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Extraction of Silica Nanoparticles from Iraqi Agricultural Waste for Eco-Friendly Technology Applications

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ABSTRACT

Bamboo is a widely distributed agricultural waste material, particularly in Iraq, due to its rapid and uncontrolled growth, which can have significant environmental and economic impacts. Silica is a major component of bamboo leaf ash, with reported contents ranging from 75.90% to 82.86%. In this study, a modified precipitation method was employed to extract silica nanoparticles from bamboo leaves. Proximate analysis revealed an ash content of 24.48% and a silica content of 76.226% in bamboo leaf ash. The extraction of silica nanoparticles from bamboo leaf ash under different operating conditions influenced the silica yield and quality. A maximum reported yield of 99.232% was achieved using a 4 N NaOH solution. Fourier-transform infrared (FTIR) spectroscopy identified Si–O–Si, Si–O, and Si–OH bonds. Furthermore, atomic force microscopy (AFM) measurements indicated an average silica nanoparticle diameter of 87.55 nm. The results indicated that pretreatment methods and leaching conditions influenced the structure, size, and quality of the synthesized silica nanoparticles (SiO_2 NPs). Additional characterization techniques, including X-ray fluorescence (XRF), X-ray diffraction (XRD), and field-emission scanning electron microscopy (FE-SEM), were employed to evaluate the properties and purity of the extracted silica. The synthesized silica nanoparticles have potential applications as reinforcing fillers in composite materials and may also be suitable for applications in the pharmaceutical, food, and nutrition industries, as well as in nanocatalysis.

1. Introduction

The intensification of agricultural activities over the past decade has significantly increased the generation of agricultural waste [1]. According to the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP), agricultural waste generation was reported to reach approximately 905 million metric tons in 2021 [2] and 1.1 billion metric tons annually by 2023 [3]. Particularly in developing countries, agricultural waste is commonly managed through open burning, uncontrolled dumping, and landfilling, which contribute to environmental pollution and

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greenhouse gas emissions and pose substantial risks to human and animal health [4, 5]. Consequently, increasing research attention has been directed toward recycling agricultural waste into value-added products with potential economic and industrial benefits [6–9].

Agricultural waste can be converted into various functional materials for industrial applications, including thermal insulation materials [10], rubber fillers [11], pozzolanic materials for wastewater treatment [12, 13], nanostructured insulating materials for metal matrix composites [14], and additives for improving the mechanical properties of concrete [15–17]. Among these applications, the extraction of silica nanoparticles from agricultural waste has emerged as a promising approach for converting silica-rich biomass into valuable nanomaterials [18]. This approach utilizes silica naturally accumulated by plants through the absorption of silicon from the soil. The resulting silica nanoparticles have potential applications in optical materials, coatings, thin films [19], catalysts [12], corrosion-resistant materials [20], and ceramics [21, 22]. Recent developments have also demonstrated the potential of silica nanoparticles derived from agricultural residues for biomedical, agricultural, and environmental applications [23, 24].

Bamboo leaves represent a promising source of silica because their ash contains relatively high silica concentrations, reportedly ranging from 75.90% to 82.86% [25]. Previous investigations have explored several techniques for extracting silica from agricultural waste, including solvent extraction, ion exchange, electrodeposition, precipitation, and sol–gel processing [26]. Ajeel et al. [27] developed a chemical extraction method to obtain high-purity amorphous silica from rice husk ash using acid pretreatment followed by alkaline leaching with different sodium hydroxide (NaOH) concentrations. Their findings indicated that increasing the NaOH concentration up to 3 N improved the purity of the extracted silica, reaching approximately 99.714%, as confirmed by X-ray fluorescence (XRF) analysis.

Similarly, Gautam et al. [18] investigated silica extraction from bamboo leaves using an alkaline extraction method. Their results indicated that increasing the NaOH concentration enhanced silica recovery, while subsequent acid leaching produced silica with a maximum reported purity of 96.13%. Thuadaiz [28] also reported that precipitation-based processing could produce amorphous silica with a specific surface area of approximately 656 m^2/g. These investigations demonstrate the potential of chemical extraction and precipitation methods for recovering silica from agricultural residues. However, extraction efficiency and the characteristics of the resulting silica depend on processing conditions, including chemical concentration, pretreatment procedures, and precipitation parameters.

The present study aims to convert bamboo leaf waste into value-added silica nanoparticles through calcination and a modified precipitation process using different NaOH concentrations. Bamboo is available in parts of Iraq, where unmanaged biomass accumulation may create environmental and waste management challenges. Conventional disposal practices, including open burning and landfilling, may contribute to environmental pollution and resource loss. Therefore, developing an effective silica extraction process could provide an alternative approach for utilizing bamboo leaf waste. Specifically, this study investigates the influence of NaOH concentration on silica extraction and evaluates the physicochemical characteristics of the resulting silica nanoparticles. The findings are expected to contribute to the development of value-added materials from locally available agricultural residues and support more sustainable biomass utilization.

2. Methodology

2.1 Materials used in this Study

Bamboo leaves (BL) were collected from Baghdad, Iraq, and used as the primary raw material for silica nanoparticle extraction. The chemical composition of the bamboo leaves was characterized by cellulose (34.22%), hemicellulose (20.5%), and lignin (20.8%), with an ash content of 24.48%. The silica content was reported to be 76.226%, as presented in Table 1. In addition, the material contained other metal oxides, including magnesium oxide (MgO), calcium oxide (CaO), and potassium oxide (K_2O), with a reported combined content of 5.81%. The chemical reagents used in the extraction process were sulfuric acid (H_2SO_4, 98.079%), hydrochloric acid (HCl, 35%), and sodium hydroxide (NaOH, 99.9%).

Table 1
Chemical composition of the Bamboo Leaf Ash (BLA)

Constituent	SiO_2	K_2O	SO_3	CaO	Cl	MgO	P_2O_2	Other
Percentage%	76.226	6.629	5.857	4.979	2.140	1.980	1.490	0.699

2.2 Preparation of Raw Agricultural Materials

Bamboo leaves were collected as the primary agricultural waste material for silica extraction. The collected leaves were initially cut into small, uniform pieces to facilitate subsequent processing. The cut leaves were then ground using a mechanical grinder to reduce their particle size. Following grinding, the bamboo leaf particles were thoroughly washed with deionized water to remove adhering dirt, dust, and soluble impurities. The washed material was subsequently dried under sunlight for 10 h to reduce its moisture content. Finally, the chemical composition of the prepared bamboo leaves was analyzed to determine their silica content and other constituents. Figure 1 illustrates the preparation procedure for the bamboo leaves.



Fig. 1. (a) Collect bamboo leaves, (b) Cutting, (c) Grinding by the mechanical grinder, (d) Washing with deionized water, (e) Drying bamboo leaves under sunlight

2.3 Chemical Treatment Process of Agricultural Materials

The pretreatment of bamboo leaves plays a crucial role in improving the quality of extracted silica nanoparticles by facilitating the removal of inorganic impurities and organic compounds from the agricultural waste. Acid leaching was performed as the initial stage of the silica extraction process. The dried bamboo leaves were immersed in a 3 N hydrochloric acid (HCl) solution and maintained at

80 °C for 6 h. Subsequently, the leaves were left in the same acidic solution at room temperature for an additional 18 h, as shown in Figures 2(a) and 2(b). This treatment was intended to remove impurities and reduce the concentration of metallic elements in the biomass. Following acid leaching, the treated leaves were repeatedly washed with warm deionized water to remove residual acid, as illustrated in Figure 2(c). Finally, the washed bamboo leaves were dried naturally under sunlight for 10 h before further processing.

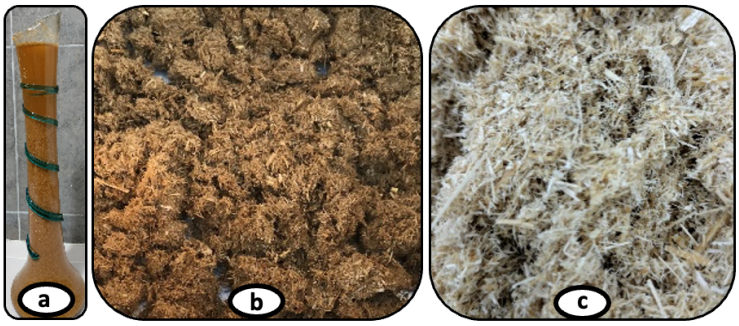


Fig. 2. (a) Bamboo leaves in an acidic solution, (b) After removing the acidic solution, (c) Bamboo leaves after complete washing

The color changes observed during pretreatment reflected the progression of the chemical treatment process. The gradual transition from dark brown to light brown and finally to an almost white appearance indicated changes in the composition of the treated material, suggesting the effectiveness of the pretreatment process in preparing bamboo leaves for subsequent silica extraction.

2.4 Thermal Treatment Process of Agricultural Materials

Following thermal analysis using thermogravimetric analysis (TGA) and differential thermal analysis (DTA) to determine the appropriate decomposition temperature, the pretreated bamboo leaves were subjected to calcination at 700 °C for 4 h. This thermal treatment was an important step in producing high-purity silica by removing organic components from the bamboo leaves. Figure 3 shows the bamboo leaf ash (BLA) obtained after calcination, illustrating the transformation of the original bamboo material into a fine, white ash.



Fig. 3. Bamboo Leaf Ash (BLA) after the calcination process

2.5 Extraction of High-Purity Nanosilica from Agricultural Waste Ash

The extraction of high-purity nanosilica from bamboo leaf ash (BLA) involved a series of chemical treatment processes, beginning with alkaline leaching. The BLA was mixed with sodium hydroxide (NaOH) solutions at different concentrations (2, 3, and 4 N) to investigate the effect of NaOH concentration on silica extraction. The mixtures were heated and continuously stirred at 80 °C for 8 h to facilitate the reaction between the silica present in the ash and the alkaline solutions. Subsequently, the mixtures were allowed to stand at room temperature for 24 h to promote further reaction. The resulting mixtures were then subjected to vacuum filtration to separate the sodium silicate solutions from the insoluble residues. During alkaline leaching, silica (SiO_2) reacted with NaOH to form sodium silicate (Na_2SiO_3) and water, as expressed in Equation (1).

The obtained sodium silicate solutions were subsequently treated with 5 N sulfuric acid (H_2SO_4) under continuous stirring to precipitate silica in the form of a white gelatinous material, as described in Equation (2). During acid addition, the pH of the solutions was gradually reduced from 14 to 4, promoting silica precipitation and gel formation. The resulting silica gels were then filtered and washed with deionized water to remove residual acid and soluble impurities, as shown in Figure 4(a). The washed gels were subsequently dried at 110 °C for 6 h. Finally, the dried silica materials were ground into fine powders, as illustrated in Figure 4(b), and stored in sealed plastic bags for subsequent characterization and potential applications. This process demonstrates the potential conversion of bamboo leaf ash into value-added silica materials through alkaline extraction and acid precipitation.

$$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O \quad (1)$$

$$Na_2SiO_3 + H_2SO_4 \rightarrow SiO_2 + Na_2SO_4 + H_2O \quad (2)$$

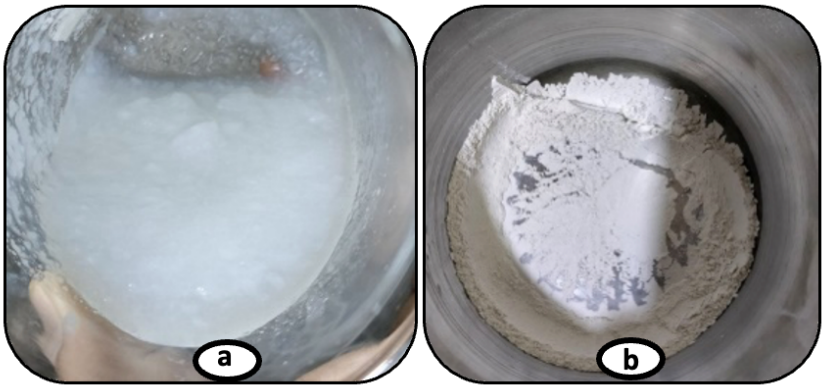


Fig. 4. (a) The precipitated nano-silica gel, (b) High-purity nano-silica (SiO_2 NPs) after milling

Each stage of the extraction process plays an important role in obtaining high-purity silica nanoparticles from bamboo leaves. The resulting white silica powder was stored in a sealed plastic bag to minimize contamination and preserve its quality for subsequent characterization and applications. Figure 5 presents a flowchart summarizing the main stages involved in the extraction and preparation of high-purity silica nanoparticles from bamboo leaf ash.

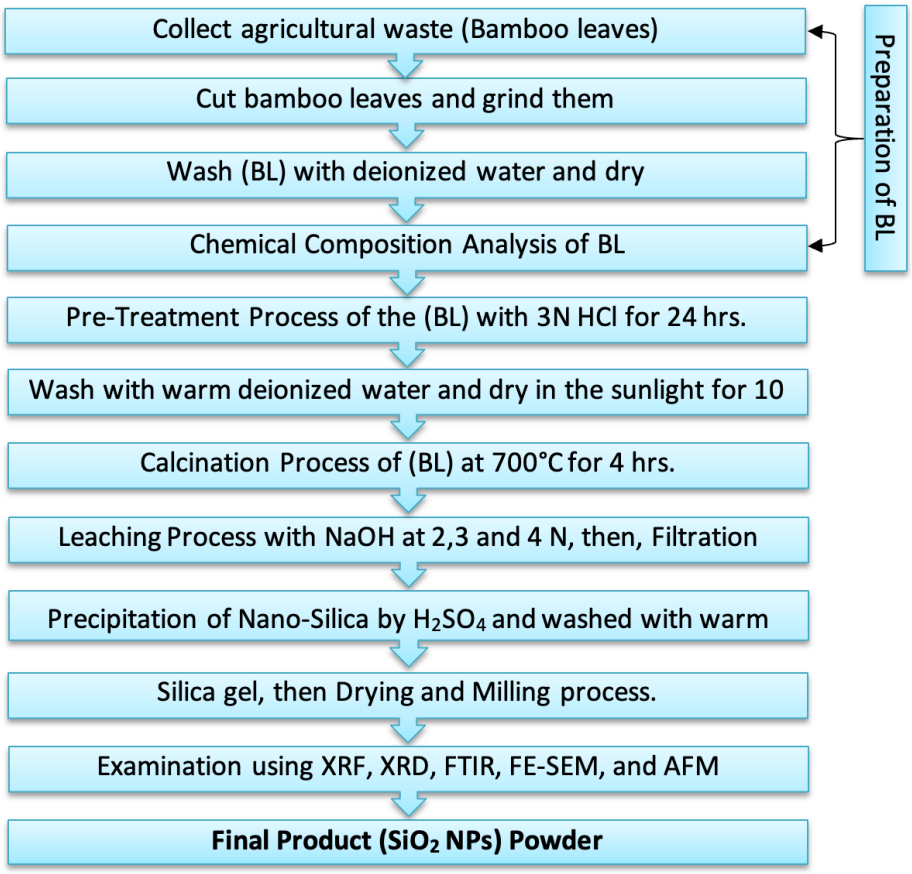


Fig. 5. Flow chart of the production method of high-purity nano-silica

3. Results

3.1 X-Ray Fluorescence Spectroscopy (XRF) Analysis of Nanosilica

X-ray fluorescence (XRF) analysis was performed to evaluate the effect of sodium hydroxide (NaOH) concentration on the purity of the extracted nanosilica powder and to quantitatively determine the presence of residual impurities. Silica nanoparticles were extracted from bamboo leaves using different NaOH concentrations following pretreatment with 3 N hydrochloric acid (HCl) and calcination at 700 °C for 4 h. The highest silica purity of 99.232% was obtained using a 4 N NaOH solution, as presented in Table 2.

Table 2
XRF analysis of the nano-silica from Bamboo leaves

Components as oxides %	NaOH (2 N)	NaOH (3 N)	NaOH (4 N)
SiO_2	96.01	97.91	99.23
SiO_3	0.272	0.100	0.008
MgO	1.930	1.100	0.510
K_2O	0.030	0.018	0.050
CaO	0.890	0.630	0.150
P_2O_5	0.023	0.040	0.020
Other	0.845	0.200	0.030

The XRF results presented in Table 2 indicate that the extracted nanosilica contains varying amounts of inorganic oxides, including CaO, MgO, P_2O_5, and K_2O, depending on the treatment conditions. The presence of these oxides influences the purity of the extracted nanosilica. As the NaOH concentration increased from 2 N to 4 N, the silica purity increased from 96.01% to 99.232%, respectively. These findings are consistent with those reported by Ajeel et al. [29] and Gautam et al. [18]. Figure 6 illustrates the relationship between NaOH concentration and nanosilica purity, demonstrating that increasing the NaOH concentration enhances the purity of the extracted nanosilica within the investigated concentration range.

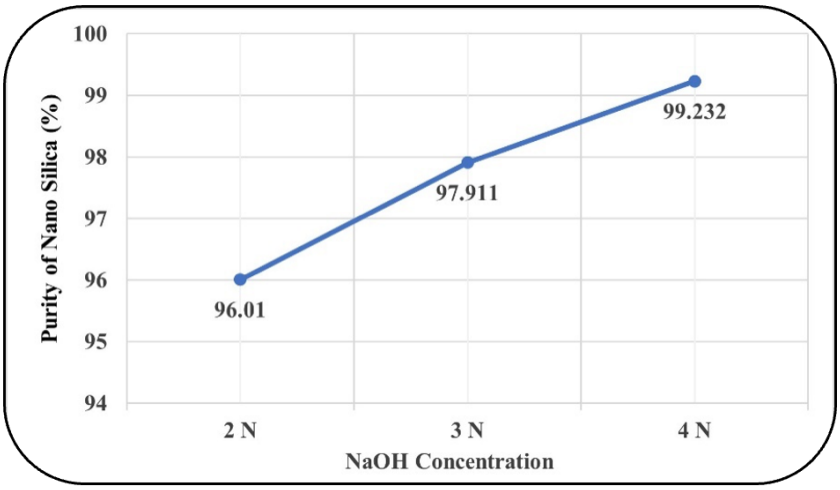


Fig. 6. Relationship between the nano-silica purity and NaOH concentration

3.2 X-Ray Diffraction (XRD) Analysis of Nanosilica

X-ray diffraction (XRD) analysis was performed to investigate the structural characteristics of nanosilica samples extracted using different NaOH concentrations (2, 3, and 4 N). As shown in Figure 7, the XRD patterns exhibited broad diffraction peaks within the 2θ range of 17°–31°, indicating the predominantly amorphous nature of the extracted silica. These patterns were reported to be consistent with the reference data (JCPDS card No. 96-900-5024). In particular, a broad diffraction peak centered at approximately 22° (2θ) indicated the absence of a well-defined long-range crystalline structure. This observation, together with the XRF results, supports the characterization of the extracted material as predominantly amorphous silica, with the highest reported purity of 99.232% obtained using a 4 N NaOH solution. The relatively smooth diffraction patterns and absence of prominent crystalline peaks suggest that the modified precipitation process effectively reduced crystalline impurities in the extracted silica. Furthermore, the diffraction patterns appeared to become smoother with increasing NaOH concentration, suggesting possible differences in the structural characteristics of the resulting silica. These findings are consistent with observations reported by Zedin et al. [30], Le et al. [31], and Chindaprasirt et al. [32].

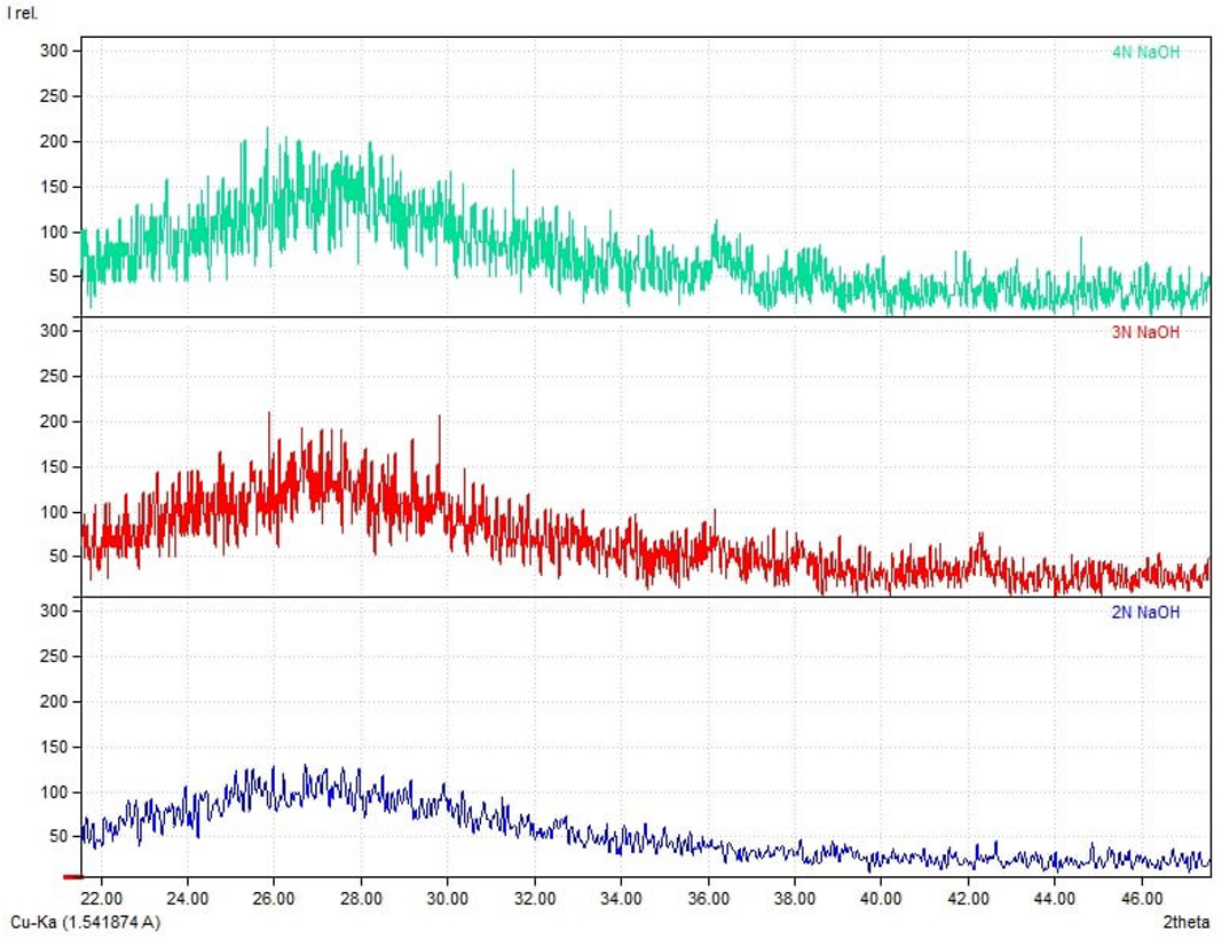


Fig. 7. XRD patterns of nano-silica were extracted at different NaOH concentrations

3.3 Fourier Transform Infrared (FTIR) Analysis of Nanosilica

Figure 8 presents the Fourier transform infrared (FTIR) spectra of nanosilica synthesized using different NaOH concentrations (2, 3, and 4 N). FTIR analysis was performed to identify the characteristic functional groups and chemical bonds present in the extracted nanosilica samples. A broad absorption band observed at approximately 3400 cm^{-1} was attributed to the stretching vibrations of hydroxyl (–OH) groups, which are commonly associated with surface silanol groups (Si–OH) and adsorbed water molecules. The prominent absorption peak at approximately 1100 cm^{-1} corresponded to the asymmetric stretching vibrations of siloxane (Si–O–Si) bonds, indicating the presence of a silica network. Additional absorption bands at approximately 800 and 450 cm^{-1} were attributed to the symmetric stretching and bending vibrations of Si–O–Si bonds, respectively, further confirming the characteristic bonding structure of silica.

The FTIR spectra of the samples obtained at different NaOH concentrations exhibited similar absorption bands, indicating that the fundamental chemical bonding structure of the extracted nanosilica remained relatively consistent under the investigated experimental conditions. Minor variations in peak intensities may be associated with differences in particle size, surface hydroxylation, or the degree of condensation within the siloxane network. The similarity of the characteristic absorption bands suggests that the extraction process produced silica materials with comparable chemical bonding characteristics despite variations in NaOH concentration. These findings are consistent with the XRD results, which indicated the predominantly amorphous nature

of the extracted silica, and complement the XRF analysis, which demonstrated the highest silica purity of 99.232% for the sample prepared using 4 N NaOH. Although FTIR spectroscopy provides information about chemical bonding and local structural characteristics, the amorphous nature of the silica is more directly supported by the broad diffraction features observed in the XRD patterns. In general, crystalline materials exhibit more clearly defined vibrational features associated with their ordered atomic arrangements, whereas amorphous materials may display broader absorption bands due to variations in local bonding environments.

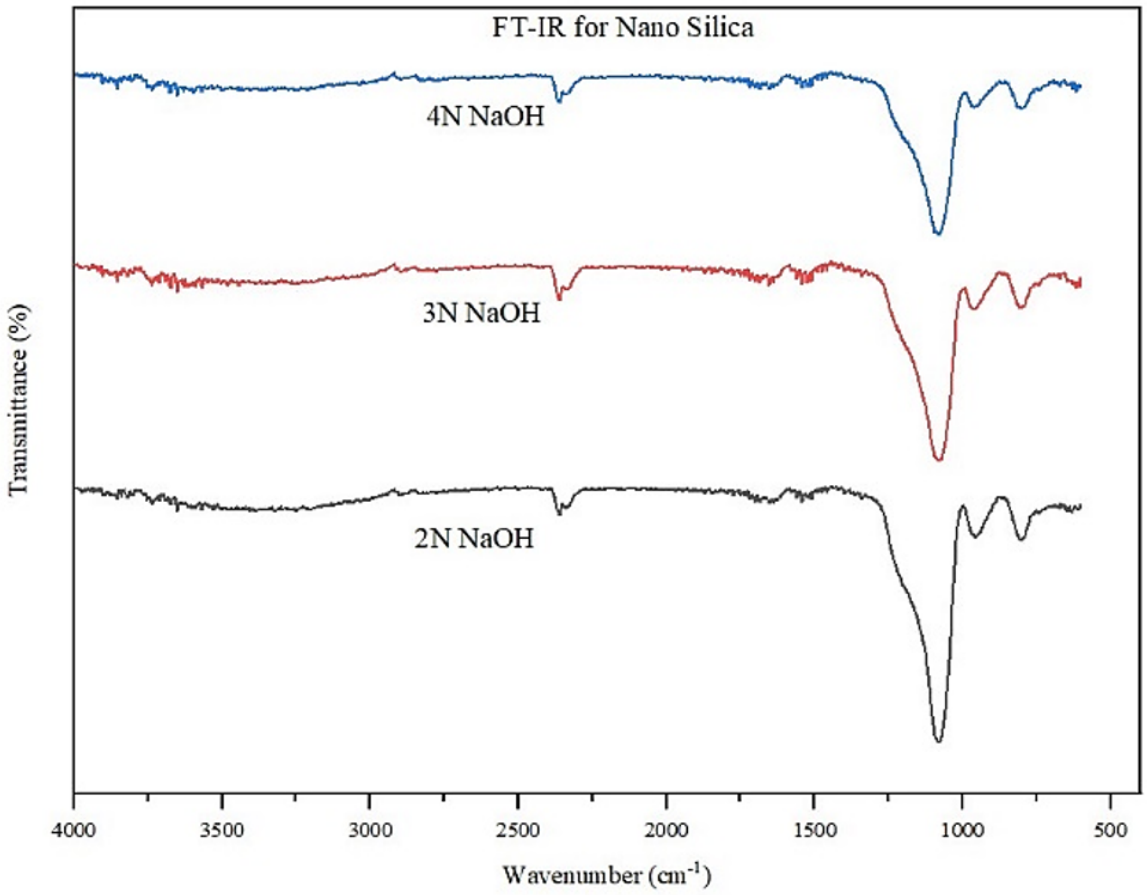


Fig. 8. FT-IR analysis of nano-silica was extracted at different NaOH concentrations

3.4 Morphological Analysis of Nanosilica Using Field-Emission Scanning Electron Microscopy (FE-SEM)

Field-emission scanning electron microscopy (FE-SEM) was employed to investigate the morphological characteristics of nanosilica extracted using a 4 N NaOH solution, which exhibited the highest silica purity of 99.232%, as determined by XRF analysis. The FE-SEM micrograph revealed nanoscale silica particles with relatively uniform morphological characteristics, consistent with observations reported by Ajeel et al. [29, 30, 33]. As shown in Figure 9, the measured particle sizes ranged from 9.859 to 21.36 nm, indicating the formation of silica nanoparticles. The particles appeared to exhibit a relatively homogeneous size distribution, with limited visible agglomeration in the examined region. The observed particle morphology and surface characteristics suggest that the modified precipitation process was effective in producing nanoscale silica particles. These observations are consistent with the predominantly amorphous structure indicated by the XRD analysis.

Based on measurements obtained from the FE-SEM micrographs, the average particle size was approximately 15 nm. The relatively narrow range of measured particle sizes suggests that the synthesis process produced nanoparticles with reasonably consistent dimensions under the investigated conditions. Such morphological characteristics may be beneficial for industrial applications requiring nanoscale silica materials. The FE-SEM results therefore provide complementary information on particle morphology and size, while the XRF and XRD analyses provide evidence of chemical purity and structural characteristics, respectively. Together, these characterization results support the successful extraction and synthesis of nanosilica from bamboo leaf ash using the modified precipitation method.

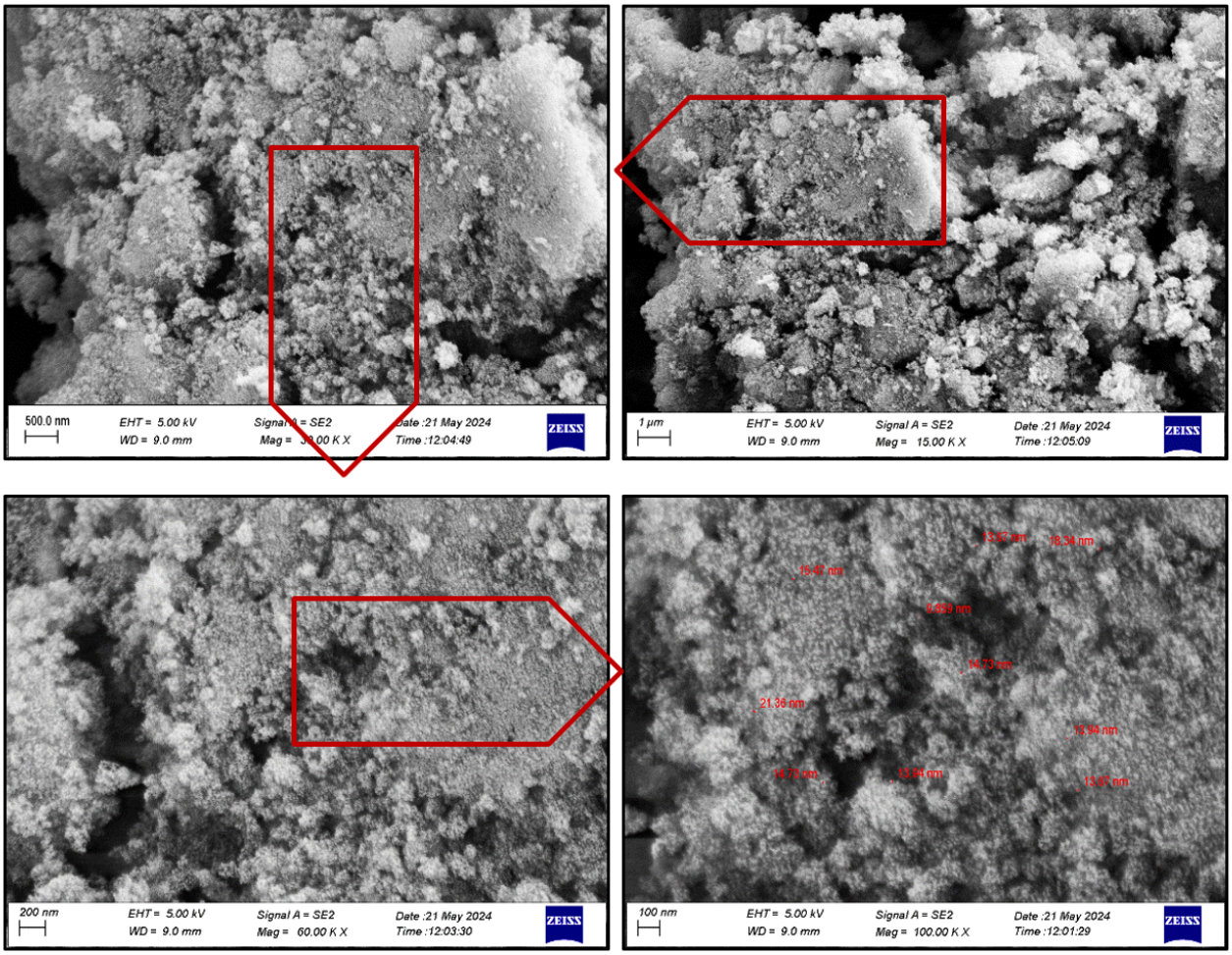


Fig. 9. FE-SEM images of Nano-Silica at 4N NaOH concentration

3.5 Atomic Force Microscopy (AFM) Analysis of Nanosilica under Optimal Extraction Conditions

Atomic force microscopy (AFM) was employed to investigate the surface morphology and particle size distribution of the synthesized nanosilica. This technique provides high-resolution, three-dimensional topographical images, allowing detailed examination of nanoscale surface features and particle characteristics. In this study, tapping-mode AFM was used to analyze the nanosilica powder. This mode employs an oscillating probe that intermittently contacts the sample surface, minimizing potential surface damage while providing detailed topographical information.

The nanosilica sample synthesized using the optimal NaOH concentration of 4 N was examined to evaluate its morphological characteristics and particle size distribution. Figure 10(a) presents a two-dimensional AFM image illustrating variations in particle size across the examined surface, while Figure 10(b) shows a histogram of the particle size distribution and corresponding particle counts. Figure 10(c) provides a three-dimensional representation of the nanosilica surface topography, highlighting the approximately spherical morphology of the particles and their relatively limited aggregation. Furthermore, Figure 10(d) presents an enhanced three-dimensional topographical image, revealing additional details of the nanosilica surface features.

The AFM results indicated an average particle diameter of approximately 87.55 nm, with most measured particle sizes ranging from 5.676 to 120 nm. These findings demonstrate the formation of nanoscale silica particles under the investigated extraction conditions. The observed particle size distribution and surface morphology provide useful information regarding the physical characteristics of the synthesized material. In addition, XRF analysis confirmed a silica purity of 99.232% for the sample prepared using 4 N NaOH. Together, the AFM and XRF results provide complementary information on the morphological characteristics and chemical purity of the extracted nanosilica, supporting its potential suitability for applications requiring nanoscale silica materials.

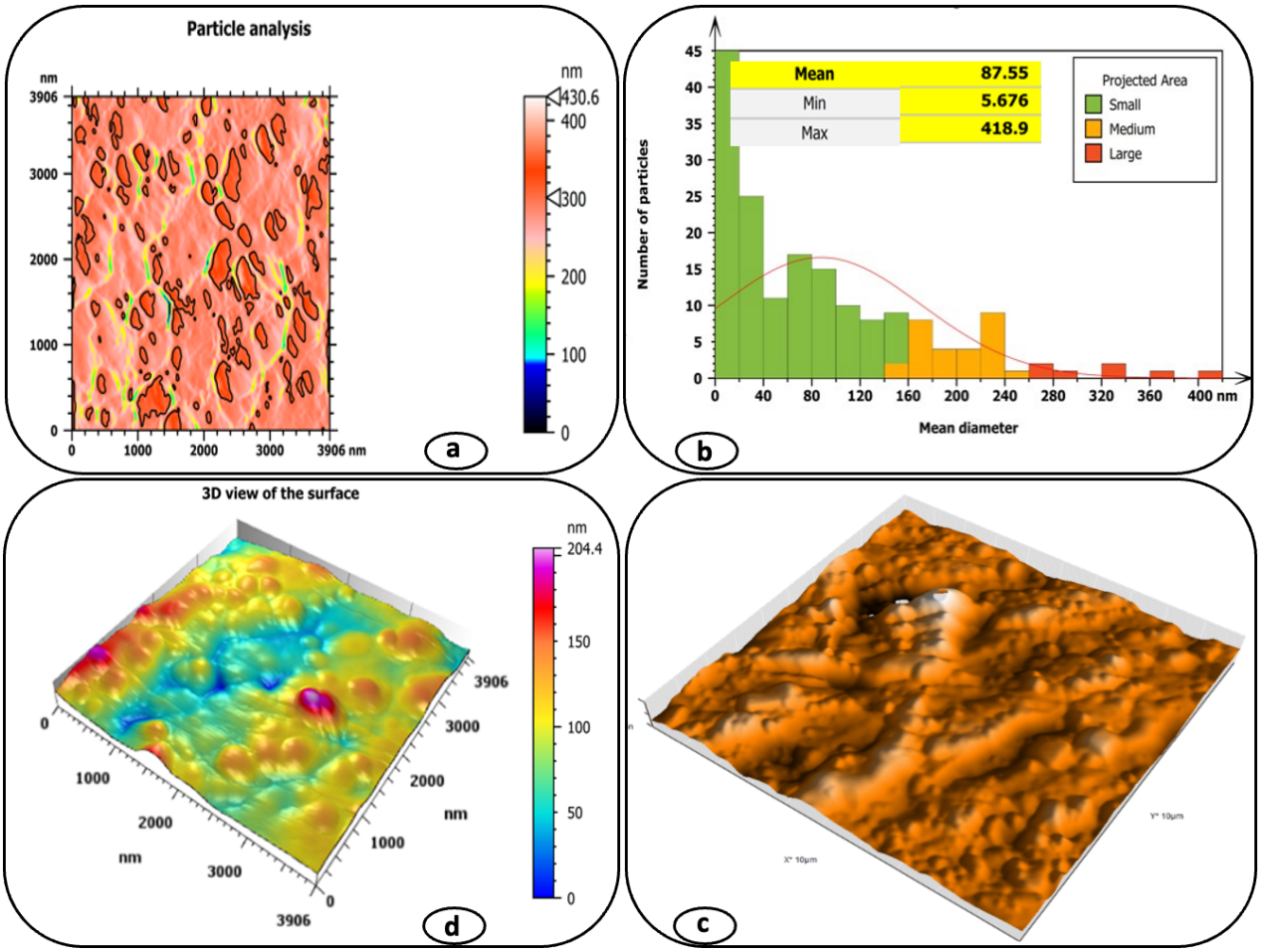


Fig. 10. AFM analysis for optimal state nano-silica (a) Two-dimensional particle analysis, (b) Histogram that depicts the distribution of particle sizes (c) Three-dimensional view of the nano-silica surface, (d) Surface features of the nano-silica

4. Conclusions

This study successfully demonstrated the extraction of high-purity nanosilica from bamboo leaves, an underutilized agricultural waste material available in Iraq. Using acid pretreatment, calcination, alkaline extraction, and a modified precipitation method, a maximum silica purity of 99.232% was achieved at a NaOH concentration of 4 N. The synthesized nanosilica exhibited an average particle diameter of 87.55 nm, as determined by AFM analysis, while FE-SEM observations revealed particle sizes ranging from 9.859 to 21.36 nm. XRD analysis indicated the predominantly amorphous nature of the extracted silica, and FTIR analysis confirmed the presence of characteristic silica-related chemical bonds. These findings demonstrate the feasibility of converting bamboo leaf waste into value-added silica nanomaterials with potential applications in various industrial sectors. Furthermore, the proposed extraction approach offers an alternative pathway for agricultural waste utilization and resource recovery, contributing to the development of more sustainable material production practices.

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Reference

[1] Cheng, Y. S., P. Mutrakulcharoen, S. Chuetor, K. Cheenkachorn, P. Tantayotai, E. J. Panakkal, and M. Sriariyanun. "Recent Situation and Progress in Biorefining Process of Lignocellulosic Biomass: Toward Green Economy." *Applied Science and Engineering Progress* 13, no. 4 (2020): 299–311.

[2] United Nations Environment Programme. *Food Waste Index Report 2021.* Nairobi: United Nations Environment Programme, 2021.

[3] Food and Agriculture Organization of the United Nations. *The State of Food and Agriculture 2023: Revealing the True Cost of Food to Transform Agrifood Systems.* Rome: FAO, 2023.

[4] Rath, Suvangi, Khitish Kumar Sarangi, Jeebanjyoti Behera, Dwity Sundar Rout, and Anbukkani P. "Agricultural Solid Waste and Its Management: An Overview." *Indian Journal of Economic Development* 20, no. 1 (2024): 167–177.

[5] Islam, A. K. M. Sadrul, and M. Ahiduzzaman. "Biomass Energy: Sustainable Solution for Greenhouse Gas Emission." *AIP Conference Proceedings* 1440 (2012): 23–32.

[6] Abdul Razak, N. A., N. H. Othman, M. S. Mat Shayuti, A. Jumahat, N. Sapiai, and W. J. Lau. "Agricultural and Industrial Waste-Derived Mesoporous Silica Nanoparticles: A Review on Chemical Synthesis Route." *Journal of Environmental Chemical Engineering* 10, no. 2 (2022).

[7] Parveen, Khadeeja, Viktoria Banse, and Lalita Ledwani. "Green Synthesis of Nanoparticles: Their Advantages and Disadvantages." *AIP Conference Proceedings* 1724, no. 1 (2016): 020048.

[8] Mohd, Nur Kamilah, Nik Nur Atiqah Nik Wee, and Alyza A. Azmi. "Green Synthesis of Silica Nanoparticles Using Sugarcane Bagasse." *AIP Conference Proceedings* 1885, no. 1 (2017): 020123.

[9] Azmi, M. A., N. A. A. Ismail, M. Rizamarhaiza, W. M. Hasif A. A. K., and H. Taib. "Characterisation of Silica Derived from Rice Husk (Muar, Johor, Malaysia) Decomposition at Different Temperatures." *AIP Conference Proceedings* 1756, no. 1 (2016): 020005.

[10] Salavati-Niasari, M., J. Javidi, and M. Dadkhah. "Ball Milling Synthesis of Silica Nanoparticle from Rice Husk Ash for Drug Delivery Application." *Combinatorial Chemistry & High Throughput Screening* 16, no. 6 (2013): 458–462.

[11] Cardona Uribe, N., C. Arenas Echeverry, M. Betancur Velez, L. Jaramillo, and J. Martinez. "Possibilities of Rice Husk Ash to Be Used as Reinforcing Filler in Polymer Sector—A Review." *Revista UIS Ingenierías* 17, no. 1 (2018): 127–142.

[12] Awizar, D. Asra, et al. "Nanosilicate Extraction from Rice Husk Ash as Green Corrosion Inhibitor." 2013.

[13] Barlaam, Sabariah, Tuan Sharifah Misnati Tuan Sayed, Zuraisah Dollah, Amalina Amirah Abu Bakar, Nurhidayati Mat Daud, and Rabitah Handan. "New Composite Adsorbent Using Agricultural Waste from Rice Husk and Banana Peels to Remove Cu(II) and Zn(II) in Synthetic Wastewater." *AIP Conference Proceedings* 2532, no. 1 (2022): 050001.

[14] Rajamani, D., R. Surender, A. Mahendran, S. Muthusubramanian, and C. T. Vijayakumar. "Bismaleimide/Rice Husk Silica-Reinforced Composites: Synthesis and Thermal Degradation Studies." *Journal of Thermal Analysis and Calorimetry* 114, no. 2 (2013): 883–893.
[15] Peter, Abiya Eldho K., M. Balasubramanian, and P. Mukilan. "Replacement of Cementitious Material by Using Agricultural Waste." *AIP Conference Proceedings* 2515, no. 1 (2022): 030003.
[16] Jamwal, Aakash, and Akhilesh Nautiyal. "Experimental Analysis on the Mechanical Properties of Concrete with Cow Dung Ash and Corn Stalk Ash as Mineral Admixtures." *AIP Conference Proceedings* 3146, no. 1 (2024): 020012.
[17] Munish, and Shalika Mehta. "Experimental Investigation of Bamboo Leaf Ash and Rice-Husk Ash as Partial Replacement of Cement in Concrete." *AIP Conference Proceedings* 3050, no. 1 (2024): 030012.
[18] Gautam, N., Y. Rajesh, N. Kale, M. Jagtap, H. Chaudhari, and S. Pansare. "Silica Extraction from Bamboo Leaves Using Alkaline Extraction Method." *Materials Today: Proceedings* (2023).
[19] Jadhav, S. A. "Incredible Pace of Research on Mesoporous Silica Nanoparticles." *Inorganic Chemistry Frontiers* 1, no. 1 (2014): 1–5.
[20] Adam, F., J. N. Appaturi, Z. Khanam, R. Thankappan, and M. A. M. Nawi. "Utilization of Tin and Titanium Incorporated Rice Husk Silica Nanocomposite as Photocatalyst and Adsorbent for the Removal of Methylene Blue in Aqueous Medium." *Applied Surface Science* 264 (2013): 718–726.
[21] Kurama, S., and H. Kurama. "The Reaction Kinetics of Rice Husk-Based Cordierite Ceramics." *Ceramics International* 34, no. 2 (2008): 269–272.
[22] Rakhimov, Firuz, and Mukhiddin Akmalov. "The Use of Polymer Compositions Based on Agricultural Waste to Improve the Moisture Resistance of Building Materials Based on Gypsum." *AIP Conference Proceedings* 3045, no. 1 (2024): 040013.
[23] Mohammad, H., S. Abu-Jdayil, and R. Hafez. "Novel Trends in the Production of Silica Nanoparticles from Waste Materials." *Journal of Environmental Chemical Engineering* 8, no. 5 (2022).
[24] Sarkar, J., D. Mridha, J. Sarkar, J. T. Orasugh, B. Gangopadhyay, D. Chattopadhyay, T. Roychowdhury, and K. Acharya. "Synthesis of Nano-Silica from Agricultural Wastes and Its Multifaceted Applications: A Review." *Biocatalysis and Agricultural Biotechnology* 37 (2021): 102175.
[25] Olawale, O., B. Akinyemi, S. J. Ogundipe, S. T. Abayomi, and A. A. Adekunle. "Response Surface Methodology for Silicon Production from Bamboo Leaves." *IOP Conference Series: Earth and Environmental Science* (2021).
[26] Farirai, F., M. Ozonoh, T. C. Aniokete, O. Eterigho-Ikelegbe, M. Mupa, B. Zeyi, and M. O. Daramola. "Methods of Extracting Silica and Silicon from Agricultural Waste Ashes and Application of the Produced Silicon in Solar Cells: A Mini-Review." *International Journal of Sustainable Engineering* 14, no. 1 (2021): 57–78.
[27] Ajeel, S. A., K. A. Sukkar, and N. K. Zedin. "Extraction of High Purity Amorphous Silica from Rice Husk by Chemical Process." *IOP Conference Series: Materials Science and Engineering* (2020).
[28] Thuadaij, Nittaya, and Apinon Nuntiya. "Synthesis and Characterization of Nanosilica from Rice Husk Ash Prepared by Precipitation Method." *Special Issue on Nanotechnology* 7, no. 1 (2008): 59.
[29] Ajeel, S. A., K. A. Sukkar, and N. K. Zedin. "Chemical Extraction Process for Producing High Purity Nanosilica from Iraqi Rice Husk." *Engineering and Technology Journal* 39, no. 1A (2021): 56–63.
[30] Zedin, N. K., S. A. Ajeel, and K. A. Sukkar. "Nanosilicon Powder Extraction as a Sustainable Source (from Iraqi Rice Husks) by Hydrothermal Process." *AIP Conference Proceedings* (2020).
[31] Le, V. H., C. N. H. Thuc, and H. H. Thuc. "Synthesis of Silica Nanoparticles from Vietnamese Rice Husk by Sol-Gel Method." *Nanoscale Research Letters* 8, no. 1 (2013).
[32] Chindaprasirt, P., and U. Rattanasak. "Eco-Production of Silica from Sugarcane Bagasse Ash for Use as a Photochromic Pigment Filler." *Scientific Reports* 10, no. 1 (2020).
[33] Dirna, F. C., I. Rahayu, A. Maddu, W. Darmawan, D. Nandika, and E. Prihatini. "Nanosilica Synthesis from Betung Bamboo Sticks and Leaves by Ultrasonication." *Nanotechnology, Science and Applications* 13 (2020): 131–136.