

SiHARKX: Simplified Synthesis and UV-Blocking Characterization of Rice Husk Ash-Derived Silica Sol with Heavy Metal Analysis

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Abstract—This study aimed to synthesize silica sol from rice husk ash (RHA) using a simplified sol-gel method and evaluate its UV-blocking efficiency and heavy metal content for safe industrial and environmental applications. RHA was purified via acid leaching, extracted with sodium hydroxide, and converted into silica sol. The UV-A (315–400 nm) and UV-B (280–315 nm) transmittances of four samples were measured using UV-Visible spectrophotometry, while heavy metal contents (Pb, Cu, Zn, Cd) were analyzed via Atomic Absorption Spectrophotometry (AAS). Results showed low UV transmittance: 0.98–1.90% for UV-A and 0.074–0.275% for UV-B, well below China's GB/T 18830-2009 limits ($\leq 5\%$ UV-A, $\leq 2\%$ UV-B). Heavy metal concentrations were within international safety standards: Pb 9.40 ppm (≤ 10 ppm), Cu 0.34 ppm (≤ 4 ppm), Zn 5.12 ppm (≤ 1500 ppm), and Cd 0.07 ppm (≤ 50 ppm). These findings confirm that RHA-derived silica sol is a sustainable, eco-friendly, and safe material suitable for UV-protective coatings and other industrial applications.

Index Terms—Rice husk ash, silica sol, sol-gel synthesis, UV-blocking performance, heavy metal analysis.

1. Introduction

A. Background of the Study

Rice husk was one of the most ample agricultural wastes produced from rice millings. When this is burned, it made rice husk ash (RHA), which has over 85% or 99% of amorphous silica. Instead of being thrown away, this byproduct could be transformed into valuable materials for sustainable and cost-efficient applications. Using RHA as a raw material not only supported lessening waste but also promoted the development of ecofriendly and renewable silica sources, lining up with circular economy principles and sustainable material innovation (Rodriguez-Otero et al., 2024).

This test was conducted based on three key processes: acid leaching, alkaline extraction, and sol-gel. The first stage involved the purification of silica by removing undesired compounds such as iron, calcium, and magnesium using hydrochloric acid (HCl). The second process was alkaline

extraction using NaOH to remove the impurities of the silica and obtain sodium silicate. Hydrolysis and polycondensation were then carried out on the solution by using sol-gel to get silica sol (Hossain et al., 2020). Heavy metals in the 4 samples of the prepared silica sol were analysed using an Atomic Absorption Spectrophotometer (AAS), that is, lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd). This test proved that the silica sol contained low levels of dangerous chemicals, which proved that it could be used sustainably and safely (Meky et al., 2024).

The optical properties of the synthesized silica sol were also tested concerning the capability to block UV. Under ultraviolet light, the silica particles reacted with the incident light by the scattering and partial absorption process, thus decreasing the UV transmittance. Transmittance and absorbance of the material of varying wavelengths were measured on a UV-Visible (UV-Vis) spectrophotometer as a quantitative measure of the behavior (Kocs et al., 2018). In general, this paper introduced a user-friendly and sustainable solution to the transformation of rice husk ash into a high-quality silica compound, which has optical and structural properties.

B. Research Questions

This study distinctly focused on answering the following inquiries:

1. How effective is rice husk ash-derived silica sol in blocking UV-A and UV-B radiation compared to China's national standard GB/T 18830-2009 thresholds ($\leq 5\%$ UV-A and $\leq 2\%$ UV-B)?
2. How does the synthesis of rice husk ash-derived silica sol affect the presence of heavy metals such as Pb, Zn, Cu, and Cd in the final product?

C. Hypothesis

H₀₁: There is no significant difference in %UV-A and %UV-B transmittance among the different synthesis conditions of rice

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husk ash-derived silica sol.

Ho2: The synthesis of rice husk ash-derived silica sol has no significant effect on the presence of heavy metals (Pb, Zn, Cu, and Cd) in the final product. Any detected concentrations are within acceptable limits and do not vary due to the synthesis process.

D. Engineering Goals

This paper aimed to produce a simplified synthesis of silica sol based on rice husk ash as a green and multifunctional substance to be used in engineering. The study intended to generate an environmentally friendly and economical silica-based product that could be applied in ceramics, protective layers, and surface finishes to block harmful UV-A and UV-B sunlight by characterizing its UV-blocking properties and analyzing its heavy metal content.

It was demonstrated in previous research that rice husk ash was a promising source of pure silica that can be used in refractory coatings and ceramics (Abdullah, Mustapha, Sallih, Ahmad, Mustapha, and Dahliyanti, 2021), hydrophobic coatings of glass (Nehan, Akbar, Nur Karim, Fahriza, and Zainuri, 2023), and in the sustainable development of materials (Farhan and Ebrahim, 2021). The findings supported the use of rice husk ash-derived silica sol in the engineering sector for applications requiring durability and UV protection.

E. Objectives

This study aimed to synthesize a transparent UV-blocking silica sol from rice husk ash (RHA) using a simplified sol-gel method under the project title SiHARKX: Simplified Synthesis and UV-Blocking Characterization of Rice Husk Ash-Derived Silica Sol with Heavy Metal Analysis.

Specifically, the study sought to:

1. Investigate the optical transmittance of the produced silica sol.
2. Analyze the heavy metal content to assess safety and quality.
3. Demonstrate the suitability of RHA-derived silica sol as a UV-protective coating.
4. Promote waste valorization, environmental conservation, and resource efficiency while supporting cost-effective, eco-friendly coatings for tropical applications.

F. Significance of the Study

This study aimed to produce a simplified synthesis process of silica sol using rice husk ash, with the goal of creating an eco-friendly, cost-effective, and UV-protecting material for various engineering processes. By describing the UV-blocking characteristics and evaluating the heavy metal content, this research contributes to sustainable material innovation and waste valorization, transforming agricultural by-products into engineered high-value products.

- Coating Ceramics and Coating Industries: Silica produced from rice husk ash enhanced the UV and heat-resistant properties of ceramics and coatings, improving surface durability and lifespan while reducing degradation due to sunlight exposure (Ali et

al., 2017).

- Building and Architecture: Applied to glass coatings and sealants, RHA-derived silica sol improved surface integrity and UV protection, promoting sustainability, reducing maintenance costs, and enhancing energy efficiency in modern constructions (Salas Montoya et al., 2023).
- Environmental Sustainability: Transforming rice husk waste into silica sol supports the circular economy, reduces waste, and promotes green technologies in line with sustainable development (Mustapha et al., 2024).
- Manufacturing and Industrial Applications: The simplified synthesis method allows scalable and cost-effective production, providing industries with a sustainable alternative to petroleum-based products, applicable in protective films, ceramics, and UV-blocking coatings (Bhat et al., 2024).
- Rice Husk Ash (RHA): Predominantly amorphous silica (up to 90% purity) obtained from burning rice husks at 500–700 °C, making it a cheap and environmentally friendly material. Nanopores in RHA promote UV scattering, particularly UVB, without affecting transparency (Thennarasu et al., 2021; Jaglarz et al., 2020).
- Sodium Silicate: Dissolving amorphous silica in NaOH produces sodium silicate, which upon neutralization forms silica sol or gel. This process is highly efficient, low-cost, and renewable, making it a sustainable precursor for UV-protective coatings (Handayani et al., 2022; Moraes et al., 2023).
- Silica Sol: Amorphous SiO₂ nanoparticles (10–100 nm) form a stable colloidal suspension capable of blocking UV radiation while allowing visible light transmission. This ensures transparency, thermal stability, and chemical resistance for energy-efficient applications (Le et al., 2023; Alhadhrami et al., 2022; Saha et al., 2024).
- Ultraviolet (UV) Rays: Two types of ultraviolet radiation from the sun affect everyday life. Most of the radiation that reaches the Earth is UV-A (315–400 nm), which penetrates windows, fades furniture, and damages skin over time. UV-B (280–315 nm) is partially blocked by the atmosphere but can still cause sunburns and degrade materials. Prolonged UV exposure breaks down polymers, coatings, and wood through photochemical reactions, weakening molecular bonds, causing discoloration, brittleness, and cracking. UV radiation is also considered a human carcinogen, damaging DNA and causing skin cancer, cataracts, and photoaging (Andrady et al., 2023; Huang et al., 2024; Youseif and Haddad, 2013; World Health Organization, 2024).
- Heavy Metals: Rice husks can contain heavy metals absorbed from soil and water, such as lead (Pb), mercury (Hg), zinc (Zn), copper (Cu), and cadmium

(Cd). These metals can come from farming practices, irrigation, or environmental contamination. The sol-gel synthesis method reduces the heavy metal content in the final silica sol, ensuring environmental safety and suitability for delicate industrial applications, including UV-protective coatings (Zakaria *et al.*, 2024; Yefremova, 2023; Gargiulo, 2024; Mathew, 2016).

G. Theoretical Framework

The theoretical basis of this study is grounded in the principles of the circular economy and green chemistry, focusing on turning waste into resources and producing environmentally safe products (Gutierrez *et al.*, 2023). Rice Husk Ash (RHA) was chosen as a model of agricultural waste and a sustainable silica source. Extracting silica from RHA and synthesizing silica-based materials through the sol-gel process represents a stepwise valorization approach. RHA was particularly suitable due to its high amorphous silica content, which was extracted to produce sodium silicate. This solution then served as the precursor for silica sol through the sol-gel method conducted under controlled pH conditions (Aprilia *et al.*, 2023). This process demonstrates a sustainable way to convert low-value agricultural waste into high-value functional material.

Characterization of the silica sol involved UV-Visible Spectrophotometric Analysis to determine its UV-blocking capacity. Studies have shown that silica nanoparticles derived from RHA can provide up to 97 percent UVA/UVB protection when applied as a coating (King Fahd University of Petroleum & Minerals, 2024). At the same time, heavy metal content was measured using Atomic Absorption Spectrophotometry (AAS) to quantify impurities such as iron, aluminum, and calcium oxides. This step ensures that the synthesized silica sol is both safe and environmentally suitable for use.

2. Methodology

A. Procedures

The experiment involved six systematic phases to produce and characterize transparent UV-blocking silica sols derived from rice husk ash (RHA). Rice husks were obtained from Alben Camaganacan Rice Mills in Tagum City and processed using sol-gel and bio-derived silica techniques under qualified supervision. All procedures adhered to ISEF safety guidelines and institutional rules, with assistance from local agricultural professionals.

1. Phase 1: Preparation of Rice Husk

a. Collection and Cleaning: Five hundred grams of rice husks were collected and washed with distilled water to remove soil, dust, and other debris. The washed samples were dried at ambient temperature for 24 hours to eliminate moisture.

b. Grinding and Storage: The dried husks were mechanically ground in a laboratory grinder to obtain fine, uniform particles suitable for combustion. The ground husks were labeled and stored in clean, airtight

containers to maintain sample integrity before ashing.

2. Phase 2: Combustion and Recovery of Rice Husk Ash

The ground rice husks were burned in a muffle furnace at 600 °C for 2.5 hours. After cooling, a second combustion was performed under the same conditions for another 2.5 hours to remove all carbon and achieve homogeneous ashing. This yielded 96.09 grams of RHA, of which 75 grams were separated for use in synthesis and stored in a clean, airtight container.

3. Phase 3: Preparation of Acid and Base Solutions

a. Acid Leaching (Preparation): A 1 M HCl solution was prepared by diluting 83 mL of concentrated 12 M HCl with distilled water and adjusting the volume to 1 liter.

b. Alkaline Extraction (Preparation): A 2 M NaOH solution was prepared by dissolving 80 grams of NaOH pellets in distilled water, the topping the volume to 1 liter. Both solutions were stored in labeled reagent bottles for subsequent use.

4. Phase 4: Formation of Sodium Silicate Acid Leaching and Alkaline Extraction

Seventy-five grams of RHA were added to 500 mL of 1M of HCl and stirred at 380 rpm for 1 hour to remove metallic impurities. The mixture was filtered using six Whatman No.1 filter papers with stem funnels and filter flasks. The purified RHA residue was then added to 500 mL of 2 M NaOH and stirred at 80 °C until complete dissolution of silica, producing 400 mL of sodium silicate solution as a precursor for sol-gel synthesis.

5. Phase 5: Sol-Gel Formation and pH Optimization

The sodium silicate solution was adjusted to pH 9.7 by adding 450 mL of 1 M HCl to 400 mL of sodium silicate, then 100 mL of ethanol was introduced to initiate gelation. The pH was gradually lowered to 6.8 with 60 mL of 2 M HCl to improve gel formation. Finally, 150 mL of 2 M HCl and 18.75 mL ethanol were added to reach pH 4.8, enhancing sol uniformity and stability. The mixture was stirred and heated at 55 °C for 400 minutes, resulting in a clear, smooth, and stable silica sol.

6. Phase 6: Characterization and Analysis

a. UV-Visible Spectrophotometric Analysis: Transmittance of the four samples at UV-B (280–315 nm) and UV-A (315–400 nm) wavelengths was measured to evaluate UV-blocking efficiency. Data collection used a slit width of 1 nm, scan speed of 480 nm/min, and 1 nm data intervals, following one measurement cycle. Samples were assessed according to GB/T 18830-2009 standards, where UV-A $\leq 5\%$ and UV-B $\leq 2\%$ define effective UV protection.

b. Atomic Absorption Spectrophotometric (AAS) Analysis: The heavy metal content (Pb, Zn, Cu, Cd) of the silica sol samples was determined using a PerkinElmer PinAAcle 500 spectrophotometer with element-specific lamps, slit widths, currents, and measurement cycles optimized for accuracy. The analysis verified chemical purity and environmental

safety, confirming the suitability of the silica sol for industrial applications.

3. Results

This section presented the major findings of the study. Results were discussed in the context of research questions, engineering goals, and objectives. Minor variations in the results were expected due to differences in pH, heating, and particle formation during the sol-gel synthesis of silica from rice husk ash.

Table 1

UV-A transmittance of the rice husk ash-derived silica sol samples (315-400 nm)

LRN	Description	% Transmittance @ 315-400 nm
25CL-07402	Sample 1	0.98
25CL-07403	Sample 2	1.95
25CL-07404	Sample 3	1.90
25CL-07405	Sample 4	1.90

Table 1 indicated the percentage of the UV-A transmittance at 315-400nm of four samples of silica sol prepared of rice husk ash. The findings showed that the UV-A transmittance values of all the samples were very low that is 0.98% to 1.95% making it that more than 98%of the UV-A radiation is blocked by the material. Sample 1 exhibited the lowest transmittance (0.98) making it the highest UV-blocking efficiency, whereas Sample 2 exhibited the highest transmittance (1.95) and thus allowed a small percentage of UV-A light to pass through.

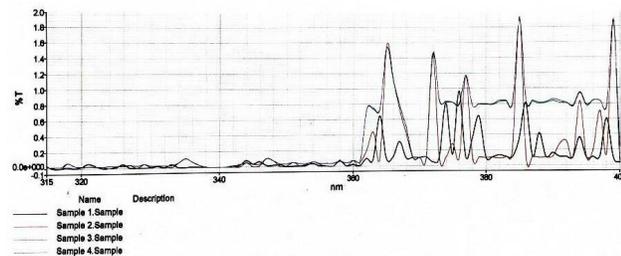


Fig. 1. UVA transmittance graph

The graph in Figure 1 illustrated the UV-A transmittance values for each sample, visually highlighting the differences in blocking efficiency.

Table 2

UVB transmittance of the rice husk ash-derived silica sol samples (280-315 nm)

LRN	Description	% Transmittance @ 280-315 nm
25CL-07402	Sample 1	0.074
25CL-07403	Sample 2	0.148
25CL-07404	Sample 3	0.162
25CL-07405	Sample 4	0.275

Table 2 presents the UV-B transmittance data for the four silica sol samples prepared from rice husk ash, measured at wavelengths of 280-315 nm. The transmittance values were extremely low, ranging from 0.074% to 0.275%, indicating that the samples successfully blocked over 99.7% of UV-B radiation. Among the samples, Sample 1 showed the lowest transmittance at 0.074%, demonstrating the highest UV-B blocking efficiency, while Sample 4 exhibited the highest

transmittance at 0.275%, allowing only a small fraction of UV-B light to pass through.

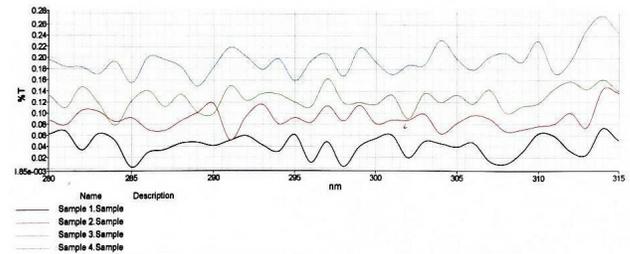


Fig. 2. UVB transmittance graph

The graph in Figure 2 showed the UV-B transmittance values for each sample, clearly depicting the differences in UV-B blocking efficiency.

Table 3

Concentration of heavy metals in rice husk ash-derived silica sol samples (ppm)

LRN	Description	ppm			
		Cu	Zn	Cd	Pb
25CL-07402	Sample 1	0.39	5.28	0.06	9.12
25CL-07403	Sample 2	0.38	5.24	0.07	10.00
25CL-07404	Sample 3	0.27	4.95	0.05	9.54
25CL-07405	Sample 4	0.32	5.02	0.09	8.95

Table 3 presents the concentrations of heavy metals—copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb)—in four silica sol samples derived from rice husk ash. The analysis was conducted using Atomic Absorption Spectroscopy (AAS). Among the detected metals, zinc and lead had the highest concentrations, with Zn ranging from 4.95 to 5.28 ppm and Pb ranging from 8.95 to 10.00 ppm. Copper concentrations were lower, ranging from 0.27 to 0.39 ppm, while cadmium showed the lowest levels, between 0.05 and 0.09 ppm. These results indicate noticeable variations in the heavy metal content among the analyzed samples.

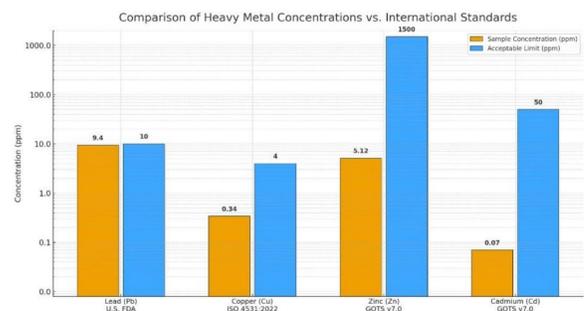


Fig. 3. Comparison of heavy metal concentration vs. international standards

Figure 14 illustrates a comparison between the concentrations of four heavy metals—Lead (Pb), Copper (Cu), Zinc (Zn), and Cadmium (Cd)—detected in the synthesized silica sol sample and their corresponding international safety limits. Among the metals analyzed, Lead (Pb) had the highest concentration at 9.4 ppm, followed by Zinc (Zn) at 5.12 ppm. Copper (Cu) was measured at 0.34 ppm, while Cadmium (Cd) had the lowest concentration at 0.07 ppm.

The established safety limits for these metals are 10 ppm for

Lead based on the U.S. FDA Guidance Document, 4 ppm for copper according to ISO 4531:2022, and 1500 ppm for Zinc and 50 ppm for Cadmium under the Global Organic Textile Standard (GOTS) Version 7.0 (2023).

4. Discussion

In this study, the UV-A and UV-B blocking abilities of rice husk ash-derived silica sol, together with its heavy metal content, were evaluated to determine its potential for practical applications.

A. UV-A Transmittance Test

The UV-A transmittance values of the silica sol samples derived from rice husk ash ranged from 0.98% to 1.90%, indicating that more than 98% of UV-A radiation was blocked by the material. According to the Chinese national ultraviolet protection standard GB/T 18830-2009, a material is considered effective in blocking ultraviolet radiation when its transmittance rate is $\leq 5\%$ for UV-A and $\leq 2\%$ for UV-B.

The measured values of the silica sol samples were significantly lower than the UV-A threshold specified by this standard, demonstrating strong UV-shielding performance. Because of this high UV-blocking capability, the material has potential applications in UV-protective coatings, window films, and protective clothing. These applications can help reduce the effects of UV radiation such as skin aging, DNA damage, and the long-term deterioration of furniture surfaces and fabrics caused by prolonged UV exposure.

B. UV-B Transmittance Test

The results of the UV-B transmittance test showed that the silica sol samples blocked nearly all UV-B radiation, with transmittance values ranging from 0.074% to 0.275%. Based on the GB/T 18830-2009 standard, a material is considered effective in blocking UV-B radiation when its transmittance is $\leq 2\%$.

Since the measured values were far below this limit, the synthesized silica sol demonstrated excellent UV-B shielding capability. UV-B radiation is more energetic than UV-A and is primarily responsible for sunburn and severe skin damage. Therefore, the extremely low UV-B transmittance further confirms the suitability of the silica sol for UV-filtering applications while maintaining transparency.

Based on the study of Onatayo *et al.*, approximately 50% to 75% of UV-A radiation passes through standard glazing without UV-blocking sol-gel coatings. In comparison, the results of this study showed that the synthesized silica sol blocked approximately 98% of UV-A radiation, demonstrating significantly improved protection. For UV-B radiation, although the referenced study reported that certain window films could reduce UV transmission by more than 99%, a specific numerical percentage was not provided. In the present study, the silica sol blocked 99.7% of UV-B radiation, further confirming its effectiveness as a UV-protective material.

C. Heavy Metal Analysis

Heavy metal analysis of the synthesized samples revealed

that all detected elements were within international safety limits, and the results were verified through Quality Assurance and Quality Control (QA/QC) procedures.

The concentration of lead (Pb) was measured at 9.40 ppm, which complies with the U.S. FDA Guidance on Industry for Lead in Cosmetic Lip Products and Externally Applied Cosmetics, where the allowable limit is ≤ 10 ppm. Copper (Cu) was detected at 0.34 ppm, well below the ISO 4531:2022 limit of ≤ 4.000 ppm for enameled articles in contact with food.

Similarly, zinc (Zn) and cadmium (Cd) were measured at 5.12 ppm and 0.07 ppm, respectively. These values are significantly lower than the Global Organic Textile Standard (GOTS) Version 7.0 (2023) limits of ≤ 1500 ppm for zinc and ≤ 50 ppm for cadmium.

The analytical procedures were validated through QA/QC protocols to ensure accuracy and reliability of the measurements. Overall, these results indicate that the synthesized silica sol meets international safety standards for heavy metal content, suggesting minimal environmental and health risks and confirming its suitability for potential industrial and environmental applications.

5. Conclusion

This study successfully synthesized silica sol from rice husk ash using a simple sol-gel process. The produced samples exhibited strong UV-blocking properties, with both UV-A and UV-B transmittance values significantly lower than the limits specified by the Chinese national standard GB/T 18830-2009, indicating that the material is an effective UV-protective agent.

Furthermore, heavy metal analysis showed that the concentrations of lead, copper, zinc, and cadmium were all within internationally accepted safety limits. With 85% recovery validated through QA/QC procedures, the results confirm that the synthesized silica sol is safe, effective, and environmentally compatible.

Therefore, rice husk ash-derived silica sol demonstrates strong potential for future applications as an eco-friendly coating base, UV-shielding coating, construction material additive, and sustainable surface treatment material.

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