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Production of Potassium-Rich Biofertilizer from Composted Banana Peels and Watermelon Rinds

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ABSTRACT

This study investigated the production of biofertilizer from composted banana peels and watermelon rinds, focusing on the mineral content and its impact on plant growth. The process involved characterizing raw materials, producing biofertilizer, analyzing mineral concentrations (potassium, nitrogen and phosphorus), and evaluating its quality through Spiny Amaranth seed growth. A compost bin with three compartments was designed, testing three composting ratios of banana peels to watermelon rinds (2:1, 1:2 and 1:1). Composting was monitored on moisture content, pH, organic matter, and temperature for 37 days. The 1:1 ratio had the lowest temperature (33.45°C) and highest pH (7.08), while the 2:1 ratio had the highest moisture content (36.47%). The 1:2 ratio, with 5.87% potassium, produced the best Spiny Amaranth growth. The potassium-rich banana peels and watermelon rinds likely provided essential nutrients for water uptake, enzyme activation, and stress tolerance. The compost also contained 1.63% and 0.75% phosphorus, promoting growth and root development. This potassium-rich biofertilizer, compared to commercial NPK fertilizers, shows potential as a potassium-mobilizing fertilizer, though additional phosphorus and nitrogen are needed for optimal growth. This study shows that organic waste - banana peels and watermelon rinds can produce potassium-rich biofertilizers, supporting sustainable agriculture and reducing synthetic fertilizer reliance.

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INTRODUCTION

Fertilizers and pesticides play a crucial role in modern agriculture, with fertilizers providing essential nutrients for plant growth and pesticides serving as vital defenses against harmful pests and diseases (Liu *et al.*, 2024). Chemical fertilizers, often regarded as the most effective and convenient way to add essential nutrients to the soil for plant growth, can be both costly and unhealthy (Mehata *et al.*, 2023). Plants require specific mineral nutrients to thrive, but due to the disproportionate application of chemical fertilizers, there has been an ongoing depletion of these nutrients in the soil, resulting in significant (50%−60%) fertility decline (Madhukar *et al.*, 2020; Yahaya *et al.*, 2023). While synthetic fertilizers provide essential nutrients like nitrogen, phosphorus, and potassium, they often lack trace minerals like magnesium, calcium, and sulfur, which are also crucial for soil health (Yahaya *et al.*, 2023; Pahalvi *et al*., 2021). This depletion of essential elements has made the soil less fertile over time, requiring even greater amounts of fertilizer to sustain crop yields, creating a vicious cycle of depletion and dependence (Timsina, 2018). To address this, it is essential to explore more sustainable and balanced agricultural practices that reduce the need for synthetic chemicals.

As environmental awareness grows, scientific communities are increasingly developing biofertilizer formulations using food and agricultural by-products (Mandal *et al*., 2024; Puglia *et al.*, 2021; Arumugam *et al*., 2021). Biofertilizers, derived from organic materials like food waste, offer an effective to chemical fertilizers by enhancing nutrient bioavailability and improving soil health (Badiyal *et al*., 2024; Mahish *et al*., 2024; Mandal *et al*., 2024). Food waste, including fruits, vegetables and kitchen scraps is rich in organic matter, that varies in composition depending on its source, such as oils, agro-industrial by-products, and meat (Mahmud *et al*., 2019; Mahish *et al.*, 2024). The organic components in solid food waste can be converted into biofertilizers through processes like anaerobic digestion (AD) or composting. Composting, a biological process involving the aerobic decomposition of organic materials by microorganisms, is a sustainable method to recycle food and agricultural waste into nutrient-rich compost (Ayilara *et al*., 2020; Amuah *et al*., 2022; Oshins *et al.*, 2022). The resulting compost is nutrient-rich, dark, crumbly material that enhances soil structure, fertility, and moisture retention (Singha *et al*., 2024; Upadhyay *et al*., 2024; Ufitikirezi *et al*., 2024). The dark color of compost stems from the decomposed carbon, lignin and tannins, while microorganisms contribute to the formation of dark compounds during decomposition (Singh *et al.*, 2021; Musa, 2023). Composting also supports environmental sustainability by improving water retention and soil stability, essential for plant growth (Quambarani *et al*., 2024; Partanen *et al.*, 2010).

Fruit waste-based biofertilizer offers numerous benefits for plants since it improves the soil pH and soil fertility (Krithika *et al*., 2024). However, improper disposal of these nutrient-rich wastes produces unpleasant odour, attracts harmful insects, and leads to microbial spoilage. This not only creates discomfort but also contributes disease spread and environmental issues, including the greenhouse gas effect (Muniappan *et al*., 2023; Raji and Onu, 2017). Research has been done to produce biofertilizers from different fruit wastes including banana, watermelon, citrus (Abobatta and El-Azazy, 2020), apple (Devi and Sumathy, 2017), pear waste, pineapple (Mataba *et al*., 2024) and others. The produced biofertilizer contains valuable nutrients like potassium, nitrogen, phosphorus, and trace minerals, which are essential for plant growth (Mataba *et al.*, 2024). While both fruit wastes have individual benefits, their combined potential remains unexplored preventing the full utilization of these organic byproducts, limiting sustainable and eco-friendly fertilizer development opportunities. This represents a notable gap in exploring the potential of these fruits waste combinations for biofertilizer production.

Both bananas and watermelons are two most important fruit crops in the world with the highest production (Suppen-Reynaga *et al*., 2024). Around 150 million tonnes of bananas are produced annually, mainly in Asia, Africa, and Central America (Vantyghem *et al*., 2022). India leads global banana production (26.8%) followed by China (9.8%) and Brazil (5.9%) (Evans *et al.*, 2020; Scott, 2021). Tanzania produces 3.5-4.0 million tonnes (3.1%) of bananas annually (Sanga, 2020; Evans *et al.*, 2020; Lucas and Jomanga, 2021), mainly for local consumption, especially in Kagera. The global production of watermelon is 120 million tonnes and China dominates watermelon production (67.6%), followed by Turkey (3.84%) (Levi *et al*., 2017; Dube *et al.*, 2021). Watermelon production in Tanzania reached 0.0375 million metric tons per annum in 2022 (Helgi Library, 2024), with an increase of 0.935% per year this will results to 0.04 million metric tons per year by 2030.

Banana peel (BP) is a significant agro-waste produced annually, particularly by food-processing industries, posing a substantial disposal challenge (Hemidat *et al.*, 2022). Banana peels constitute about 40% of total weight of fresh bananas with slight variations based on species and maturity (Rodrigues *et al.*, 2024; Sahoo and Lenka, 2024). In Tanzania, the annual banana production results in approximately 1.6 million metric tonnes of banana peels (Lucas and Jomanga, 2021). Similarly, watermelon rinds, which make up 30% of the fruit's total weight (Rezagholizade-Shirvan *et al.*, 2023), represent an estimated 12.1 kilo tonnes annually by 2030. Despite being discarded, watermelon rinds the tough, green outer layer surrounding the flesh; are rich in fiber, antioxidants, and vitamins, offering valuable potential for various application (Du *et al.*, 2022; Beegum *et al.*, 2024). If properly composted, both banana peels and watermelon rinds can significantly contribute to nutrient-rich compost, improving soil fertility. Their combination may enhance microbial activity, yielding higher-quality compost with a more balanced nutrient profile, boosting soil health (Erugo *et al.*, 2022).

As the production and consumption of bananas and watermelon rise, their associated waste also increases, leading to significant environmental issues such as waste accumulation, water pollution and greenhouse gas emissions, (Kumar *et al.*, 2020*)*. Research on valorising these wastes has been done on bio refinery (Pathak *et al.*, 2016). Biorefinery research has established foundations for valorizing banana and watermelon waste; however, significant gaps remain in utilizing rinds and their combination with banana peels for biofertilizer production (Bui *et al.*, 2025; Nurin *et al.*, 2024). Both systems aim to convert biological waste or biomass into valuable products while minimizing environmental impact. When multiple feedstocks such as banana peels and watermelon rinds are mixed in suitable proportions, they create favorable composting conditions (Rynk *et al.*, 2022). Balancing the carbon-to-nitrogen (C:N) ratio, moisture, and aeration is crucial for optimal composting (Guo *et al.*, 2012; Azis *et al.*, 2023). Banana waste, rich in carbon and potassium (Islam *et al.*, 2019), pairs well with watermelon waste, which has a lower C:N ratio and high-water content. Together, they create a balanced nutrient profile, enhancing microbial activity and compost quality.

Garden wastes, such as grass clippings, fallen dry leaves, and pruned branches, are often discarded but can be highly beneficial for composting (Mataba *et al*., 2024). Dry leaves help absorb excess moisture, promote aeration, prevent compaction, and provide essential carbon to balance the compost's nitrogen content (Youngman, 2023; Wang *et al.*, 2021). Fresh grass clippings help to supply nitrogen and balance the carbon-to-nitrogen ratio enhancing microbial activity and improve the overall composting process (Youngman, 2023). This study investigated the production of biofertilizer through the composting of banana peels and watermelon rinds, with the incorporation of garden waste to enhance the efficiency of the composting process.

MATERIALS AND METHODS

Raw materials collection and preparation

Raw materials used were banana peels, watermelon rinds, dry leaves and fresh grass clippings. Fresh banana peels from ripe banana and watermelon rinds were sourced from the Mabibo market, Dar es Salaam Tanzania. Mabibo Market was chosen as a representative of the busiest and most popular markets, offering a wide range of fruits, vegetables, and other food items, with bananas, watermelons, mangoes, pineapples, papayas, and citrus fruits being commonly available. The loamy garden soil, grass clippings and leaves were obtained from gardens around the University of Dar es Salaam. Simple random sampling was used to avoid any bias and have broad selection of samples. All experiments and analysis were conducted at the Chemical and Water resource laboratories at College of Engineering and Technology (CoET). To speed up the decomposition process, samples were chopped to reduce their size to 10-15 mm by using a stainless-steel serrated knife with a sharp edge to allow precise cutting. Figure 1 show the raw materials used in this study.

Figure 1: Raw materials for production process.

Physical-chemical characterization of banana peels and watermelon rinds

The banana peels and watermelon rinds wastes passed through a series of physical and chemical assessments to determine their appropriateness for composting, intending to produce biofertilizer.

Moisture content: The determination of moisture content was done by adopting the method as prescribed by Nielsen, (2010). The chopped samples were crushed and ground using a mortar and pestle to increase the surface area for more efficient moisture evaporation. A measured quantity of the ground sample was placed in a weighing dish, and its initial weight (W1) was recorded on an analytical balance. The sample was then transferred to a drying pan and placed in a preheated oven set at 105°C, where it was dried until it reached a constant weight. After drying, the sample was removed and placed in a desiccator to cool, preventing moisture absorption from the air. Once at room temperature, the final weight (W2) was recorded, and the moisture content was calculated using Equation 1.

$$\%MC = \frac{W1 - W2}{W1} \times 100\% \dots \dots \quad (1)$$

where W_1 represents the weight of the wet sample, and W_2 represents the weight of the dry sample.

Total organic matter: The method by Pezzolla *et al*., (2021) for total organic matter analysis was adopted. Samples were first dried in an oven at 105°C to remove excess moisture and dry weight (W2) was recorded. The dried samples were placed in a crucible and ashed in a muffle furnace at 550–600°C for 2 hours to burn off the organic. After a 2-hour incineration period, the crucible was removed from the furnace using tongs and transferred to a desiccator to allow cooling. After cooling in a desiccator, the weight of the residual ash (W3) was recorded. The total organic matter was then calculated by subtracting the ash weight from the dry weight and expressing it as a percentage of the dry weight using Equation 2.

$$Total\ organic\ matter\ (\%) = \frac{(W2 - W3) \times 100\%}{(W2 - W1)} \dots \dots \quad (2)$$

pH level: The standard method for pH measurement using the suspension method was used. The pH of banana peels and watermelon rinds was determined by first grinding the samples into a fine powder using a mortar and pestle. For each analysis, 2 grams of ground samples was weighed into a 100 mL beaker. Next, 50 mL of distilled water (pH ~7.0) was added, creating a compost-to-water ratio of 1:5. The mixture was stirred for 5 minutes and allowed to settle for 1 hour to ensure that larger particles settle while fine particles remains in suspension. After settling, the pH was measured using a calibrated handheld Hanna pH meter H198128 by inserting the electrode just below the surface of the clear solution to avoid disturbing sediment. Three measurements were taken per sample, and the average was recorded. The pH meter was calibrated using pH 7.00 buffer solutions.

Production of bio fertilizer

Composting bin design

The composting method for biofertilizer production by Mataba *et al*., (2024) was adopted in this study with slight modification on the bin design. The compost bin (Figure 2) was made using wood (sturdy framework and for natural ventilation), a dump-proof membrane (DMP) (1 mm thick to prevents leakage of compost or moisture), nails (for solid and intact structure), plywood (for additional support and strength), pipes, and pins. The internal fitted pipes were used to ensure proper air circulation, creating favorable conditions for composting. The compost bin had 3 compartments, each compartment with a size of 21.21 cm in height, 25.98 cm in width and 27.42 cm in length. These dimensions of the compartments are large enough to promote heat generation but not too large, so that the heat is retained evenly and allows efficient aeration, easy handling, turning and monitoring of process parameters such as moisture and temperature (Waqas *et al*., 2023; Kong *et al*., 2024; Anand *et al*., 2016).

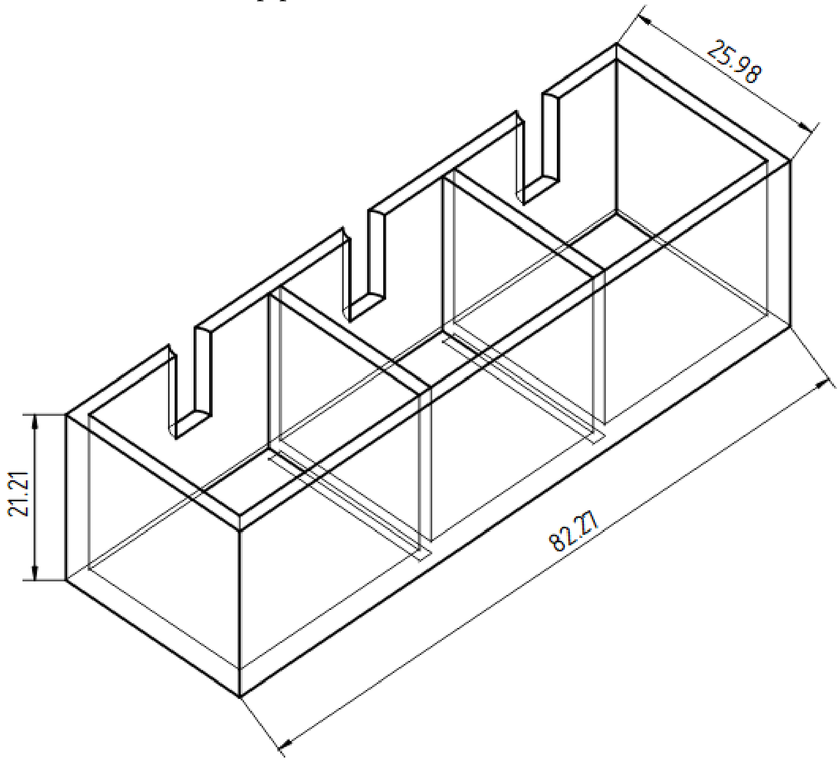

Figure 2: The designed compost bin (size in cm).

The Composting Process

The study utilized a total of 36 kg of composting materials, comprising 9 kg of banana peels, 9 kg of watermelon rinds, 6 kg of dry leaves, 4.5 kg of grass clippings, and 7.5 kg of garden soil. Three composting piles were employed for the three different mixing ratios of banana peels and watermelon rinds. For each composting pile, 12 kg of a mixture made up of these materials' banana peels, watermelon rinds, dry leaves, grass clippings, and soil was used as shown in Table 1. The ratios were designed to assess how different proportions of banana peels and watermelon rinds impact compost quality and decomposition speed. The process involved layering different materials systematically depending on their specific function in the process. First, a layer of garden soil was spread at the base to establish a foundation of microorganisms crucial for breaking down organic matter. Next, a base layer of dry leaves was placed at the bottom of the compost pile to help absorb moisture, promote aeration, and add carbon to the compost (Mataba *et al*., 2024).

Next, banana peels and watermelon rinds were added as a layer to supply nitrogen and potassium to the compost. Above this, fresh grass clippings were layered to provide additional nitrogen and help balance the carbon-to-nitrogen ratio in the compost pile.

The layering process continued in alternating layers of nitrogen-rich and carbon-rich materials until the compost pile reached a height of approximately 0.19 meters. Water was added at the beginning (2.5-5 cm) of water per layer, to establish the proper moisture level for the compost (Tang *et al.*, 2023; Li *et al.*, 2021; Meena *et al.*, 2021). This initial watering ensured that each layer—garden soil, dry leaves, banana peels, watermelon rinds, and grass clippings—had adequate moisture to support the decomposition process.

The temperature of the composting system was continuously monitored with a handheld thermometer (20 cm height) by inserting it into the compost mixture in three different locations: the center of the bin, the upper part of the compost mixture and the lower part of compost mixture, where the average temperature values were taken and recorded

Table 1: Raw materials and their proportions as used in the composting process

Components	1:1 (Kg)	2:1 (Kg)	1:2 (Kg)	Total (Kg)
Banana peels	3	4	2	9
Watermelon rinds	3	2	4	9
Dry leaves	2	2	2	6
Grass clippings	1.5	1.5	1.5	4.5
Soil	2.5	2.5	2.5	7.5
Total	**12**	**12**	**12**	**36**

The temperature of the sample was calculated using Equation 3.

$$Temperature = \frac{T_1 + T_2 + T_3}{3} \dots\dots\dots\dots \quad (3)$$

where, T_1 = Center of the bin, T_2 = Upper part of compost mixture, T_3 = Lower part of compost mixture.

Determination of biofertilizer mineral concentration

The mineral concentration for the three nutrients nitrogen, phosphorous and potassium were analyzed to determine the quality of the biofertilizer produced.

Nitrogen Concentration Determination: The nitrogen concentration in compost biofertilizer was determined using a Kjeldahl digestion method by Goyal *et al.*, (2022). A 2 g portion of sample was weighed and placed in a Kjeldahl flask, to which 67 mL of potassium sulfate, 67 mL of 0.02 M concentrated sulfuric acid (H_2SO_4), 366 mL of distilled water, and 3.65 g of copper sulfate were added to facilitate digestion. The mixture in a Kjeldahl flask was constantly heated at 150°C for 60 minutes until the fumes were formed and solution became clear, indicating the conversion of organic nitrogen to ammonium sulfate. The solution was allowed to cool to room temperature before distillation to avoid any risk of splashing or damage to the distillation flask (El hag and Sudan, 2022; Getachew and Mosneh, 2024). After cooling, 75 mL of distilled water was added to the Kjeldahl flask, which was then connected to a distillation flask. The ammonia released during digestion was distilled into a boric acid (H_3BO_3) solution with sodium hydroxide (NaOH) and sodium thiosulphate as base traps and then titrated with sulfuric acid (H_2SO_4). The volume of acid consumed was recorded and the nitrogen content was calculated using equation 4. This was done three times, and the average was recorded and reported. Each sample was analyzed in triplicate to ensure data robustness, and the average nitrogen content from these replicates was reported. Samples were stored in airtight containers at 4-10°C before analysis to maintain stability.

$$\%N = \left(\frac{Vol\ of\ H_2SO_4 \times Conc\ of\ H_2SO_4 \times 14}{Vol\ of\ sample}\right) \times 100 \ldots\ldots\ldots\ldots \quad (4)$$

***Phosphorous concentration Determination*:** The analysis of Phosphorous content was done by adopting the method described by Ameer *et al.*, (2024). A portion of sample was collected from the composting bin, placed in a crucible, and dried for 24 hours at 105°C in an oven to eliminate moisture and speed up the digestion process by breaking down organic compounds. The drying continued until a constant weight was achieved to ensure that the phosphorus concentration in the sample was not affected by water content, which could impact the accuracy of the results. After drying, the sample was ground into a fine powder using a mortar and pestle. A 2 g portion of the ground sample was then weighed and mixed with 100 ml of distilled water. The mixture was shaken and left to soak for 24 hours to ensure complete extraction of soluble phosphorus from the compost into the water. This soaking period maximizes phosphorus release, ensuring consistency and accuracy in concentration measurements prior to the filtration process (Jakubus, 2016). The mixture was filtered and a clear solution was kept in a conical flask, then the mixture was diluted in 1 ml of sample to 9 ml of distilled water to reduce concentration in the falcon tube. The sample was kept in test tube cuvettes to measure phosphorus concentration using a Palin test 7100 photometer. This was done three times, and the average was recorded and reported.

***Potassium concentration determination*:** Potassium concentration in the biofertilizer sample was determined using the method described by Yang *et al*., (2021) with a Palin test 7100 flame photometer, ideal for high-throughput potassium analysis. Prior to analysis, a 5 g representative sample was carefully weighed, dried in an oven at 105°C for 24 hours to remove moisture and break down organic compounds, then sieved through a 2 mm mesh to ensure uniformity. The dried sample was mixed with 100 mL of 1 N ammonium acetate and shaken for 90 minutes to ensure proper mixing. The mixture was then filtered, and clear solution was collected in a conical flask, and then transferred to test tubes cuvettes for potassium measurement. This procedure was repeated in triplicate to ensure data reliability, and the average potassium concentration was calculated and reported. The samples were stored in airtight containers at ambient temperature prior to analysis to preserve their chemical integrity and prevent any degradation or contamination.

Quality assurance (QA) and quality control (QC) of the composting process

The quality assurance and quality control of the composting process ensures the production of biofertilizer with high quality. This can be monitored through turning frequency and maturity assessments.

Turning frequency: The turning frequency in this study was carefully documented, with the material being turned once for every three to four days over a period of 37 days. This was done to ensure proper mixing of materials and provide enough oxygen to the microorganisms responsible for breaking down the organic matter and hence accelerating the decomposition process (Totàno *et al.*, 2015). Environmental parameters, including temperature and moisture content, were monitored and the calibrated equipment was used to ensure precision. Additionally, the decomposition process was indirectly validated through periodic sampling and analysis of material composition, providing confirmation of the turning frequency's effectiveness in facilitating microbial breakdown and accelerating decomposition.

Compost sampling and testing: Compost sampling was conducted every three to four days using a random sampling method to assess the quality of the compost. Samples were collected from the compost pile using a spatula, transferred to a beaker, and subsequently analyzed for moisture content, total organic matter, and pH. This systematic approach allowed for regular monitoring of the compost quality, providing indirect validation of the turning frequency's effectiveness in promoting proper decomposition.

Maturity assessment and Process parameter monitoring: The maturity of compost, a key indicator of its quality, stability, and suitability for various applications (e.g., soil amendment, gardening, or agriculture), was regularly assessed alongside process parameters such as temperature, moisture content, and color. These parameters are critical indicators of microbial activity and compost maturity. In the initial stages of composting, high temperatures were maintained to kill pathogens, seeds, and break down organic matter, while mature compost no longer generates significant heat (Chen *et al*., 2011; Lepesteur, 2022). The color of the matured biofertilizer, typically dark brown, signified the breakdown of organic materials into humic substances (Mataba *et al*., 2024). To ensure optimal composting conditions, process parameters were closely monitored and adjusted throughout the decomposition process. The turning frequency was reduced when the temperature was low and increased during higher temperatures. The moisture content was monitored by adding water when the moisture content was low and adding materials when moisture content is high (Totàno *et al*., 2015). This proactive management of process parameters helped ensure the compost's consistent quality and facilitated the decomposition process.

Testing the effectiveness of the compost

To evaluate the effect of different mixing ratios on compost effectiveness, *Spiny Amaranth* seeds were used. The plants were grown in three controlled environments, with factors such as soil type, watering, temperature, light exposure, and planting density carefully regulated. Three separate bins, each containing a distinct mixing ratio (2:1, 1:2, and 1:1), were prepared, with the soil (pH of 6.5), thoroughly mixed to ensure uniformity and eliminate bias in growth results. Each bin received the same amount of water, and natural sunlight was used to maintain consistent light exposure, all plants were exposed to sunlight for 10 hours daily to ensure optimal photosynthesis. Planting density was kept uniform by monitoring seedling spacing, seeds were planted 10 cm apart to ensure all plants had the same access to nutrients, water and light. Watering was controlled by ensuring that during germination stage (0 – 7 days) each bin received 1 L of water daily to keep it moist. At mature stage (week 2 – 3) containers were watered with 2 L after every 2 days as their root system developed. After 21 days, plant growth was observed, including measurements of plant height and the number of plants.

RESULTS AND DISCUSSION

Characterization of banana peels and watermelon rinds

The characterization results for banana peels and watermelon rinds in terms of moisture content, organic matter, and pH indicate values of 59.1%, 75%, 5.6 for banana peels and 62.8%, 65%, 5.5 for watermelon rinds, respectively. Both banana peels and watermelon rinds are moisture-rich, which aids composting but may need to be combined with dry, carbon-rich materials (like dry leaves, straw, or sawdust) to avoid anaerobic conditions (Youngman, 2023; Wang *et al*., 2021). The organic content ensures the compost nourishment and supports microbial activity, with watermelon rinds decomposing faster due to their higher water content, while banana peels take longer but contribute more structurally through cellulose and lignin (Emmanuel *et al*., 2025;

Abubakar *et al*., 2024). Both materials have slightly acidic pH, which can help create a more favorable environment for composting (Nurin *et al*., 2024; Bui *et al*., 2025).

Production of Biofertilizer from banana peels and watermelon rinds

The study used a total of 36 kg of composting materials, including 9 kg of banana peels, 9 kg of watermelon rinds, 6 kg of dry leaves, 4.5 kg of grass clippings, and 7.5 kg of garden soil. It was possible to produce 4.5 kilograms of biofertilizer for each kg of banana and watermelon rinds used despite the ratio used. Thus, using 0.009 metric tonnes of banana peels and 0.009 metric tonnes of watermelon rinds can generate approximately 0.0045 metric tonnes of bio fertilizer. This trend was also observed by Mataba *et al*., (2024) when composted pineapple tops for biofertilizer production. The annual production of bananas and watermelons in Tanzania, along with their projected estimates for 2030, will significantly increase their contribution. Figure 3 shows the matured biofertilizer in a composting bin. As shown in the figure, the amount produced is almost the same despite the ratio used. The dark brown color of the compost signifies the breakdown of organic materials into humic substances, indicating its maturity.

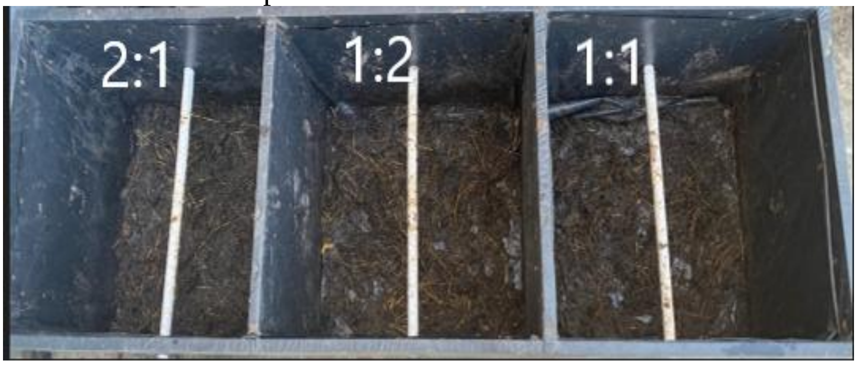

Figure 3: Produced biofertilizer in compost bin.

The variation of temperature, moisture content, pH and total organic matter during production

Temperature:

During the composting process, high temperatures were initially maintained to eliminate pathogens, seeds, and break down organic matter. However, as the compost matured, it no longer generated significant heat (Chen *et al.*, 2011; Lepesteur, 2022). The process temperature was monitored by reducing the turning frequency when the temperature was low and increasing turning frequency when the temperature was high. The temperature variation during composting is shown in Figure 4. The temperature trends in the composting process for different ratios of banana peels to watermelon rinds reveal varying levels of microbial activity. In the 2:1 ratio, the temperature rapidly rises from 33°C to 63°C within the first five days, indicating strong mesophilic microbial activity. It peaks at 70°C by Day 10, showing intense thermophilic activity essential for decomposing complex organic matter and sanitizing the compost. The temperature then gradually decreases to 55°C by Day 20 during the cooling phase and stabilizes around 35°C by Day 35 in the maturation phase. For the 1:2 ratio, the temperature similarly rises from 33°C to 58°C within five days, peaking at 65°C by Day 10. However, this peak is slightly lower than in the 2:1 ratio, indicating less intense microbial activity. The temperature drops to about 50°C by Day 20 and stabilizes around 35°C by Day 35. In the 1:1 ratio, the temperature increases from 33°C to 53°C within five days, with a peak of 63°C by Day 10, suggesting moderate thermophilic activity. The cooling phase sees the temperature drop to 48°C by Day 20, stabilizing at 35°C by Day 35.

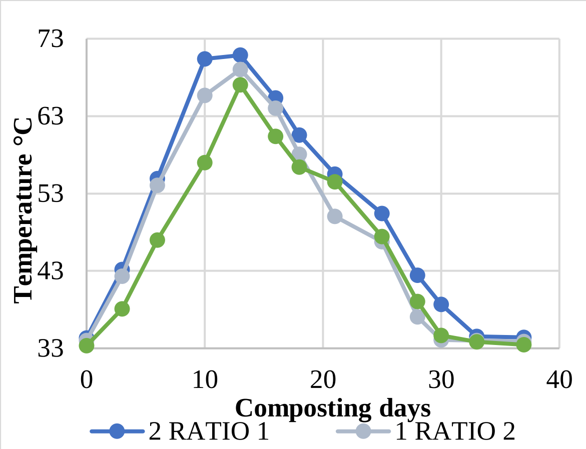

Figure 4: Temperature variations during composting periods at different ratios.

It is clearly that when banana was higher than watermelon rinds, there was intense thermophilic activity. This is due to the fact that banana peels have higher organic matter compared to watermelon rinds (Islam et *al*., 2019), creating a more favorable environment for thermophilic bacteria (Yunus *et al*., 2022). In contrast, watermelon rinds, with their higher moisture content, decompose faster, leading to less heat buildup.

pH:

The pH variations during the composting process reflect different dynamics of microbial activity for the three ratios of banana peels to watermelon rinds. In the 2:1 ratio, the pH begins at 5.8 and steadily rises, peaking at 6.8 by Day 25, indicating robust microbial activity and effective organic matter breakdown (Bernal *et al*., 2009). The 1:2 ratios start with a lower pH of 5.6 but show a rapid initial increase, peaking at 6.9 by Day 25; the 1:1 ratio starts with a higher pH of 6.2, rising gradually to peak at 7.1 by Day 20, indicating balanced microbial activity and optimal composting conditions. By Day 35, all ratios stabilize around a pH of 7.0, signalling the maturation of the compost and the decrease in microbial activity. The different ratios of banana peels to watermelon rinds influence microbial dynamics, which, in turn, affect the pH progression. More organic matter in banana peels resulted in a slower, steady pH rise, while higher moisture and nitrogen in watermelon rinds lead to faster decomposition and quicker pH changes. This trend was also observed by Kalemelawa *et al.*, (2012), who composted banana peels, and Yusuf *et al.,* 2016 who analyzed the effect of various combinations of materials on compost quality.

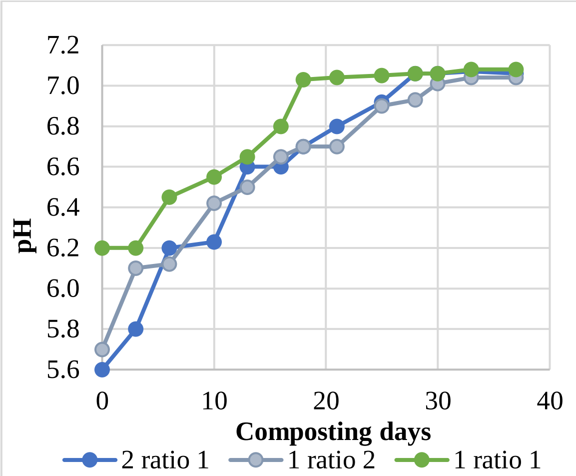

Figure 5: pH variation during composting period.

Moisture content: Figure 6 shows that in the 2:1 ratio, moisture content decreases consistently from about 58% to 34% over the 35-day composting period. The initial sharp drop in moisture reflects intense microbial activity as mesophilic microorganisms break down organic matter, generating heat and consuming moisture. As composting progresses, thermophilic microorganisms become more active, further reducing moisture and stabilizing the compost (Finore *et al*., 2023). The consistent decrease in moisture content in the 2:1 ratio can be due to the combined effects of microbial heat generation, continued breakdown of organic matter, and the transition from active microbial decomposition to the maturation phase where microbial activity slows and moisture stabilizes (Villar *et al*., 2026; Ge *et al*., 2022). The steady decline towards the end indicates a shift to the maturation phase, where microbial activity decreases, and the compost becomes more stable and mature (Kong *et al*., 2024; Lamourou *et al*., 2023).

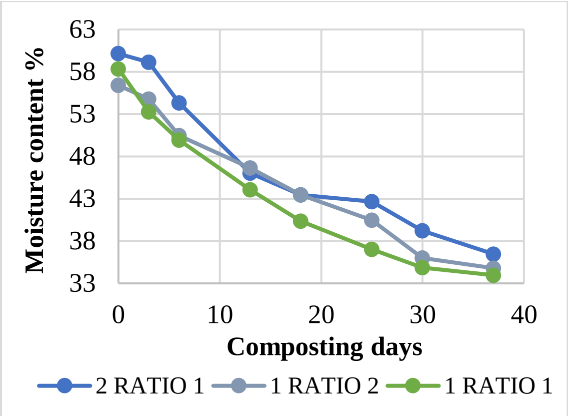

Figure 6: Moisture content variation during composting period.

In the 1:2 ratio, moisture content decreases from 58% to about 35% over 35 days; with a rapid initial decline indicating high microbial activity, supported by the increased organic material. This decline slows as the process transitions from active decomposition by thermophilic microbes to stabilization, ending with reduced microbial activity and mature compost (Lamourou *et al*., 2023). In the 1:1 ratio, moisture content drops from 54% to 34%, with a more gradual decrease reflecting balanced microbial activity due to the equal proportion of materials. This ratio shows a controlled and steady decomposition process, with moisture stabilizing as the compost matures. All three ratios display a similar trend of decreasing moisture content, with differences in the rate and reduction pattern illustrating the impact of the initial organic material ratio on the composting process and microbial dynamics.

Total organic matter:

Figure 7 illustrates the variation in total organic matter across different compost ratios. The 2:1 ratio starts with the highest initial organic matter at 79% and steadily declines to about 34% over 35 days, indicating consistent microbial activity. The high organic matter is mainly from banana peels, which are rich in complex compounds like cellulose and lignin (Emaga *et al*., 2011; Singh *et al*., 2023). These materials decompose more slowly, requiring more time for microorganisms to break them down. Over the 35-day period, the decomposition of these complex compounds by mesophilic and thermophilic microorganisms leads to a gradual decrease in organic matter. As a result, the decline in organic matter is steady, but it doesn't disappear quickly because of the slower microbial breakdown of the more complex organic matter in banana peels.

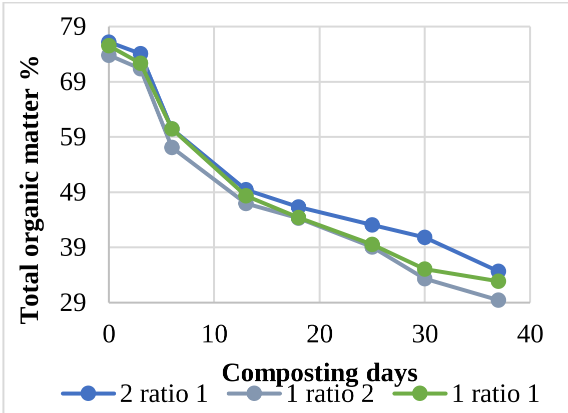

Figure 7: The graph of total organic matter against composting days.

The 1:2 ratio starts with slightly lower organic matter at 74% and decreases to about 29%, the lowest final percentage among the three ratios, suggesting a more efficient decomposition process. This is because watermelon rinds, which make up a larger portion of the mix, contain simpler sugars (Islam, 2017; Méndez *et al*., 2021; Ahamad *et al*., 2022) and less complex organic matter compared to banana peels, allowing for faster microbial breakdown. The 1:1 ratio, starting at 74% and ending at approximately 31%, reflects a stable environment for microbial activity due to the balanced mix of banana peels and watermelon rinds. This ratio provides a moderate but steady decomposition rate, balancing the breakdown of complex and simpler organic materials.

The results on the effect of different ratios of banana peels and watermelon rinds during composting shows that, the 1:1 ratio had the lowest temperature (33.45°C) and highest pH (7.08). The 2:1 ratio had the highest moisture content (36.47%), while the 1:2 ratio had the lowest final organic matter percentage among the three ratios, suggesting a more efficient decomposition process.

Determination of biofertilizer mineral concentration

The mineral analysis results of the biofertilizer produced in this study reveal important insights into the nutrient composition of the composted materials. As shown in Table 3, the mineral concentration of the key nutrients such as phosphorous, potassium and nitrogen vary between the different compost ratio (2:1, 1:2, and 1:1). These variations are likely due to the differences in the organic matter composition of the banana peels and watermelon rinds, which serve as the primary raw materials for composting.

Table 3: Mineral concentration of biofertilizer produced

Minerals	2:1	1:2	1:1
Phosphorous (%)	1.18	0.75	1.92
Potassium (%)	3.67	5.87	4.34
Nitrogen (%)	1.46	1.63	1.77

The most notable finding is the high concentration of potassium in all ratios, particularly in the 1:2 ratio, which has the highest potassium content at 5.87%. This result is consistent with the fact that both banana peels and watermelon rinds are potassium-rich materials. Kalemelawa *et al.*, (2012) found that banana peels contributed significantly to the potassium content in compost, while the nitrogen and phosphorus levels were relatively moderate. Yusuf *et al.*, (2016) reported that composts with banana peels and fruit rinds often showed higher potassium concentrations, further supporting the idea that these materials are potassium rich. This potassium dominance in the biofertilizer indicates that the compost can be classified as a potassium-mobilizing fertilizer, as potassium is the key nutrient present in higher concentration compared to nitrogen and phosphorus. The potassium-rich biofertilizer is essential for plants water uptake, enzyme activation, and stress tolerance (Hasanuzzaman *et al*., 2018; Ismail and Zed, 2024). This suggests that the compost produced from these raw materials may be particularly beneficial for crops that require potassium, such as tomatoes, potatoes, and citrus fruits. Phosphorus levels in the compost are lower compared to potassium, with the highest concentration found in the 1:1 ratio at 1.92%, while the 1:2 ratio shows the lowest at 0.75%. Phosphorus obtained in this study is higher compared to what was reported by Hemidat *et al*., (2022) and Asadu *et al*., (2019). Phosphorus is essential for root development and energy transfer in plants, but it is often present in lower concentrations in organic compost, especially when the raw materials do not have high phosphorus content. The variation in phosphorus concentration across the ratios could reflect differences in the availability of phosphorus from banana peels and watermelon rinds, both of which may contribute lower amounts of this nutrient relative to potassium. Nitrogen is also present in lower concentrations than potassium but shows a relatively steady distribution across the ratios, with the 1:1 ratio having the highest nitrogen content at 1.77%. The Nitrogen content found in this study is closer to what was reported by Yang *et al.,* (2021). Nitrogen is a crucial nutrient for vegetative growth, and while the compost contains nitrogen, its concentration is not as high as that of potassium, which is characteristic of organic compost made from plant residues that are not rich in nitrogen.

Despite the findings, it is challenging to determine which material contributed the most potassium, as this study included dry leaves and fresh grass clippings alongside banana peels and watermelon rinds. Banana peels typically contain 1.5–2.0% potassium (Tsado *et al*., 2023; Abubakar *et al.*, 2023), watermelon rinds contain 0.5–1.0% (Dada *et al.*, 2019; Feizy *et al*., 2020), grasses range from 2–5% depending on species and growth stage (Ştef *et al*., 2011; Johnson *et al*., 2022), and green leaves generally contain 1–3%, all of which could contribute notably to the compost's potassium content. Since the total amount of leaves and grass clippings was consistent and low across all ratios, it is evident that banana peels and watermelon rinds played the dominant role in potassium contribution. However, a pre-composting analysis of the individual materials (banana peels, watermelon rinds, grasses, and green leaves) is necessary for a more precise understanding of their respective contributions.

While commercial NPK fertilizers offer a more balanced nutrient profile (Mtaki *et al.*, 2021), the biofertilizer produced in this study is particularly rich in potassium and could be more effective in promoting potassium-dependent processes like water retention, enzyme activation, and photosynthesis. However, its lower nitrogen and phosphorus content means it might need to be supplemented with additional nitrogen or phosphorus fertilizers for optimal plant growth, especially in nitrogen-hungry crops. This study makes a significant contribution by demonstrating that organic waste materials, such as banana peels and watermelon rinds, which are typically discarded, can be transformed into biofertilizers rich in potassium. The ability to produce a potassium-mobilizing fertilizer from these materials opens new possibilities for waste recycling and sustainable farming practices. Such compost can potentially reduce the dependency on synthetic fertilizers, which are often expensive and environmentally harmful. Moreover, the varying concentrations of nitrogen, phosphorus, and potassium in different ratios provide useful insights for tailoring compost products to meet the specific nutrient needs of different crops, which could lead to more targeted and efficient agricultural applications.

Determination of quality of biofertilizer produced

The quality of biofertilizer produced was determined by growing *spiny amaranth* in different soil mixtures as shown in Figure 8. The loamy garden soil with pH around 6.5 was used to facilitate optimal nutrients uptakes by the plants. As it can be seen in the figure, the number of plants in the 1:2 ratio bin is higher compared to the other ratios. This might be due to high potassium content in the ratio.

Figure 8: Spiny Amaranth growth from biofertilizer.

Table 4 further elaborates the results of determination of biofertilizer quality on plant growth by giving the mean plant height, standard deviation and number of plants of *Spiny Amaranth*.

Table 4: Plant growth observation

Ratios	Mean plant height (cm)	Standard deviation (cm)	Number of plants
2:1	8	1.73	17
1:2	9.5	1.44	23
1:1	8	1.15	18

As shown in Table 4, the 1:2 ratio supports the highest number of plants (23) and exhibited the greatest mean plant height of 9.5 cm. Based on the mean plant height and standard deviation this ratio appears to be the most effective for promoting *Spiny Amaranth* growth in terms of height. However, the 1:2 ratio shows more variability in height, which might indicate inconsistent growth. The 1:2 ratio biofertilizer had the highest potassium content at 5.87%, which plays a vital role in regulating water uptake, enzyme activation, photosynthesis, and stress tolerance, contributing to stronger stems and healthier roots. It also contained 1.63% nitrogen, essential for vegetative growth, amino acids, and chlorophyll, supporting rapid leaf and stem development. Though phosphorus was lower at 0.75%, it is crucial for root development, flowering, and fruiting, helping establish strong root systems for better nutrient absorption and plant stability. These mineral concentrations likely explain the superior growth and overall health of *Spiny Amaranth* in the 1:2 ratio.

CONCLUSION AND RECOMMENDATION

The study successfully produced 4.5 kg of biofertilizer from a total of 18 kg of raw materials (9 kg each of banana peels and watermelon rinds). This study demonstrates that the 1:2 ratio biofertilizer produced the highest potassium content at 5.87%, which aligns with previous research by Kalemelawa *et al.*, (2012) and Yusuf *et al.*, (2016), showing that banana peels and watermelon rinds are rich in potassium. Potassium is essential for regulating water uptake, enzyme activation, photosynthesis, and stress tolerance, contributing to healthier roots and stronger stems. The high potassium concentration in the 1:2 ratio suggests that the biofertilizer can be classified as a potassium-mobilizing fertilizer, which may benefit crops like tomatoes, potatoes, and citrus fruits, which require higher potassium levels. In addition to potassium, the biofertilizer contained 1.63% nitrogen, crucial for vegetative growth, amino acid production, and chlorophyll synthesis, which supports rapid leaf and stem development. Although phosphorus was lower at 0.75%, it is still important for root development and flowering, contributing to better nutrient absorption and plant stability. These mineral concentrations likely explain the superior growth observed in Spiny Amaranth in the 1:2 ratio. Compared to commercial NPK fertilizers, which offer a balanced nutrient profile, the biofertilizer in this study is rich in potassium. While lower phosphorus and nitrogen levels may require supplementation for optimal plant growth, this study highlights the potential of using organic waste materials, such as banana peels and watermelon rinds, to produce sustainable potassium-rich fertilizers. The ability to produce potassium-mobilizing fertilizers from organic waste opens new possibilities for waste recycling and sustainable farming. This compost reduces reliance on expensive, harmful synthetic fertilizers. Additionally, the variation of nitrogen, phosphorus, and potassium concentrations in different ratios used in this study, offer insights for tailoring compost to meet specific crop nutrient needs, enhancing agricultural efficiency.

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