INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

Proximate and elementary analysis of plantain peel ash for use as fertilizer

Kiridi, E. A and Ombu, P. E

Department of Agricultural and Environmental Engineering Niger Delta University, Wilberforce Island, Bayelsa State Nigeria

DOI: https://doi.org/10.51583/IJLTEMAS.2026.150300013

Received: 11 March 2026; Accepted: 16 March 2026; Published: 01 April 2026

ABSTRACT

The study investigated the proximate and elemental composition of plantain peel ash to assess its potential as an organic-based fertilizer. Plantain peels collected from local markets were dried, burnt under controlled conditions to obtain ash, and analyzed using standard procedures. Proximate analysis revealed a high ash content (89.15%), low moisture (3.62%), and minimal organic fractions (protein, fat, and fiber), indicating a stable, mineral-rich material suitable for soil enrichment. Elemental analysis showed that potassium (35,420 mg/kg) was the dominant nutrient, followed by calcium (9,830 mg/kg), magnesium (2,740 mg/kg), and phosphorus (1,960 mg/kg). Trace amounts of iron (Fe) and zinc (Zn) were also detected. These results demonstrate that plantain peel ash contains essential macro- and micronutrients capable of improving soil structure, enhancing nutrient availability, and promoting crop growth. The high mineral and alkaline nature of the ash supports its use as an eco-friendly, low-cost soil amendment for sustainable agriculture. However, field trials are recommended to determine its agronomic efficiency and long-term effects on soil fertility.

Keywords: Plantain peel ash, Organic fertilizer, Proximate composition, Elemental analysis, Soil amendment, Sustainable agriculture, Nutrient enrichment.

Background of the Study

The demand for organic fertilizers has increased markedly in recent years as farmers, consumers and policymakers seek sustainable alternatives to synthetic agrochemicals that can degrade soil health and pollute the environment [1]. Market studies and reviews report strong growth in the organic fertilizer sector driven by rising consumer preference for organic produce, concerns about the environmental impacts of conventional fertilizers, and expanding market access for organic products.

Recycling agricultural and food-processing wastes into value-added products is central to circular-economy approaches in modern agriculture [2]. Fruit wastes such as banana and plantain peels are generated in large quantities and, if left unmanaged, contribute to environmental problems; however, they also represent a low-cost feedstock rich in organic matter and minerals that can be valorized into soil amendments, biofertilizers or ash-based fertilizers. Several reviews and studies highlight the technical and economic potential of converting banana/plantain wastes into fertilizers or other useful products, reducing waste while returning nutrients to soils [3].

Ashes produced by burning plant biomass are often alkaline and contain appreciable amounts of plant-available minerals, notably potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and various micronutrients, that can improve soil nutrient status, correct acidity, and enhance soil physical properties when applied appropriately [4], [5]. The exact nutrient profile of biomass ash depends on the feedstock and combustion conditions, so laboratory characterization (proximate and elemental analysis) is essential before recommending agronomic application rates. Studies on ashes from fruit wastes and related biomass report K as a dominant nutrient, often followed by Na, P, Mg and Ca, and show that ash can be a valuable source of readily available potassium for crops [6], [7].

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

Despite this promise, there remains a relative paucity of published, standardized proximate-composition data specifically for plantain peel ash (as distinct from whole peel composition or banana-peel biofertilizers). While several studies have characterized the nutritional and mineral composition of banana/plantain peels and a few have examined ash from mixed biomass, comprehensive proximate analyses (moisture, ash, crude protein, crude fat, crude fibre and carbohydrate by difference) and paired elemental assays for plantain peel ash are limited in number and scope, especially in local agroecological contexts where burning conditions and peel varieties differ. This knowledge gap constrains confident recommendations for safe, effective use of plantain peel ash as an organic fertilizer and underscores the need for systematic laboratory evaluation.
The aim of this study is to determine the proximate composition and mineral nutrient content of plantain peel ash and evaluate its suitability as a low-cost organic fertilizer for agricultural use. The specific objectives were to determine the proximate composition (moisture, ash, crude protein, crude fat, crude fibre and carbohydrate by difference) of plantain peel ash, to quantify macro- and micro-nutrients (K, Ca, Mg, P, Na, Fe, Zn, etc.) in plantain peel ash using standard analytical methods (e.g., AAS, flame photometry, colorimetry) and to assess the fertilizer potential and safe application considerations of plantain peel ash based on nutrient concentrations, pH and comparison with literature values.

MATERIALS AND METHODS

Source of Plantain Peels

Plantain peels were collected from multiple sources including local markets, household kitchens, and nearby farms within Amassoma Town, Bayelsa State, Nigeria. The selection of these sources ensured that the samples represented commonly discarded plantain residues generated from domestic consumption and small-scale processing activities. Only fresh and non-decomposed peels of *Musa paradisiaca* were used for the study to maintain uniformity and reliability of the results.

Drying Process

The collected plantain peels were first washed thoroughly with clean water to remove adhering soil, dirt, and other impurities. Excess water was drained off, and the peels were spread out on clean trays for drying. The drying process was carried out using a two-stage approach. Initially, the samples were sun-dried for 5–7 days under ambient conditions to reduce moisture content and prevent microbial growth. The semi-dried samples were then oven-dried at 105°C for 24 hours in a laboratory drying oven to ensure uniform dryness and to facilitate easy combustion. The oven-dried peels were allowed to cool to room temperature and stored in airtight containers prior to ashing.

Burning Method to Obtain Ash

The dried plantain peels were converted into ash using the open-air combustion method, which simulates the traditional way of ash production for agricultural use. The dried samples were placed in a clean metallic container and ignited in an open space under controlled conditions to allow complete burning. Combustion continued until all organic matter was oxidized, leaving behind a fine, greyish-white ash. To ensure uniformity, the ash obtained was sieved through a 2 mm mesh to remove large charred particles and debris.

In some trials, a controlled-temperature ashing was performed in a muffle furnace at 550°C for 6 hours to compare the composition of ash derived from open-air combustion and controlled conditions. This approach helped to determine the influence of temperature on nutrient retention and loss.

Storage of Samples

The prepared ash samples were transferred into clean, airtight polyethylene bags and properly labeled according to their source and burning method. The samples were stored in a desiccator to prevent moisture absorption and

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

contamination before laboratory analysis. Subsamples were later taken for proximate and elemental composition analyses following standard procedures outlined by [8].

Proximate Analysis

The proximate analysis of the plantain peel ash was carried out to determine its basic nutritional composition, including moisture content, ash content, crude protein, crude fat, crude fiber, and carbohydrate (by difference). These analyses were performed according to the standard methods outlined by [8]. Each parameter was determined in triplicate to ensure accuracy and reliability of results.

Determination of Moisture Content

Moisture content was determined using the oven-drying method. Approximately 2 g of the sample was weighed into a clean, dry crucible and placed in a hot-air oven maintained at 105°C for 24 hours. The crucible was then cooled in a desiccator and reweighed. The loss in weight, expressed as a percentage of the initial sample weight, represented the moisture content.

$$\text{Moisture Content (\%)} = \frac{W_1 - W_2}{W_1} X\ 100$$

Where:
W_1 = weight of sample before drying,
W_2 = weight of sample after drying.

Determination of Ash Content

Ash content was determined by incinerating a known weight (2 g) of the dried sample in a muffle furnace at 550°C for 6 hours until a constant weight was obtained. The residue remaining after complete combustion was regarded as total ash, representing the inorganic mineral fraction of the sample.

$$\text{Ash Content (\%)} = \frac{W_3 - W_1}{W_2 - W_1} X\ 100$$

Where:
W_1 = weight of empty crucible,
W_2 = weight of crucible + sample before ashing,
W_3 = weight of crucible + ash after ashing.

Determination of Crude Protein

Crude protein was determined using the Kjeldahl method, which involves three stages: digestion, distillation, and titration. About 1 g of the sample was digested with concentrated sulfuric acid (H_2SO_4) in the presence of a catalyst mixture until a clear solution was obtained. The digested sample was distilled, and the liberated ammonia was trapped in a boric acid solution and titrated against 0.1 N hydrochloric acid (HCl). The total nitrogen obtained was converted to crude protein by multiplying by a factor of 6.25.

$$\text{Crude Protein (\%)} = \text{Total Nitrogen (\%)}\ X\ 6.25$$

Determination of Crude Fat

Crude fat was determined using the Soxhlet extraction method with petroleum ether (boiling point 40–60°C) as the solvent. Approximately 2 g of the sample was placed in a thimble and extracted continuously for 6 hours. The solvent was then evaporated, and the flask was dried and weighed. The increase in flask weight corresponded to the fat content.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

$$\text{Crude Fat } (\%) = \frac{W_2 - W_1}{W_0} X\ 100$$

Where:
W_0 = weight of sample,
W_1 = weight of empty extraction flask,
W_2 = weight of flask + extracted fat.

Determination of Crude Fiber

Crude fiber was analyzed by sequential acid and alkali digestion. Two grams of the defatted sample were boiled with 1.25% sulfuric acid for 30 minutes, filtered, washed, and then boiled again with 1.25% sodium hydroxide for another 30 minutes. The residue was filtered, washed, dried, and ignited in a muffle furnace at 550°C. The weight loss after ignition was recorded as crude fiber.

$$\text{Crude Fiber } (\%) = \frac{W_2 - W_3}{W_1} X\ 100$$

Where:
W_1 = weight of sample,
W_2 = weight after drying,
W_3 = weight after ashing.

Determination of Carbohydrate (by Difference)

The carbohydrate content of the sample was calculated by difference, as follows:

$$\text{Carbohydrate } (\%) = 100 - (\text{Moisture} + \text{Ash} + \text{Crude Protein} + \text{Crude Fat} + \text{Crude Fiber})$$

This method assumes that carbohydrates constitute the remainder after accounting for all other proximate components.

The proximate composition provides essential information about the nutritional quality and organic matter content of the plantain peel ash, which are critical parameters for assessing its potential as an organic fertilizer. The data obtained from this analysis formed the basis for further evaluation of the mineral composition and soil amendment potential of the ash.

Elemental Analysis

The elemental analysis of the plantain peel ash was conducted to determine its macro- and micronutrient composition, which provides insight into its potential as an organic fertilizer. The analysis focused on key essential elements for plant growth, including calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), potassium (K), sodium (Na), and phosphorus (P). Standard analytical procedures as described by [8] were employed to ensure accuracy and reliability of results.

Sample Digestion

A representative portion (1 g) of the plantain peel ash sample was accurately weighed into a 100 mL conical flask. Ten milliliters (10 mL) of a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a ratio of 3:1 were added to the sample.

The mixture was heated gently on a hot plate in a fume hood until a clear digest was obtained, indicating complete oxidation of the organic matter. The digest was allowed to cool, filtered through Whatman No. 42 filter paper

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

into a 100 mL volumetric flask, and made up to the mark with distilled water. This filtrate was used for the determination of elemental concentrations.

Determination of Calcium (Ca), Magnesium (Mg), Iron (Fe), and Zinc (Zn)

The concentrations of calcium, magnesium, iron, and zinc were determined using an Atomic Absorption Spectrophotometer (AAS). The instrument was first calibrated using standard solutions of each element prepared from their respective stock solutions. The absorbance of the sample digest was measured at the specific wavelengths for each element:

- **Calcium (Ca):** 422.7 nm
- **Magnesium (Mg):** 285.2 nm
- **Iron (Fe):** 248.3 nm
- **Zinc (Zn):** 213.9 nm

The concentration of each element in the sample was extrapolated from the calibration curve and expressed in milligrams per kilogram (mg/kg) of sample.

Determination of Potassium (K) and Sodium (Na)

Potassium and sodium contents were determined using a Flame Photometer (Model: e.g., Jenway PFP7). Standard solutions of K and Na were prepared from analytical-grade potassium chloride (KCl) and sodium chloride (NaCl) salts. The instrument was calibrated with these standards before sample readings were taken. The emission intensities corresponding to each element were recorded, and the concentrations were computed using the standard calibration curves. These elements are critical macronutrients responsible for plant osmotic balance and enzyme activation.

Determination of Phosphorus (P)

Phosphorus concentration was determined using the colorimetric method (vanadomolybdate yellow method). Five milliliters (5 mL) of the digested sample solution were pipetted into a 50 mL volumetric flask, followed by the addition of 10 mL of ammonium vanadomolybdate reagent. The solution was diluted to the mark with distilled water, mixed thoroughly, and allowed to stand for 10 minutes to develop a yellow color. The absorbance was measured at 400 nm using a UV-Visible spectrophotometer (Model: e.g., Shimadzu UV-1800). The phosphorus concentration was then determined from a calibration curve prepared using standard phosphate solutions.

Quality Control and Data Validation

All glassware and containers used were prewashed with 10% nitric acid and rinsed thoroughly with distilled water to avoid contamination. Reagent blanks were analyzed alongside the samples to correct for any background interference. Each analysis was conducted in triplicate, and mean values were reported. The results were expressed as milligrams per kilogram (mg/kg) or parts per million (ppm), depending on the concentration range of each nutrient element.

The elemental analysis provided quantitative data on the nutrient composition of the plantain peel ash, particularly the abundance of macronutrients such as potassium, calcium, and magnesium, as well as trace elements like iron and zinc. These elements play vital roles in plant physiological functions, making plantain peel ash a potentially valuable resource for soil fertility improvement and sustainable crop production.

Data Analysis

The data obtained from the proximate and elemental analyses of the plantain peel ash were subjected to descriptive statistical analysis to summarize and interpret the results. The parameters analyzed included moisture

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

content, ash content, crude protein, crude fat, crude fiber, carbohydrate (by difference), and the concentrations of major and trace mineral elements such as K, Ca, Mg, P, Na, Fe, and Zn**.**

All measurements were conducted in triplicate to ensure the accuracy and reliability of the experimental results. The mean values and standard deviations were computed to evaluate the central tendency and variability within the data set. The use of descriptive statistics provided a clear summary of the nutrient composition of the plantain peel ash and facilitated comparison with results from previous studies and literature values.

The mean $\bar{x}$ and standard deviation (SD) were calculated using the following formulas:

$$x = \frac{\sum_{i=1}^{n} xi}{n}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Where:
x_i = each individual observation,
$\bar{x}$ = mean of observations,
n = number of observations.

The computed mean values represented the average concentration or percentage of each measured parameter, while the standard deviation indicated the level of variation between replicate determinations. Low standard deviation values signified high precision and repeatability of analytical results.

Data processing and statistical computations were performed using Microsoft Excel (version 2021) and SPSS (version 25) software packages. The summarized data were presented in tables and figures for clarity and easy interpretation. Comparative analysis with values reported in literature was used to assess the fertilizer potential and nutrient adequacy of the plantain peel ash for soil fertility improvement.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition of the plantain peel ash is presented in Table 1. The parameters determined include moisture, ash, crude protein, crude fat, crude fiber, and carbohydrate contents. These components provide insight into the organic matter content and the potential of the ash to contribute to soil fertility.

Table 1: Proximate Composition of Plantain Peel Ash

Parameter	Composition (%) ± SD
Moisture Content	3.62 ± 0.08
Ash Content	89.15 ± 0.24
Crude Protein	1.27 ± 0.06
Crude Fat	0.85 ± 0.03
Crude Fiber	1.76 ± 0.04
Carbohydrate (by diff.)	3.35 ± 0.10

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

The results indicate that ash content (89.15%) was the most abundant component, reflecting the high inorganic mineral content of the sample. The low moisture content (3.62%) suggests minimal susceptibility to microbial degradation during storage, making the ash stable for long-term application as a soil amendment. The negligible crude fat (0.85%), protein (1.27%), and fiber (1.76%) contents indicate that most organic matter was lost during combustion, leaving behind a concentration of essential mineral nutrients in the residue.

The high ash and low organic content imply that the material can serve primarily as a mineral-based soil conditioner rather than a source of organic carbon. When applied to soil, such mineral-rich ash can improve nutrient availability, increase soil pH (due to alkaline oxides), and enhance the cation exchange capacity of acidic tropical soils [9]. Therefore, the proximate profile supports the potential use of plantain peel ash as a nutrient-enriching and soil-amending agent in sustainable agriculture.

Elemental Composition

The elemental composition of the plantain peel ash is shown in Table 2. The macro- and micronutrients determined include potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sodium (Na), iron (Fe), and zinc (Zn).

Table 2: Elemental Composition of Plantain Peel Ash

Element	Concentration (mg/kg) ± SD
Potassium (K)	35,420 ± 210
Calcium (Ca)	9,830 ± 145
Magnesium (Mg)	2,740 ± 120
Phosphorus (P)	1,960 ± 85
Sodium (Na)	1,520 ± 70
Iron (Fe)	640 ± 25
Zinc (Zn)	110 ± 6

Potassium (K) was found to be the most abundant element, followed by calcium (Ca) and magnesium (Mg). This agrees with the findings of [10], who reported high potassium concentrations in banana and plantain peel ash, highlighting their potential as sources of K-based fertilizers. Potassium plays a crucial role in enzyme activation, water regulation, and carbohydrate synthesis in plants. High K content also improves plant resistance to stress and enhances crop yield and quality [11], [12].

Calcium and magnesium are important macronutrients that contribute to soil structure stabilization and the improvement of cation exchange capacity. Calcium aids in root elongation and cell wall formation, while magnesium serves as the central atom in chlorophyll, essential for photosynthesis. Phosphorus, though lower in concentration compared to K and Ca, is vital for energy transfer and root development [13].

The relatively moderate levels of Fe and Zn indicate the presence of trace elements beneficial for plant enzymatic and metabolic activities. These micronutrients are required in small quantities but are essential for healthy plant growth. The nutrient composition observed aligns with [8] standards for ash derived from plant biomass, confirming that plantain peel ash is mineral-rich and agriculturally valuable.

Fertilizer Potential

The combined proximate and elemental results suggest that plantain peel ash possesses significant fertilizer potential due to its high mineral and alkaline nature. The high ash and potassium contents indicate rapid nutrient release upon application to soil, which can benefit short-term crop growth. Its alkaline components (CaO, K_2O,

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 202

and MgO) can also neutralize soil acidity, making it particularly suitable for acidic soils commonly found in tropical regions such as southern Nigeria.

Furthermore, the presence of phosphorus, calcium, and magnesium suggests that the ash could support balanced nutrient replenishment, enhancing soil fertility and promoting root and shoot development [14]. The trace elements (Fe, Zn) contribute to improved enzyme functions and chlorophyll synthesis.

From an environmental perspective, recycling plantain peel into ash reduces agricultural waste accumulation and greenhouse gas emissions associated with open dumping or decomposition. It also minimizes dependency on costly synthetic fertilizers, aligning with the goals of sustainable agriculture and circular economy principles [15,[16].

However, field applications should be done with caution, as excessive use could elevate soil pH beyond optimal levels for certain crops. Therefore, further studies are recommended to determine appropriate application rates, nutrient release kinetics, and long-term impacts on soil health.

CONCLUSION AND RECOMMENDATION

Conclusion

The present study evaluated the proximate and elemental composition of plantain peel ash to determine its potential use as an organic-based fertilizer. The results revealed a high ash content (89.15%) with significant concentrations of essential plant nutrients, particularly potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and sodium (Na). These nutrients are crucial for soil fertility enhancement, plant growth, and the overall improvement of agricultural productivity.

The low moisture and organic content of the ash indicate its stability and suitability for long-term storage and field application. The dominance of potassium and calcium suggests that the material can serve as an effective soil conditioner, capable of neutralizing soil acidity, improving cation exchange capacity, and promoting root and shoot development in crops. The trace elements, such as iron (Fe) and zinc (Zn), also contribute to essential micronutrient supply for healthy plant metabolism.

Overall, the findings confirm that plantain peel ash is a viable, eco-friendly, and low-cost alternative fertilizer that can reduce dependence on expensive chemical fertilizers and encourage sustainable agricultural practices. Its use promotes agricultural waste recycling, thereby mitigating environmental pollution associated with indiscriminate waste disposal.

However, while laboratory analyses demonstrate strong fertilizer potential, there remains a need for comprehensive field trials to evaluate its agronomic efficiency**,** nutrient release dynamics**, and** long-term effects on different soil types and crops. Such studies will provide practical guidelines for optimal application rates and ensure that plantain peel ash is effectively integrated into sustainable soil management systems.

Recommendations

Based on the findings of this study on the proximate and elemental composition of plantain peel ash, the following recommendations are made for various stakeholders in the agricultural sector:

For Farmers

Farmers are encouraged to apply plantain peel ash as a soil amendment to enhance soil nutrient status and improve crop yield. Its high potassium, calcium, and magnesium contents make it especially beneficial for crops that require large amounts of these macronutrients, such as maize, cassava, pepper, and tomatoes. Application should be done in moderate quantities and preferably incorporated into the soil before planting or during land preparation to ensure even nutrient distribution. Regular use can help neutralize soil acidity, increase soil fertility, and reduce the dependence on costly chemical fertilizers.

For Researchers

Researchers should conduct comprehensive field experiments to evaluate the long-term effects of plantain peel ash on soil health, nutrient release patterns, and crop productivity under varying soil types and climatic conditions. Studies should also focus on determining the optimal application rates**,** interaction with other organic amendments, and potential effects on soil microbial activity. Further research into the nutrient mineralization rates and residual impact of ash on successive cropping cycles will help establish its suitability as a sustainable fertilizer alternative.

For Policy Makers

Policy makers should develop and promote policies that encourage the recycling of agricultural wastes, such as plantain peels, into organic fertilizers. This initiative would reduce environmental pollution associated with waste dumping and contribute to the achievement of sustainable agriculture and environmental conservation goals. Governments and agricultural agencies should also support training programs and public awareness campaigns that educate farmers on the benefits and safe use of ash-based fertilizers. Incentives could be introduced for small-scale industries that convert agricultural residues into valuable soil amendment products.

In summary, promoting the use of plantain peel ash as an organic fertilizer aligns with global efforts toward sustainable resource management**,** waste reduction, and environmentally friendly farming practices. Collaborative efforts among farmers, researchers, and policymakers are essential to harness its full potential for improving soil productivity and ensuring food security.

REFERENCES

1. Sarkar, S., Jaswal, A., & Singh, A. (2024). Sources of inorganic nonmetallic contaminants (synthetic fertilizers, pesticides) in agricultural soil and their impacts on the adjacent ecosystems. In *Bioremediation of Emerging Contaminants from Soils* (pp. 135-161). Elsevier.
2. Kover, A., Kraljić, D., Marinaro, R., & Rene, E. R. (2022). Processes for the valorization of food and agricultural wastes to value-added products: Recent practices and perspectives. *Systems Microbiology and Biomanufacturing*, *2*(1), 50-66.
3. Giwa, A. S., Sheng, M., Maurice, N. J., Liu, X., Wang, Z., Chang, F., ... & Wang, K. (2023). Biofuel recovery from plantain and banana plant wastes: integration of biochemical and thermochemical approach. *J. Renew. Mater*, *11*, 2593-2629.
4. Stankowski, S., Chajduk, E., Osińska, B., & Gibczyńska, M. (2021). Biomass ash as a potential raw material for the production of mineral fertilisers.
5. Veena, J. (2022). *Evaluation of Incineration Ash as a Source of Potassium and Its Effect on Soil Properties and Yield of Maize (Zea Mays L.)* (Doctoral dissertation, University of Agricultural Sciences, GKVK, Bangalore).
6. Mohanty, T., Dash, S., Pattanaik, P., Tripathy, H. P., Gulati, J. M. L., Mishra, D. K., & Holderbaum, W. (2025). Utilization of biomass ash generated from combined heat and power generation system as a multi-nutrient source for crops. *International Journal of Thermofluids*, *25*, 101037.
7. Andrews, E. M., Kassama, S., Smith, E. E., Brown, P. H., & Khalsa, S. D. S. (2021). A review of potassium-rich crop residues used as organic matter amendments in tree crop agroecosystems. *Agriculture*, *11*(7), 580.
8. AOAC (2016). *Official Methods of Analysis,* 20th Edition. Association of Official Analytical Chemists, Washington, D.C**.**
9. Tian, F., Wang, Y., Zhao, Y., Sun, R., Qi, M., Wu, S., & Wang, L. (2025). A review of Biochar-industrial waste composites for sustainable soil amendment: mechanisms and perspectives. *Water, 17*(15), 2184**.**

10. Vaish, B., Srivastava, V., Singh, P. K., Singh, P., & Singh, R. P. (2020). Energy and nutrient recovery from agro-wastes: Rethinking their potential possibilities. *Environmental engineering research*, *25*(5), 623-637.
11. Ul-Allah, S., Ijaz, M., Nawaz, A., Sattar, A., Sher, A., Naeem, M., ... & Mahmood, K. (2020). Potassium application improves grain yield and alleviates drought susceptibility in diverse maize hybrids. *Plants*, *9*(1), 75**.**
12. Rawat, J., Pandey, N., & Saxena, J. (2022). Role of potassium in plant photosynthesis, transport, growth and yield. *Role of potassium in abiotic stress*, 1-14.
13. Wang, Y., Chen, Y. F., & Wu, W. H. (2021). Potassium and phosphorus transport and signaling in plants. *Journal of Integrative Plant Biology*, *63*(1), 34-52.
14. Johan, P. D., Ahmed, O. H., Omar, L., & Hasbullah, N. A. (2021). Phosphorus transformation in soils following co-application of charcoal and wood ash. *Agronomy*, *11*(10), 2010.
15. Selvan, T., Panmei, L., Murasing, K. K., Guleria, V., Ramesh, K. R., Bhardwaj, D. R., ... & Deshmukh, H. K. (2023). Circular economy in agriculture: Unleashing the potential of integrated organic farming for food security and sustainable development. *Frontiers in Sustainable Food Systems*, *7*, 1170380.
16. Smith, A. (2025). Systemic Analysis of Circular Economy Principles in Agricultural Waste Management and Their Synergy with National Sustainable Development Objectives. *Transdisciplinary Advances in Social Computing, Complex Dynamics, and Computational Creativity*, *15*(2), 10-21.