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Extraction and Characterization of Potassium Chloride from Banana Peels for Potential Application as a Sustainable Fertilizer

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ABSTRACT

With growing interest in sustainable and affordable fertilizer alternatives, agricultural waste has gained considerable attention as a potential source for nutrient recovery. This study investigated the extraction and characterization of potassium chloride (KCl) from banana peels, a readily available agricultural waste material. Banana peels were dried, ground, ashed, subjected to acid digestion, concentrated, filtered, and processed for the recovery of KCl. The extraction process yielded 1.21 g of KCl from 4 kg of banana peels, with a reported recovery of 77.1%. The extracted KCl was characterized using physical and chemical tests, including solubility, pH, flame, cobalt nitrite, perchloric acid, tartaric acid, and melting-point tests. The extracted salt exhibited a white crystalline appearance, high water solubility, and a neutral pH. A characteristic lilac flame and confirmatory chemical tests indicated the presence of potassium ions. Fourier-transform infrared (FTIR) spectroscopy and X-ray diffraction (XRD) analyses were further used to characterize the extracted material, while flame photometry was employed to determine potassium concentration. The findings demonstrate the potential of banana peels as a source of recoverable potassium compounds and support their further investigation for sustainable fertilizer applications and agricultural waste valorization.



KEYWORDS: banana peel; potassium chloride (KCl); nutrient recovery; agricultural waste; potassium extraction; sustainable fertilizer; waste valorization

1. INTRODUCTION

Bananas (*Musa* spp.), belonging to the family Musaceae, are among the most widely cultivated and consumed fruits worldwide. Their popularity is attributed to their nutritional value, year-round availability, and widespread cultivation in tropical and subtropical regions. Bananas are a rich source of carbohydrates, dietary fibre, and essential micronutrients, particularly potassium, magnesium, vitamin B6, and vitamin C (Wall, 2006; World Health Organization, 2012). Beyond the edible pulp, banana peels are generated in substantial quantities as agricultural and food waste and contain valuable nutrients and bioactive components that may be recovered for beneficial applications (Anhwange, 2008; Emaga et al., 2007).

Banana peels contain appreciable amounts of minerals, particularly potassium, together with calcium, magnesium, phosphorus, sodium, iron, and zinc (Anhwange, 2008; Bishnoi et al., 2023). Potassium is an essential macronutrient for plant growth and contributes to several physiological processes, including enzyme activation, osmoregulation, photosynthesis, protein synthesis, and stomatal regulation. Inadequate potassium availability can adversely affect crop growth, yield, quality, and tolerance to environmental stresses.

Potassium chloride (KCl), commonly known as muriate of potash, is widely used as a potassium source in agricultural fertilizers. However, the recovery of potassium from agricultural residues represents an alternative approach that may contribute to nutrient recycling and waste valorization. Banana peels are particularly promising because of their potassium content and widespread availability as a food-processing and household waste stream. Previous studies have investigated

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the recovery of potassium compounds from banana peels using approaches such as ashing, leaching, hydrothermal extraction, and biochar-based processes (Mustaqim et al., 2018; Islam et al., 2019; Bishnoi et al., 2023).

The conversion of banana peel waste into potassium-containing products is consistent with circular-economy principles by transforming an underutilized biomass residue into a potentially valuable agricultural input. In addition to reducing organic waste, such approaches may contribute to more sustainable nutrient management and reduce reliance on conventional mineral resources. The conversion of banana-peel waste into value-added products is consistent with circular-economy principles by transforming an underutilized biomass residue into potentially useful agricultural and industrial inputs. Recent studies have highlighted considerable opportunities for banana-peel valorization through different extraction and processing approaches, including the recovery of valuable components and development of biofertilizers and other value-added products (Putra et al., 2022; Bishnoi et al., 2023). Such approaches may simultaneously reduce organic waste, improve resource recovery, and contribute to more sustainable biomass utilization. Banana peels contain a diverse range of nutrients and bioactive constituents, including carbohydrates, dietary fibre, structural polysaccharides, minerals, and phytochemicals. Their composition may vary depending on cultivar, maturity stage, geographical origin, and analytical conditions. Among the minerals present, potassium is particularly abundant, making banana peels a potentially valuable raw material for potassium recovery and subsequent agricultural applications. More recently, banana-peel-derived fertilizers have received increasing attention because of the potassium-rich nature of this biomass and its potential contribution to soil fertility and crop production (Khanyile et al., 2024). The reported proximate, mineral, and phytochemical composition of banana peels is summarized in Table 1.

Table 1. Reported proximate, mineral, and phytochemical composition of banana peels

Composition category	Component	Reported content
Proximate composition	Moisture	8–12%
	Crude ash	6–12%
	Crude protein	6–9%
	Crude fibre	10–18%
	Carbohydrates	50–60%
	Lipids/fat	1–3%
	Pectin	10–21%
	Cellulose	7–12%
	Hemicellulose	6–9%
	Lignin	6–12%
Mineral composition	Potassium (K)	5–12%
	Calcium (Ca)	2–4%
	Magnesium (Mg)	0.5–1.2%
	Phosphorus (P)	0.1–0.3%
	Sodium (Na)	0.2–0.5%
	Iron (Fe)	80–150 mg/kg
	Zinc (Zn)	20–50 mg/kg
Phytochemical composition	Phenolic compounds	1–3%
	Flavonoids	Low–moderate
	Tannins	2–4%
	Saponins	Trace–low
	Alkaloids	Trace–low

Note. The values presented are literature-reported ranges and were not experimentally determined in the present study. Proximate composition values were compiled from Anhwange (2008), Emaga et al. (2007), and Bishnoi et al. (2023); mineral composition from Anhwange (2008), Hossain et al. (2015), and Bishnoi et al. (2023) and phytochemical composition from Mokbel and Hashinaga (2005), Someya et al. (2002), and Pereira and Maraschin (2015).

Therefore, the present study aimed to extract potassium chloride from banana peels and characterize the recovered material using physicochemical tests, Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), and flame

photometry. The study further evaluates the potential of banana-peel-derived potassium chloride as a sustainable resource for future fertilizer applications.

2. Materials and Methods

2.1. Study Site and Plant Material

The study was conducted at the Nutrition Laboratory, Pakistan Council of Scientific and Industrial Research (PCSIR), Lahore, Pakistan. Ripe banana peels were obtained from MTS Farm, Lahore, Pakistan.

2.2. Chemicals and Reagents

All chemicals used in this study were of analytical grade and included sodium chloride, hydrochloric acid, sodium cobalt nitrite, acetone, glycerol, ethanol, acetic acid, perchloric acid, sodium sulfide, tartaric acid, and lithium chloride. Distilled water was used for the preparation of all solutions.

2.3. Apparatus and Materials

Standard laboratory glassware and equipment, including beakers, conical flasks, crucibles, evaporation dishes, test tubes, funnels, Whatman No. 42 filter paper, pH paper, aluminium foil, a Bunsen burner, spatula, knife, 0.5-mm sieve, and digital balance, were used during the experimental procedures.

2.4. Preparation of Solutions

A 10% (w/v) sodium cobalt nitrite solution was prepared by dissolving 10 g of sodium cobalt nitrite in distilled water and adjusting the final volume to 100 mL.

A 15% tartaric acid solution was prepared by dissolving 15 g of tartaric acid in distilled water and adjusting the final volume to 100 mL.

A 4 M potassium chloride (KCl) solution was prepared by dissolving 298.2 g of KCl in distilled water and adjusting the final volume to 1 L.

A 3 M hydrochloric acid (HCl) solution was prepared by diluting 289.29 mL of concentrated HCl (10.37 M) with distilled water to a final volume of 1 L.

2.5. Sample Preparation

A total of 4 kg of ripe banana peels were collected, thoroughly washed, and cut into small pieces. The peels were initially air-dried in a well-ventilated area and subsequently oven-dried at 100 °C for 10 min. After drying, approximately 1.9 kg of dried peel material was obtained. The dried peels were ground using a mortar and pestle and passed through a 0.5-mm sieve. Drying, size reduction, and extraction are commonly employed as preparatory steps in the valorization of banana-peel biomass (Putra et al., 2022).

2.6. Ashing and Acid Digestion

The extraction procedure was based on the conversion of banana-peel biomass into ash followed by acid-assisted extraction of the mineral fraction, with modifications to the experimental conditions used in the present study. The powdered banana peel was subjected to charring at 110 °C for 40 min, yielding 35.68 g of ash. The resulting ash was digested with 1 L of 3 M HCl and heated on a hot plate for 30 min. The mixture was subsequently allowed to stand for 30 min to facilitate the dissolution of potassium salts.

2.7. Concentration and Filtration

The digest was concentrated by heating until approximately one-fourth of its original volume remained. The mixture was then allowed to cool and filtered. The residue was washed with distilled water to remove residual acid.

2.8. Precipitation and Recovery

Potassium was precipitated from the filtrate by adding 6 g of sodium chloride. The resulting precipitate was collected using Whatman No. 42 filter paper, and the recovered potassium chloride crystals were washed with distilled water.

2.9. Drying and Storage

The recovered crystals were dried in an evaporating dish over a Bunsen burner until completely dry and subsequently stored in airtight containers to minimize moisture absorption.

2.10. Yield and Characterization

The recovered product was characterized using physicochemical and instrumental techniques. Solubility, flame, melting-point, sodium cobalt nitrite, perchloric acid, tartaric acid, and pH tests were performed for preliminary physicochemical assessment. FTIR spectroscopy was employed to examine the spectral characteristics of the recovered material, whereas

XRD analysis was used to evaluate its crystalline characteristics. Flame photometry was subsequently used for potassium determination.

2.11 Statistical Analysis

Experimental data were summarized using descriptive statistics, where applicable. The relationship between potassium concentration and emission response in the flame-photometric analysis was evaluated using linear regression. Potassium-to-lithium (K^+/Li^+) intensity ratios were used to construct the calibration curve and assess the linearity of the analytical response. Statistical and graphical analyses were performed using Microsoft Excel. A coefficient of determination (R^2) was used to evaluate the goodness of fit of the calibration model. Statistical procedures were selected according to the nature and distribution of the experimental data, following established principles for statistical analysis in food science research (Granato et al., 2014).

3. Results and Discussion

3.1. Extraction Yield and Physicochemical Characterization

A total of 4 kg of fresh banana peels was processed for the extraction of potassium chloride (KCl). Following drying, approximately 1.9 kg of dried peel material was obtained and subsequently subjected to ashing, acid digestion, concentration, filtration, and recovery. The extraction process yielded 1.21 g of crystalline material. Based on the theoretical KCl content considered in the experimental calculation, the recovery was reported as 77.1%.

The recovered material appeared as white, crystalline solids, as shown in Figure 1. The recovery of potassium-containing material from banana peels demonstrates the potential of this agricultural waste as a source of valuable mineral compounds. Banana peels contain appreciable amounts of potassium, as summarized in Table 1, and previous studies have investigated potassium recovery and utilization from banana peels through extraction, ashing, hydrothermal processing, and biochar-based approaches (Mustaqim et al., 2018; Islam et al., 2019; Bishnoi et al., 2023; Khanyile et al., 2024). More recent studies have further emphasized banana-peel valorization and its potential conversion into nutrient-rich and agricultural products (Mustaqim et al., 2018; Islam et al., 2019; Bishnoi et al., 2023; Khanyile et al., 2024).



Figure 1. Potassium chloride crystals recovered from banana peels following extraction and purification.

The recovered material was further evaluated through physicochemical and qualitative analyses, including assessment of colour, odour, texture, solubility, pH, flame response, sodium cobalt nitrite reaction, perchloric acid reaction, tartaric acid reaction, and melting point. The results are summarized in Table 2.

Table 2. Physicochemical and qualitative characteristics of potassium chloride extracted from banana peels

Property/Test	Observation	Interpretation
Colour	White	Characteristic appearance of the recovered crystalline material
Odour	Odourless	Consistent with an inorganic crystalline salt
Texture	Crystalline	Formation of crystalline material
Solubility in cold water	Completely soluble	High aqueous solubility
Solubility in hot water	Completely soluble	High aqueous solubility
Solubility in glycerol	Completely soluble	Soluble under the tested conditions
Solubility in ethanol	Partially soluble	Limited solubility
Solubility in acetone	Insoluble	No observable solubility
pH	7	Neutral under the tested conditions
Flame test	Lilac-coloured flame	Indicates the presence of K^+

Property/Test	Observation	Interpretation
Sodium cobalt nitrite test	Yellow precipitate	Supports the presence of K ⁺
Perchloric acid test	White precipitate	Positive precipitation response
Tartaric acid test	White crystalline precipitate	Supports the presence of potassium
Melting point	760 °C	High melting point characteristic of an inorganic salt

As shown in Table 2, the recovered material was white, odourless, and crystalline. It was completely soluble in hot and cold water and in glycerol, partially soluble in ethanol, and insoluble in acetone. A 4 M solution of the recovered material exhibited a neutral pH of 7. These physicochemical characteristics were consistent with the behaviour expected for a water-soluble inorganic potassium salt.

The flame test produced a characteristic lilac-coloured flame, providing qualitative evidence for the presence of potassium ions (K⁺). This observation was further supported by the sodium cobalt nitrite test, which produced a yellow precipitate, and the tartaric acid test, which resulted in the formation of white crystalline precipitates. Treatment with perchloric acid also produced a white precipitate. Collectively, these qualitative reactions supported the presence of potassium in the recovered crystalline material.

The experimentally determined melting point was approximately 760 °C, close to the reference value of approximately 770 °C used for comparison in the original analysis. The high melting point further supported the inorganic crystalline nature of the recovered product. However, physicochemical and qualitative tests alone provide limited structural information; therefore, FTIR spectroscopy and X-ray diffraction (XRD) were employed for further characterization. Collectively, these qualitative reactions supported the presence of potassium in the recovered crystalline material. These findings are consistent with the broader literature identifying banana peels as potassium-rich biomass with potential for nutrient recovery and agricultural utilization (Islam et al., 2019; Bishnoi et al., 2023; Khanyile et al., 2024).

3.2. FTIR and XRD Characterization

Fourier-transform infrared (FTIR) spectroscopy was used to investigate the spectral characteristics of the extracted material. The FTIR spectrum exhibited a prominent absorption band at 721.1 cm⁻¹, which was assigned in the experimental analysis to the K–Cl-related region. The FTIR spectrum of the recovered material is presented in Figure 2.

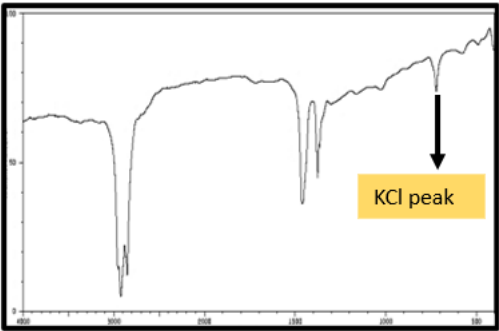


Figure 2. FTIR spectrum of potassium chloride extracted from banana peels.

The absorption feature observed at 721.1 cm⁻¹ provided additional information regarding the chemical characteristics of the recovered material. When considered together with the physicochemical and qualitative results presented in Table 2, the FTIR analysis supported the characterization of the extracted potassium-containing crystalline product.

X-ray diffraction analysis was subsequently performed to investigate the crystalline characteristics of the recovered material. The XRD pattern exhibited distinct diffraction peaks at 2θ values of approximately 28.3°, 40.5°, 50.2°, 58.7°, 66.4°, and 74.4°. These peaks were assigned in the original analysis to the (200), (220), (400), (420), and (422) crystallographic planes, respectively. The XRD characteristics are summarized in Table 3.

Table 3. X-ray diffraction characteristics of potassium chloride extracted from banana peels

2θ (°)	Miller indices (hkl)	Relative intensity (a.u.)	Peak characteristics
~28.3	(200)	~4200	Strongest, well-defined peak
~40.5	(220)	~2200	Strong secondary peak
~50.2	(222)	~850	Medium-intensity peak
~58.7	(400)	~750	Medium-intensity peak
~66.4	(420)	~1000	Well-defined peak
~74.4	(422)	~700	Weak but sharp peak

As presented in Table 3, the diffraction pattern was dominated by the strong peak at approximately 28.3°, with several additional well-defined peaks observed across the measured range. The peak positions were reported to be in close agreement with the standard diffraction data for crystalline KCl according to JCPDS Card No. 41-1476. The sharp and distinct nature of the diffraction peaks indicated a well-defined crystalline structure.

The corresponding XRD pattern is presented in Figure 3.

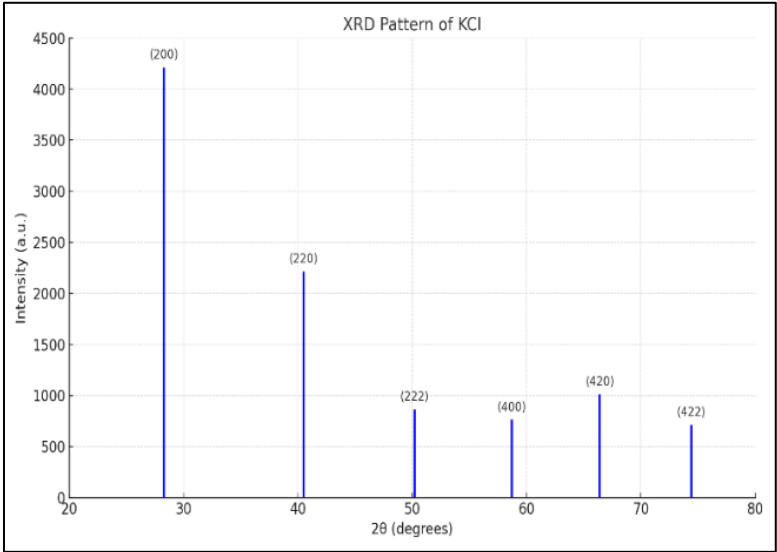


Figure 3. X-ray diffraction (XRD) pattern of potassium chloride extracted from banana peels.

The XRD findings complemented the physicochemical and FTIR observations. While the qualitative tests provided evidence for the presence of potassium ions, XRD analysis provided additional information regarding the crystalline characteristics of the recovered product. Taken together, the physicochemical tests, FTIR spectroscopy, and XRD analysis supported the characterization of the recovered potassium-containing crystalline material. Overall, instrumental characterization complemented the qualitative analyses and provided further evidence regarding the chemical and crystalline characteristics of the recovered material. Instrumental characterization of banana-peel-derived products has increasingly been incorporated into recent valorization studies to establish their physicochemical and structural properties (Putra et al., 2022; Bishnoi et al., 2023).

3.3. Flame Photometric Analysis

Flame photometry was employed to evaluate potassium in the extracted sample. Lithium was used as an internal standard to improve the analytical response. The initial potassium emission intensity data did not exhibit satisfactory linearity when considered independently. Therefore, the potassium signal was normalized against the lithium internal standard by calculating the K⁺/Li⁺ emission intensity ratio.

The K⁺/Li⁺ intensity ratios obtained for the potassium standards and extracted sample are presented in Table 4.

Table 4. Potassium-to-lithium emission intensity ratios for potassium standards and the extracted sample

Flask No.	K ⁺ concentration	K ⁺ /Li ⁺ intensity ratio
1	1.0	1.0000
2	2.0	2.0400
3	5.0	5.1029
4	7.5	7.6706
5	10.0	9.5800
6	20.0	19.0000
7	Extracted KCl sample	5.1978

As shown in Table 4, the K^+/Li^+ intensity ratio increased progressively with increasing potassium concentration in the standard solutions. The extracted sample exhibited a K^+/Li^+ intensity ratio of 5.1978. Normalization of the potassium response against the lithium internal standard improved the linear relationship compared with the potassium emission intensity considered independently.

The relationship between potassium concentration and the K^+/Li^+ intensity ratio is presented in Figure 4.

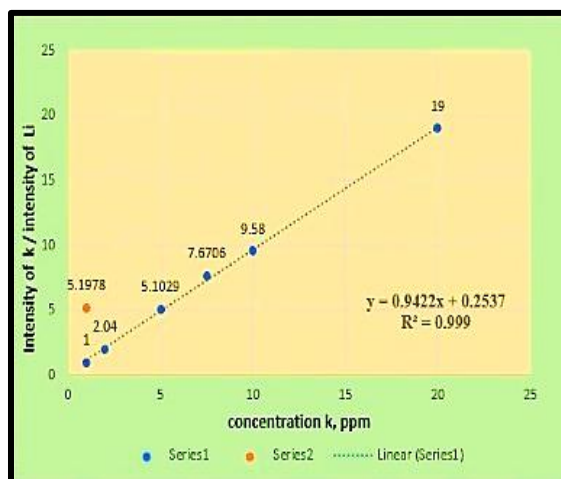


Figure 4. Calibration relationship between potassium concentration and the K^+/Li^+ emission intensity ratio using lithium as an internal standard.

The improved linearity observed following normalization against lithium indicates that the internal-standard approach reduced variation in the analytical response. The flame photometric analysis therefore provided additional analytical evidence for potassium in the extracted sample and complemented the qualitative flame test and instrumental characterization. The quantitative assessment of potassium is particularly relevant to banana-peel valorization because potassium represents one of the major mineral constituents associated with its potential agricultural use. Previous studies have highlighted potassium recovery and utilization from banana-peel-derived materials (Mustaqim et al., 2018; Islam et al., 2019), while recent literature has further emphasized the potential of potassium-rich banana-peel biomass for fertilizer and soil-enhancement applications (Khanyile et al., 2024).

3.4. Implications for Waste Valorization and Sustainable Fertilizer Development

The recovery of potassium-containing material from banana peels represents a potential approach for the valorization of an abundant agricultural and food waste stream. Banana peels are commonly discarded despite containing appreciable concentrations of potassium and other valuable constituents. Their utilization as a raw material for potassium recovery may therefore contribute to nutrient recycling while simultaneously reducing agricultural and food waste.

Previous studies have demonstrated the potential of banana-peel-derived materials as alternative potassium sources and agricultural inputs. Mustaqim et al. (2018) investigated potassium recovery from banana peels through hydrothermal treatment, reporting substantial recovery of potassium from the resulting liquid fraction. Islam et al. (2019) explored banana-peel biochar as an alternative potassium source for plant productivity and sustainable agriculture. Nossier (2021) further demonstrated interest in the agricultural utilization of organic fertilizers derived from fruit-peel waste. More recent studies have expanded this concept toward broader banana-peel valorization and sustainable fertilizer development (Bishnoi et al., 2023; Khanyile et al., 2024). More recent research has expanded this concept from basic nutrient recovery toward broader banana-peel valorization and sustainable agricultural applications. Putra et al. (2022) reviewed different extraction approaches for recovering value-added components from banana-peel waste, while Bishnoi et al. (2023) highlighted its wider potential for effective valorization. Khanyile et al. (2024) specifically examined the preparation of banana-peel-based biofertilizers and their potential effects on soil properties and crop performance. More recently, Kumar et al. (2025) demonstrated the conversion of banana-peel waste into a value-added nano-biofertilizer formulation. Collectively, these earlier and recent studies demonstrate the growing potential of banana-peel waste as a resource for nutrient recovery and sustainable agricultural product development.

In the present study, physicochemical and qualitative tests, FTIR spectroscopy, XRD analysis, and flame photometry collectively supported the recovery and characterization of a crystalline potassium-containing material from banana peels. The findings complement both earlier studies on potassium recovery from banana-peel biomass Mustaqim et al. (2018) and Islam et al. (2019) and more recent efforts directed toward sustainable banana-peel valorization and fertilizer development (Bishnoi et al., 2023; Khanyile et al., 2024; Kumar et al., 2025). The present approach therefore contributes to circular-economy strategies emphasizing resource recovery, waste reduction, and sustainable biomass utilization.

Nevertheless, the present study focused primarily on the extraction and characterization of the recovered material. Its performance as a fertilizer was not evaluated through soil or plant-growth experiments. Consequently, further studies are required to determine its agronomic effectiveness, appropriate application rate, nutrient-release behaviour, potential phytotoxicity, and effects on soil and plant growth before practical fertilizer application can be recommended.

Conclusion

This study demonstrated the recovery and characterization of a potassium-containing crystalline material from banana peels, highlighting the potential of this agricultural waste as a resource for potassium recovery and waste valorization. The extraction process yielded 1.21 g of crystalline material from 4 kg of fresh banana peels. Physicochemical and qualitative analyses showed a white crystalline appearance, high water solubility, neutral pH, and characteristic responses associated with potassium ions. FTIR spectroscopy, XRD analysis, and flame photometry provided further information on the chemical and crystalline characteristics of the recovered material.

The findings support the potential utilization of banana peels as a low-cost feedstock for potassium recovery and contribute to circular-economy approaches aimed at converting agricultural residues into value-added products. However, the present study focused on extraction and characterization rather than agronomic performance. Further soil and plant-growth studies are required to determine fertilizer effectiveness, appropriate application rates, nutrient-release behaviour, phytotoxicity, and effects on soil properties before practical agricultural application can be recommended.

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