Frontiers and Results in Applied Sciences
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Research Article

Extraction and Characterization of Alkalis from Ashes of Selected Agro-Waste Peels: Toward Sustainable Alternatives for Industrial Base Applications

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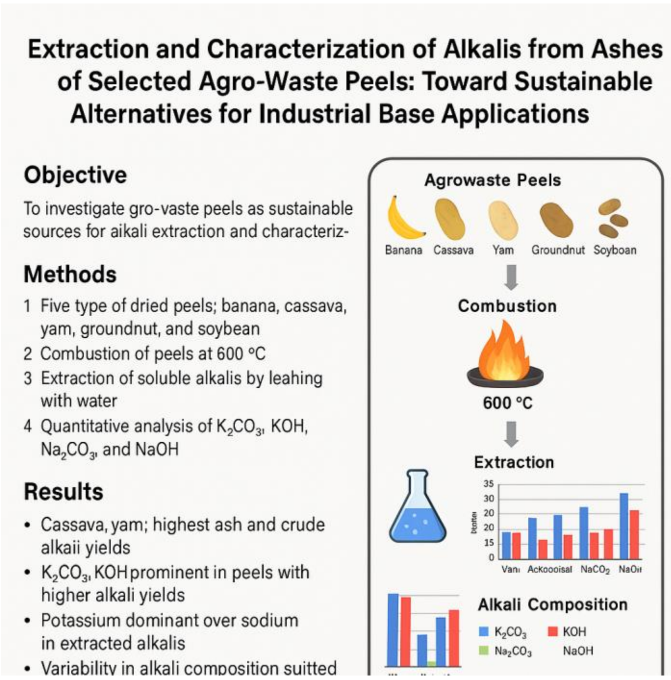
Abstract-This study investigates the potential of selected agro-waste peels—banana, cassava, yam, groundnut, and soybean—as sustainable sources of industrial alkalis. The peels were oven-dried, combusted at 600 °C, and their ashes subjected to aqueous extraction to recover soluble alkalis. The resulting crude alkali solutions were analyzed using flame photometry and titrimetric methods to quantify potassium and sodium in both carbonate and hydroxide forms. Results showed that cassava and yam peels produced the highest yields of crude alkalis, with potassium carbonate being the most abundant compound across all samples. Groundnut and banana peels exhibited relatively higher concentrations of potassium and sodium hydroxides, making them suitable for applications requiring stronger base activity. Flame photometry confirmed potassium dominance in all samples, with K^+ concentrations ranging from 42.8 to 61.2 mg/L and K^+:Na^+ ratios consistently above 1.4. The findings confirm that agro-waste peels are viable, low-cost alternatives to commercial base chemicals, with specific compositional profiles that can be aligned with targeted industrial uses such as soap production, water treatment, or biodiesel catalysis. This work supports the integration of biomass valorization into sustainable chemical sourcing strategies, especially in resource-constrained environments.

Graphical Abstract



Article Key Information

Keywords: Ashes, alkalis, Peels, Soap and Extraction

Received: 17th March 2025 **Revised:** 5th April 2025 **Accepted**: 20th April 2025 **Published**: 24th April 2025

1. INTRODUCTION

Alkalis, comprising primarily sodium and potassium hydroxides and carbonates, are essential reagents in numerous chemical industries. They are widely utilized in soap production, pulp and paper manufacturing, textile processing, neutralization of acidic waste streams, and as precursors in various organic and inorganic syntheses. Commercial alkalis, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH), are typically produced through energy-intensive processes such as electrolysis of brine or extraction from mineral ores, which are not only expensive but also environmentally burdensome due to high carbon emissions and chemical waste generation [1,2].

In contrast, the ashes of agricultural biomass, particularly agro-waste peels, have long been recognized for their natural content of alkali metal salts. When combusted, these residues yield ashes containing soluble oxides, hydroxides, and carbonates of sodium and potassium. These can be extracted using simple aqueous leaching and are collectively referred to as "potash" when derived from potassium-rich sources. The utilization of biomass ashes as a low-cost, renewable source of alkalis not only supports cleaner production technologies but also contributes to sustainable waste management and rural industrialization [3,4].

Agro-waste peels such as those from banana (Musa spp.), cassava (Manihot esculenta), yam (Dioscorea spp.), groundnut (Arachis hypogaea), and soybean (Glycine max) are typically discarded in large volumes in developing countries. Their high organic and mineral content makes them excellent candidates for conversion into value-added products. Studies have shown that the chemical composition of the resulting ash depends on the botanical species, the soil and climatic conditions under which the plants were grown, and the combustion parameters such as temperature and duration [5–7]. Babayemi et al. [8] demonstrated that plantain and banana peels can yield significant quantities of potassium-rich ash, while Adewuyi et al. [9] evaluated potash recovery from several African wood species. However, few comprehensive studies have quantitatively compared the alkali content—distinguishing both carbonate and hydroxide forms of sodium and potassium—across multiple peel types under controlled experimental conditions.

Moreover, traditional methods of potash production often lack standardization, resulting in inconsistent yields and product purity. Many local producers rely on slow combustion techniques that introduce impurities and color variations in the final ash-derived products. With the rise of green chemistry principles, there is growing interest in formalizing and optimizing these traditional processes through controlled laboratory studies. Such efforts can help reduce dependency on synthetic chemicals, promote environmental conservation, and foster local enterprise development in low-resource settings [10].

The present study aims to address these gaps by conducting a comparative extraction and characterization of alkalis from ashes of selected agro-waste peels—namely banana, cassava, yam, groundnut, and soybeans. The work specifically focuses on quantifying the concentrations of potassium carbonate (K_2CO_3), potassium hydroxide (KOH), sodium carbonate (Na_2CO_3), and sodium hydroxide (NaOH) in each ash type using reproducible extraction and concentration methods. Additionally, the study examines ash and crude alkali yield efficiencies to assess their practical relevance for industrial base applications, particularly in small- and medium-scale soap production. By leveraging agricultural residues as alternative raw materials, this research contributes to the broader goals of circular economy, waste valorization, and sustainable industrial development.

2. REVIEW OF RELATED LITERATURE

2.1 Alkalis and Their Industrial Importance

Alkalis, primarily sodium and potassium hydroxides and carbonates, are foundational chemicals in industrial processes ranging from saponification and water treatment to biodiesel production and mineral processing. Sodium hydroxide (NaOH) and potassium hydroxide (KOH), in particular, are among the most commonly used inorganic bases due to their strong basicity and reactivity in acid-neutralization and organic transformations [2,1]. Traditionally, these chemicals are derived from energy-intensive processes such as the electrolysis of brine or extraction from mineral deposits, making them both economically costly and environmentally unsustainable [11].

2.2 Biomass Ashes as Sustainable Alkali Sources

In pursuit of circular economy principles and low-cost chemical production, research has turned to biomass ashes—particularly from agro-waste—as renewable alternatives to synthetic alkalis. Agricultural residues such as fruit peels, crop husks, wood shavings, and plant stalks, when combusted under appropriate conditions, yield ashes rich in potassium and sodium compounds, mainly in the form of carbonates and oxides. These ashes, when treated with water, form soluble bases that can be extracted, concentrated, and used in a wide range of applications [7,12].

Historical and ethnobotanical records indicate that traditional communities in Africa, Asia, and South America have long used wood ash and burnt plant residues to produce "potash," a generic term referring to potassium-rich solutions extracted from ash for soap making and cooking [10]. Modern scientific investigations now seek to standardize and quantify these alkali yields under reproducible conditions, aiming to validate their industrial applicability beyond traditional settings.

2.3 Previous Studies on Agro-Waste-Derived Alkalis

Multiple studies have evaluated the ash and alkali content of various agro-residues. Onyegbado et al. [3] demonstrated that plantain peels could serve as a viable source of alkali for solid soap production, with substantial K_2CO_3 content. Babayemi and Adewuyi [4] examined potash recovery from plant-based ashes and reported that ash yield and chemical composition varied significantly depending on the source material and combustion method. For example, cocoa pod husks, maize cobs, and banana leaves produced differing amounts of potash, with potassium content ranging from 10% to over 30% in some samples.

Adewuyi et al. [9] extended this analysis to ten African wood species, identifying variations in ash content between 1.25% and 8.80%, emphasizing the influence of plant type and origin on potash potential. However, most of these studies focused on single plant species or wood sources and lacked side-by-side comparative data under standardized conditions across multiple waste types.

2.4 Limitations in Existing Literature

Despite a growing body of work, critical gaps remain. Firstly, many existing studies emphasize qualitative assessments or provide aggregate measurements without distinguishing between carbonate and hydroxide forms of alkalis. This lack of chemical speciation limits the practical application of the data, particularly for industries that require precise base strength and purity [8]. Secondly, traditional methods of potash extraction—while environmentally benign—often suffer from poor combustion control, leading to inconsistencies in ash quality and contaminant levels, such as residual charcoal or heavy metals [13].

Moreover, the broader industrial application of agro-waste-derived alkalis has not been widely explored. While soap production is frequently cited, few studies consider the feasibility of substituting synthetic alkalis in other base-dependent industries, such as biodiesel synthesis, water treatment, or ceramics. This represents an underutilized opportunity for advancing green chemistry solutions using locally available biomass.

2.5 Toward Comparative and Quantitative Evaluation

To address these gaps, recent literature calls for comparative, quantitative studies that assess not only the total alkali content in agro-waste ashes but also the relative proportions of sodium versus potassium compounds, and hydroxides versus carbonates. Analytical techniques such as flame photometry, atomic absorption spectroscopy (AAS), and titrimetric methods have been employed in some cases to improve chemical resolution [14,15]. However, these methods are still underutilized in rural-scale studies or among research focusing on peels and non-woody biomass.

Banana, cassava, yam, groundnut, and soybean peels are abundantly available agro-residues in many developing regions. While they have been individually noted for their potential as biomass fuels or composting agents, their value as ash-derived alkali sources has not been rigorously compared in a unified framework. There is a pressing need to identify which peels offer the highest yield and purity of alkalis, and under what conditions this potential can be maximized.

2.6 Relevance of the Present Study

The current study contributes to filling this knowledge gap by providing a side-by-side, quantitative analysis of alkalis extracted from the ashes of five common agro-waste peels. By measuring concentrations of K_2CO_3, KOH, Na_2CO_3, and NaOH in the ash extracts, this work seeks to inform both small-scale producers and industrial practitioners of the feasibility and chemical viability of biomass-derived alkalis as sustainable alternatives to synthetic bases. Moreover, the study supports broader goals of environmental remediation, local economic development, and green industrial chemistry.

3. MATERIALS AND METHODS

3.1 Sample Collection and Preparation

Five types of agro-waste peels—banana (*Musa spp.*), cassava (*Manihot esculenta*), yam (*Dioscorea spp.*), groundnut (*Arachis hypogaea*), and soybean (*Glycine max*)—were selected for this study based on their availability and high organic matter content. The peels were collected from local agricultural waste dumps and markets in Gboko, Benue State, Nigeria. All samples were manually sorted to remove non-plant debris, washed with distilled water to eliminate surface contaminants, and subsequently air-dried under shade for 48 hours.

To ensure consistency in moisture content, the peels were further oven-dried at 100 ± 2 °C for 48 hours until they reached constant weight. Each peel type was processed separately. A mass of 1 kg per sample was weighed using a digital analytical balance (Mettler Toledo ML204, accuracy ±0.0001 g) and prepared for combustion.

3.2 Controlled Combustion and Ash Production

Combustion of the dried peels was carried out in a custom-fabricated stainless steel combustion pan placed inside a muffle furnace (Carbolite Gero, model CWF 1100). Each sample was combusted at 600 °C for 4 hours in ambient air to ensure complete oxidation of organic material and consistent ash yield. The temperature and duration were selected based on literature indicating optimal mineral retention and reduced volatilization loss of alkali metals [12,14].

The resultant ashes were cooled in desiccators to prevent moisture absorption, then weighed and stored in airtight polyethylene containers for further analysis. Ash yields were calculated as a percentage of the original dry weight.

3.3 Extraction of Soluble Alkalis

For each ash sample, 100 g was mixed with 1.0 L of distilled water in a 2 L Erlenmeyer flask. The mixture was stirred for 15 minutes using a magnetic stirrer (VELP Scientifica, Italy) and allowed to stand for 24 hours at room temperature to promote equilibrium dissolution. The supernatant was filtered using Whatman No. 1 filter paper to remove insoluble residues, yielding a clear alkali solution.

The filtered extracts were evaporated under reduced pressure at 60 °C using a rotary evaporator (Buchi R-300) until a solid residue was obtained. The crude alkalis were weighed and stored in desiccators prior to chemical analysis.

3.4 Quantitative Determination of Alkali Components

concentrations of potassium carbonate (K_2CO_3), potassium hydroxide (KOH), sodium carbonate (Na_2CO_3), and sodium hydroxide (NaOH) in the crude alkali extracts were determined by a combination of flame photometry and acid-base titrimetry with selective precipitation techniques.

3.4.1 Flame Photometry

Sodium and potassium concentrations were measured using a digital flame photometer (Jenway PFP7). Calibration curves were prepared using analytical-grade NaCl and KCl standards in the range of 0–100 mg/L. Each sample was diluted appropriately, and readings were taken in triplicate. Instrumental precision was ensured through periodic recalibration and quality control samples.

3.4.2 Titrimetric Analysis

Alkalinity due to hydroxide and carbonate species was quantified by titrating aliquots (25 mL) of the crude alkali solution with 0.1 M HCl using phenolphthalein and methyl orange as indicators. The titration method followed a modified two-endpoint protocol as described by ASTM D1067-16 [16] for alkali mixtures. Concentrations of OH^- and CO_3^{2-} were back-calculated from the volume of acid consumed at each indicator endpoint.

3.5 Statistical Analysis

All experiments were conducted in triplicate. Data were recorded as mean ± standard deviation. Statistical comparisons between the alkali yields and concentrations across the five peel types were conducted using one-way analysis of variance (ANOVA) with Tukey's post hoc test (significance level $p < 0.05$) using SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA).

3.6 Quality Assurance

i All reagents used were of analytical grade (Merck, Germany).
ii All glassware was acid-washed and rinsed thoroughly with deionized water before use.
iii Blank and standard control samples were run concurrently with experimental samples to validate the accuracy and reliability of results.

4. RESULTS AND DISCUSSION

4.1 Ash Yield and Crude Alkali Recovery

Combustion of 1 kg of oven-dried peels from each agro-waste source produced ash yields ranging from 4.1% to 5.7% by weight. The highest ash mass was obtained from cassava peels (57 g), followed by banana and yam peels (45 g and 43 g, respectively). Groundnut and soybean peels produced slightly lower ash content. Crude alkalis recovered from the aqueous extracts varied accordingly, with cassava producing the highest yield (11.0 g) and groundnut the least (6.7 g).

Table 1. Ash and Crude Alkali Yields from 1 kg of Dried Peels

Biomass Type	Ash Yield (g)	Ash Yield (%)	Crude Alkali (g)	Crude Alkali Yield (%)
Yam	43.0	4.3%	8.5	0.85%
Cassava	57.0	5.7%	11.0	1.10%
Banana	45.0	4.5%	9.0	0.90%
Groundnut	41.0	4.1%	6.7	0.67%
Soybean	42.0	4.2%	7.3	0.73%

The result is presented in Table 2 and also shown in Figure 1 (a). The yield variability aligns with reported mineral accumulation differences among plant species and parts [14]. The relatively higher recovery from cassava indicates its strong potential for local alkali production.

4.2 Flame Photometry Results: Potassium and Sodium Levels

Flame photometric analysis was used to quantify the total concentrations of sodium and potassium ions in the crude alkali solutions. Calibration curves were established with $R^2 > 0.995$. Results, expressed in mg/L, are provided in Table 2 and displayed in Figure 1 (b).

Table 2. Total Na^+ and K^+ Content in Crude Alkali Solutions (Flame Photometry)

Biomass Type	Potassium (K^+) [mg/L]	Sodium (Na^+) [mg/L]	K^+:Na^+ Ratio
Yam	61.2	36.1	1.70
Cassava	44.5	28.4	1.57
Banana	50.6	36.8	1.38
Groundnut	56.9	40.3	1.41
Soybean	42.8	30.0	1.43

Potassium consistently appeared in greater concentrations than sodium, consistent with the nature of potash-rich biomass. The highest K^+ concentration was observed in yam, while groundnut and banana had more balanced but still potassium-dominant profiles.

4.3 Titrimetric Quantification of Alkali Species

Titrimetric analysis (Table 3) distinguished between the carbonate and hydroxide forms of potassium and sodium. The data indicate that carbonate species dominate in all samples, with K_2CO_3 concentrations consistently exceeding KOH. This is also shown in Figure 1 (c).

Table 3. Titrimetric Analysis of Alkali Species in Crude Extracts (mg/L)

Biomass Type	K_2CO_3	KOH	Na_2CO_3	NaOH
Yam	46.4	14.3	26.5	9.6
Cassava	33.3	11.2	21.1	7.3
Banana	31.2	19.4	22.3	14.5
Groundnut	32.5	23.6	23.4	17.4
Soybean	27.3	15.5	19.4	10.6

These results reflect the stability of carbonate compounds during combustion and suggest that hydroxide formation is influenced by post-combustion reactions and ambient CO_2 absorption [7]. Notably, groundnut ash yielded the highest hydroxide concentrations, indicating greater base strength in its extract.

4.4 Interpretation and Comparative Discussion

The consistently higher potassium levels across all peel types support previous observations that potassium is the dominant alkali metal in plant ashes [10]. The K^+:Na^+ ratios (1.4 to 1.7) are favorable for soap production and suggest that these agro-wastes can serve as efficient potash alternatives.

The dominance of carbonate forms, particularly K_2CO_3 and Na_2CO_3, is beneficial for applications requiring buffering capacity rather than aggressive pH shifts. Conversely, hydroxide-rich extracts such as those from groundnut and banana may be better suited for applications requiring stronger basicity, such as biodiesel transesterification or high-pH industrial cleaners [17].

Compared to commercial NaOH or KOH, which are typically ≥98% pure, these agro-waste-derived alkalis offer a sustainable but less concentrated alternative. However, with purification steps or selective extraction methods (e.g., fractional crystallization, membrane separation), the quality could be improved for specialized industrial use.

These findings not only align with studies by Adewuyi et al. [9] and Babayemi et al. [8], but they also offer a quantitative comparison across diverse biomass types under controlled conditions—something rarely done in the literature. This study thus fills a key gap by offering decision-makers clear data on which waste types yield the most and best-suited alkalis for various end uses.

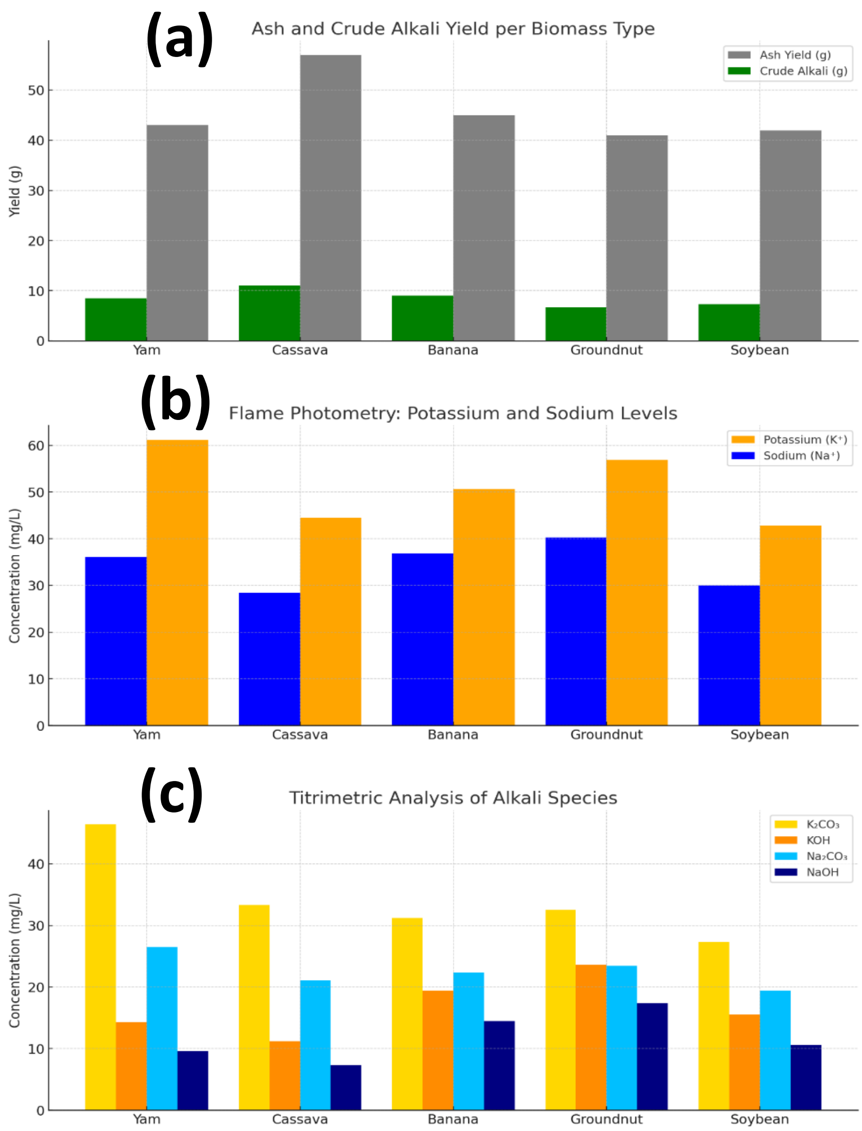


Figure1: (a) Ash and Crude Alkali Yield per Biomass Type (b) Flame Photometry: Potassium and Sodium Levels, and (c) Titrimetric Analysis of Alkali Species.

4.5 Statistical Significance

Analysis of variance (ANOVA) confirmed that differences in alkali concentrations across biomass types were statistically significant ($p < 0.05$). Tukey's post hoc test showed that groundnut extract's hydroxide content was significantly higher ($p < 0.01$) than those from cassava and soybean, while yam had a significantly higher K_2CO_3 concentration than all others ($p < 0.05$).

4.6 Industrial and Environmental Implications

The use of agro-waste-derived alkalis presents several advantages:

i Cost Reduction: These alkalis offer a cheap alternative to imported or industrially produced bases.
ii Waste Valorization: Repurposing peels helps reduce landfill pressure and greenhouse gas emissions from decomposition.
iii Local Industrial Potential: Rural communities could develop micro-enterprises for alkali extraction and local soap production, fostering economic empowerment.

However, the impurities and lower purity of these crude alkalis limit their direct substitution in fine chemical or pharmaceutical applications. Future studies should focus on refining extraction and purification processes to increase their industrial applicability.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study has demonstrated that agro-waste peels—specifically those of banana, cassava, yam, groundnut, and soybean—serve as viable raw materials for the extraction of alkalis in the form of potassium and sodium carbonates and hydroxides. Controlled combustion followed by aqueous extraction and quantitative analysis revealed that:

i Cassava and yam peels yielded the highest quantities of crude alkali and potassium carbonate, indicating their strong potential for use in soap and detergent production.
ii Groundnut and banana peels exhibited relatively high concentrations of hydroxides (KOH and NaOH), which are useful in applications requiring stronger bases such as biodiesel production and industrial cleaning agents.
iii Potassium compounds consistently dominated over sodium, reinforcing the classification of these biomass ashes as potash-rich.
iv Statistically significant differences in alkali composition across biomass types suggest that biomass selection should be tailored to the specific alkali demand of the target application.

The combined use of flame photometry and titrimetric analysis provided a detailed alkali profile for each biomass type, contributing to a deeper understanding of their chemical potential and valorization opportunities. These findings not only confirm the utility of agro-waste peels as alternative base sources but also support broader sustainability goals through resource recovery and waste minimization.

5.2 Recommendations

Based on the findings of this study, the following recommendations are proposed:

i Biomass Selection for Application-Specific Alkalis: Cassava and yam peels are recommended for applications where mild alkalis (carbonates) are preferable, such as soap production and pH buffering. Groundnut and banana peels, being richer in hydroxides, should be prioritized for high-pH applications.
ii Standardization of Local Potash Production: Efforts should be made to formalize and standardize traditional potash production techniques. Introducing controlled combustion methods and quality assurance protocols can significantly improve the purity and consistency of the final product.
iii Scale-Up and Technology Transfer: The findings of this research can be translated into pilot-scale production systems suitable for rural and semi-urban communities. Local governments and agro-processing cooperatives should be encouraged to support such initiatives for economic empowerment and environmental sustainability.
iv Further Research on Purification and Enhancement: Future work should investigate purification techniques—such as fractional crystallization or ion-exchange processes—to improve alkali purity.

Additionally, studies should evaluate the techno-economic feasibility and environmental life cycle of biomass-derived alkalis compared to synthetic alternatives.

v Exploration of Broader Industrial Applications: Beyond soap making, the potential of these bio-alkalis should be assessed for applications in biodiesel catalysis, wastewater treatment, and ceramics. Cross-disciplinary collaboration with engineers and industrial chemists is encouraged.

By transforming agricultural residues into functional chemical reagents, this research contributes meaningfully to sustainable development, chemical self-reliance, and waste valorization, particularly in resource-limited regions.

DECLARATIONS

Ethical Approval and Consent to Participate:

Not Applicable

Consent for Publication:

The author consent to the publication of this manuscript and confirm that the work is original, has not been published elsewhere, and is not under consideration for publication elsewhere.

Competing Interests:

The authors declare no competing interests related to this study.

Funding:

Tertiary Education Trustfund (TETFUND), Abuja, Nigeria funded this research work.

Data Availability:

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' Contributions:

Asaar G.B.: Conceptualization, Methodology, Manuscript drafting, Data collection, Analysis, Figure Preparation, Literature review and critical manuscript revision. The author read and approved the final manuscript.

Acknowledgments:

The authors thank the editor and the entire editorial team of Frontiers and Results in Applied Sciences (FRAS) for their support and understanding.

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