

## Extraction, Prototype Design for the Process Automation of Pure Amorphous Silica from Rice Milling Waste (Husk)

Abdulkarim Muhammad Hamza<sup>1\*</sup>, Ahmed Abdullahi Sule<sup>1</sup>, Umar Sa'ad Aliyu<sup>1</sup>, Atanyi Yusuf<sup>2</sup>, Sani Muhammad<sup>1</sup>, Muhammad Mustapha Adejo<sup>1</sup>, Adejo Andrew Ojonugwa<sup>3</sup> & Hassan Shaibatu Ibrahim<sup>4</sup>

<sup>1</sup>Department of Physics, Federal University of Lafia, Nigeria

<sup>2</sup>Department of Mathematics, Federal University of Lafia, Nigeria

<sup>3</sup>Department of Glass and Silicate Technology, Federal University of Lafia, Nigeria

<sup>4</sup>National Agency for Science and Engineering Infrastructure, Abuja, Nigeria

### Abstract

The global shift to sustainable materials has intensified research on agricultural waste materials like rice husk as they can produce high-purity silica. The process of silica extraction through traditional hot leaching methods requires excessive energy and creates environmental pollution. The research project aims to investigate how leaching processes affect material composition. The researchers assessed silica through multiple methods which included Scanning Electron microscopy-energy dispersive spectroscopy (SEM-EDS) X-ray fluorescence (XRF) X-ray Diffraction (XRD) and Thermogravimetric Analysis-Differential Thermal Analysis (TGA-DTA). The treated silica reached 97 % purity while maintaining a dense structure and minimal impurities and it demonstrated thermal stability that extended beyond 600 °C. The H<sub>2</sub>SO<sub>4</sub>-treated silica achieved 96 % purity but its thermal stability decreased to 680 °C while HNO<sub>3</sub>-treated silica with 95 % purity exhibited carbon content of 3.05 % and reduced thermal stability because of incomplete organic matter removal. XRD confirmed that all the samples exist as amorphous materials. The SEM-EDS analysis showed that HCL treatment resulted in the most effective impurity reduction because this sample showed the best compact morphology. The (TGA-DTA) analysis demonstrated weight-loss at various stages which occurred during moisture loss and organic matter decomposition while the material maintained stable thermal properties at high temperatures.

**Keywords:** Automation, prototype, purity, pozzolana, rice husk, silica

### Article History

*Submitted*

February 02, 2026

*Revised*

April 19, 2026

*First Published Online*

April 22, 2026

*\*Correspondences*

A. M. Hamza ✉

[elhamabdul2@yahoo.com](mailto:elhamabdul2@yahoo.com),

[abdulkarim.hamza@science.fulafia.edu.ng](mailto:abdulkarim.hamza@science.fulafia.edu.ng)

[doi.org/10.62050/ljsir2026.v4n1.811](https://doi.org/10.62050/ljsir2026.v4n1.811)

### Introduction

Silica occurs in amorphous to crystalline form in some sedimentary, igneous and metamorphic rocks [1]. The chief forms of silica are hydrous opal and crystalline quartz [2]. As a by-product of the combustion of rice husk to generate energy, rice husk ash which constitute of silica and carbon, besides some small amounts of other constituents. This ash is a potential source of amorphous reactive silica, which has a variety of applications in material science. Several treatments can be used to increase the purity of the silica obtained, or even produce 99.99 % pure silica. With such a large ash content and silica content in the ash it becomes economical important to extract silica from the ash, which will not only provide value addition to the market but also solve the problem of large amount of waste disposal. Rice husk ash can be used as pozzolana when calcinated below the crystallization temperature of 780 °C [3].

Silica is not a new commodity in the plastic market. Its usage as extenders and reinforcing fillers, as pozzolana material and as glass microspheres for specific engineering application are well known in the market

[4]. The growth of silica as a market is driving by its increasing applications in paints and coatings, rubber reinforcement (tire industry), green concrete, high performance concrete, ceramic glaze, bio-fertilizer, pesticides and insecticides [5]. With growing environmental concern, open burning has been outlawed in many major rice producing countries. With the over 90 % of Silica in rice husk, it can be an economically viable raw material for production of Silica based materials. Therefore, venturing in to this field will give rise to a readily available new material with low capital investment and high rates of return. This project is aimed at improving the purity to 99.99 % and large-scale production of silica from rice husk.

### Materials and Methods

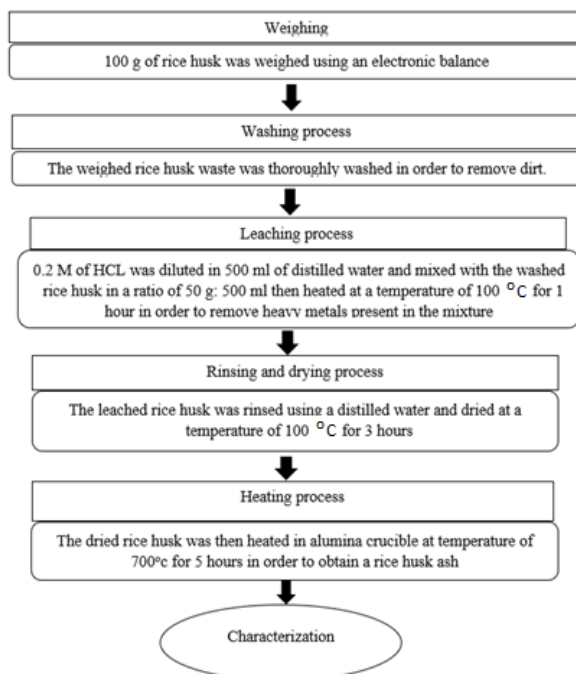
#### Experiments

##### Silica extraction

For this green silica extraction, raw rice husk of the FARO 44 variety was collected from Bagudu Local Government Area, Kebbi State, Nigeria, selected based on literature-supported evidence that geographical origin, rice genotype, and agronomic practices



influence the purity and structural characteristics of silica in plant biomass. A 100 g of the rice husk was weighed with an electronic balance and washed so as to remove dirt and other impurities; the rice husk was rinsed with deionized water in order to eliminate contaminated residual ions. The washed rice husk was then treated with 0.2 M of HCl acid solution at 100 °C for 1 h to so as to remove metallic oxides. After leaching, the rice husk was repeatedly washed with distill. The treated rice husk was then dried in a microwave and later transferred into a porcelain crucible and calcinated in a furnace at a temperature of 700 °C for 5 h. The resulting white silica powder was collected and stored for further characterization.



**Figure 1: The flow charts for the silicate extraction from rice husk**

### X-ray diffraction (XRD)

The phase nature of the obtained silica was characterized using a Rigaku Miniflex X-ray Diffractometer at the National Steel Raw Materials Exploration Agency, Kaduna, Nigeria. About 2 g of silica sample was weighed and loaded into a standard sample holder, followed by manual compaction with a glass slide to ensure a smooth and uniform surface. The sample holder was then injected into the XRD multi-sample chamber. The diffraction patterns were recorded automatically by the instrument, and the data were digitally stored. Analysis of data was carried out using STUDIO SMART LAB II software, incorporating the ICDD PDF-4 database for the identification of phases.

### Scanning electron microscopy and energy dispersive spectroscopy (SEM-EDS)

Elemental and morphological characterizations of the extracted silica were carried out using a Phenom ProXSEM-EDS system (PhenomWorld, Eindhoven, Netherlands) at the Materials Characterization Laboratory of the Nigerian Building and Road Research Institute (NBRRI), Abuja. The powders were mounted on aluminum stubs using double-sided carbon tape and sputter-coated with a 5 nm gold layer using a Quorum Q150R sputter coater in order to improve surface conductivity and minimize charging. Samples were primarily aligned and focused under the NaVCaM mode and later switched to SEM mode for high-resolution imaging. Images were obtained at a magnification of 4607× and electron beam energy of 127.4 eV. For elemental analysis, the energy dispersive spectroscopy (EDS) detector was used to quantify elemental composition.

### Thermogravimetric and differential thermal analysis (TGA-DTA)

The thermal behavior of the silica samples was assessed using a PerkinElmer TGA/DTA 4000 system at the Central Laboratory of Ahmadu Bello University (ABU), Zaria, Nigeria. Before the analysis started, each sample was weighed and placed inside an alumina crucible which was suspended with a hang-down wire (stirrup) in the analysis chamber. The system used high-purity nitrogen gas (99 %) which purged at a flow rate of 20 mL/min to establish an inert atmosphere inside. The sample underwent dynamic heating from 30 to 950 °C after it reached stabilization at a rate of 10 °C/min. The heating cycle recorded TGA weight changes and DTA thermal events which occurred during that time. The furnace reached room temperature after completion, and thermal profiles were sent for analysis to study moisture desorption and organic decomposition and structural transformations in the silica matrix.

### Prototype design for the extraction automation and large-scale production

After achieving the 99.9 silica purity in the extraction, a system will be designed for the automation of the extraction process and large-scale production of amorphous silica at commercial quantity. The plant design will contain the following chambers; The Reactor Chamber: at this chamber, the rice husk from the milling factory will be washed and a series of leaching process will take place. The dryer: the drying chamber is where the leached and rinsed husk will be dried. The Incinerator: This is the chamber where the dried leached husk will be burnt to ashes. The automation process is shown in Fig. 2.



**Figure 2: Process of automation in large scale silica production**



**Figure 3: Extracted rice husk SiO<sub>2</sub>**

## Results and Discussion

### Extracted silica

The green extraction technique adopted in this study effectively synthesized high-purity silica from *Faro 44* rice husk, sourced from Bagudu Local Government Area, Kebbi State, Nigeria. As illustrated in Fig. 3, the process yielded a fine, white powdered silica with a distinct granular texture, with a yield of 20 wt% relative to the weight of the raw husk. The yield obtained is similar to what Chukwunonso [6] found in a study on similar lines-thus emphasizing the method's viability when scaled.

The figure depicted the extracted silica as a fine, white, granulated powdered material which demonstrated effective extraction of all non-silica materials including lignin and cellulose and metallic impurities according to extraction methods shown in Hossain *et al.* [7]. The absence of any remaining char or color change demonstrates that all organic materials including lignin and cellulose have been successfully removed [3]. The indicators of high material purity are necessary for advanced applications which need precise control over chemical composition and surface morphology in photovoltaic glass and high-performance ceramics and adsorbents and functional fillers [5]. The efficiency of the silica extraction process depends on multiple factors which are all interconnected with each other. The key variables include chemical agent concentration which determines treatment reactivity and the soaking duration which affects non-silica constituent dissolution and the solvent-to-raw-material ratio which determines extraction kinetics and resource optimization and the thermochemical conditions which include temperature and reaction time that control phase transitions and ash formation according to some researchers [6, 7]. The optimization of these parameters is essential because it enables both maximum silica recovery and the creation of materials with specific surface area and porosity and structural order required for their intended use. The extraction process in this study produced rice husk silica with both high yield and valuable properties

which demonstrates its effectiveness for commercial use in advanced material synthesis particularly for photovoltaic glass development according to Setiawan and Chiang [8].

### Compositional analysis

The extracted silica chemical composition was determined through X-ray fluorescence (XRF) oxide analysis which produced results shown in Table 1. The analysis confirms that the silica derived from *Faro 44* rice husk, sourced from Bagudu LGA, Kebbi State, is predominantly composed of silicon dioxide (SiO<sub>2</sub>), with a purity of 98.89 wt.%. with traces of minor oxides as impurities.

**Table1: XRF analysis of the extracted rice husk silica ash**

Oxides	% Concentration in Silica Powder
SiO <sub>2</sub>	98.89
V <sub>2</sub> O <sub>5</sub>	0.002
Cr <sub>2</sub> O <sub>3</sub>	0.007
MnO	0.033
Fe <sub>2</sub> O <sub>3</sub>	0.119
NiO	0.001
CuO	0.035
Nb <sub>2</sub> O <sub>5</sub>	0.001
P <sub>2</sub> O <sub>5</sub>	0.026
SO <sub>3</sub>	0.109
CaO	0.423
K <sub>2</sub> O	0.057
BaO	0.001
Al <sub>2</sub> O <sub>3</sub>	0.204
Ta <sub>2</sub> O <sub>5</sub>	0.001
TiO <sub>2</sub>	0.043
ZnO	0.005
Ag <sub>2</sub> O	0.001
Cl	0.04
ZrO <sub>2</sub>	0.001
PbO	0.001

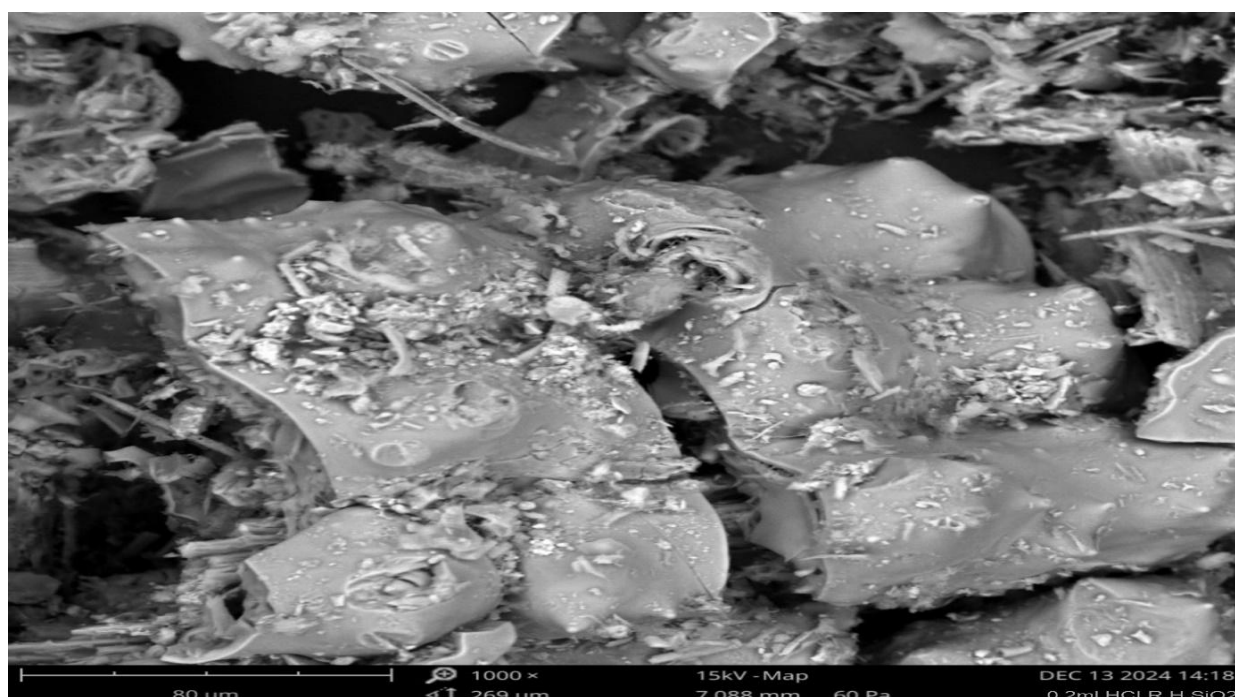


The extraction protocol which applied acid leaching and thermal treatment demonstrated its extraction efficiency through its high SiO<sub>2</sub> content. The present study results match previous research results which Table 2 shows because the current sample reached higher silica purity than some documented values while matching other documented values. This process achieves its effectiveness in removing non-siliceous impurities while it concentrates silica content of materials through these purity levels. The XRF results

showed that samples contained only small amounts of metallic oxides as impurities which indicated that all associated impurities from soil and fertilizer which the husk had absorbed remained in the product after the leaching process [9]. The research produced high-purity rice husk silica which possesses outstanding properties that make the material an excellent and eco-friendly resource for producing amorphous silica used in multiple industrial processes [10, 11].

**Table 2: Summary of the silica percentage purity from previous studies**

Author	Literature	SiO <sub>2</sub> Percentage purity
Sami <i>et al.</i> [12]	Evaluation of acid leaching process and calcination temperature on the silica extraction efficiency from the sustainable sources	96.83
Yury <i>et al.</i> [13]	Chemical and structural properties of silica obtained from rice husk and its potential as a catalytic support	99.93
Soran <i>et al.</i> [14]	Extraction of highly pure silica from rice husk as an agricultural by-product and its application in the production of magnetic mesoporous silica MCM-41	95.48
Noratiqah <i>et al.</i> [15]	Extraction of silica from rice husk via acid leaching treatment	82.8–98.6
Setyawan and Yuliani [16]	Synthesis of silica from rice husk by sol-gel method	95.34
Cahyani and Purwanto [17]	Sustainable industrial approaches: Utilizing organic acid for purity enhancement in green silica production	92.21
Azat <i>et al.</i> [18]	Extraction of high-purity silica from rice husk via hydrochloric acid leaching treatment.	99.7
Hamza [19]	Physical, optical and thermal properties of erbium-doped borotellurite silicate glass system incorporated with silver oxide	98.624
Aliyu [20]	Structural, elastic and optical properties of rice husk silicate borotellurite glass system doped with micro- and nanoparticles of erbium oxide	98.54
Geidam <i>et al.</i> [21]	Oxide ion polarizabilities and gamma radiation shielding features of TeO <sub>2</sub> -B <sub>2</sub> O <sub>3</sub> -SiO <sub>2</sub> glasses containing Bi <sub>2</sub> O <sub>3</sub> using Phy-X/PSD software	98.36
Ajeel <i>et al.</i> [22]	Extraction of high-purity amorphous silica from rice husk by chemical process	99.71



**Figure 4: SEM Micrograph of the extracted rice husk silica ash**

### Morphological analysis

The scanning electron microscopy analysis shows the morphological characteristics of acid-leached and thermally processed silica from Faro 44 rice husk (Fig. 4). The HCl-treated sample micrograph shows a solid mass that exhibits a crosshatched mesh pattern. The surface shows a hard and uneven texture because all metallic oxides and lignocellulosic materials and additional natural contaminants had been completely eliminated through the processing method [23–25].

The image demonstrates that the silica particles possess an irregular shape because they do not have any consistent dimensions or shapes. Most of the fragments show irregular shapes which differ from both spherical and platelet structures. The synthetic fumed silica (microsilica) material shows a distinct morphology which includes uniformly sized spherical particles. The silica maintains its original rice husk microstructure because its irregular shapes show the retained biogenic features of the original material which has non-crystalline properties [26]. The silica surface demonstrates distinct porosity through its display of a web-like or tracery texture. The particle surfaces display numerous open pores which mostly exist in the micrometer range but may also reach the nanometer dimension. The silica derived from rice husk ash exhibits extensive porosity which results in high specific surface area according to established scientific knowledge. Prior studies have described rice husk ash (RHA) particles as possessing a sponge-like or foam-like texture due to the abundance of surface pores [26]. The typical structure of biogenic silica consists of hierarchical porosity which develops when plants create tissues that contain silica as a nanoporous network with nanoscale voids and fine tunnels. The thermal treatment procedure maintains most of the native architecture, which results in ash production that contains micro- to mesoporous structures [27, 28]. The silica particles in the SEM analysis display a tendency to form clusters instead of remaining as separate particles. The particles combine together because surface silanol (Si–OH) groups enable their hydrogen bonding, which facilitates inter-particle interactions. The micrograph shows clumped structures which demonstrate that the particles have formed aggregates that exist in a loosely bonded state [29]. The particles maintain their porous structure which prevents sintering while showing visible inter-

particle spaces between their agglomerated structures. The particles maintain their high-surface-area morphology because they cluster together while keeping their unique characteristics which distinguish them from densified or sintered silica.

### Structural analysis

The structural characteristics of the acid-leached and thermally treated rice husk silica were analyzed using X-ray diffraction (XRD) as shown in Fig. 5. The diffractogram exhibits a broad diffuse hump which centers between  $20^\circ$  and  $25^\circ$   $2\theta$  and shows no sharp peaks throughout the complete scanning range from  $5^\circ$  to  $70^\circ$   $2\theta$ . The material contains amorphous silica which produces a diffuse hump that confirms the lack of long-range crystalline structure in the substance.

The analytical results show no evidence of peaks which would indicate the presence of crystalline silica forms including quartz and cristobalite because these minerals produce specific diffraction peaks at  $2\theta$  angles of approximately  $26.6^\circ$  and  $21.9^\circ$  respectively. The peak analysis shows that the obtained rice husk silica exists mainly as amorphous material. This observation matches previous research which identified the diffraction pattern of glassy and vitreous silica materials. The tempered soda-lime glass used in photovoltaic systems exhibits a broad hump that extends over the  $20^\circ$  to  $30^\circ$   $2\theta$  range [30]. The broad hump position at  $22^\circ$   $2\theta$  demonstrates the presence of an amorphous silica structure which contains disordered siloxane networks. The XRD analysis results show that biosilica extraction results in a material which contains short-range ordered  $[\text{SiO}_4]$  tetrahedral units that follow amorphous solid structure but lacks long-range order. The results of this study match the outcomes of previous research which employed the same processing methods. The study conducted by Dorairaj *et al.* [31] found that acid-leached rice husk silica calcined at  $700^\circ\text{C}$  showed a broad halo which centered at approximately  $22^\circ$   $2\theta$  proving that it contained a completely disordered silicate network without any crystalline structures. Islam *et al.* [32] demonstrated that biogenic amorphous silica obtained from plant biomass maintains broad XRD characteristics which define its composition.

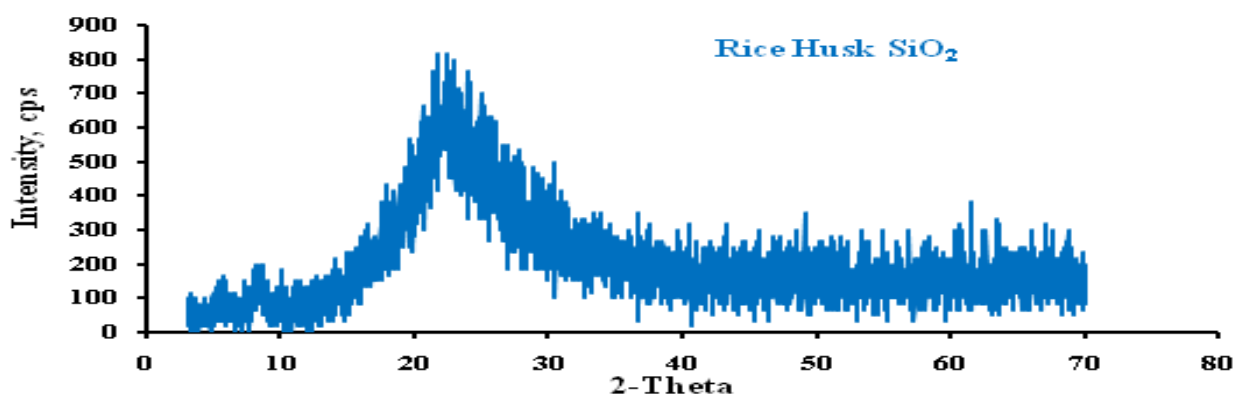


Figure 5: XRD spectra pattern of the extracted rice husk silica ash

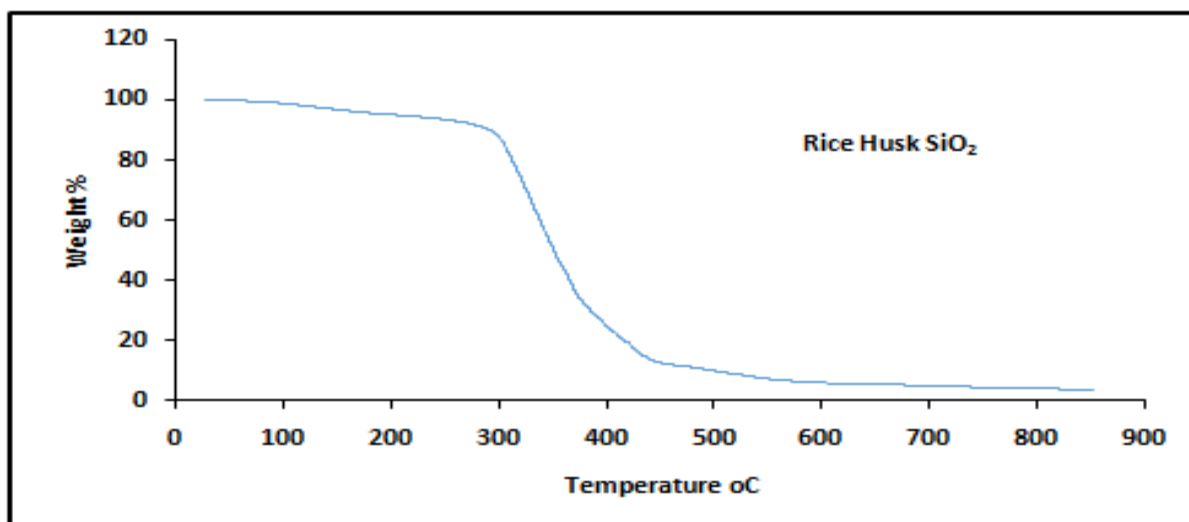


Figure 6: TGA pattern of the extracted rice husk silica ash

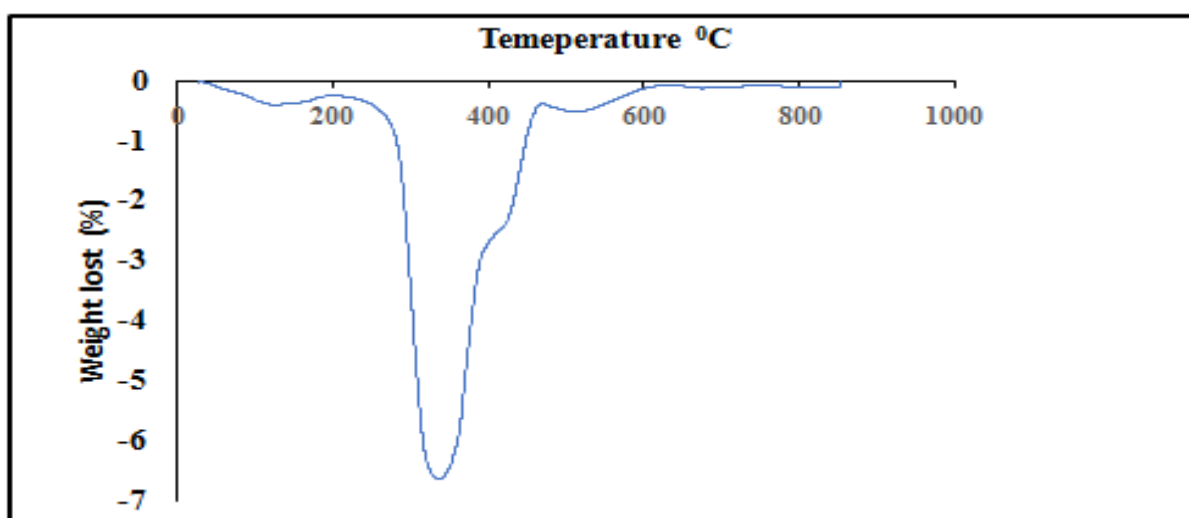


Figure 7: DTA pattern of the extracted rice husk silica ash

### Thermal analysis

The thermal stability and decomposition profile of the extracted rice husk silica were evaluated using thermogravimetric analysis (TGA) and differential thermal analysis (DTA), as presented in Figs 6 and 7, respectively. The TGA curve shows a biogenic silica weight loss pattern which occurs in multiple stages, while the DTA curve shows all the endothermic and exothermic reactions that took place during the experiment.

The first mass loss between 30 and 150 °C occurs because water that sticks to the surface of hydrophilic silica evaporates. The rice husk silica material undergoes a desorption process that produces weight loss between 1 and 3 %, which matches the findings of Trans *et al.* [33] and Jeong *et al.* [34] who studied the biosilica hygroscopic characteristics within this temperature range. The weight loss during this stage occurs at 200 to 400 °C because residual organic materials undergo thermal decomposition, which includes hemicellulose and cellulose that might stay

intact after the calcination process. The organic impurities were mostly eliminated through acid-leaching and thermal pretreatment, but this phase shows the burning process of the remaining small residue [24]. The research conducted by Guo *et al.* [11] showed that untreated rice husk silica exhibits significantly higher mass losses in this region when compared to samples that underwent acid treatment, which they demonstrated through their comparative TGA analysis. Through acid leaching, the process achieves successful reduction of thermally labile content while enhancing the thermal stability of silica.

The weight decrease between 450 and 600 °C occurs because lignin-derived materials undergo their final decomposition process. The silica maintains stability across this temperature range, which demonstrates that the purification method functions effectively. Tran *et al.* [33] discovered that thermal resistance improved through optimized leaching processes, while Popova *et al.* [35] found that treated rice husk samples lost all their organic content after reaching 600 °C. The mass

decreases imperceptibly from 600 °C until it reaches 800 °C. The dehydroxylation process occurs when silanol groups ( $\equiv\text{Si}-\text{OH}$ ) lose their hydroxyl groups and the silica network undergoes structural changes. Silanol groups transform into siloxane linkages ( $\equiv\text{Si}-\text{O}-\text{Si}\equiv$ ) through condensation reactions that happen when temperatures increase, and this process produces water as a byproduct. The transformation process starts at 170 °C which becomes faster from 400 °C until it finishes at 750 °C. The TGA curve lengthens when structural densification occurs, which causes weight loss because hydroxyl groups contribute only a small portion to the overall mass [34].

#### The differential thermal analysis (DTA)

The profile of rice husk silica was extracted and displayed in Figure 6 as it demonstrated a series of thermal transitions which led to both physical and chemical alterations in the material. The transitions which were observed matched the established thermochemical properties of biogenic silica while they confirmed the outcomes of TGA testing.

The first endothermic peak occurs between 100 and 200 °C because it results from desorption of physically adsorbed moisture together with loosely bound water molecules that exist on silica surfaces. The material demonstrates this response because biosilica functions as a hygroscopic substance that absorbs moisture from surrounding air. The literature demonstrates that rice husk-derived materials display identical thermal properties as they produce endothermic patterns which correspond to moisture release [13, 36].

The thermal degradation of residual organic matter proceeds through two distinct temperature ranges which begin with an endothermic peak that shows greater intensity between the temperatures of 300 and 400 °C. The process of acid leaching together with calcination, eliminates most organic substances from materials but a small amount of organic matter, can become trapped inside the porous structure of silica. The hemicellulose decomposition process takes place between 200 and 300 °C while cellulose decomposition begins at 300 °C and continues until 400 °C, during which glycosidic bonds break and volatile organic compounds are released. The degradation pattern demonstrates similarities to the results obtained by Zhou *et al.* through their thermal analysis of lignocellulosic biomass research which identified matching endothermic characteristics in DTA curves.

The DTA curve shows weak exothermic shifts in the temperature range between 600 and 800 °C. The silica network structure undergoes changes which result from the surface silanol groups ( $\equiv\text{Si}-\text{OH}$ ) turning into siloxane linkages ( $\equiv\text{Si}-\text{O}-\text{Si}\equiv$ ). The process of transforming amorphous silica into its densified and stabilized form requires this specific transformation which decreases hydroxyl content while increasing network connectivity. The exothermic nature of this reaction occurs because energy gets released when bonds form and the lattice structure strengthens [37]. High-surface-area amorphous silica materials have been

shown to experience these transformations which scientists use to improve their thermal stability [38]. The material shows thermal behavior that proves its transition to a stable silica matrix while the rice husk-derived silica shows suitability for high-temperature applications which include glass production ceramic reinforcement refractory composite materials and functional fillers for thermally stressed environments.

#### Conclusion

The research investigated the complete composition and structural characteristics and surface patterns and thermal behavior of silica derived from rice husk. The study demonstrated that leaching serves as an environmentally friendly method which operates with low energy requirements to produce industrial-grade amorphous silica of high purity. The Hydrochloric acid-treated silica demonstrated superior purity and thermal stability because it formed a dense structure which contained only trace impurities that testing with XRF and SEM-EDS and TGA and DTA methods confirmed. The  $\text{H}_2\text{SO}_4$ -treated silica, while comparable in purity, showed a slightly higher impurity content and less thermal stability at elevated temperatures. The study demonstrates that silica properties depend on three major factors which include the specific leaching conditions used and the choice of acid and the characteristics of the raw materials. Further research should focus on optimizing leaching parameters and expanding the scope to other agro-wastes. The findings contribute valuable insights to the development of green silica for industrial applications, in line with the global initiative for sustainable development.

**Conflict of interest:** The authors declare no conflicts of interest.

**Acknowledgement:** The authors appreciate the financial support for the work from the Tertiary Education Trust Fund (TETFund) for funding this research through the 2025 Institution Based Research grant at the Federal University of Lafia.

#### References

- [1] Park, J. Y., Gu, Y. M., Chun, J., Sang, B. I. & Lee, J. H. (2023). Pilot-scale continuous biogenic silica extraction from rice husk by one-pot alkali hydrothermal treatment and ball milling. *Chem. Biol. Technol. Agric.*, 10(1), 1–7. DOI: 10.1186/s40538-023-00479-4
- [2] Mezan S. O., Al Absi, S. M., Jabbar, A. H., Roslan, M. S. & Agam, M. A. (2021). Synthesis and characterization of enhanced silica nanoparticle ( $\text{SiO}_2$ ) prepared from rice husk ash immobilized of 3-(chloropropyl) triethoxysilane. *Mater. Today Proc.*, 42, 2464–2468. DOI: 10.1016/j.matpr.2020.12.564



- [3] Salim, Z. A. S. A., Hassan, A. & Ismail, H. (2019). The effect of high purity rice husk silica synthesised using solvent-thermal extraction method on the properties of natural rubber compounds. *BioResources*, 13(3), 6936–6951. DOI: 10.15376/biores.13.3.6936-6951
- [4] Onoja, T. F., Ahemen, D. A. & Iorfa, T. F. (2019). Synthesis and characterization of cellulose based nanofibres from rice husk. *J. Appl. Phys.*, 11(2), 80–87. DOI: 10.9790/4861-1102038087
- [5] Luthfiah, A., Deawati, Y., Lutfi Firdaus, M., Rahayu, I. & Eddy, D. R. (2021). Silica from natural sources: A review on the extraction and potential application as a supporting photocatalytic material for antibacterial activity. *Sci. Technol. Indones.*, 6(3), 144–155. DOI: 10.26554/sti.2021.6.3.144-155
- [6] Chukwunonso, J. A. J. (2023). Synthesis of pure desiccant using rice husk from Nigeria. *Int. J. Sci. Res.*, 12(7), 751–757. DOI: 10.21275/mr23709072023
- [7] Hossain, S. S., Mathur, L. & Roy, P. K. (2018). Rice husk/rice husk ash as an alternative source of silica in ceramics: A review. *J. Asian Ceram. Soc.*, 6(4), 299–313. DOI: 10.1080/21870764.2018.1539210
- [8] Setiawan, W. K. & Chiang, K. Y. (2021). Eco-friendly rice husk pre-treatment for preparing biogenic silica: Gluconic acid and citric acid comparative study. *Chemosphere*, 279, 130541. DOI: 10.1016/j.chemosphere.2021.130541
- [9] Steven, S., Restiawaty, E., Pasymi, P. & Bindar, Y. (2021). An appropriate acid leaching sequence in rice husk ash extraction to enhance the produced green silica quality for sustainable industrial silica gel purpose. *J. of the Taiwan Insti. of Chem. Engineers*, 122, 51–57. <https://doi.org/10.1016/j.jtice.2021.04.053>
- [10] Nzereogu, P. U., Omah, A. D., Ezema, F. I., Iwuoha, E. I. & Nwanya, A. C. (2023). Silica extraction from rice husk: Comprehensive review and applications. *Hybrid Adv.*, 4, 100111, DOI: 10.1016/j.hybadv.2023.100111
- [11] Guo, W., Li, G., Zheng, Y. & Li, K. (2021). Nano-silica extracted from rice husk and its application in acetic acid steam reforming. *RSC Adv.*, 11(55), 34915–34922, DOI: 10.1039/d1ra05255a
- [12] Ajeel, S. A., Sukkar, K. A. & Zedin, N. K. (2021). Evaluation of acid leaching process and calcination temperature on the silica extraction efficiency from the sustainable sources. In: *J. of Physics: Conference Series*, 1773(1). DOI: 10.1088/1742-6596/1773/1/012014
- [13] Peralta, Y. M., Molina, R. & Moreno, S. (2024). Chemical and structural properties of silica obtained from rice husk and its potential as a catalytic support. *J. Environ. Chem. Eng.*, 12(2). DOI: 10.1016/j.jece.2024.112370
- [14] Kamari, S. (2020). Extraction of highly pure silica from rice husk as an agricultural by-product and its application in the production of magnetic mesoporous silica MCM-41. *Biomass Conversion and Biorefinery*, 11(6), 3001-3009. <https://doi.org/10.1007/s13399-020-00637-w>
- [15] Noratqiah, S. M. Z., Shahrul, A. A. & Noorina, H. J. (2019). Extraction of silica from rice husk via acid leaching treatment. In: *The European Proceedings of Social & Behavioural Sciences*, pp. 176–183.
- [16] Setyawan, N., Hoerudin, & Yuliani, S. (2021). Synthesis of silica from rice husk by sol-gel method. In: *IOP Conference Series: Earth and Environmental Science*, 733(1), 012149. DOI: 10.1088/1755-1315/733/1/012149
- [17] Cahyani, A. & Purwanto, P. (2025). Sustainable industrial approaches: Utilizing organic acid for purity enhancement in green silica production. *Engr. Proceedings*, 84(1), 29. <https://doi.org/10.3390/engproc2025084029>
- [18] Azat, S., Sartova, Z., Bekseitova, K. & Askaruly, K. (2019). Extraction of high-purity silica from rice husk via hydrochloric acid leaching treatment. *Turkish J. Chem.*, 43(5), 1258–1269. DOI: 10.3906/kim-1903-53
- [19] Hamza, A. M. (2019). Physical, optical and thermal properties of erbium-doped borotellurite silicate glass system incorporated with silver oxide. A doctoral thesis: Universiti Putra Malaysia.
- [20] Aliyu, U. A. (2018). Structural, elastic and optical properties of rice husk silicate borotellurite glass system doped with micro and nanoparticles of erbium oxide. A doctoral thesis: Universiti Putra Malaysia.
- [21] Geidam, I. G., Matori, K. A., Halimah, M. K., Chan, K. T., Muhammad, F. D., Ishak, M. & Umar, S. A. (2022). Oxide ion polarizabilities and gamma radiation shielding features of TeO<sub>2</sub>-B<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> glasses containing Bi<sub>2</sub>O using Phy-X/PSD software. *Materials Today Communications*, 31, 103472. <https://doi.org/10.1016/j.mtcomm.2022.103472>
- [22] Abualnoun Ajeel, S., Sukkar, K. A. & Zedin, N. K. (2020). Extraction of high purity amorphous silica from rice husk by chemical process. In: *3rd International Conference on Sustainable Engineering Techniques (ICSET 2020)*, p. 881. DOI: 10.1088/1757-899X/881/1/012096
- [23] Zou, Y. & Yang, T. (2019). *Rice Husk, Rice Husk Ash and Their*. Elsevier Inc. DOI: 10.1016/B978-0-12-812828-2.00009-3
- [24] Azat, S., Sartova, Z., Bekseitova, K. & Askaruly, K. (2019). Extraction of high-purity silica from rice husk via hydrochloric acid leaching treatment. *Turkish J. of Chemistry*, 43(5), 1258-1269. DOI: 10.3906/kim-1903-53

- [25] Aliyu, A. S., Aliyu, U. S. A., Hamza, A. M., Nyakuma, B. B., Liman, M. S., Gaya, U. I., ... & Liman, M. M. (2025). Synthesis and characterisation of rice husk and palm fruit bunch silica: compositional, structural, and thermal analyses. *Biomass Conversion and Biorefinery*, 15(3), 3533-3544. DOI: 10.1007/s13399-024-05525-1
- [26] Yeasmin, M. N., Sultana, M., Siddika, A., Tabassum, S., Ullah, S. M. & Bashar, M. S. (2022). Structural, optical, and morphological characterization of silica nanoparticles prepared by sol-gel process. *J. Turkish Chem. Soc. Sect. A Chem.*, 9(4), 1323–1334. DOI: 10.18596/jotcsa.1071086.
- [27] Habte, G. A., Bullo, T. A. & Ahmed, Y. (2025). Statistical optimization characterizations and Eco- friendly synthesis of silica from sugarcane bagasse. *Sci. Rep.*, 15(1), 1–17. DOI: 10.1038/s41598-025-89366-6
- [28] Islam, M. T., Hossen, M. F., Asraf, M. A., Kudrat-E-Zahan, M. & Zakaria, C. M. (2024). Production and characterization of silica from rice husk: An updated review. *Asian J. Chem. Sci.*, 14(2), 83–96. DOI: 10.9734/ajocs/2024/v14i2296
- [29] Kaleli, M. J., Kamweru, P. K., Gichumbi, J. M. & Ndiritu, F. G. (2020). Characterization of rice husk ash prepared by open air burning and furnace calcination. *J. Chem. Eng. Mater. Sci.*, 11(2), 24–30. DOI: 10.5897/jcems2020.0348
- [30] Surowiak, A. & Wahman, M. (2024). Thermal–mechanical delamination for recovery of tempered glass from photovoltaic panels. *Energies*, 17(17), 4444. DOI: 10.3390/en17174444
- [31] Dorairaj, D., Govender, N., Zakaria, S. & Wickneswari, R. (2022). Green synthesis and characterization of UKMRC-8 rice husk-derived mesoporous silica nanoparticle for agricultural application. *Sci. Rep.*, 12(1), 1–11. DOI: 10.1038/s41598-022-24484-z.
- [32] Antiohos, S. K., Papadakis, V. G. & Tsimas, S. (2014). Rice husk ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. *Cement and Concrete Research*, 61, 20-27. <https://doi.org/10.1016/j.cemconres.2014.04.001>
- [33] Tran, T. D., Le, V. & Nguyen, N. T. (2024). Cellulose nanocrystals extracted from rice husk using the formic/peroxyformic acid process: Isolation and structural characterization. *RSC Advances*, 14(3), 2048-2060. DOI: 10.1039/d3ra06724f
- [34] Jeong, H. W., Park, K. T., Oh, S. M., Shim, S. E. & Qian, Y. (2025). Sustainable reinforcement of biosilica from rice husk and conventional silica. *Polymers (Basel)*, 17(3). DOI: 10.3390/polym17030406
- [35] Popova, M., Mitova, V., Dimitrov, M., Rosmini, C., Tsacheva, I., Shestakova, P., ... & Koseva, N. (2024). Mesoporous silica with an alveolar construction obtained by eco-friendly treatment of rice husks. *Molecules*, 29(15), 3540. DOI: 10.1016/j.jclepro.2018.05.028
- [36] Santana Costa, J. A. & Paranhos, C. M. (2018). Systematic evaluation of amorphous silica production from rice husk ashes. *J. Clean. Prod.*, 192, 688–697. DOI: 10.1016/j.jclepro.2018.05.028
- [37] Zhou, Y., Hu, Y., Tan, Z. & Zhou, T. (2024). Cellulose extraction from rice straw waste for biodegradable ethyl cellulose films preparation using green chemical technology. *J. Clean. Prod.*, 439, 140839. DOI: 10.1016/j.jclepro.2024.140839
- [38] Jagnade, P. & Panwar, N. L. (2024). Kinetic and thermogravimetric analysis of rice husk and its derived biochar. *Lett. Appl. NanoBioSci.*, 13, 86. <https://doi.org/10.33263/LIANBS132.086>

#### Citing this Article

Hamza, A. M., Sule, A. A., Aliyu, U. S., Yusuf, A., Muhammad, S., Adejo, M. M., Ojonugwa, A. A., & Ibrahim, H. S. (2026). Extraction, prototype design for the process automation of pure amorphous silica from rice milling waste (husk). *Lafia Journal of Scientific and Industrial Research*, 4(1), 189–197. <https://doi.org/10.62050/ljsir2026.v4n1.811>