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Green Synthesis of Nanosilicates from Rice and Maize Husk Biomass as Sustainable Precursors-A Comparative Approach Towards Valorisation of Agro Waste

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Abstract:
Agricultural biowaste offers a sustainable and eco-friendly source for the synthesis of value-added nanomaterials. A Comparative investigation, carried out on green synthesis of nanosilicate, derived from rice husk and maize husk biomass reveals that both biomaterials are rich in silica content and are abundantly available as agricultural waste. The husks were processed through controlled thermal treatment followed by chemical extraction to obtain silica, which was further converted into nanosilicate form. The synthesized nanosilicates were characterized using standard analytical techniques such as FTIR, XRD, and particle size analysis to evaluate their structural, functional, and morphological properties. The results revealed noticeable differences in silica yield, particle size, and crystallinity between maize husk-derived and rice husk-derived Nanosilicates. Rice husk showed comparatively higher silica content and better crystallinity, whereas maize husk produced nanosilicate with finer particle size under optimized conditions. This comparative study highlights the potential of both maize and rice husk as low-cost, renewable sources for nanosilicate synthesis and emphasizes their possible applications in agriculture, environmental remediation, and sustainable material development.
Keywords; *Nanosilicate, Environmental remediation, Biowaste, Sustainable material development.*

I. Introduction:

Rapid industrial growth and intensive farming practices have led to the generation of a large amount of agricultural waste. Rice husk and maize husk form a major portion of this agro-residue, especially in developing countries. These wastes are usually burned in open fields or dumped in landfills, which causes air pollution, releases greenhouse gases, and results in the loss of materials that could otherwise be reused (Chandrasekhar et al., 2003) [(1)].

Rice husk is rich in silica, with a silica content typically between 15 and 25 wt%, making it a promising renewable source for silica-based materials (Kalapathy et al., 2000) **[(4)]**. In comparison, maize husk contains a lower amount of silica, but it is widely available and has not been explored much for nanomaterial production (Teja et al., 2023) **[(8)]; (**Rodríguez-Otero et al., 2023) **[(6)].** With increasing focus on green chemistry and sustainable material development, silica obtained from biomass is being considered a suitable alternative to conventional mineral-based sources (Singh & Satapathy et al., 2020) **[(7)].**

Nanosilicates have gained significant interest because of their applications in polymer nanocomposites, catalysis, adsorption processes, biomedical coatings, and environmental remediation. However, traditional synthesis methods generally involve high energy consumption and the use of harmful chemicals, which are not environmentally friendly (Hamidu, I. 2023) **[(3)].** Hence, the use of agricultural waste for nanosilicate synthesis offers a greener approach, helping to reduce environmental impact while also creating value from biomass residues (Yadav & Fulekar, 2019) **[(9)]**.

In this study, a comparative approach is used to investigate the green synthesis of nano-silicates from rice husk and maize husk. The work focuses on evaluating process efficiency, material properties, and the overall sustainability potential of both agro-waste sources.

The available literature shows that only a few environmentally friendly methods are commonly used to produce amorphous silica or Nanosilica from biomass sources.

One widely used approach is controlled calcination (Della et al., 2002) **[(2)],** where the dried biomass is heated to convert it into ash. In most studies, calcination is carried out in the temperature range of 500–700 °C to remove organic matter while preserving silica in its amorphous form. Careful control of temperature and heating time is important, as lower temperatures may leave unburnt carbon, whereas excessive heating can lead to the formation of crystalline silica, which is not desirable for many Nanosilica applications.

Another commonly adopted method is **alkaline extraction followed by acid precipitation [(**Liou, T. H., 2004) **[(5)]; (**Yalçin, N., & Sevinç, V. 2001) **[(10)]**]. In this process, the ash is treated with a dilute alkaline solution such as sodium hydroxide or potassium hydroxide to dissolve silica in the form of soluble silicates. The solution is then filtered and neutralized using a weak acid, resulting in the formation of a silica precipitate. This precipitate is aged, washed, and dried to obtain Nanosilica. This method is considered one of the simplest and most effective green routes, as it operates under mild conditions and produces amorphous silica with good surface properties.

More advanced techniques involve **sol–gel, templating, or hydrothermal processes**. After obtaining soluble silicate, sol–gel reactions—often assisted by surfactants or templates—are used to control particle size, shape, and porosity, leading to the formation of mesoporous or spherical Nanosilica. Hydrothermal treatment or low-temperature ageing can further modify the material structure. Although these methods allow better control over Nanosilica characteristics, they are comparatively more complex. In recent years, **mechanochemical and assisted methods** have also been explored. Techniques such as microwave heating, ultrasonic treatment, and the use of green solvents help reduce reaction time, lower energy consumption, and improve silica yield while minimizing waste generation. These approaches represent promising directions for making biomass-based silica synthesis even more sustainable.

II. Material and Methods:

2.1 Raw Material Collection and Pre-Treatment

Rice husk and maize husk were obtained from nearby agricultural processing facilities. The collected biomass was washed several times with distilled water to eliminate dust, soil particles, and other surface impurities. After cleaning, the husks were dried in an oven at 80 °C for 24 hours and then ground into a fine powder for further use.

2.2 Green Extraction of Silica

The dried biomass powders were heated under controlled conditions to convert them into ash. Calcination was performed at temperatures ranging from 500 to 700 °C to remove organic components while preventing excessive crystallization of silica. The obtained ash was then treated with a dilute alkaline solution, such as sodium hydroxide, under mild reaction conditions to extract soluble silicates. The solution was filtered and slowly neutralized using a weak acid, which led to the formation of silica as a precipitate. This precipitate was allowed to age, washed several times with deionized water, and dried at a low temperature to obtain nano-silicate powder. The entire process was designed to use minimal chemicals and generate less wastewater, in accordance with green chemistry principles.

2.3 Characterization Techniques

The synthesized Nanosilicates were characterized using:

- **X-ray diffraction (XRD)** to determine structural phase and crystallinity.
- **Fourier Transform Infrared Spectroscopy (FTIR)** to identify functional groups.
- **Scanning Electron Microscopy (SEM)** for morphology analysis.
- **Particle size analysis** to assess nanoscale distribution.
- X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and particle size analysis are essential characterization techniques used to evaluate the structural, chemical, and morphological properties of synthesized nanosilicates.
- XRD is primarily employed to determine the crystalline phase and degree of crystallinity of the material by analysing diffraction patterns produced when X-rays interact with atomic planes. It helps in identifying whether the extracted silica is amorphous or crystalline and confirms phase purity.
- FTIR spectroscopy is used to identify functional groups and chemical bonding within the material by measuring the absorption of infrared radiation at specific wavelengths. In silica-based materials, FTIR confirms the presence of Si–O–Si and Si–OH bonds and ensures the removal of organic impurities after calcination.
- SEM provides detailed images of the surface morphology by scanning the sample with a focused electron beam, enabling visualization of particle shape, surface texture, porosity, and agglomeration behaviour. This technique helps in understanding the structural uniformity and microstructural characteristics of the synthesized product.

III. Results and Discussion:

3.1 Yield and Extraction Efficiency

Rice husk exhibited a significantly higher silica yield compared to maize husk, consistent with its higher inherent silica content. The extraction efficiency from rice husk was found to be superior, producing a purer silica phase with fewer residual impurities. Maize husk, while yielding lower quantities, demonstrated acceptable silica recovery, highlighting its potential as a supplementary or alternative precursor, especially in regions with high maize cultivation.

3.2 Structural and Morphological Analysis

XRD patterns of both samples indicated predominantly amorphous silica, which is desirable for many industrial applications. FTIR spectra confirmed the presence of Si–O–Si and Si–OH bonds, validating successful Nanosilicate formation. SEM images revealed that rice husk-derived Nanosilicates had more uniform particle distribution, whereas maize husk-derived materials showed slightly agglomerated structures. Despite this, both samples fell within the nanoscale range, confirming the effectiveness of the green synthesis route.

3.3 Sustainability and Environmental Impact

From a sustainability perspective, the use of rice and maize husk aligns with waste-to-wealth strategies. Rice husk offers higher efficiency, while maize husk contributes to waste diversification and broader agro-waste utilization. The low-temperature processing and reduced chemical input significantly lower the carbon footprint compared to conventional silica synthesis.

Fig. 1. Maize husk–derived silicates prepared under similar green synthesis conditions, illustrating comparatively lower silica yield and the presence of minor impurities influenced by the initial biomass composition.

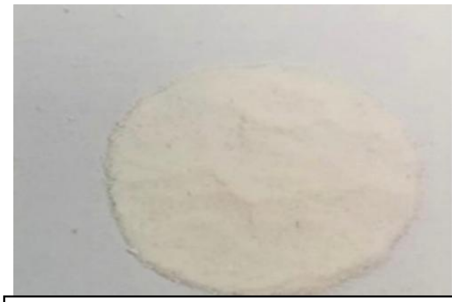

Fig. 2. Rice husk–derived silicates synthesized through controlled calcination and alkali extraction method, showing the formation of amorphous nano-silica with high purity due to the naturally high silica content of rice husk biomass.

Table 1: shows the Rice husk exhibited higher silica content and better extraction efficiency compared to maize husk, indicating its superior potential for nanosilicate production. In contrast, maize husk showed moderate silica content but wider availability and emerging valorisation potential. [1]

Table 1: Comparative Assessment

Parameter	Rice Husk	Maize Husk
Silica content	High	Moderate
Yield	Higher	Lower
Particle uniformity	Better	Moderate
Availability	Region-specific	Widely available
Valorisation potential	High	Emerging

Table 2: shows the proximate composition analysis revealed that rice husk contains higher ash content (20–25%), which contributes to greater silica recovery, whereas maize husk possesses lower ash content (5–10%) with comparatively higher fixed carbon composition. [2]

Table 2: Proximate Composition Comparison

Parameter	Rice Husk	Maize Husk
Moisture Content (%)	10–12	5–10
Volatile Matter (%)	69–72	69–74

Fixed Carbon (%)	**10–15**	**15–20**
Ash Content (%)	**20–25**	**5–10**

Table:3 shows the extracted silica from rice husk demonstrated higher purity (95–99%) and smaller average particle size (25–85 nm), while maize husk-derived silica showed slightly lower purity (87–95%) and comparatively larger particle dimensions. [3]

Table 3: Silica Characteristics after Extraction

Property	Rice Husk Silica	Maize Husk Silica
Silica Purity (%)	**95–99**	**87–95**
Crystallinity	**Mostly amorphous**	**Amorphous**
Average Particle Size (nm)	**25–85**	**46–120**
Specific Surface Area (m²/g)	**High**	**Moderate–High**

Table:4 shows Calcination studies indicated that rice husk required an optimal temperature range of 550–750 °C for effective silica extraction with low crystallization risk, whereas maize husk showed moderate crystallization tendency at elevated temperatures during thermal treatment. [4]

Table 4: Calcination Parameters

Parameter	Rice Husk	Maize Husk
Optimal Calcination Temp (°C)	**550–750**	**500–750**
Calcination Time (hours)	**2–4**	**3–5**
Ash Yield (%)	**20–25**	**5–10**
Risk of Crystallization	**Low**	**Moderate (at higher temp)**

The comparative study indicates that while rice husk remains the preferred precursor for Nanosilicate synthesis, maize husk represents a promising alternative for decentralized and region-specific applications.

IV. Application of Biomass-Derived Silicates:

The synthesized Nanosilicates can be effectively used in:

- Polymer and rubber nanocomposites
- Adsorbents for wastewater treatment
- Catalyst supports
- Agricultural and environmental remediation materials

Their renewable origin further enhances their suitability for sustainable industrial use [(Yadav & Fulekar, 2019) [9]; (Rodríguez-Otero et al., 2023) [6]].

V. Conclusion:

This study highlights a green and sustainable method for synthesizing Nanosilicates from rice husk and maize husk biomass. These agricultural wastes are abundantly available and often create environmental disposal issues. Converting them into value-added nanomaterials supports effective agro-waste valorisation. Rice husk proved to be more efficient due to its higher silica content and better extraction yield.

Maize husk, though lower in silica, also showed strong potential as an alternative precursor. The successful synthesis from both sources confirms the feasibility of eco-friendly production routes. This approach reduces dependence on conventional, energy-intensive silica manufacturing processes. The produced nano-silicates demonstrated desirable structural and morphological properties. The method aligns with green chemistry principles and promotes resource efficiency. Overall, biomass-derived nanosilicates offer a sustainable alternative supporting circular economy and future scalable material development.

VI. Future work:

Future research should primarily focus on optimizing the extraction process for silica from maize husk, as its lower silica content compared to rice husk requires careful control of calcination conditions, alkaline concentration, and extraction time to improve yield and purity. Detailed studies on reaction parameters such as temperature, pH, and solid-to-liquid ratio can help establish an efficient and reproducible process. In addition, surface modification of the synthesized nanosilicates deserves significant attention, since functionalization can enhance their compatibility and performance in applications such as polymer nanocomposites, adsorption, and catalysis. Tailoring surface chemistry through chemical or physical treatments may improve dispersion, stability, and reactivity of the nanoparticles. Another important area for future work is the assessment of environmental sustainability through life cycle analysis (LCA). LCA studies can provide quantitative insights into energy consumption, chemical usage, emissions, and overall environmental impact of the biomass-based synthesis routes in comparison to conventional methods. Furthermore, efforts should be directed toward scaling up the laboratory-scale processes to industrial levels. This includes evaluating process feasibility, cost effectiveness, reagent recovery, and waste management strategies. Addressing these aspects will support the practical implementation of agro-waste-derived nano-silicates as sustainable materials for large-scale industrial applications.

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