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Latest Review On - Extraction Of Silica From Rice Husk Ash

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ABSTRACT

Rice husk and rice husk ash are recognized as abundant and sustainable silica sources due to their significant silica composition and accessibility. The present review synthesizes recent developments in extraction methodologies including acid leaching, alkali treatment, and pyrolysis, and considers the impact of processing conditions on the purity and structures of the silica obtained. Applications pertaining to cement composites, adsorption of heavy metals, and nanomaterials are considered as well. This review aims to provide a concise overview of current methods, challenges, and future possibilities for rice husk-based silica.

Keywords: *Rice husk ash, silica extraction, acid leaching, sustainable materials.*

INTRODUCTION

Rice husk ash (RHA) is a significant byproduct of the processes of rice milling and biomass burning, which are mostly used to generate energy. RHA consists of upwards of 90% silica, making it a plentiful and low-cost feedstock. The increasing demand for high-purity silica in a range of industries such as pharmaceuticals, construction, rubber, electronics, and nanotechnology has resulted in significant research into the various efficient and eco-friendly means to extract silica materials. Converting RHA into high-purity silica serves both the role of providing an economically viable feedstock while also addressing the public environmental issues associated with disposing RHA.

Numerous methods of extraction were developed for the extraction of silica from RHA, such as acid extraction, alkali dissolution, precipitation and thermal techniques. Acid extraction is the most commonly used method for removing metallic impurities, while alkali entails the dissolution of silica, which will then form sodium silicate that can be converted to pure silica. Both calcination and controlled thermal treatments influence properties of silica, such as its crystallinity and surface properties.

While there may be a positive aspect of using silica sourced from RHA, there are still factors to be considered, such as scale-up, the use of chemical reagents, and energy consumption. New approaches in the green extraction of silica (RHA) have recently been developed using bio-acids, microwave extraction, and bio-nanoparticles that may provide alternatives to traditional extraction methods.

This review aims to explore the different extraction methods of silica from RHA and compare efficiencies, challenges, and potential applications. New trends and recommendations for future research will also be discussed, regarding RHA-silica for sustainability and applications of a circular economy.

The leaching efficiency depends on factors such as acid concentration, leaching time, temperature, and the solid-to-liquid ratio.

Many authors have concluded that rice husks are an excellent source of high-grade amorphous silica. This silica has been shown to be a good material for the synthesis of very pure silicon, silicon nitride, silicon carbide and magnesium silicide. Utilization of rice husk as a resource of silica is based on removal of impurities with low effort and the high specific surface. In previous literature, they have shown that reasonably pure silica can be obtained from rice husk ash by a simple acid-leaching procedure,

They also have shown that, by mineral acid leaching, silica of >99% purity can be obtained by burning rice husks at 600°C under inert atmosphere. Further studies investigated the effects of incineration time and temperature on the ash structure. Specific surface areas reached ~260 m²/g (600°C). The present study strives to achieve completeness of combustion, high purity and high specific surface area at the same time in order to establish rice husk silica as a competitive product. The objective of the present work is also to make structural property studies (XRD, SEM, TEM and BET) of silica prepared from rice husk ash. [1]

SEPARATION PRINCIPLE

Extraction is a separation process where a component (solute) is transferred from one phase (feed) to another (solvent) based on differences in solubility, density, or chemical affinity. Preparation: The material to be extracted is prepared, which may involve crushing, grinding, or drying to increase surface area. Solvent Selection: A suitable solvent is chosen based on its ability to dissolve the desired component while leaving impurities behind. Extraction: The material is combined with the solvent, allowing the target component to dissolve. This can be done through various methods, including:

- Liquid-Liquid Extraction: Using two immiscible liquids.
- Solid-Liquid Extraction: Using a solid matrix and a liquid solvent.
- Supercritical Fluid Extraction: Using supercritical fluids (like CO₂) for better solubility.

There 4 major Extraction Processes namely:

1. Single-Stage Extraction
2. Multi-Stage Extraction
3. Continuous Extraction
4. Batch Extraction

Separation: The mixture is then separated, often through filtration, centrifugation, or decantation, to isolate the liquid containing the extracted component. Concentration: The solvent may be evaporated or removed to concentrate the extracted component. Purification: Further purification techniques (like distillation, and chromatography) may be applied to achieve the desired purity.

Characterization: Finally, the extracted substance is analyzed to confirm its identity and purity. This process is widely used in various fields, including chemistry, pharmaceuticals, and food science.

Key Factors for extraction are Equilibrium data (distribution coefficient), Mass transfer coefficients, Interfacial area, Solvent-to-feed ratio, Temperature, and Pressure.

The Chemical Engineering Principles used to extract components in extraction are: Material balance, Energy balance, Momentum balance, Kinetics and thermodynamics.

Equipment used in extraction process are:

1. Mixers-settlers
2. Column extractors
3. Centrifugal extractors
4. Membrane extractors

Extraction is a widely used separation principle/ technique so is its applications namely:

1. Hydrometallurgy
2. Biotechnology
3. Pharmaceutical industry
4. Food processing
5. Petrochemical industry

Understanding extraction in mass transfer operations is crucial for designing and optimizing separation processes in various industries.

LITERATURE REVIEW

Park et al. (2021) – *Two-Stage Continuous Process for the Extraction of Silica from Rice Husk*. Park et al. have proposed a two-stage continuous process to extract silica from rice husk with the first stage being attrition ball milling, and second stage being alkaline leaching. The milling process promotes surface area and disrupts the structure of the biomass, thus improving silica release in the leaching process phase. This two-phase process allows for high purity amorphous silica to be extracted using minimal energy and chemicals. The authors utilized systematic approaches in Agitation development to optimise milling times, sodium hydroxide concentration, and temperature, resulting in an economic, sustainable, and scalable process for the industrial silica. The extraction process was complete when the milling was imaged and characterized by SEM, purity and morphology are determined by XRD and FTIR respectively. The continuous process was demonstrated and designed to improve overall yield and operational continuity which allows for less labor intensity compared to a batch style approach. The authors emphasized how eco-friendly the process is, resolving rice husk which is otherwise disposed of as an agricultural waste product into a high value products in many applications such as in rubber, paints, cement, and electronic applications. This study is a significant contribution to green chemistry, sustainable material that embodies effective resources management, and valorization of waste into high-value products. It also illustrates potential opportunities to convert biomass into commercially entered industrial product, and is in line with initiatives across the globe towards circular economy and reducing dependency on non-renewable sources of silica. [2]

Ahmad & Ismail (2022) – *Extraction of Silica from Rice Husk via Acid Leaching Treatment*. Ahmad and Ismail investigated the utilization of an acid leaching approach for extracting silica from rice husk, with hydrochloric acid (HCl) being the primary leaching acid. The objective was to achieve a higher purity and yield of silica by optimizing the key operational parameters, such as acid concentration, leaching temperature, and reaction time. The acid leaching process achieved the removal of metallic and organics from rice husk ash, resulting in a fine white amorphous silica product with good purity. The extracted silica was characterized using FTIR and XRD techniques and together confirmed the removal of crystalline phases yielding amorphous silica. The acid leaching process presents a relatively low cost, environmentally sustainable approach to extract silica from agricultural waste. The authors also propose that the resulting silica has potential applications in various industries, including cement, glass, rubber fillers, and adsorbents. This work illustrates how low-value extracted waste products can effectively be processed into high-value industrial raw materials using relatively simple chemical treatment techniques. It also furthers the principles of circular economy with waste to wealth principles. The authors conclude that acid leaching provides an efficient and environmentally sustainable approach to extract silica from rice husk, supporting both sustainable waste management and blue-sky advancements in producing green materials. [3]

An, Guo & Zou (2021) – *Extraction of High-Purity Amorphous Silica Using Alkali Pretreatment and Acid Leaching*. An, Guo, and Zou proposed a combined technique of alkali pretreatment and acid leaching to extract high purity amorphous silica from rice husk. In the study they alkali treated the rice husk using sodium hydroxide to disintegrate the lignocellulosic structure and solubilize metal oxides in the material. As a result, the material was rendered better suited for further purification. Acid leaching, usually with HCl, is performed in a separate step to remove the remaining metal ions and impurities. The study showed silica produced was both amorphous and high purity verified by XRD and SEM. The merits of employing this two-step separation in regards to efficiency was shown to advance in a way that adheres to the relationship between chemical consumption, environmental features based performance and product quality specification. The silica produced exhibited high surface area, and implementation possibilities in various applications involved in electronics, catalysts or advanced composite materials. The authors indicated the environmental and economic benefits of this method especially with relation to large scale application and demonstrated how rice husk, a commonly discarded and low-cost agricultural waste, can be transformed into a value commodity as organized by optimized chemical treatment. This research presented an alternative towards sustainable materials science in developing a process to valorize waste through a green, efficient and scalable approach, while decreasing the environmental burden associated with traditional silica mining methods. [4]

Amin & Khan (2020) – *Use of Micro-Silica Extracted from Rice Husk in Sustainable Cement Mortar*. Amin and Khan have studied rice husk ash (RHA) obtained micro-silica to enhance the performance of the cement mortar. The study prepared silica from rice husk through controlled combustion, and machine milling was performed to produce very finely sized silica particles. Incorporation in cement mortar showed increased compressive strength, less water absorption, improved durability and was partly if not fully explained by the pozzolanic reaction of the micro-silica. The particles produced by the two methods of processing were finer in size than many commercially available silica fume types and would help refine the pore structure of the matrix and would allow for denser and stronger structures compared to normal mortar. The study compared the performance of micro-silica and commercial silica fume and came to the conclusion that rice husk derived-silica was a viable and economic alternative. The study performed SEM along with mechanical testing and the material demonstrated excellent compatibility with cement systems. The study advances sustainable construction by lowering cement along with use of an agricultural waste for a bulk product. It also presents a means to reduce the carbon footprint of cement production. All of this discovery is consistent with green building principles and circular economy that provide environmental benefits while providing an economic path. This study advances the impact of use of agricultural waste by valorizing rice husk due to its abundant supply and demonstrates a sustainable resource with all properties that indicate a high performance construction material. [5]

Bakdash et al. (2020) – *Rice Husk-Derived Aminated Silica for Heavy Metal Removal*. Bakdash et al. synthesized aminated silica from rice husk and explored its removal efficiency for toxic heavy metals like lead and cadmium from aqueous solutions. The process started with rice husk ash and included silica extraction and surface modification with amine groups to enhance the adsorbent's adsorptive capacity. Characterization indicated a high surface area and favorable surface charges that would enhance the adsorption of positively charged heavy metal ions. Overall, the study showed excellent removal efficiencies under various pH conditions, fast adsorption kinetics, and good reusability over multiple cycles to demonstrate the feasibility of using the aminated silica in real-world circumstances for wastewater treatment. The research suggested the importance of converting agricultural waste to high-value adsorbents for the remediation of polluted environments. Compared to conventional treatment methods, the approach is more sustainable and economically viable with fewer secondary pollutants. Additionally, in experiments where the aminated silica was used, the adsorbent was more effective than unmodified forms, demonstrating the benefits of having chemically modified surfaces. This study provides a new approach to water purification, while addressing waste management issues by exploiting the rice husk for environmental protection purposes, thus covering aspects of a circular economy and pollution control. [6]

Bakar, Yahya & Gan (2016) – *Production of High Purity Amorphous Silica from Rice Husk*. Bakar, Yahya, and Gan proposed a simple and efficient process to produce high-purity amorphous silica from rice husk using controlled thermal treatment and acid leaching. Their research focused on optimizing burning temperature to minimize carbon impurities and retain the amorphous characteristic of the silica. Once the rice husk was combusted, the ash underwent acid leaching (either HCl or HNO₃) to remove remaining metal contaminants. As a result of this process, the final product contained over 99% silica, and purity was confirmed by X-ray diffraction (XRD) and Fourier transform infrared (FTIR) analyses. Furthermore, the process was cost-effective and scalable for larger production and demonstrated the potential impact for industrial use (rubber, ceramics, paints, and electronics). They emphasized that accurate burning temperature must be maintained to prevent the crystallization of silica. Furthermore, they produced white, fine silica powder, which is ideal for high-end applications. This research furthers the applications of sustainable material science through utilizing an abundant agricultural waste product and converting it into a commercially valuable material. It also provided energy-efficient and environmentally friendly alternatives to traditional silica extraction and synthesis methods and adheres to the principles of green chemistry and strategies for environmental conservation. [7]

Bie et al. (2015) – *Effect of Burning Conditions and RHA Blending on Cement*. Bie and co-authors investigated the impacts of varying burning conditions of rice husk and the blending ratio of rice husk ash (RHA) on cement composites mechanical properties. The study indicated that combusting at selectively optimised conditions produces amorphous RHA of high pozzolanic activity which positively influences concrete compressive strength and durability. All RHA used as a partial cement replacement produced a lower porosity of concrete and reduced chloride penetration increasing the concrete's chemical attack resistance performance and exposing cement composites to longer durability periods. Significantly the influence of dry blended RHA was created by optimising both silica reactivity and ash fineness, low rates of fired RHA produced crystalline silica as a by-product which will lower the evolved reactivity and influence performance. The research validated the use of RHA is not only sustainable, but a suitable mineral additive to the construction industry by increasing sustainability through the use of RHA, specifically on reduction of cement demand, a reduction to CO₂ emissions, and allowing for on-site rice husk waste management solutions. The paper demonstrated through microstructural and performance evaluations that the characteristics of RHA are influential in creating high-performance concrete, while contributing to sustainable construction approaches and providing agricultural waste products with a new opportunity for the circular use cycle. [8]

Chen, Wang & Wei (2022) – *Mesoporous Silica from Rice Husk Ash for Heavy Metal Adsorption*. Chen and Wang and Wei synthesized mesoporous silica from rice husk ash without using any surfactant or organic templates. Ultimately, the researchers sought to produce a cost-effective and eco-friendly adsorbent material with the capability to remove heavy metals from water (specifically Pb²⁺ and Cd²⁺ ions). The prepared silica generally exhibited relatively high surface area and an appropriate pore structure (mesoporous), which are important metrics in relation to adsorption. Different pH conditions, adsorption times, and initial concentrations of metals added into the silica adsorption were analyzed. Rates of adsorption were rapid, while removal rates and regeneration were high as well. Structural characterization (BET, XRD, and SEM) confirmed the adsorption and removal efficiency associated with the unstructured and porous silica. The silica was produced by use of mild acid and thermal activation only and demonstrates sustainable attributes. The authors noted that the researchers were able to mitigate an agricultural waste (rice husk ash) to produce a low-impact, functional adsorbent material to treat metal from wastewater, yielding both waste valorization and an eco-friendly remediation material calls for the overall benefits the effects of the production process have on the environment. The developed mesoporous silica would be an even better outcome at an industrial scale to improve the global issue surrounding heavy metal pollution in wastewater. [9]

Ghosh & Ghosh (2021) – *Review on Nano-Silica from Rice Husk Ash in Cementitious Composites*. According to Ghosh and Ghosh, there have been several methods for extracting nano-silica from rice husk ash (RHA) with the intent to use them in cementitious composites. They reviewed chemical and mechanical means, which included acid leaching, sol gel synthesis, and ball milling. As noted in the review, the resulting nano-silica from RHA displayed excellent pozzolanic properties; thus leading to better-than-expected or intended strength, durability and microstructure improvement in concrete. The micromorphology was attributed to pore refining and impermeability. The review also assessed and explained how nanosilica improved the hydration process and the formation of Calcium-Silicate-Hydrate (C-S-H) gel, contributing to enhanced concrete early strength and later strength. Finally, RHA nano-silicas compatibility with supplementary cementitious materials (SCMs) and polymers was reviewed for incorporation as well. Environmental and financial advantages of producing concrete with RHA-Silica sources have included reduced rates of cement consumption, waste disposal, and saving potentially saving costs. Overall, the review article found that RHA-based nanosilica had significant potential for environmentally friendly construction materials. The authors emphasized the need to improve scales in production methods and support these materials in more modern scalable sustainable construction technologies. [10]

Gu et al. (2021) – *Two-Stage Continuous Process for Silica Extraction*. In the companion study to Park et al.(2021), Gu and co-authors highlight an attrition ball milling – alkaline leaching two-stage continuous silica extraction method as mentioned in the 2021 study, demonstrating the advantages of the method. The mechanical milling step increases the silica surface area exposure to the leaching reagent, sodium hydroxide. The wreckage of rice husk grain particles due to milling and the breakage of cell wall structures increase the surface area of the silica as indicated in the study. Leaching of the silica using an alkaline solution successfully dissolves the silica. The mechanochemical silica photochemical process was more efficient and consistent than the traditional batch processes. Researchers formally studied and optimized process parameters of the mechanochemical silica process which included optimizing the mechanical milling speed, NaOH concentration and temperature. Characterization was done via a variety of techniques and demonstrated high-quality silica with minimal impurities. The study described that scaled processes can be completed and demonstrated that the operations were environmentally prudent as they take agricultural waste and convert it into industry useful material and wastes as little chemicals and energy as possible. They mentioned applications for the silica could be in paints, cement, ceramics and high tech materials. The work supported resource efficiency and green economy initiatives and illustrated a low-value by-product of agricultural waste, rice husk, could become an economically and environmentally useful product through innovative and sustainable processing technologies. [11]

Dey & Ghosh (2019) – *Synthesis of Nano Silica from Rice Husk Ash: A Review*. Dey and Ghosh conducted an extensive review on the synthesis approaches and applications of nano-silica developed from rice husk ash (RHA). The paper reviewed the various methods of extraction that are available, including acid leaching, sol-gel methods and controlled combustion, indicating the type of silica synthesized, which was an amorphous form that could be produced with a high level of purity. The authors emphasized that nano-silica has a high specific surface area and high reactivity, allowing for various applications, including concrete, rubber, paint, pharmaceuticals. The review showed that the addition of nano-silica to concrete mixtures considerably improved compressive strength, setting time and durability of the concrete tested. The reviewers also examined the benefits of using agro-waste to produce nano-silica, thereby reducing the requirements of mined silica in industry, as well as the particular benefits of an agricultural waste product that had the intended effect. The authors identified some challenges to scaling up its production, along with the reproducibility of nano-silica synthesis and recommended that more research should focus on establishing standard operating procedures for the production of nano-silica. The authors concluded that with its lower cost compared to industrial silica, eco-sustainability and equal, and in some cases, superior performance, RHA-derived nano-silica was viable and a promising alternative to commercial silica. This review paper was an excellent overview of nano-silica extraction progression using rice husk and its application across diverse industry sectors. [12]

Dong, Li & Jin (2020) – *Preparation of Silica Aerogel from RHA Using Supercritical Ethanol Drying*. Dong, Li, and Jin made silica aerogels from rice husk ash (RHA) - treated Rice Husk Ash (RHA) via supercritical ethanol drying. The first step was acid leaching, followed by a sol-gel synthesis then aging, finished with supercritical ethanol drying. The resulting aerogels had high porosity, low density, and high surface area, making them suitable for thermal insulation, catalysis, and drug delivery. Through various characterization, the aerogels were confirmed to be amorphous and had a uniform pore distribution. The findings demonstrate that silica RHA is a useful highly-valued source for aerogels, replacing other traditional sources such as tetraethyl orthosilicate (TEOS). The use of supercritical ethanol was based upon lower toxicity constituents compared to CO₂ and to retain the gel structure without shrinkage. The authors emphasized the economic, environmental and social implications of converting agricultural waste into high-value functional materials. This method fits within the principles of green chemistry and waste valorization schemes. With some pursuit of costs and production scale, the present study provides a mechanistic platform towards highly performance materials from waste biomass that have benefits of environmental sustainability and contribution towards eco-based nanomaterials. [13]

Hossain, Mathur & Roy (2020) – *Extraction of Amorphous Silica from Rice Husk*. Hossain, Mathur and Roy studied the extraction of amorphous silica from rice husk biomass using the acid leaching and controlled burning approaches. The study focused on optimizing process parameters such as acid concentration, leaching time, and calcination temperature to extract silica with high purity and amorphous characteristics. The process removed metallic impurities (notably potassium and iron) known to detrimentally affect silica purity. The amorphous silica was characterized using FTIR, SEM and XRD techniques. The authors summarized the key features of the amorphous silica production under optimized process parameters including an emphasis on burning temperature since burning temperatures higher than 700 °C can produce crystalline silica. The authors claim the findings describe a sustainable and cost-effective method of producing silica, especially in countries where rice is extensively produced. The paper, to support their conclusions, references discussions regarding increasing agricultural waste and creating value-added industrial inputs. Hence, this paper contributes positively to an emerging field of research on the efficient use of agricultural waste and circular economies with consequential positive impacts. The paper also describes a low-cost, sustainable alternative to existing silica production processes including substantially lower carbon emissions, therefore, contributes to achieving UN sustainable development goals. [14]

Jafari & Mahjoub (2019) – *Silica Nanoparticles from RHA as Rubber Filler*. Jafari and Mahjoub produced silica nanoparticles from rice husk ash, and examined the successfulness of their unique silica nanoparticles of rice husk ash as reinforcing fillers in natural rubber composites. Silica was extracted from rice husk ash using an alkaline leaching process. The silica was then acid precipitated and dried before characterization was performed. The nanoparticles were characterized by TEM and FTIR to confirm the particles were amorphous silica and their small particle size. Their incorporation in rubber revealed that the silica nanoparticles improved mechanical properties, including tensile strength, elongation at break, and abrasion resistance. The researchers compared the silica extracted from RHA to silica from commercial silica sources, and RHA derived silica exhibited a comparable or sometimes superior performance compared with commercial silica sources for lower or equal cost. The authors note, the environmentally sustainable aspect of agro-waste utilization, and encourage rubber industry segment to consider large-scale uses. The research and findings will be relevant to the rubber industry, having shown good yields in processing and reproducibility. With this work being an example of sustainable material development, it also demonstrates advancement towards the circular economy model by enabling bio-mass waste to be diverted away from landfills and converted into high-performance industrial materials. [15]

Jang & Lee (2016) – *Microstructural Densification and CO₂ Uptake in RHA-Cement Blends*. Jang and Lee researched the effect of carbonation curing on microstructural densification and CO₂ uptake in cement blends containing rice husk ash (RHA). The research showed that carbonation curing improved compressive strength and reduced porosity. The silica content of RHA contributes to pozzolanic reactions for calcium carbonate formation, leading to densification of the matrix and better durability. The study concluded that RHA as an ingredient with carbonation curing has two-fold benefits: reducing cement use and sequestering CO₂. It also supports sustainability practices for the construction industry through improvement in

performance of material properties and mitigation of environmental impacts. This research applies to the development of innovative green cement technologies that utilize agricultural waste. [16]

Arivalan Muralli et al. (2025) – *Characterizations of Rice Husk-Based Silica Made from Acid Leaching Extraction Method*. This research examines the extraction of silica from rice husks with a simple acid leaching method. The rice husks underwent leaching with 0.1 M HCl at room temperature for various times from 6 to 24 hours. The study sought to rid the rice husk of its metallic impurities; thus, elevate the silica purity. The silica was characterized by XRD, EDX, and SEM, with the 24-hour leaching period producing adequate quality of amorphous silica, the morphology being smooth and purer than the other time durations listed in the study. The study identifies the method as inexpensive and energy efficient therefore scalable for industrial purposes. Further, it contributes to sustainable material development by obtaining products from agricultural waste. [17]

Yuan et al. (2024) – *Improving the Grindability of Rice Husk-Based Green Silica through Pyrolysis Process Optimization Employing the Taguchi Method and Response Surface Methodology*. This study introduces a new approach to increase both the grindability and purity of silica derived from rice husk ash (RHA). The authors utilized the Taguchi approach and response surface methodology (RSM) to determine optimal pyrolysis and torrefaction conditions to manipulate amorphous silica yield and particle size. 36 experiments were conducted (L36 orthogonal array) to identify major influences, as well as an R^2 statistical validation (R^2 values between 96%–99%). Overall, the authors conducted a useful study that provides an effective method for continually optimizing thermal treatment parameters for quality green silica extraction. The implications of this study go beyond process conditions as they offer economic sustainability and environmental sustainability in material use. [18]

Park et al. (2023) – *Pilot-Scale Continuous Biogenic Silica Extraction from Rice Husk by One-Pot Alkali Hydrothermal Treatment and Ball Milling*. This research illustrates a scalable continuous "one-pot" process for the easy extraction of silica from rice husk as it incorporates both ball milling with alkali hydrothermal treatment into a pilot-scale continuous flow system. The key feature is the ability to incorporate something that is traditionally associated with batch-wise extraction into a continuous flow system, tackling issues associated with poor bulk density of biomass and rice husk. The process yields highly pure amorphous silica, demonstrating that this silica can be used industrially to generate byproducts employed in industries such as cement and composite materials. This study has bridged technology that was previously identified as lab-based and on a small scale, and validates the scale-up for commercial applications to develop eco-friendly technology for biogenic silica recovery while supporting biorefineries and valorization of agricultural waste. Furthermore, it highlights cost efficiency and flexibility for different processing conditions. [19]

Salim et al. (2024) – *Characterisation of High Purity Rice Husk Silica Synthesised Using Solvent-Thermal Treatment with Different Concentration of Acid Leaching*. This study examines the feasibility of producing high-purity amorphous silica from rice husk using solvent-thermal treatment followed by acid leaching using different concentrations of hydrochloric acid (HCl). The goal was to provide an alternative method to release and remove the metallic impurities found in rice husk in order to obtain a better product. This study found that 1.0 M HCl had the best silica purity with 99.99% purity and BET surface area of 234.25 m²/g. All samples were amorphous after calcination at 700°C for four hours. The use of techniques such as XRD, FTIR, and SEM-EDX on the characterized material indicated the structure and the product was of high purity. The study suggests that the acid leaching treatment method is a low-cost and environmentally friendly approach to creating silica from rice husk, which can be applied in the polymer industry, coatings, construction composites, and catalysis. In conclusion, this procedure is a paradigm for recycling materials in the agricultural waste stream, while providing a different pathway to the generating silica based materials from traditional silica sources. Ultimately, this study has contributed to global sustainability efforts. [20]

Akinjokun et al. (2024) – *Template-Free Conversion of Rice Husk Silica into Nano-Zeolite X and Its Application in Adsorption of Heavy Metal Ions*. This study examines the transformation of rice husk silica into nano-zeolite X by template-free synthesis, as an inexpensive and sustainable method of producing value-added products from agricultural wastes. The rice husk silica was obtained from rice husk ash, and the silica was converted hydrothermally under controlled conditions, producing nano-zeolite X. The nano-zeolite X

produced exhibited a homogeneous morphology, with high crystallinity and surface area, that is suitable for adsorption processes. In this investigation, the material showed excellent potential heavy metal ion removal with a focus on lead (Pb^{2+}) and cadmium (Cd^{2+}), from aqueous solutions. Adsorption experiments showed excellent capacity and reusability, indicating the overall material appeared promising for water purification applications. This study showed not just a cost-effective way to valorize rice husk ash, but this work contributes to environmental protection by advancing the use of biogenic silica in wastewater treatment technologies. The template-free method not only reduces production costs and does not use surfactants or organic templates, but is also aligned with green and sustainable chemistry. Ultimately this research is a case study for the synergetic case of agricultural waste valorization and environmental remediation through nano-engineered materials. [21]

CONCLUSION

The extraction of silica from rice husk (RH) and rice husk ash (RHA) represents a new sustainable approach to dealing with declining globally with two issues; waste from agricultural activities and supply high purity silica to industries throughout the world. This review article highlighted recent advances in extraction techniques, such as acid and alkaline leaching, heat treatments, ball-milling, and new extraction methods like solvent-thermal and template-free synthesis, that all have the goal of maximizing yield, purity, surface area, and particle size of the silica extracted while minimizing energy and environmental impacts. There has been significant progress in the efficiency and scalability of these techniques which are now more suited for industries.

For instance, pilot scale continuous processes and optimizing the extraction process through some statistical method like Taguchi method for optimization has increased both feasibility and improved the product. High-purity amorphous silica from these processes has been reported in further uses from commercial construction materials, high-performance composites, environmental remediation, catalysis, and electronic applications. The recent shift to template-free, green, and low-cost construction over the last decade will assist in meeting circular economy ideals and sustainable development goals. Corn that is relied upon as feedstock can indirectly eliminate pollution and replace traditional silica from energy-intensive and unsustainable processes.

Moving into the future, additional research should include hybrid extraction techniques that have the benefits of combining and aggregating extraction techniques, improved energy efficiency, and commercialization of nano-silica applications and products. Additionally, standardized characterization techniques will be necessary for reproducibility and quality control. In a greater context, silica extraction from agricultural waste—rice husk or otherwise—can offer an innovative solution to feed sustainable and eco-friendly material applications that embed agricultural waste practices into one or more new product areas.

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