evaluate the performance of Spinach in presence of banana waste compost.

Crop	Spinach (<i>Spinacia oleracea</i>)
Season	Rabi 2022
Design	Completely Randomized Design(CRD)
Number of treatments	7
Replications	3
Total number of pots	$7 \times 3 = 21$
Weight of per pot	Avg.7 kg

Table 3. Treatment details of polybag experiment to evaluate the performance of Spinach with different compost preparations.

S. No.	Treatment	Compost Details
1	T1	Banana plant waste (leaf, stem)
2	T2	Banana plant waste + <i>S. cerevisiae</i>
3	T3	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1
4	T4	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + <i>S. cerevisiae</i>
5	T5	Banana plant waste + <i>S. cerevisiae</i> + Vegetable waste
6	T6	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + Vegetable waste
7	T7	Banana plant waste + <i>P. aeruginosa</i> AMBCD-1 + <i>S. cerevisiae</i> + Vegetable waste

coefficients, the amount of chlorophyll is calculated (Arnon, 1949).

Extraction: 0.2 g of fresh plant leaf material was placed in a test tube and ground with 10 mL of 80% acetone in a mortar using a pestle. The total chlorophyll was calculated using the formula:

$$\frac{\text{mgtotalchlorophyll}}{\text{gtissue}} = \frac{20.2(A645) + 8.02(A663) \times V}{1000 \times W}$$

where, A = absorbance at specific wavelength; V = final volume of chlorophyll extract; W = fresh weight of tissue extracted.

Statistical analysis

All the observations were recorded and tabulated in a systematic manner with the help of MS Excel. The final observations were statistically analyzed by using MS Excel. The analysis was laid out in a completely Randomized Design (CRD). The data obtained from various characters under study was analyzed by the method of analysis of variance as described by Gomez and Gomez (1984). The level of significance for the “F” test was given at 1%. Critical difference

values are given in the table at a 1% level of significance, wherever the “F” test was significant at a 1% level.

3. Result and discussion

Banana plant waste degradation experiment

The colour of banana plant waste changed from green to dark black (Fig. 1 (a) and (b)). The change of colour and other physical properties was also noticed by several other worker (García et al., 1990; Yuanita et al., 2022).

Nitrogen content

The recorded observations of nitrogen content in banana plant waste compost are presented in Table 4. The maximum nitrogen content was significantly high in T3 (Banana plant waste + AMBCD-1) (1.73%) followed by T2 (Banana plant waste + *S. cerevisiae*) (1.67%) & the minimum nitrogen content recorded was in T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (1.47%) followed by T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (1.50%).

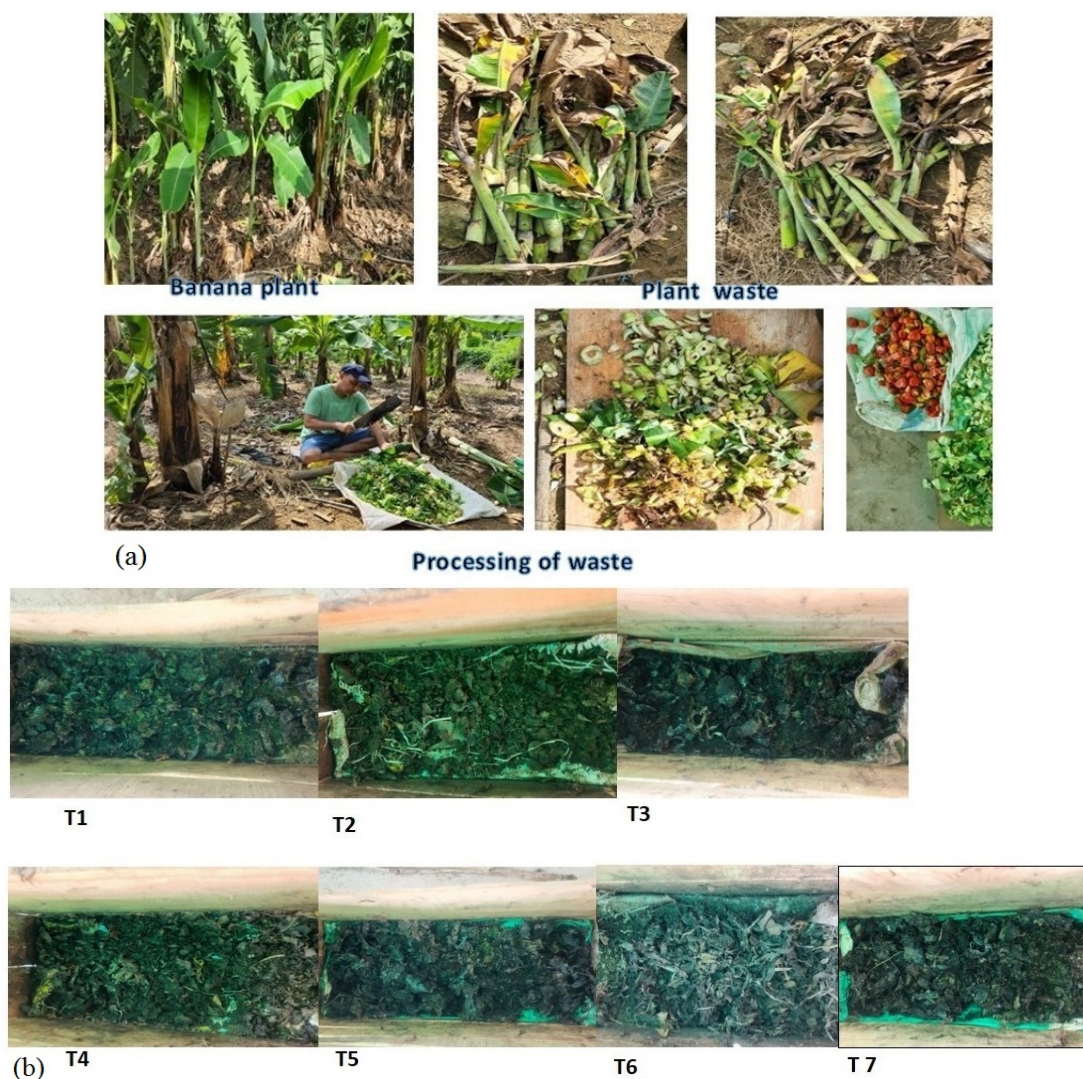


Figure 1. (a) Preparation of raw materials for composting experiment. (b) Colour Change of degraded banana waste due to different treatments (treatment as per Table 2).

Table 4. Nitrogen, Phosphorus, Potassium, Organic carbon, Moisture, pH and Electrical conductivity content of Banana plant waste compost at 45 days.

Treatment	N %	P %	K %	OC %	Moisture %	pH %	EC (dSm ⁻¹)
T1 (Banana plant waste)	1.57 ^{cd}	0.348 ^b	2.493 ^{cd}	29.74 ^a	30 ^{bc}	7.07 ^b	1.77 ^{ab}
T2 (Banana plant waste + <i>S. cerevisiae</i>)	1.67 ^{ab}	0.292 ^d	2.488 ^d	20.34 ^b	27 ^c	7.77 ^{ab}	1.4 ^{ab}
T3 (Banana plant waste + <i>P. aeruginosa</i>)	1.73 ^a	0.369 ^a	2.621 ^a	31.19 ^a	28.67 ^{bc}	7.53 ^b	2 ^a
T4 (Banana plant waste + <i>P. aeruginosa</i> + <i>S. cerevisiae</i>)	1.61 ^{bc}	0.335 ^{bc}	2.563 ^b	24.9 ^{ab}	28 ^{bc}	7.03 ^b	1.27 ^b
T5 (Banana plant waste + <i>S. cerevisiae</i> + Vegetable waste)	1.52 ^{de}	0.3 ^d	2.505 ^c	23.77 ^{ab}	33 ^{abc}	7.23 ^b	1.53 ^{ab}
T6 (Banana plant waste + <i>P. aeruginosa</i> + Vegetable waste)	1.5 ^{de}	0.327 ^c	2.415 ^e	26.82 ^{ab}	36.67 ^a	7.6 ^{ab}	1.1 ^b
T7 (Banana plant waste + <i>P. aeruginosa</i> + <i>S. cerevisiae</i> + Vegetable waste)	1.47 ^e	0.305 ^d	2.109 ^f	17.58 ^b	33.67 ^{ab}	8.33 ^a	1.23 ^b

Note: Different letters as superscript of each data indicate significant differences among the observations, as calculated by Tukey's HSD test at $P \leq 0.05$.

Phosphorus content

The recorded observations are presented in Table 4. The maximum phosphorus content was significantly high in T3 (Banana plant waste + *AMBCD-1*) (0.369%) followed by T1 (Banana plant waste) (0.348%) & the minimum phosphorus content was recorded in T2 (Banana plant waste + *S. cerevisiae*) (0.292%) followed by T5 (Banana plant waste + *S. cerevisiae* + Vegetable waste) (0.3%).

Potassium content

The recorded observations are shown in Table 4. The maximum potassium content was significantly high in T3 (Banana plant waste + *AMBCD-1*) (2.621%) followed by T4 (Banana plant waste + *AMBCD-1* + *S. cerevisiae*) (2.563%) & the minimum potassium content recorded was in T7 (Banana plant waste + *AMBCD-1* + *S. cerevisiae* + Vegetable waste) (2.109%) followed by T6 (Banana plant waste + *AMBCD-1* + Vegetable waste) (2.415%).

Organic carbon

The recorded observations of organic carbon content in the banana plant waste compost are presented in Table 4. The maximum Organic carbon content was significantly high in T3 (Banana plant waste + *AMBCD-1*) (31.19%) followed by T1 (Banana plant waste) (29.7%) & the minimum Organic carbon content recorded was in T7 (Banana plant waste + *AMBCD-1* + *S. cerevisiae* + Vegetable waste) (17.58%) followed by T2 (Banana plant waste + *S. cerevisiae*) (20.34%).

Moisture test

The recorded observations of moisture content in the banana plant waste compost are presented in Table 4. The maximum moisture content was significantly high in T6 (Banana plant waste + *AMBCD-1* + Vegetable waste) (37%) followed by T7 (Banana plant waste + *AMBCD-1* + *S.*

cerevisiae + Vegetable waste) (34%) & the minimum moisture content recorded was in T2 (Banana plant waste + *S. cerevisiae*) (27%) followed by T4 (Banana plant waste + *AMBCD-1* + *S. cerevisiae*) (28%).

pH test

The recorded observations of pH content in the banana plant waste compost are presented in Table 4. The maximum pH content was significantly high in T7 (Banana plant waste + *AMBCD-1* + *S. cerevisiae* + Vegetable waste) (8.3) followed by T2 (Banana plant waste + *S. cerevisiae*) (7.8) and the minimum pH content recorded was in T4 (Banana plant waste + *AMBCD-1* + *S. cerevisiae*) (7.0) followed by T1 (Banana plant waste) (7.1).

Electrical conductivity

The recorded observations of electrical conductivity content in the banana plant waste compost are presented in Table 4. The maximum electrical conductivity content was significantly high in T3 (Banana plant waste + *AMBCD-1*) (2.0 dS/m) followed by T1 (Banana plant waste) (1.8 dS/m) & the minimum Electrical conductivity content recorded was in T6 (Banana plant waste + *AMBCD-1* + Vegetable waste) (1.0 dS/m) followed by T7 (Banana plant waste + *AMBCD-1* + *S. cerevisiae* + Vegetable waste) (1.2 dS/m).

Effect of banana plant waste compost on growth and development of spinach

Plant height at 45 DAS

The plant height of spinach was recorded with the help of a measuring scale at 45 DAS. The results are summarized in Table 5. The maximum plant height at 45 DAS was recorded in T3 (Banana plant waste + *AMBCD-1*) (20.7 cm/plant) followed by T4 (Banana plant waste + *AMBCD-1* + *S. cerevisiae*) (20 cm/plant). All the treatments were at par with other treatments except T7 (Banana plant waste + *AMBCD-*

Table 5. Plant height, root length, chlorophyll, nitrogen, phosphorus, potassium content of spinach at 45 DAS.

Treatment	Plant height (cm)	Root length (cm)	Chlorophyll content (mg/g)	N %	P %	K %
T1 (Banana plant waste)	18.97 ^a	23.77 ^{ab}	0.52 ^{ab}	2.22 ^{ab}	0.28 ^{ab}	1.72 ^a
T2 (Banana plant waste + <i>S. cerevisiae</i>)	19.5 ^a	22.63 ^{ab}	0.45 ^b	2.21 ^{ab}	0.22 ^c	1.28 ^{bc}
T3 (Banana plant waste + AMBCD-1)	20.73 ^a	23.1 ^{ab}	0.54 ^a	2.87 ^a	0.3 ^a	1.39 ^b
T4 (Banana plant waste + AMBCD-1 + <i>S. cerevisiae</i>)	20.03 ^a	21.17 ^{bc}	0.51 ^{ab}	2.55 ^{ab}	0.24 ^{bc}	1.13 ^{bcd}
T5 (Banana plant waste + <i>S. cerevisiae</i> + Vegetable waste)	18.43 ^a	22 ^{ab}	0.53 ^{ab}	2.18 ^{ab}	0.2 ^{cd}	1.07 ^{cd}
T6 (Banana plant waste + AMBCD-1 + Vegetable waste)	18.77 ^a	24.6 ^a	0.53 ^{ab}	2.1 ^{ab}	0.17 ^d	1.04 ^{cd}
T7 (Banana plant waste + AMBCD-1 + <i>S. cerevisiae</i> + Vegetable waste)	16.23 ^a	18.2 ^c	0.52 ^{ab}	1.95 ^b	0.17 ^d	0.96 ^d

Note: Different letters as superscript of each data indicate significant differences among the observations, as calculated by Tukey's HSD test at $P \leq 0.05$.

1 + *S. cerevisiae* + Vegetable waste) (16.2 cm/plant). The minimum plant height was recorded in T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (16.2 cm/plant).

Root length at 45 DAS

The recorded observations are presented in Table 5. The maximum root length at 45 DAS was observed in T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (24.6 cm/plant) which was at par with T1 (Banana plant waste) (23.8 cm/plant) & the minimum was recorded in T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (18.2 cm/plant). The treatments T6 (Banana plant waste + AMBCD-1 + Vegetable waste) and T1 (Banana plant waste) significantly increased over all the treatments but in comparison to T1 (Banana plant waste) and T3 (Banana plant waste + AMBCD-1) which was at par with each other.

Chlorophyll content in spinach leaves at 45 DAS

Chlorophyll content of spinach was significantly affected by treatments and shown in Table 5. The maximum chlorophyll content was observed in the treatment T3 (Banana plant waste + AMBCD-1) (0.54 mg/g) which was at par with T5 (Banana plant waste + *S. cerevisiae* + Vegetable waste) (0.53 mg/g), T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (0.53 mg/g), T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (0.52 mg/g) and T1 (Banana plant waste) (0.52 mg/g). All the treatment was significantly higher over T2 (Banana plant waste + *S. cerevisiae*) (0.45 mg/g) and T4 (Banana plant waste + AMBCD-1 + *S. cerevisiae*) (0.51 mg/g). The minimum average chlorophyll content was observed in the treatment T2 (Banana plant waste + *S. cerevisiae*) (0.45 mg/g).

Nitrogen content in aerial parts of the plant at 45 DAS

The recorded observations of nitrogen content in the aerial parts of spinach are presented in Table 5. The maximum

nitrogen content was significantly high in T3 (Banana plant waste + AMBCD-1) (2.871%) followed by T4 (Banana plant waste + AMBCD-1 + *S. cerevisiae*) (2.554%) & the minimum nitrogen content recorded was in T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (1.953%) followed by T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (2.102%).

Phosphorus content in aerial parts of the plant at 45 DAS

The phosphorus content of spinach was presented in Table 5. The maximum phosphorus content was recorded as significantly high in T3 (Banana plant waste + AMBCD-1) (0.30%) which was significantly higher over all the treatment and T1 (Banana plant waste) (0.28%) and the minimum phosphorus content was recorded in T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (0.17%) and T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (0.17%).

Potassium content (%) in the aerial parts of the plant at 45 DAS

The potassium content of spinach was presented in Table 5. The maximum potassium content was observed in T1 (Banana plant waste) (1.725%) which was significantly higher over all the treatments. In the case of inoculation of microorganisms was the T3 (Banana plant waste + AMBCD-1) (1.393%) significantly higher over other inoculated treatments and minimum was recorded in the treatment T7 (Banana plant waste + AMBCD-1 + *S. cerevisiae* + Vegetable waste) (0.963%) followed by T6 (Banana plant waste + AMBCD-1 + Vegetable waste) (1.036%).

This study was divided into two sections: the manufacture of compost from vegetable and banana plant waste using microbial inoculation with bacteria *P. aeruginosa* and yeast *S. cerevisiae*. The compost products were then further evaluated for their effects on spinach growth and development. Through the biodegradation process, it was revealed that

the banana plant waste inoculated with bacteria *P. aeruginosa* AMBCD-1 exhibited significantly higher nitrogen, phosphorus, and potassium contents about 1.73%, 0.36%, and 2.62% respectively, particularly in treatment T3 (banana plant waste + AMBCD-1). Also, the total organic carbon content was approximately about 31.19% in treatment T3 (banana plant waste + AMBCD-1) which was higher than in other treatments. While a minimum organic carbon content was recorded in the treatment T7 (banana plant waste + AMBCD-1 + *S. cerevisiae* + vegetable waste) about 17.58%. Since fatty acids, CO₂, and nitrification are produced at the beginning of the aerobic degradation process, the pH will always drop; nevertheless, it will rise once more when microorganisms break down organic matter (Sundberg et al., 2013). Grgić et al. (2019) also reported that inoculation of *P. aeruginosa* bacteria accelerate biodegradation process.

The maximum pH was recorded in treatment T7 (banana plant waste + AMBCD-1 + *S. cerevisiae* + vegetable waste) at about 8.3 while in treatment T3 (banana plant waste + AMBCD-1) the pH measured about 7.5. Changes in pH values may be an important indicator of microbiological activity.

However, the pH of banana waste compost is also depends on other factors. As studied by Kalemelawa et al. (2012), who reported that high K concentrations in banana waste forms a strong base (KOH) that change the pH value. The current findings are consistent with research findings that the composting material steadily breaks down over time, stabilizes, and eventually maintains a pH of between 7 and 8 (Ranalli et al., 2001; Adebayo et al., 2011; Himanen and Hanninen, 2011; Sarker et al., 2013). The highest organic carbon content was recorded in the treatment T3 (banana plant waste + AMBCD-) about 31.19% representing an increased rate of decomposition compared to other treatments. Furthermore, to study the effects of biodegradable banana plant compost products on the growth and development of spinach, a polybag experiment was performed with 7 treatments and 3 replications using a completely randomized design (CRD). The plant growth parameters like plant height and root length showed a significant increase in treatment T3 (banana plant waste + AMBCD-) approximately about 20.7 cm and 23.1 cm respectively. Our results are in close conformity with the work done by Virk et al. (2021) who reported an increasing pattern in plant height of maize with the application of prepared banana residue compost. The chlorophyll content was significantly maximum in the treatment T3 (banana plant waste + AMBCD-1) at about 0.54 mg/g compared to the control. Similarly, Aisha et al. (2013) also reported that on application of biofertilizer, there was a significant increase in chlorophyll content.

The chemical analysis of the dried plant sample showed increased concentrations of nitrogen (2.8%), phosphorus (0.3%), and potassium (1.3%) in the treatment T3 (banana plant waste + *P. aeruginosa*) when compared to other treatments. Our results are by the work done by Rahman et al. (2014) who reported that the application of different composts increased organic matter, nitrogen, phosphorus, and potassium contents, which indicated improvement in

soil fertility and thereby enhanced the growth and yield of red amaranth and spinach. However, the application of banana waste compost was also reported in other crops. Suganthi and Saravana (2022) reported that the banana spathe compost could be used as an effective organic fertilizer for the growth of rice plants. Similarly, all banana peel compost enhanced and improved plant growth performance and yield (Fernando and Seran, 2023; Teshome, 2022).

4. Conclusion

The experiment conducted to evaluate banana plant waste degradation through microbial inoculation concluded that the nitrogen, phosphorus, and potassium concentrations of banana plant waste compost were higher when degraded with bacteria *P. aeruginosa* than inoculation with *S. cerevisiae*. Further assessment of growth performance of spinach under microbial inoculation with bacteria *P. aeruginosa* and yeast *S. cerevisiae* revealed that treatments inoculated with *P. aeruginosa* exhibited maximum plant height (20.7 cm) particularly in treatment T3 (Banana plant waste + *P. aeruginosa*), also a higher chlorophyll content of about 0.54 mg/g was measured in treatment T3 and also significant higher value of nitrogen and phosphorus content in aerial parts of spinach. From the present study, we can conclude that bacteria *P. aeruginosa* possess biodegradation ability to degrade banana plant waste effectively. Similarly, microbial inoculation with bacteria *P. aeruginosa* can enhance the overall growth performance of spinach. Further the use of banana composting is a sound technology for combating soil poverty. Though, socio-ecological constant need to be mitigated in order to increase the adoption of new compost technology at the large scale leading to zero wastes. Moreover, studies may also be conducted on different aspects of compost making from banana crop residues by enriching with other organic sources to improve crop nutrition.

Authors contributions

LK Verma & R Soni: Conceptualization, Methodology, Investigation, Formal analysis and Writing original draft, review. KK Raj & Deeppal: Investigation, Methodology, Statistical analysis, Writing original draft. S Ismail: review, english editing. T. Chowdhury: review, editing and resource availability.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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