

# Green Synthesis of Nano Silica from Agricultural Waste

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**Abstract:** The escalating volume of agricultural waste poses significant environmental and disposal challenges globally. Concurrently, the demand for nanomaterials, particularly nano silica, continues to grow across various industries due to its exceptional properties. Conventional production of nano silica is often energy-intensive and relies on hazardous chemicals, creating a need for more sustainable pathways. This paradigm shift is addressed by the green synthesis of nano silica from abundant and renewable agricultural wastes, such as rice husk, sugarcane bagasse, corn cob, and wheat straw. These residues are ideal, low-cost precursors due to their high silica content and wide availability. This green synthesis approach employs environmentally benign methods like chemical precipitation, sol-gel techniques, and thermal treatments to extract high-purity, amorphous silica nanoparticles. A key focus of these methods is to minimize ecological impact by reducing energy consumption, avoiding toxic reagents, and utilizing waste as a primary resource. The resulting biogenic nano silica is characterized by its high surface area, controlled particle size, and excellent reactivity, making it comparable or even superior to silica produced from traditional sources. The valorization of agricultural waste into nano silica offers profound economic and environmental advantages, contributing to a circular economy model where waste is transformed into a valuable commodity.

**Index Terms -.** Nanomaterial, hazardous, valorization

## I. INTRODUCTION

Nanotechnology is one of the fastest-growing fields in modern science and engineering, focusing on the manipulation of materials at the nanoscale, typically between 1 and 100 nanometers. At this scale, materials exhibit unique physical, chemical, and mechanical properties that differ significantly from their bulk forms. These differences mainly arise due to the high surface-to-volume ratio and quantum effects present at the nanoscale. Because of these unique characteristics, nanomaterials have attracted significant attention in areas such as electronics, medicine, environmental science, energy storage, and materials engineering.

Among various nanomaterials, silica nanoparticles have gained considerable importance because of their exceptional physicochemical properties. Nano silica possesses a high surface area, excellent thermal and chemical stability, good biocompatibility, and the ability to be easily functionalized. These properties make silica nanoparticles suitable for a wide range of applications including catalysis, drug delivery systems, environmental remediation, coatings, polymer composites, and construction materials. In addition, nano silica can improve the mechanical strength, durability, and chemical resistance of materials, making it highly valuable in modern technological applications.

Silica (SiO<sub>2</sub>) is one of the most abundant materials found in nature and occurs mainly in sand, quartz, and mineral deposits. Conventionally, silica nanoparticles are synthesized from these sources using methods such as sol-gel processing, chemical vapor deposition, flame synthesis, and precipitation techniques. Although these approaches produce high-quality nanoparticles, they often involve expensive chemical precursors, high energy consumption, complex

equipment, and strict reaction conditions. Moreover, these methods may generate hazardous by-products that can harm the environment. Therefore, researchers have increasingly focused on developing sustainable alternatives for nanomaterial synthesis.

Green synthesis has emerged as an environmentally friendly approach for producing nanomaterials using renewable resources, non-toxic reagents, and energy-efficient processes. This approach aims to minimize environmental impact while maintaining product quality and efficiency. One promising method involves the use of agricultural waste as a raw material for nano silica production.

Agricultural residues such as rice husk, wheat husk, sugarcane bagasse, corn cobs, and bamboo leaves contain significant amounts of silica and are produced in large quantities worldwide.

Rice husk is particularly attractive because it contains about 15–20% silica, and when burned under controlled conditions it produces rice husk ash containing up to 90% silica. Utilizing such waste materials not only provides an inexpensive silica source but also helps address waste disposal problems and environmental pollution caused by open burning.

In conclusion, the green synthesis of nano silica from agricultural waste offers a sustainable and cost-effective alternative to conventional methods. This approach supports waste management, reduces environmental pollution, and promotes resource efficiency. With continued research and technological improvements, it has strong potential for large-scale applications in industrial, environmental, and biomedical fields.

## II. LITERATURE REVIEW

The growing demand for sustainable materials has intensified research in nanotechnology, particularly in producing nanomaterials from renewable resources. Silica nanoparticles (SiNPs) have attracted attention due to their high surface area, thermal stability, chemical inertness, and biocompatibility, making them suitable for catalysis, drug delivery, environmental remediation, electronics, agriculture, and construction. However, conventional synthesis methods often require expensive chemicals, high energy, and can generate hazardous waste. Consequently, green synthesis using renewable resources such as agricultural waste has gained prominence.

Agricultural residues are rich in silica, making them promising raw materials for nanoparticle production. Rice husk, wheat husk, rice straw, corn cobs, sugarcane bagasse, and bamboo leaves contain significant silica content. Rice husk is especially valuable, containing 15–20% silica, and its ash can contain 80–90% silica after controlled combustion. Similarly, rice straw ash provides a high silica yield along with organic compounds like lignin and polysaccharides. Utilizing these residues not only reduces the cost of silica production but also addresses environmental pollution from open burning or disposal, supporting the principles of sustainable development and circular economy.

Green synthesis approaches aim to minimize toxic chemicals and energy consumption. Common methods include sol-gel processing, precipitation, hydrothermal synthesis, and biological synthesis using plant extracts or microorganisms. In sol-gel processing, silica is extracted from biomass ash using alkaline solutions to form sodium silicate, which is acidified to produce silica gel and then converted into nanoparticles through drying and calcination. Silica nanoparticles synthesized via this method from rice husk ash typically exhibit spherical morphology with particle sizes of 60–80 nm, confirmed using techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). Biological methods offer further sustainability, operating under mild conditions without harmful reagents.

Nano silica derived from agricultural waste has diverse applications. In environmental engineering, it serves as an effective adsorbent for heavy metals and dyes in wastewater. In agriculture, silica nanoparticles have demonstrated insecticidal activity, such as against *Callosobruchus maculatus*. In polymers and nanocomposites, they enhance mechanical strength, thermal stability, and barrier properties, useful in biodegradable films for food packaging. In biomedicine, their biocompatibility and porous structure enable drug delivery, imaging, and biosensing applications.

Challenges remain, including variability in biomass composition, optimizing synthesis for uniform particle size, and ensuring safety and scalability. Future research should focus on advanced green methods such as microwave-assisted or ultrasonic synthesis to improve efficiency. Overall, agricultural waste provides a cost-effective and sustainable source of silica nanoparticles, supporting eco-friendly nanomaterial production and efficient use of renewable resources.

## III. MATERIALS AND METHODS

Rice husk was used as the primary raw material for nano silica synthesis due to its high silica content and availability. The rice husk was collected from a local mill, thoroughly washed with distilled water to remove dust and impurities, and dried under sunlight followed by oven drying. Analytical grade chemicals, including sodium hydroxide (NaOH) and hydrochloric acid (HCl), were used for silica extraction and precipitation, while distilled water was used throughout the experiments.

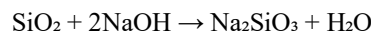
### i. Preparation of Rice Husk Ash

Cleaned and dried rice husk was subjected to controlled combustion in a muffle furnace at 500–700 °C for 4–6 hours to remove organic components such as cellulose, hemicellulose, and lignin, leaving silica-rich ash. The ash was cooled and ground to a uniform fine powder.

### ii. Silica Extraction

Silica was extracted using an alkaline method. Rice husk ash was mixed with NaOH solution and heated at 80–90 °C for one hour

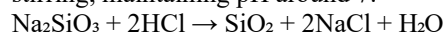
to form sodium silicate solution:



The mixture was filtered to remove insoluble impurities, and the clear filtrate served as the precursor for nanoparticle synthesis.

### iii. Synthesis of Nano Silica

Nano silica was synthesized via precipitation by titrating the sodium silicate solution with dilute HCl under continuous stirring, maintaining pH around 7:



Silica gel formed was aged to promote uniform particle formation. The gel was filtered, washed with distilled water to remove salts,

dried at ~100 °C for 12–24 hours, and gently ground.

### iv. Calcination

The dried silica powder was calcined at 500–600 °C for 2–3 hours to remove residual organics and enhance purity and stability.

### v. Characterization

## IV. RESULT AND DISCUSSION

The synthesized nanoparticles were characterized using X-ray diffraction (XRD) for structural analysis, scanning electron microscopy (SEM) for morphology and particle size, Fourier transform infrared spectroscopy (FTIR) for functional group identification (Si–O–Si), and particle size analysis to confirm nanoscale dimensions.

All experiments were conducted under controlled laboratory conditions, following green chemistry principles by using renewable agricultural waste and minimizing hazardous chemicals.

This study focused on the green synthesis of nano silica using rice husk as a renewable raw material. Rice husk was cleaned, dried, and subjected to controlled combustion at 500–700 °C to produce rice husk ash rich in silica. Silica was extracted via alkaline treatment with NaOH to form sodium silicate, followed by precipitation with HCl at neutral pH to obtain silica nanoparticles.

Characterization confirmed the successful synthesis of nano silica: SEM images showed spherical, uniform particles below 100 nm; XRD patterns indicated amorphous structure;

and FTIR spectra confirmed Si–O–Si bonds with surface hydroxyl groups. Purification by washing and calcination ensured high purity and improved stability.

The green synthesis approach offers several advantages: it utilizes low-cost agricultural waste, reduces environmental pollution, requires moderate temperatures, and minimizes hazardous chemicals. The resulting nano silica exhibits desirable structural and morphological properties suitable for

diverse applications, including construction (cement and concrete additives), environmental remediation (adsorption of pollutants), polymer and composite reinforcement, coatings, and biomedical applications.

This work demonstrates that rice husk is a sustainable, effective source for high-quality silica nanoparticles, highlighting the potential of green nanotechnology in waste valorization and sustainable material production.

**Table: Summary of Nano Silica Synthesis and Findings**

Step / Aspect	Details / Conditions	Observations / Outcome
Raw Material	Rice husk, distilled water	Washed and dried to remove impurities and moisture
Rice Husk Ash	Combustion at 500–700 °C, 4–6 h	Greyish-white ash, high silica content, organic matter removed
Silica Extraction	NaOH treatment at 80–90 °C	Formation of clear sodium silicate solution
Precipitation	Gradual addition of HCl, pH ~7	Formation of silica gel, aged for uniform particle formation
Washing & Drying	Distilled water wash, oven dry at ~100 °C	Removal of residual salts and moisture
Calcination	500–600 °C for 2–3 h	Removal of remaining organics, enhanced purity and stability
Morphology	SEM analysis	Spherical, smooth particles, uniform distribution, <100 nm
Structure	XRD analysis	Amorphous silica confirmed by broad diffraction peaks
Functional Groups	FTIR analysis	Si–O–Si bonds and surface hydroxyl groups present
Advantages	Green synthesis	Cost-effective, environmentally friendly, high purity, nanoscale particles
Potential Applications	Construction, environment, polymers, biomedical	Enhanced strength, adsorption, reinforcement, biocompatibility

## V. CONCLUSION

This study demonstrated the green synthesis of nano silica from rice husk, an abundant agricultural waste, providing a sustainable and eco-friendly raw material. Rice husk was converted into silica nanoparticles through controlled combustion, alkaline extraction, acid precipitation, purification, and calcination. Characterization using XRD, SEM, and FTIR confirmed amorphous, spherical nanoparticles with nanoscale size, high surface area, and good purity. The green synthesis approach is cost-effective, energy-efficient, and environmentally friendly. The resulting nano silica has potential applications in construction, environmental remediation, polymer composites, and biomedical fields, highlighting the value of converting agricultural waste into high-value nanomaterials.

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