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PHYSICOCHEMICAL CHARACTERIZATION AND FUNCTIONAL EVALUATION OF MAIZE COB ASH WITH ANTIMICROBIAL POTENTIAL

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Abstract:

Maize cob ash, an abundant agricultural waste material, was investigated for its potential application as a sustainable fertilizer and antimicrobial agent. Two ash samples (Ash A and Ash B), prepared under different conditions, were characterized using physicochemical and analytical techniques including pH analysis, FTIR, XRD, SEM, and EDX. Both samples exhibited strong alkaline properties, with pH values ranging from 11.2 to 9.4, indicating their suitability for neutralizing acidic soils. Elemental analysis confirmed the presence of essential plant nutrients such as potassium, calcium, magnesium, and phosphorus, with Ash A showing a significantly higher potassium content (13.0 wt%), highlighting its superior fertilizer potential. FTIR and XRD analyses revealed the presence of functional groups and crystalline mineral phases associated with stable inorganic compounds. SEM analysis demonstrated distinct morphological differences, with Ash A exhibiting a fine and compact structure and Ash B showing a porous and irregular surface, influencing nutrient availability and adsorption behaviour. Additionally, both samples exhibited antimicrobial activity, attributed to their alkaline nature and mineral composition. Overall, the findings indicate that maize cob ash possesses dual functionality as a nutrient-rich soil amendment and a natural antimicrobial agent, offering a sustainable alternative to conventional fertilizers and contributing to agricultural waste valorisation.

Key words: Maize cob ash, Waste valorisation, Sustainable fertilizer; Antimicrobial activity; FTIR; XRD; SEM; EDX; Soil amendment; Biomass ash

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Ethics, Consent to Participate, and Consent to Publish declarations

Not applicable. This study did not involve human participants, human data, or animal subjects.

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Data Availability Statement

All data generated or analysed during this study are included in this published article.

Competing Interests

The authors declare that they have no known financial or non-financial competing interests that could have influenced the work reported in this paper.

1.Introduction:

The growing concern over the long-term impact of chemical fertilizers on soil health has created a need for more sustainable and environmentally friendly alternatives. Continuous application of synthetic inputs often leads to soil degradation, nutrient imbalance, and reduced microbial diversity. In this context, the use of agricultural waste as a resource rather than a by-product has gained increasing attention Chen et al (2025).

One such widely available agricultural residue is maize cob, particularly in regions like Virudhunagar district, Tamil Nadu, where maize cultivation is extensive. Large quantities of maize residues are generated during harvesting, and these are often disposed of through open burning or left unused Smil (1999). This not only contributes to environmental pollution but also results in the loss of potentially valuable biomass. Converting this waste into ash provides a simple and effective way to recover mineral-rich material that can be reused in agricultural systems.

The ash derived from biomass is typically alkaline and contains essential plant nutrients such as potassium, calcium, and magnesium. These properties make it suitable for improving soil conditions, especially in acidic environments. At the same time, the high alkalinity and mineral composition of ash can influence microbial activity, suggesting a possible role in reducing soil-borne pathogens. However,

the functional performance of such ash is not fixed and largely depends on how it is prepared, as processing conditions directly affect its composition, structure, and reactivity Borowski & Ozga (2020).

Despite this potential, studies on maize cob ash remain limited, particularly in understanding how different preparation methods influence both its fertilizer efficiency and antimicrobial behaviour. This creates a gap in linking processing → structure → function, which is essential for practical application.

Therefore, the present study investigates two differently prepared maize cob ash samples (Ash A and Ash B) and systematically evaluates their physicochemical characteristics and functional performance. The study aims to establish how variations in preparation influence nutrient availability, surface properties, and antimicrobial activity, thereby assessing their suitability as sustainable soil amendments Pathan et al (2003)

2. Materials and Methods

2.1 Sample Collection

Maize cob residues were collected from agricultural fields in Virudhunagar district, Tamil Nadu, India, where maize cultivation is extensively practiced. The collected samples were cleaned to remove dust and impurities and then air-dried prior to further processing.

2.2 Preparation of Maize Cob Ash

Dried maize cob residues were subjected to controlled thermal treatment to obtain ash. Initially, the samples were washed with distilled water to remove adhering impurities and oven-dried at 105 °C for 24 h to remove moisture content Nethaji et al (2015).

The dried samples were then combusted in a muffle furnace at a temperature of 500–600 °C for 4 h under limited air conditions. After complete combustion, the obtained ash was allowed to cool to room temperature inside the furnace to avoid moisture absorption.

Two types of ash samples were prepared based on post-treatment:

Ash A: The ash was finely ground using a mortar and pestle and sieved to obtain a uniform fine powder (<100 µm).

Ash B: The ash was used in its coarse form without further grinding to retain its porous structure.

The prepared samples were stored in airtight containers for further analysis.

2.3 pH Analysis

The pH of maize cob ash was determined by preparing an aqueous ash suspension. Known quantities of ash were mixed with distilled water at different ratios (1:2.5, 1:5, and 1:10 w/v) and stirred for 30 min to ensure proper dispersion. The suspension was then allowed to stand for 10–15 min for equilibration, and the pH was measured using a calibrated digital pH meter at room temperature. The measurements were carried out in triplicate, and average values were reported Neina et al (2020).

2.4 FTIR Analysis

FTIR analysis was carried out to identify the functional groups present in the maize cob ash samples. A small amount of each sample was prepared for analysis, and the spectra were recorded in the range of 4000–400 cm⁻¹. The obtained spectra were analysed, and the characteristic peaks were assigned to corresponding functional groups based on standard reference data Gandam et al (2022).

2.5 XRD Analysis

X-ray diffraction (XRD) analysis was performed to determine the crystalline phases present in the ash samples. The powdered samples were subjected to XRD measurement over a 2θ range of 10° – 80° . The diffraction patterns obtained were analysed to identify the mineral phases formed during the combustion process Font et al (2010).

2.6 SEM and EDX Analysis

The surface morphology of the maize cob ash samples was examined using scanning electron microscopy (SEM). For analysis, a small quantity of the sample was mounted on a specimen holder and coated appropriately to improve conductivity Zhang et al (2020). Elemental composition was determined using energy-dispersive X-ray (EDX) analysis attached to the SEM system Wang et al (2017). The elemental distribution was recorded and expressed in terms of weight percentage (wt%).

2.7 Antimicrobial Activity

The antimicrobial activity of maize cob ash samples was evaluated using the agar well diffusion method. Sterile agar plates were inoculated with *Escherichia coli* (Gram-negative), and wells were created in the agar medium. The ash samples were introduced into the wells, and the plates were incubated at 37°C for 24 h. After incubation, the antimicrobial activity was assessed by measuring the diameter of the zone of inhibition (mm) around each well Alterary et al (2020).

3.RESULTS AND DISCUSSION

3.1 pH Characteristics of Maize Cob Ash

The pH analysis clearly demonstrated the strongly alkaline nature of both ash samples (Table 1), with Ash A ranging from 11.2 to 10.0 and Ash B from 10.6 to 9.4. A consistent decrease in pH with increasing dilution was observed, indicating that alkalinity is governed by the concentration of soluble basic constituents Noble et al (1996).

A noticeable difference between the two samples was evident, with Ash A consistently exhibiting higher pH values than Ash B. This difference can be attributed to the finer particle size of Ash A, which enhances dissolution and availability of alkaline minerals.

This high alkalinity is a key functional property, as it directly supports the use of maize ash as a liming material for acidic soils Komonweeraket et al (2015). At the same time, such elevated pH levels can contribute to microbial inhibition, linking the physicochemical properties of the ash with its biological activity Shithi et al (2024).

Table 1. pH values of maize cob ash at different dilution ratios

3.2 Functional Group Analysis (FTIR)

The FTIR spectra of maize cob ash samples (Ash A and Ash B) revealed the presence of multiple functional groups, indicating variations in chemical composition due to differences in preparation (Fig. 1). The detailed peak assignments are presented in Table 2 (Ash A) and Table 3 (Ash B).

Ash A exhibited characteristic peaks corresponding to hydroxyl (O–H), carbonyl (C=O), and hydrocarbon (C–H) functional groups. A strong band observed at 2992 cm^{-1} indicates O–H stretching associated with carboxylic acids, while peaks in the range of 2822 – 2889 cm^{-1} correspond to C–H stretching of aliphatic compounds. The presence of peaks at 1670 cm^{-1} (C=O stretching) and 1482 cm^{-1} (C=C stretching) suggests the existence of carbonyl and aromatic structures. These features indicate that Ash A contains reactive functional groups linked with mineral components, which may enhance its interaction with soil nutrients.

In contrast, Ash B showed relatively stronger peaks associated with aromatic and carbon-rich structures. Peaks at 1485 and 1584 cm^{-1} correspond to aromatic C=C stretching, indicating conjugated carbon systems. The band at 1705 cm^{-1} represents carbonyl groups, while peaks between 2821–2989 cm^{-1} indicate aliphatic C–H stretching. Additionally, the peak at 3777 cm^{-1} corresponds to hydroxyl groups.

The differences between the two samples are significant. Ash A is dominated by mineral-associated functional groups, whereas Ash B shows a higher carbonaceous character. This suggests that Ash A may exhibit better nutrient reactivity, while Ash B may contribute more to adsorption and soil structural properties Dlapa et al (2013).

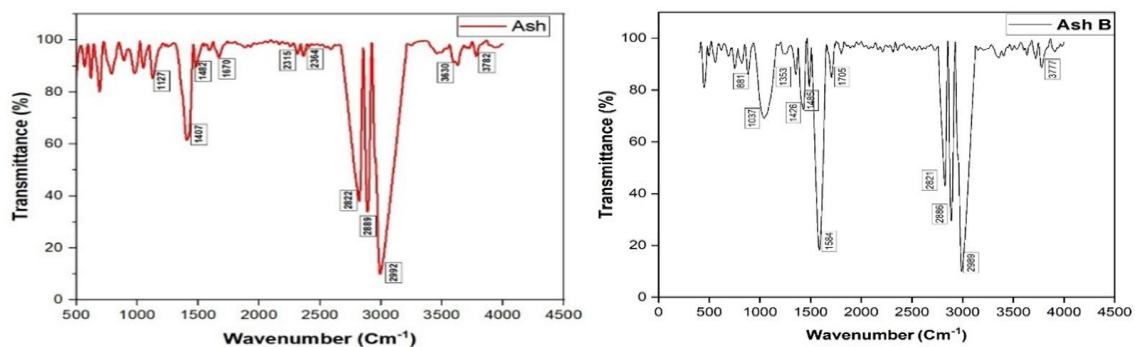


Figure 1. FTIR spectra of maize cob ash samples (Ash A and Ash B)

Table 2. FTIR peak assignments of maize cob ash (Ash A)

Table 3. FTIR peak assignments of maize cob ash (Ash B)

3.3 Elemental Composition (EDX)

The elemental composition of maize cob ash samples (Ash A and Ash B) determined by EDX analysis is presented in Table 4. A clear difference in composition was observed between the two samples.

Ash A exhibited a significantly higher concentration of potassium (13.0 wt%), along with the presence of calcium, magnesium, and phosphorus. This is a critical observation, as potassium is a major macronutrient involved in plant growth, enzyme activation, and stress resistance. Therefore, the higher potassium content indicates that Ash A has greater potential as a nutrient-rich fertilizer Arfiana et al (2021).

In contrast, Ash B showed a dominant carbon content (70.3 wt%), indicating a higher proportion of carbonaceous material. While this may reduce immediate nutrient availability, it can contribute to soil structure improvement and adsorption properties Ma et al (2016).

Overall, the results indicate a functional distinction between the samples:

Ash A → nutrient-dominant (fertilizer role)

Ash B → carbon-rich (soil conditioning role)

Table 4. Elemental composition of maize cob ash samples determined by EDX analysis

3.4 Surface Morphology (SEM)

The surface morphology of maize cob ash samples (Ash A and Ash B) was analysed using SEM, and the micrographs are presented in Fig. 2. Clear differences in surface structure were observed between the two samples.

Ash A exhibited a relatively fine and compact morphology with closely packed particles. This structure suggests limited porosity but enhanced uniformity, which may support faster dissolution and immediate availability of mineral components Thipse et al (2002).

In contrast, Ash B showed a highly porous and irregular structure with visible cavities and rough surfaces. This increased porosity indicates a larger surface area, which can enhance adsorption capacity and interaction with soil particles and microorganisms Ersoy et al (2010).

The difference in morphology can be attributed to the variation in preparation methods, particularly particle size and combustion characteristics. The porous structure of Ash B may improve nutrient retention and gradual release, whereas the finer structure of Ash A may facilitate rapid nutrient availability.

These observations are consistent with the EDX and FTIR results, where Ash A showed higher mineral content and Ash B exhibited a more carbon-rich composition. Thus, the SEM analysis further supports the functional distinction between the two samples:

Ash A → nutrient availability

Ash B → adsorption and soil conditioning

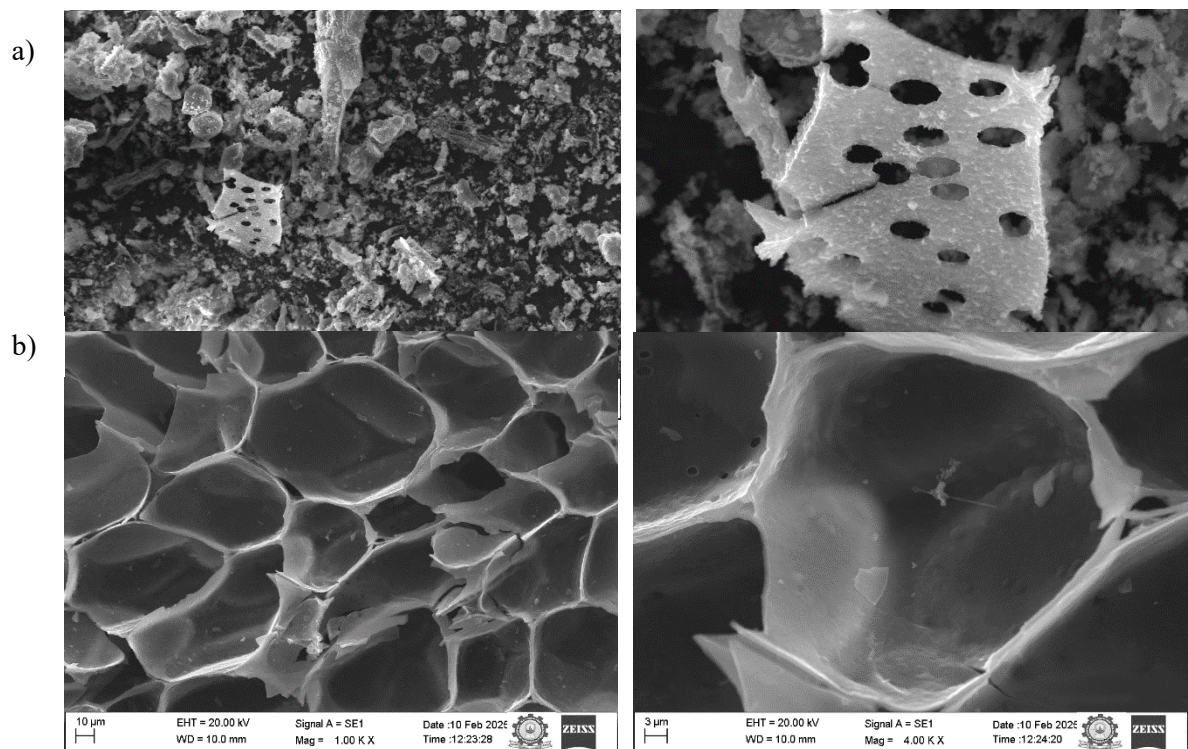


Figure 2. SEM images of maize cob ash showing surface morphology of (a) Ash A and (b) Ash B.

3.5 Mineralogical Characteristics (XRD)

The XRD patterns of maize cob ash samples (Ash A and Ash B) are presented in Fig. 3, confirming the presence of crystalline mineral phases formed during combustion.

Both samples exhibited diffraction peaks corresponding to mineral compounds typically associated with calcium- and potassium-based phases, which are essential for soil fertility. These crystalline phases

indicate that the ash contains stable inorganic constituents capable of contributing to long-term nutrient availability.

A noticeable difference between the samples can be inferred from their overall composition. Ash A, which showed higher mineral content in EDX analysis, is expected to contain a greater proportion of mineral-rich crystalline phases, supporting its role as a nutrient source. In contrast, Ash B, with higher carbon content, likely contains comparatively fewer mineral phases but may contribute to structural and adsorption properties Zhao et al (2017).

The presence of stable crystalline minerals is significant, as such phases are known to act as slow-release sources of nutrients, reducing rapid leaching and improving soil sustainability. Similar mineral compositions, including calcium carbonate and calcium oxide phases, have been reported in biomass-derived ash materials, contributing to their liming effect and fertilizer potential.

Overall, the XRD analysis supports the dual functional behaviour of maize cob ash, where mineral phases contribute to nutrient supply, while structural characteristics influence soil interaction.

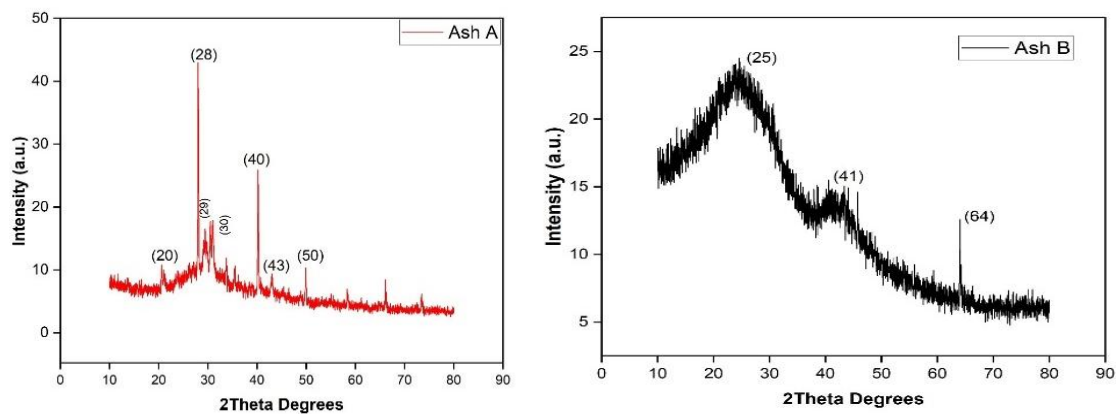


Figure 3. XRD patterns of maize cob ash samples

3.6 Antimicrobial Activity

The antimicrobial activity of maize cob ash samples (Ash A and Ash B) was evaluated against *Escherichia coli* (Gram-negative) and the results are presented in Fig. 4. Both samples exhibited noticeable inhibitory effects, confirming their antimicrobial potential.

A clear difference in activity was observed between the two samples. Ash A demonstrated relatively higher antimicrobial effectiveness, which can be attributed to its stronger alkaline nature and higher mineral content, particularly potassium and calcium. In contrast, Ash B showed comparatively lower inhibition, likely due to its higher carbon content and reduced availability of active mineral components Das et al (2022).

The antimicrobial behaviour can be primarily explained by the high alkaline pH of the ash, which creates unfavourable conditions for microbial survival. Additionally, the presence of mineral ions such as potassium and calcium may disrupt microbial cell membranes and interfere with metabolic processes Zhao et al (2020).

The surface morphology observed in SEM analysis further supports this behaviour. The fine and reactive surface of Ash A may enhance interaction with microbial cells, while the porous structure of Ash B may contribute to adsorption but with relatively lower direct antimicrobial efficiency.

These findings indicate that maize cob ash possesses dual functionality, acting not only as a nutrient-rich fertilizer but also as a natural antimicrobial agent capable of reducing soil-borne pathogens.

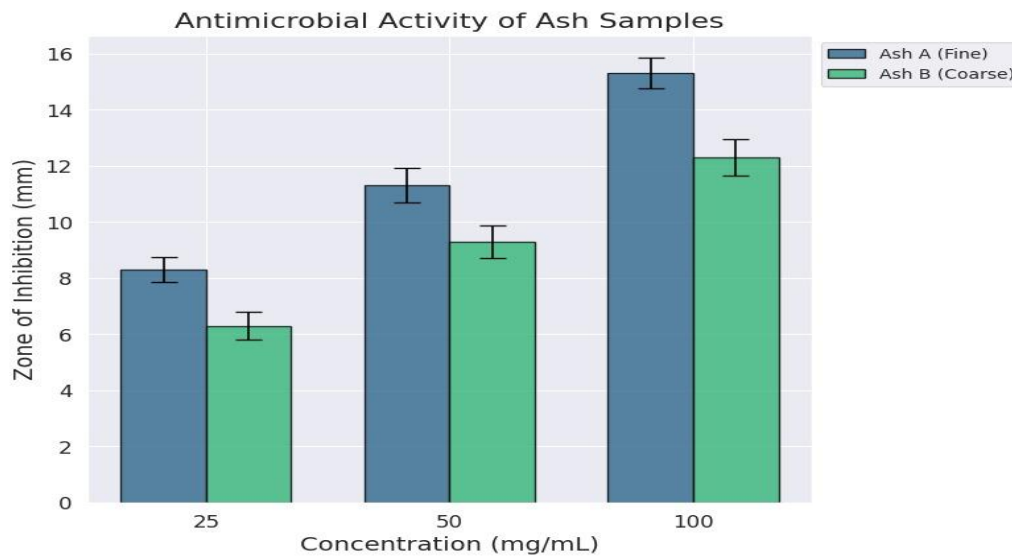


Figure 4. Antimicrobial activity of maize cob ash (Ash A and Ash B) against selected microorganisms, expressed as zone of inhibition (mm).

4. Conclusion:

The present study demonstrates that the functional performance of maize cob ash is strongly governed by its preparation conditions, which influence its physicochemical and structural properties. The higher alkalinity and mineral content observed in Ash A are directly reflected in its enhanced nutrient availability, particularly due to the presence of potassium, making it more suitable as a fertilizer material. In contrast, the porous morphology and higher carbon content of Ash B contribute to improved surface interaction and adsorption behaviour, indicating its role in soil conditioning.

These differences highlight a clear structure–composition–function relationship, where variations in processing lead to distinct application potential. The antimicrobial activity observed in both samples further supports this relationship, as the combined effect of alkaline pH, mineral composition, and surface characteristics contributes to microbial inhibition.

Overall, maize cob ash can be considered a multifunctional material, where its properties can be tuned based on preparation to achieve either nutrient supply or soil conditioning benefits. This study provides a practical approach for converting agricultural waste into value-added products, supporting sustainable agriculture and efficient resource utilization.

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Data availability statement

All data generated or analysed during this study are included in this published article.

Conflicts interest

Not applicable

5. Reference:

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Table 1. pH values of maize cob ash at different dilution ratios

Sample	Ratio (w/v)	Trial 1	Trial 2	Trial 3
Ash A	1:2.5	11.2	11.1	11.3
Ash A	1:5	10.6	10.5	10.7
Ash A	1:10	10.0	9.9	10.1
Ash B	1:2.5	10.6	10.5	10.7
Ash B	1:5	10.0	9.9	10.1

Table 2. FTIR peak assignments of maize cob ash (Ash A)

Wavenumber (cm ⁻¹)	Functional Group	Interpretation
1127	C–F stretching	Weak halide-related vibration
1407	S=O stretching	Presence of sulphate groups
1482	C=C stretching	Aromatic compounds
1670	C=O stretching	Carbonyl/amide groups
2315	C≡N stretching	Nitrile groups
2364	CO ₂ stretching	Atmospheric CO ₂
2822–2889	C–H stretching	Aliphatic hydrocarbons
2992	O–H stretching	Carboxylic acids
3630–3782	O–H / N–H stretching	Alcohols and amines
Wavenumber (cm ⁻¹)	Functional Group	Interpretation
1127	C–F stretching	Weak halide-related vibration

Table 3. FTIR peak assignments of maize cob ash (Ash B)

Wavenumber (cm ⁻¹)	Functional Group	Interpretation
881	C–H bending	Vinylidene compounds
1037–1353	C–F stretching	Halide-related compounds
1426	COO ⁻ stretching	Carboxylate salts
1485–1584	C=C stretching	Aromatic structures
1705	C=O stretching	Carbonyl compounds
2821–2989	C–H stretching	Aliphatic hydrocarbons
3777	O–H stretching	Hydroxyl groups
Wavenumber (cm ⁻¹)	Functional Group	Interpretation
881	C–H bending	Vinylidene compounds
1037–1353	C–F stretching	Halide-related compounds
1426	COO ⁻ stretching	Carboxylate salts

Table 4. Elemental composition of maize cob ash samples determined by EDX analysis

Element	Ash A (wt%)	Ash B (wt%)	Role in Soil/Fertilizer
C	31.3	70.3	Organic/carbon content
O	40.4	21.4	Oxide formation
Na	0.7	1.0	Minor nutrient
Mg	2.5	1.0	Essential plant nutrient
Al	0.5	0.4	Soil mineral component
Si	5.4	1.2	Soil structure improvement
P	1.4	0.4	Energy transfer in plants
S	0.5	0.2	Secondary nutrient
Cl	2.0	0.4	Micronutrient
K	13.0	3.3	Major plant nutrient (key finding)
Ca	1.7	0.5	Soil pH regulation