CHAPTER

5 Synthesis of silica nanoparticles from agricultural waste

Evidence Akhayere[a,b] and Doga Kavaz[b,c]

[a]*Department of Environmental Science, Cyprus International University, Nicosia, Mersin, Turkey,*
[b]*Environmental Research Centre, Cyprus International University, Nicosia, Mersin, Turkey,*
[c]*Department of Bioengineering, Cyprus International University, Nicosia, Mersin, Turkey*

1 Introduction

The global environment experiences a massive production of waste materials daily, which are generated by various industries. This problem of high waste generation contributes to continuous environmental pollution since the cost of recycling these wastes has become an even greater problem. According to previous research by (Fatma et al., 2014) waste materials from agricultural process can cause very significant waste disposal issues. Some of these waste includes sawdust, coconut husk and shells, fibers, sludge, rice waste etc. The study of nanotechnology is a highly active and vital field with productive research involving a variety of industrial areas. These areas include but are not limited to medical and dental studies, aviation and defense, and the electronics and energy fields. The study of nanotechnology involves the design, synthesis, characterization, and application of synthesized materials (Silva, 2004; Buzea et al., 2007; Sharma et al., 2017). One important property of nano-scale materials is that their biological, chemical, and physical properties differ from those of the same elements at a macro-and micro-scale. This generally provides nanoparticles with the opportunity to develop new classes of technologically advanced materials that can solve problems by meeting the demands of highly technological applications. Additionally, nanoparticles (including noble metals) have been prepared for rapid progression in biomedical applications such as drug transportation, gene delivery, labelling and tracking agents, sensors, hyperthermia, and tissue engineering (Chugh et al., 2018; Vial et al., 2017; Wang et al., 2019). Silicon (Si) is the second-most accessible component on the Earth after oxygen. While plants obtain silicon from the soil, it is generally accessible in amorphous and crystalline states as silicon dioxide (silica, SiO_2). Silica is believed to assume a significant physiological role in plant development as an expulsion agent of abiotic and biotic stress. Notably, silica-based nanoparticles are a driving component in biomedical applications due to their high biocompatibility and bioactivity (Chang, 2019; Adebisi et al., 2019).

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Agricultural waste especially from plants (e.g., husks, shells, straw, etc.) can either be disposed of after harvest or used as a valuable antecedent for the creation of various materials. Barley and wheatgrass, which are common agricultural waste products, possess a high amount of silicon content that makes them helpful materials to use as precursors for the production of silicon substances (Chen et al., 2010; Rovani et al., 2019). As agricultural exercises continue to expand, the production of waste is increasing daily. To address the handling of such waste in this research, we present a simple and sustainable technique for converting an agricultural waste product (barley grass (BG) into a more useful material known as nanosilica (NS), which has an extremely high economic value.

Previous works have described BG as a major agricultural waste product containing high silica content, which makes BG a good starter material for the production of silicon-based particles such as silica, pure silicon, zeolite, and other silicon-based products (Bogush et al., 2013; Singh and Endley, 2020). Previous studies have also noted that many methods can be applied for the preparation of silica nanoparticles (Carmona et al., 2013; Anuar et al., 2020), including microwave hydrothermal processes (Imoisili et al., 2020; Naddaf et al., 2020), sol-gel processes, and synthesis by combustion, among others. However, the methods used to produce silica on a large scale involve the use of high temperatures and processes that could also be hazardous to the environment due to the production of large amounts of CO_2 gas. Generally, the majority of silica production methods are time- and energy-consuming and produce low-purity silica. Therefore, the need for a sustainable, low-energy, low-CO_2-generating and sustainable method for the synthesis and production of silica cannot be overemphasized.

Notable qualities of silicon include it serving as the antecedent for silica-based nanoparticle synthesis and generally being an excellent adsorbent with high effectiveness and low effluent production. Nanoparticles and nanomaterials have been considered to fulfill the rising need for the production of low-cost adsorbents with a high surface area and adsorption limit (Mathew et al., 2019; Wee et al., 2019). Nanoparticles have a wide scope of applications in the clinical, technological, environmental, and energy fields (Chen et al., 2010). Adsorbents are typically considered more effective and efficient in their nano form because nanoparticles can be modified with properties that suit specific purposes (e.g. material that is not magnetic in its microstate that can be modified to be magnetic in the nano state).

This research aims to highlight the importance of utilizing agricultural waste and its potential. On a national level, the amount of waste generated by agriculture depends on both the number of agricultural activities occurring and the available crops and farmland; thus, nations with a high population or high agricultural exports would produce more agricultural waste. Such waste can remain on agricultural lands for long periods until the farmers decide to either burn them or store them in another location, which can negatively affect the environment and facilitate the spread of certain diseases (Hansen and Cheong, 2019; Raut and Panthi, 2019; He et al., 2019). BG is an agricultural waste product of concern for both farmers and waste managers. In the present research, BG was used to produce NS, which can also be used as a precursor for nanozeolite (NZ) production (Seyed et al., 2013; Akhayere et al., 2019a). The objective of this chapter is to provide the readers with the understanding of agricultural wastes as well as well as provide knowledge to researchers on a low-cost method for synthesizing NS at a very high percentage purity, which could serve as a solution to agricultural and environmental waste problem. It is also very important that countries where agricultural activities is at its peak, would give keen considerations to the findings of this research this is because it would help them gain reasonable knowledge on how to explore cost-effective methods of converting the waste from their products, to useful adsorbents for numerous applications.

2 Agricultural waste

Agriculture is the main basis for sustaining human societies. In many countries, millions of jobs are provided by the agricultural sector, which makes it a significant source of income and economic activity. As a result, the demand for agricultural products is continuously increasing and producing massive amounts of agricultural waste that can provide the massive potential for use in different products related to biochemistry, biofuels, and biomaterials. However, any changes in social performance must seriously consider how to ensure an adequate supply of people (Table 1) (Zhou et al., 2018; Soemphol et al., 2020).

In the agricultural production process, discarded organic substances are defined as agricultural waste. Such substances include livestock, plant waste, processing waste from agricultural and sideline products, and poultry manure (Dai et al., 2018; Sapawe, 2018). Agricultural waste is also recognized as unwanted materials or foods that were once fit for human consumption but could later not be consumed by humans. According to (Ramírez-García et al., 2019; Soni et al., 2018), agricultural wastes from fruits, vegetables, meat, poultry, and dairy products contain many carbohydrates and various bioactive compounds; therefore, these waste types can be harnessed as a useful resource in many industries. In food processing, methods such as dissolved air flotation, aerated lagoons, anaerobic lagoons, activated sludge processing, and disinfection are most commonly used for treating agricultural waste (Figs. 1 and 2).

Table 1 Agricultural waste classifications.

Agricultural waste classification	Examples
Crop wastes	Oat straw, rice straw, corn Stover, wheat straw, barley straw, etc.
Industrial processing wastes	Sugarcanes bagasse, Rice bran, De-oiled seed cakes, Rice husk, apple pomace, orange peel, amla pomace, etc.
Livestock wastes	cattle manure, swine manure, animal fat, etc.
Food wastes	mango, apple, cabbage, tomato, lettuce, etc.

FIG. 1

Examples of agricultural waste: (A) food waste (B) rice husks (C) orange peels, and (D) sugarcane bagasse.

FIG. 2

Examples of agricultural waste: (A) animal manure and (B) dried fish waste.

According to (Pattanaik et al., 2019; Yu et al., 2018), the classification of agricultural waste includes four main categories: crop residue, industrial process waste, livestock waste, and food waste. This classification system ensures the channelling of waste for various utilizations, including fertilizer, feed, industrialization, raw construction materials, energy, and production optimization. Crop stalks and animal dung are considered an agricultural waste from livestock. This form of waste is available in large quantities and biodegradable and environmentally harmless. Agricultural wastes are classified as lignocellulosic materials with cellulose, lignin, and hemicellulose components. Lignin is an aromatic polymer consisting of hydroxyl, carbonyl, and methyl, whereas hemicellulose and cellulose consist of oxygen functional groups such as hydroxyl groups, carbonyl groups, and ether (Dai et al., 2018; Kasaai, 2015).

Pesticides and herbicides used to control pests on farms are also considered agricultural wastes. Their continuous use may lead to accumulation in the soil, where it might harm beneficial microorganisms and cross-fertilization. The water solubility of pesticides and herbicides makes them dangerous due to leaching and entry into food items and the body, which increases the risk of developing Parkinson's disease, cancer, reproductive disorders, and birth defects in humans (Ramírez-García et al., 2019). One of the major agricultural issues arising from fertilizer use is eutrophication (over-enrichment of minerals and nutrients) due to the minerals in fertilizers increasing productivity (Gomiero, 2018; Ramírez-García et al., 2019) (Table 2).

Table 2 Agricultural wastes and resource utilization.

Agricultural wastes	Utilization	Aim
Organic fertilizers: it contains only plant- or animal-based materials such as manure, leaves, and compost	Fertilizer utilization	• Using organic fertilizers to increase the organic content in the soil • Provides the organic minerals for the growth of plants • Improving the structure of the soil • Substituting the fertilizers and chemical pesticides
Crop straws	Feed utilization	• Using the straw to help the animal in the process of absorption and digestion • To reduce greenhouse gases by holding back the burning of straw
Papermaking and the output of polymer panels instead of wood	The industrialization and construction raw materials	• To improve safety, sustainability, effectiveness, productivity, and efficiency
Livestock, rice husk, breeding waste, corncob, and slaughterhouse waste such as carcasses or wastewater	Energy utilization	• Converting agricultural waste into electricity • To reduce acid rain occurrence
Any kind of agricultural wastes	Optimization	• To provide a substrate material for vegetable and mushroom production by using proper treatments

3 Effects of agricultural wastes

Agriculture is a critical factor in human existence and one of the major factors causing environmental degradation. Notably, poor soil health, natural gases (CO_2, N_2, and O_2), water irrigation, and insect pollination without appropriate management are the main factors affecting agricultural productivity. Long-term environmental deterioration can occur due to the intensive and inappropriate management of agricultural wastes, which can also play a role in the deterioration of overall environmental health. Agricultural wastes can be defined as organic byproducts stemming from the agricultural production process that have been discarded by humans. Notably, the classification of agricultural waste can be useful for producing end products that can be useful in daily life, such as biofuel and organic fertilizers (Guerrero et al., 2018). Currently, agricultural waste treatment and the bioprocessing of waste from agricultural environments are strongly recommended due to the subsequent reduction of public health risk, environmental burden, and because biowaste treatment technologies move value into the economy (Nisha et al., 2014). It is important to first examine the types of waste and their composition to highlight that waste consists of different materials. Most of the solid waste from developing countries is organic waste that largely includes food waste (e.g., fruit, vegetable, poultry, and livestock wastes) from agricultural facilities. If we can safely manage this fraction, it can substantially contribute to an improved solid waste management system in which organic waste can be transformed into a broad range of products with high value and very high demand. Agricultural waste is a valuable resource that can be collected separately and treated to generate nanoparticles through very careful synthesis. Notably, plants, garden waste, food industry remnants, fruit seeds, carbohydrates, bacteria, yeasts, and viruses have been used for the production of selenium, silica, titania, quantum dots, magnetite, as well as gold-silver alloy and uraninite nanoparticles (Narayanan and Sakthivel, 2008). In recent years, a great deal of interest has surrounded the environmentally friendly and sustainable synthesis of nanoparticles that require no toxic chemicals or extreme conditions—hence the term ‘green synthesis’. Using this process, agricultural waste can be examined as a prospective and likely biofactory for the budding synthesis of nanoparticles such as gold, silver, silica, platinum, lead, and cadmium (Table 3).

4 Silica nanoparticles

Silica is the most common material on Earth. However, although it has an abundant presence in Earth’s crust, it can also be collected via synthesis from different materials such as agricultural waste. Since silica nanoparticles serve diverse roles in broad areas of industry (e.g., electronic components and drug delivery systems), silica is found in many areas of our lives. Therefore, silica has a projected market value of 8.8.B in 2020 (Surayah and Sapawe, 2019). Silicon is the element found in silica, and this material is usually available in a crystalline or polycrystalline form (also called

Table 3 Countries and their top agricultural wastes.

Country	Waste	Refrences
Australia	Bagasse (30M tons) 2016–2017	Dai et al. (2018)
Germany	Horticulture, perennial crops, viniculture, hop cultivation in agriculture and forestry (62.3%)	Carmona et al. (2013)
Israel	Fruit & Vegetables (565,000 ton) in 2017	Hansen and Cheong (2019)
United Kingdom	Sugar beet, potatoes, and carrots make up more than 50% of 1.6 million tons per annum in 2017	Dai et al. (2018)
Vietnam	Rice husk, sugar beet, maize and cassava	Hai and Tuyet (2010)
Turkey	Barley, wheat, vegetables, fruits.	Akhayere et al. (2019a, 2019b)
Malasiya	Grains, vegetables, straws, rice husk	Duque-Acevedo et al. (2020)
USA.	Shells, vegetables, hops, fruits	Haq and Easterly (2006)
Nigeria	Vegetables, straws, shells, sugar beats, peels	Obi et al. (2016)
China	Grains, vegetables, straws, husk	Duque-Acevedo et al. (2020)

silicon dioxide). Apart from its role in industry, silica is utilized in other areas such as plant growth by helping to remove biotic and abiotic stress (Akhayere et al., 2019a; Akhayere and Kavaz, 2020). Generally, silica is synthesized from chemical sources such as tetramethyl orthosilicate (TEOS) or sodium silicate. However, natural silica sources include sand, flint, or quartz and require high amounts of energy to complete the synthesis process, which is typically very complex. It should also be noted that the high energy and temperature requirements for silica production are usually very expensive, unsustainable, and not environmentally friendly. This problem prompts the provision of an alternative source to produce silica nanoparticles using an easier method that is relatively inexpensive and more sustainable and environmentally friendly. Solid wastes are becoming more problematic to the environment and alternative methods aiming to reduce the amount of global waste represents an emerging area of research. Solid agricultural wastes are an optimal candidate for the production of silica nanoparticles. In agriculture, the production of rice, corn, barley, wheat, sugarcane, and many other products produce solid waste. Therefore, the remaining solid waste material should be used as an alternative source for other important materials. Products that possess high silicon content can be used for the production of silica, which can also solve an environmental problem. Moreover, converting waste materials into useful materials can help to reduce the cost of silica nanoparticle production. Byproducts such as rice husks, wheat straw, BG, and other agriculture wastes can be used to synthesize silica nanoparticles (Surayah and Sapawe, 2019; Kumar et al., 2013). In this study, we introduce an alternative method for the production of NS particles and highlight the importance of agricultural waste in this process.

4.1 Synthesis of nanosilica

Much research has been conducted on the synthesis of NS using various methods. Some of these methods have been modified, while other researchers have used the same methods outlined in the literature. One variation in these methods can include the temperature used. An initial study conducted by (Akhayere et al., 2019b) compared variations in temperature applications to identify an optimal NS synthesis method.

For the experimental synthesis of NS in the present study, BG waste was washed using deionized water. It was then dried at 100°C for 24h. After the drying process, the resulting sample was then powdered into fine particles using a laboratory standard mill operator. The powdered waste was then boiled in HNO_3, (10% *w*/*v*), washed with deionized water, and allowed to dry in an oven for 24h at 60°C. The subsequent sample was then refluxed with 2M HCl for 6h. Thereafter, the sample was heated in a furnace at 400°C, 500°C, 600°C, and 700°C, respectively. Using this process, it was discovered that NS formation was more visible and available at 700°C.

To synthesize NS particles, BG waste was rinsed using distilled water to eradicate soil and other particles and then dried for 24h at 100°C. After obtaining the optimal conditions and temperatures for NS synthesis, these conditions were applied for the synthesis of NS. The BG sample was powdered using a laboratory standard mill operator to obtain fine and smooth samples of BG powder. To obtain pure NS particles, 50g of powdered BG waste was boiled in a solution of 250mL 10% w/v HNO_3 and then allowed to cool. The resulting sample was then flushed with distilled water and then refluxed in 250mL of 2M HCl for 6h. After acid refluxing, the sample was transferred to a furnace where it is heated at 700°C for 5h. The experimental procedure used for NS particle synthesis was developed by (Akhayere et al., 2019a, 2019b). After synthesis, 46.4g of NS was recovered from 50g of BG powder, which provided a 92.4% yield. This validates the synthesis method (Akhayere et al., 2019a) as an NS synthesis method that can be used for the green synthesis of NS from any agricultural waste that is known to contain silicon. Notably, straw or waste should be cut into small pieces and allowed to dry to facilitate easy size reduction. Also, thorough washing using distilled water should be performed with care to ensure the sufficient removal of sand, soil, and visible particles. It should then be dried in the oven for 24h at 100°C. The purpose of drying the straw is to allow for easy grilling in the miller since straws with moisture content usually result in rough and uneven powder. Straws should be ground in a miller to obtain fine powder particles (Akhayere et al., 2019a, 2019b; Akhayere and Kavaz, 2020).

4.2 Characterization of synthesized nanosilica

The characterization of synthesized NS illustrated that this NS synthesis strategy (corrosive treatment and warmth treatment) delivered high measures of silica. Nanomaterials are typically size-ward and display unique physical and compound properties when compared with the majority of the material (at the micro and macro scale). Notably, some or most of the properties are generally unknown until further characterization is completed. Likewise, nano-scale powders were found to limit easily and their temperature decreased when compared to regular micro-scale powders. This extraordinary property can be credited to the high surface area of the nanoparticles, which provides more atom contacts than standard particles. In a study by (Ghorbani et al., 2013; Sarawade et al., 2010), it was observed that the optimal temperature for silica extraction from BG waste was 700°C, which is consistent with the results of this study.

To study the nature of the synthesized particles, characterization was employed. Previous studies accounted for the treatment of waste and biomass with HCl, HNO_3, H_2SO_4, NH_4OH, and NaOH before completing heat treatment, which is an extremely intense method of expelling a high measure of metallic impurities that results in white-colored silica in high quantities. The characterization of synthesized silica nanoparticles was performed by X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray (EDX) analysis as well as Brunauer–Emmett–Teller (BET), Fourier transform infrared (FTIR) and X-ray fluorescence (XRF) spectrometry analysis. To obtain the desired NS with appropriate properties for the applications, extra treatments were tested. The results of our examination affirm the discoveries of previous studies since a gray color was observed in the entirety of untreated ash samples, independent of the temperature applied. Regardless, the treatment of barley husk waste with 2M hydrochloric acid followed by heat treatment was found to give the product a brighter color. Moreover, the XRF results indicated higher measures of SiO_2 particles for the synthesized NS at 700 ˚C. This suggests that applying a reasonable amount of heat as soon as acid treatments are done further removes impurities and increases the amount of pure silica obtained. To obtain the XRD pattern of NS, samples were measured using an X-ray diffractometer (Bruker D8 Advance model). FTIR spectra were carried out using an IR Prestige – 21 (Shimadzu, Japan), which was also used to examine the individual properties of NS particles. Significant peaks were recorded between 400 and 4000 cm^{-1}. The FTIR investigation was accurate in determining the functional groups available in the NS particles. To determine the establishing elements of NS particles, XRF and EDX investigations were performed. The EDX investigation created X-rays by utilizing a standard of the electrons that were centered mainly around the sample in the SEM analysis. However, this makes it sufficiently inadequate to provide a full representation of the entire sample, which created the need for XRF analysis to be conducted. Notably, XRF investigation represents an increasingly proficient strategy for determining the constituent elements of nanoparticles.

According to the XRF results presented in Table 4, it is evident that the amount of silicon oxide available in the examples was 95.5% at 700°C. This further demonstrates that our results correlate with those from previous studies. Potassium, manganese, and phosphorus were observed as a portion of the significant polluting influences found in the treated NS powder. Evidently, high amounts of these compounds may have resulted from the utilization of fertilizers and soil supplements in agricultural activities. The sources of manganese and phosphorus can likewise be linked to the basal media. Phosphate is a significant supplement for some microorganisms. Numerous lignocellulosic organisms degrade lignin via the strategic delivery of an enzyme called manganese peroxidase (MnP) that can depolymerize lignin or convert it into water-soluble products. Notably, the acid treatment helped to expel metal oxides and contaminants from our BG waste.

Table 4 XRF results for raw BG powder and NS.

Composition	Barley	Nano silica
SiO_2	55.0	94.5
CaO	4.0	0.9
MgO	11.9	0.8
K_2O	10.1	1.0
Fe_2O_3	2.5	0.3
P_2O_5	8.6	0.6
Al_2O_3	2.7	0.7
Na_2O	2.0	0.5
B_2O_3	3.2	1.2

The importance of removing impurities during NS synthesis can be understood from the XRF results. Since silica is the major target for all of the chemical elements and oxides present in the agricultural waste, it is important to eliminate these elements and oxides as much as possible because they have no importance in agricultural waste samples. The XRF results indicate that this NS synthesis method was completely effective. When compared to EDX, XRF provides a well-defined expression of the chemical composition of a larger representation of a sample.

The FTIR spectra of the synthesized silica nanoparticles at 700°C temperature calcination are presented in Fig. 4. The domineer peaks suggest the formation of silica. The peak at 1080 cm^{-1} is due to the vibrations that relate to the stretching of silicon bonds (Si-O-Si) for NS synthesized from BG. Moreover, there is a low critical stretching peak in the vibrations of BG. The transmission spectrum for the FTIR of NS synthesized from BG was approximately 400–4000 cm^{-1} (Dang et al., 2018; Liou and Yang, 2011). Also, the peak at 2250 cm^{-1} was related to the C=H bond stretching of an aromatic methyl group. The peak at 800 cm^{-1} showed siloxane bonds (Si-O-Si) framing silica from silicon, which demonstrates that the results acquired in this investigation are compatible with those of past works (Pieła et al., 2020). The SEM images of NS particles presented in Fig. 4 indicate nearly no aggregation in the structures since only well-defined circular and less agglomerated structures are observed. Notably, (Hui et al., 2010; and Zaky et al., 2008) observed permeable and aggregated structures around a portion of the particles. The SEM strategy was utilized to provide information on the size and morphology of the NS particles. The results of AFM analysis indicate that the NS particles had a somewhat round shape on their surface and a lack of pores (Fig. 3).

To further identify the elements present in the samples, EDX investigations were performed (Fig. 4A). The EDX range facilitated the significant elemental study of successful NS synthesis with silicon as the significant segment (showing the most essential peak). A sharp silicon top was observed at approximately 2.0 keV for NS with 88.6% synthesis for silicon. The C and O tops indicate that NS particles contained normal photochemical substances (Stöber et al., 1999; Barisik et al., 2014; Cendrowski et al., 2011). Moreover, the EDX result indicated that NS was synthesized at 700°C,

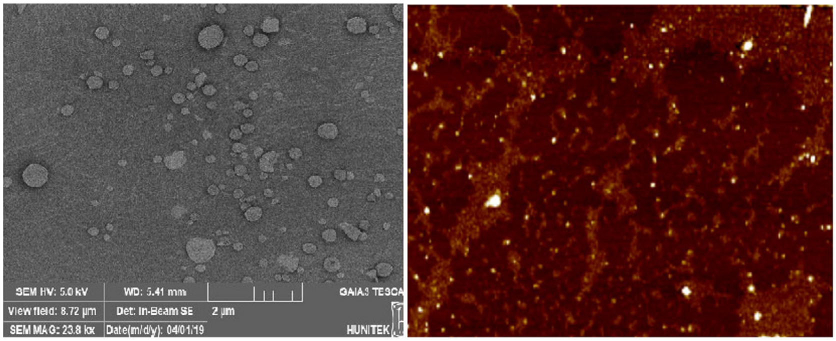

FIG. 3

SEM and AFM images of NS synthesized from BG.

with silicon and oxygen having the most noteworthy top, which conflicts with results from previous research (Tzong and Chen Chen, 2011; Hui et al., 2010) in which NS synthesized from rice husks appeared to have silicon peaks at lower heights. The results presented in Fig. 4A show that the presence of silica is confirmed by the elemental analysis curve. The presence of oxygen in the results showed that the silica was in oxide or dioxide form. Based on these results, the prepared samples resulted in exceptionally pure silica nanoparticles.

The mechanical performance results presented in Fig. 4D feature the elongation limits of NS from (Akhayere et al., 2019a, 2019b; Maurice and Faouzi, 2014). NS showed high performance at 700 °C, which may suggest a lower penchant for the consistency of materials to be tempered at high temperatures. This circumstance (700°C temperature) shows that synthesized NS displayed better mechanical properties at 700°C.

It is classified as a positive property when nanoparticles display high elongation for breakage and can withstand high measures of stress when reused. The NS synthesized from BG displayed a high elongation limit at 700°C. These mechanical properties are similar to the results acquired by Okonkwo et al. (2018).

The synthesis of NS from BG in this research has provided answers to two significant issues: agricultural waste production and the feasible utilization of waste to propose solutions to environmental problems. Additionally, this research provides a solution to address the increasing demand for NS. Synthesized NS particles are a promising material that can be utilized as an adsorbent in the cleanup of wastewater (Akhayere et al., 2020). By obtaining 94.1% pure NS at 700°C, this research presents a viable method of creating highly pure NS.

4.3 Benefits of silica nanoparticles

Silica nanoparticles hold numerous benefits for a wide variety of industries. For example, a procedure that involves coating has been developed to facilitate the modification of poly(urethane) leather coating with NS. Moreover, the removal of cement

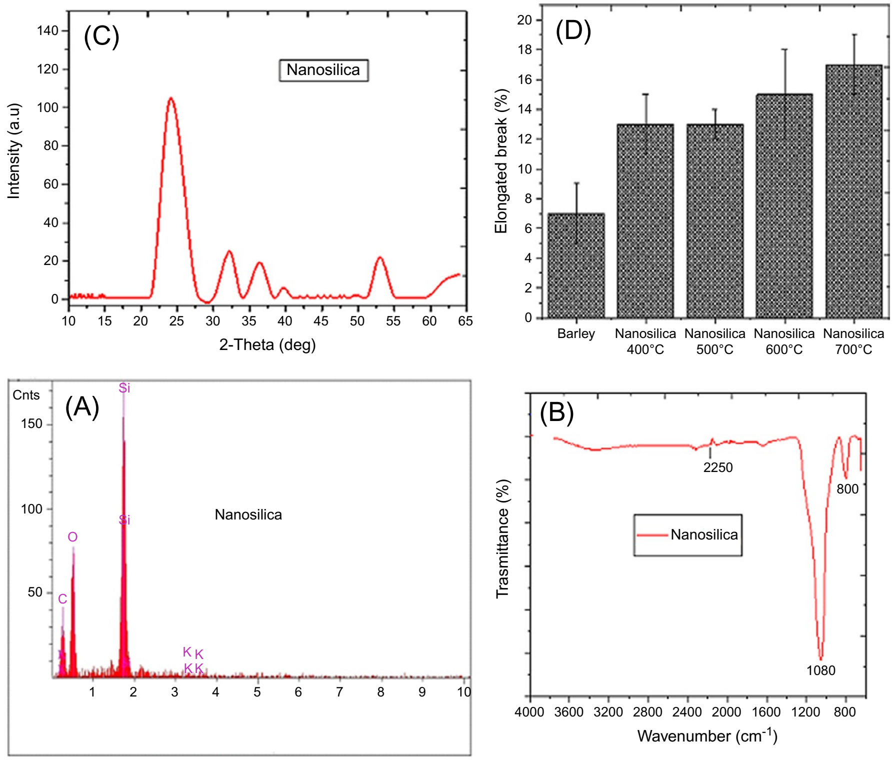

FIG. 4

(A) EDX results for NS, (B) FTIR results for NS, (C) XRD results for NS, and (D) mechanical properties of NS.

and its replacement with other materials such as pozzolanic materials, NS, and nanofillers has been proposed. Furthermore, NS applications for compatibilized nanostructured polymer blends have also been highlighted. Additionally, epoxy resins process structure-property relationships in poly(butylene terephthalate) nanocomposites. As fillers, nanoparticles for high-performance concrete (HPC) have been functionalized FMO alone, while hybrid fillers (e.g., NS and GO) can be used in composites. Nano-sized silica is also used as a food additive in food technology. Silica nanoparticles (SNPs) are also constantly being used as drug delivery systems (DDS) and for biomedical imaging. Notably, it is also possible to incorporate therapeutic and diagnostic agents into the matrix of the silica to improve the stability and dissolution of drug substances in biological systems.

4.4 Nanosilica applications in agriculture and the environment

Based on previous studies, it has been observed that silicon is used by plants to strengthen their cell walls. However, some plants will not survive naturally in nutrient solutions that do not contain silicon, thus making it an essential element for such plants (Younesi and Ghasemi, 2011; Le et al., 2013, Lu and Hsieh, 2012). Usually, nanoparticles exhibit properties that vary from their bulk material, which is a result of their small size, shape organization, and larger surface area. NS also exhibits these properties, which enables it to interact differently within natural environments. These unique properties hold the possibility of great potential in agriculture and the environment when compared to bulk silica. NS greatly impacts plant growth and it has been demonstrated as a useful material for nano pesticides, nano herbicides, and nano fertilizers.

It is speculated that NS particles act as a strengthening agent against fungal, bacterial, and nematode infection, thereby increasing disease resistance. Researchers have also established that an NS layer may cause a reduction in plant transpiration and thus prepares the plants to be more resistant to drought and high levels of temperature and humidity. The unique physicochemical properties of NS particles can be utilized in diverse sectors, including the agricultural and environmental sectors. Among the properties exhibited by NS were heightened mechanical strength, which would allow the agricultural sector to cope with agricultural damage that could occur as a result of climate change and/or abiotic stress (Zulfiqar et al., 2016). According to (Akhayere et al., 2019a), NS particles were shown to be greatly useful as a tool to mitigate heavy metal toxicity in both agricultural water and poultry feeds. Moreover, Akhayere and Kavaz (2020) noted that the crude oil and petroleum contamination of water is the greatest environmental challenge and that synthesized nanoparticles have been highly useful in the removal of petroleum contamination in water. NS particles are also very sustainable since can be reused for four cycles (Fig. 5).

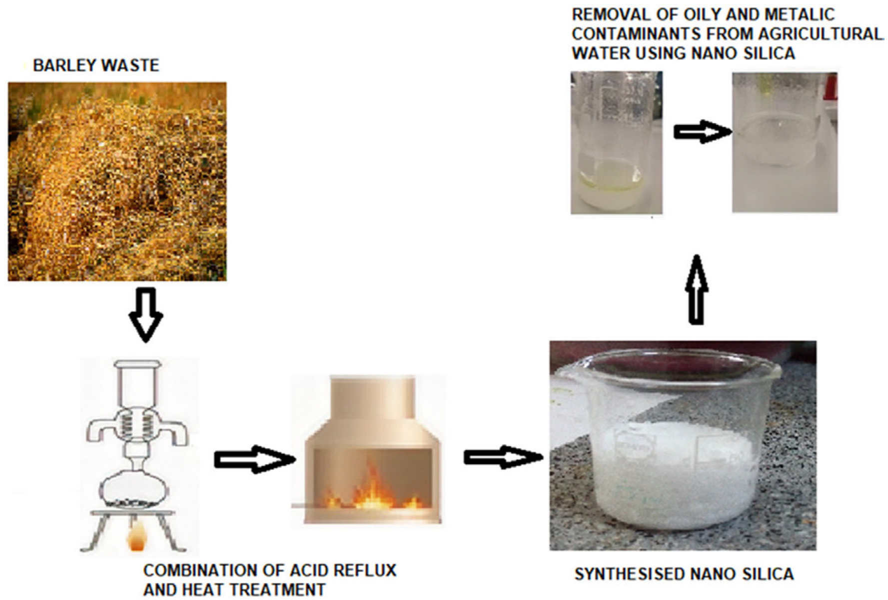

FIG. 5

Synthesis and application of NS.

5 Conclusion

Agricultural waste is no longer merely disposed of by farms worldwide. The advent of renewable uses such waste contributes immensely to modern science and the global environment. Nanotechnology has benefited largely from the contributions from these biological sources of nanoparticles, which have become beneficial in medicine, cosmetics, healthcare, agriculture, and engineering. Different sizes and shapes of nanoparticles of the same material exhibit different physical and chemical properties. Due to these different properties, nanoparticles are used in most fields of science and they also have a wide array of applications in industries that will likely be utilized well into the future. The use of nanoparticles has increased drastically in the past few decades due to cutting-edge scientific research being conducted worldwide. There are now emerging biomedical uses for nanoparticles from biological sources as biomaterials in the development of many healthcare devices and treatments. In this study, we outlined the synthesis of NS from BG waste. Using a combination of acid and heat treatment, the nanoparticles were successfully synthesized via a green process. The synthesized NS was then characterized using XRF, SEM, and EDX analysis as well as FTIR and BET. The importance of material synthesis using a sustainable method cannot be overemphasized since it is not only environmentally friendly but also cost-effective. Previous studies have been conducted on several NS synthesis methods. These methods were typically time- and energy-consuming and also contributed large amounts of CO_2 to the environment. The method applied in this study proven to be environmentally friendly, sustainable, inexpensive, and highly effective. NS was synthesized at 700°C, while characterization of the synthesized nanoparticles was carried out and the mechanical properties were also observed. The results showed that NS has a great resistance to elongation, which suggests that the nanoparticles can withstand a high amount of stress when reused. The vast use of silica nanoparticles in various modern technologies alongside its high adsorption limit makes the synthesis of NS from agricultural waste a potential endeavor. Grain grass also has a treatment framework for the expulsion of metallic polluting impacts, which further improves its quality and properties when utilized as a forerunner for the synthesis of NS. This investigation highlights the novel development of super-filtered nanoparticles from agricultural waste and suggests avenues for the feasible utilization of such waste. The resulting NS particles are a promising material that can be utilized as an adsorbent in the cleanup of wastewater or other contaminated water.

References

Adebisi, J.A., Agunsoye, J.O., Ahmed, I.I., Bello, S.A., Haris, M., Ramakokovhu, M.M., Hassan, S.B., 2019. Production of silicon nanoparticles from selected agricultural wastes. Mater. Today: Proc. 38, 669–674. https://doi.org/10.1016/j.matpr.2020.03.658.

Akhayere, E., Essien, E.A., Kavaz, D., 2019a. Effective and reusable nano-silica synthesized from barley and wheatgrass for the removal of nickel from agricultural wastewater. Environ. Sci. Pollut. R. 26-25, 25802–25813.

Akhayere, E., Kavaz, D., 2020. Nano-silica and nano-zeolite synthesized from barley grass straw for effective removal of gasoline from aqueous solution : a comparative study. Chem. Eng. Commun., 1–17. https://doi.org/10.1080/00986445.2020.1786373.

Akhayere, E., Kavaz, D., Vaseashta, A., 2019b. Synthesizing nano-silica nanoparticles from barley grain waste: effect of temperature on mechanical properties. Pol. J. Environ. Stud. 28-4, 2513–2521.

Akhayere, E., Vaseashta, A., Kavaz, D., 2020. Novel magnetic nano silica synthesis using barley husk waste for removing petroleum from polluted water for environmental sustainability. Sustainability (Switzerland) 12 (24), 1–16. https://doi.org/10.3390/su122410646.

Anuar, M.F., Fen, Y.W., Zaid, M.H.M., Matori, K.A., Khaidir, R.E.M., 2020. The physical and optical studies of crystalline silica derived from the green synthesis of coconut husk ash. Appl. Sci. 10 (6), 2128.

Barisik, M., Atalay, S., Beskok, A., Qian, S., 2014. Size-dependent surface charge properties of silica nanoparticles. J. Phys. Chem. C 118, 1836–1842.

Bogush, G.H., Tracy, M.A., Zukoski, C.F., 2013. Preparation of monodisperse silica particles: control of size and mass fraction. J. Non-Cryst. Solids 104, 95–106.

Buzea, C., Pacheco, I.I., Robbie, K., 2007. Nanomaterials and nanoparticles: sources and toxicity. Biointerphases 2 (4), 17–71.

Carmona, V. B., Oliveira R. M., Silva W. T. L., Mattoso L. H. C, and Marconcini J. M., 2013. Nano silica from rice husk: extraction and characterization. Ind. Crop. Prod. 43, 291–296.

Cendrowski, K., Chen, X., Zielinska, B., Kalenczuk, R.J., Rümmeli, M.H., Büchner, B., Klingeler, R., Borowiak-Palen, E., 2011. Synthesis, characterization, and photocatalytic properties of core/shell mesoporous silica nanospheres supporting nanocrystalline titania. J. Nanopart. Res. 13, 5899–5908.

Chang, T.M.S., 2019. Artificial cell evolves into nanomedicine, biotherapeutics, blood substitutes, drug delivery, enzyme/gene therapy, cancer therapy, cell/stem cell therapy, nanoparticles, liposomes, bioencapsulation, replicating synthetic cells, cell encapsulation/scaffold. Artif. Cells, Nanomed. Biotechnol. 47, 997–1013.

Chen, H.F., Wang, C., Zhang, Y., Shi, G., Jin, S., Yuan, S., 2010. Preparation of nano-silica materials: the concept from wheat straw. J. Non-Crystalline Solids 356 (50–51), 2781–2785.

Chugh, H., Sood, D., Chandra, I., Tomar, V., Dhawan, G., Chandra, R., 2018. Role of gold and silver nanoparticles in cancer nano-medicine. Artif. Cells, Nanomed. Biotechnol. 46, 1210–1220.

Dai, Y., Sun, Q., Wang, W., Lu, L., Liu, M., Li, J., Zheng, W., 2018. Utilizations of agricultural waste as adsorbent for the removal of contaminants: a review. Chemosphere 211, 235–253.

Dang, N., Nguyen, T., Phan, T., Tran, H., Dang, P., Nguyen, H., 2018. Synthesis of silica nanoparticles from rice husk ash. Sci. Technol. Development J. 20 (K7), 50–54.

Duque-Acevedo, M., Belmonte-Ureña, L.J., Cortés-García, F.J., Camacho-Ferre, F., 2020. Agricultural waste: review of the evolution, approaches and perspectives on alternative uses. Global Ecol. Conservation 22.

Fatma, A., Saudi, M., Ahmed, B., 2014. Nano silica and SiO_2/$CaCo_3$ nanocomposite prepared from semi burned rice straws ash as modified paper making filter. Arab. J. 234-239.

Ghorbani, F., Habibollah, Y., Mehraban, Z., Çelik, M.S., Ghoreyshi, A.A., Anbia, M., 2013. Preparation and characterization of highly pure silica from sedge as agricultural waste and its utilization in the synthesis of mesoporous silica MCM-41. J. Taiwan Inst. Chem. Eng. 44 (5), 821–828.

Gomiero, T., 2018. Agriculture and degrowth: state of the art and assessment of organic and biotech-based agriculture from a degrowth perspective. J. Clean. Prod. 197, 1823–1839.

Guerrero, A.B., Ballesteros, I., Ballesteros, M., 2018. The potential of agricultural banana waste for bioethanol production. Fuel 213, 176–185.
Hai, H.T., Tuyet, N.T.A., 2010. Benefits of the 3R Approach for Agricultural Waste Management (AWM) in Vietnam. Under the Framework of joint Project on Asia Resource Circulation Policy Research, Institute for Global Environmental Strategies.
Hansen, C.L., Cheong, D.Y., 2019. Agricultural waste management in food processing. In: Handbook of Farm, Dairy and Food Machinery Engineering. Academic Press, pp. 673–716.
Haq, Z., Easterly, J.L., 2006. Agricultural residue availability in the United States. Appl. Biochem. Biotechnol. 129 (1–3), 3–21.
He, X., Deng, H., Min, H., Wang, H., 2019. The current application of nanotechnology in food and agriculture. J. Food Drug Anal. 27, 1–21.
Hui, C., Fen, W., Congyum, Z., Yuanchang, S., Guiyum, J., Shiling, Y., 2010. Preparation of Nano silica materials, the concept from wheat straw. J. Non-Cryst. Solids 356, 2781–2785.
Imoisili, P.E., Ukoba, K.O., Jen, T.C., 2020. Green technology extraction and characterization of silica nanoparticles from palm kernel shell ash via sol-gel. J. Mater. Res. Technol. 9, 307–313.
Kasaai, M.R., 2015. Nanosized particles of silica and its derivatives for applications in various branches of food and nutrition sectors. J. Nanotechnol. 2015. https://doi.org/10.1155/2015/852394, 852394.
Kumar, A., Chisti, Y., Chand, U., 2013. Synthesis of metallic nanoparticles using plant extracts. Biotechnol. Adv. 31, 346–356.
Le, V.H., Thuc, C.N.H., Thuc, H.H., 2013. Synthesis of silica nanoparticles from Vietnamese Rice husk by sol-gel method. Nanoscale Res. Lett. 8, 58.
Liou, T.H., Yang, C.C., 2011. Synthesis and surface characteristics of nano silica produced from alkali-extracted rice husk ash. Mater. Sci. Eng. B 176, 521–529.
Lu, P., Hsieh, Y.L., 2012. Highly pure amorphous silica Nano-Disks from Rice straw. Powder Technol. 225, 149–155.
Mathew, J., Joy, J., George, S.C., 2019. Potential applications of nanotechnology in transportation a review. J. King Saud Univ. Sci. 31, 586–594.
Maurice, A.R., Faouzi, H., 2014. Synthesis and characterization of amorphous silica nanoparticles from andalous silica using catione surfactants. J. Metals, Mater. Minerals 24, 37–42.
Naddaf, M., Kafa, H., Ghanem, I., 2020. Extraction and characterization of Nano-silica from olive stones. SILICON 12 (1), 185–192.
Narayanan, K.B., Sakthivel, N., 2008. Coriander leaf mediated biosynthesis of gold nanoparticles. Mater. Lett. 62 (30), 4588–4590. https://doi.org/10.1016/j.matlet.2008.08.044.
Nisha, S.N., Aysha, O.S., Rahaman, J.S.N., Kumar, P.V., Valli, S., Nirmala, P., Reena, A., 2014. Lemon peels mediated synthesis of silver nanoparticles and its antidermatophytic activity. Spectrochim. Acta - A: Mol. Biomol. Spectrosc. 124, 194–198.
Obi, F.O., Ugwuishiwu, B.O., Nwakaire, J.N., 2016. Agri Wastes 35 (4), 957–964.
Okonkwo, E.C., Essien, E.A., Akhayere, E., Abid, M., Kavaz, D., Ratlamwala, T.A.H., 2018. Thermal performance analysis of a parabolic trough collector using water-based green-synthesized nanofluids. Solar Energy 170, 658–670. https://doi.org/10.1016/J.SOLENER.2018.06.012.
Pattanaik, L., Pattnaik, F., Saxena, D.K., Naik, S.N., 2019. Biofuels from agricultural wastes. In: Second and Third Generation of Feedstock. Elsevier, pp. 103–142.
Pieła, A., Żymańczyk-Duda, E., Brzezińska-Rodak, M., Duda, M., Grzesiak, J., Saeid, A., Mironiuk, M., Klimek-Ochab, M., 2020. Biogenic synthesis of silica nanoparticles from corn cobs husks. Dependence of the productivity on the method of raw material processing. Bioorg. Chem. 103773.

Ramírez-García, R., Gohil, N., Singh, V., 2019. Recent advances, challenges, and opportunities in bioremediation of hazardous materials. In: Phyto Management of Polluted Sites, pp. 517–568.

Raut, B.K., Panthi, K.P., 2019. Extraction of silica nanoparticles from rice husk ash (rha) and study of its application in making composites. J. Nepal Chem. Soc. 40, 67–72.

Rovani, S., Santos, J.J., Corio, P., Fungaro, D.A., 2019. An alternative and simple method for the preparation of bare silica nanoparticles using sugarcane waste ash, an abundant and despised residue in the Brazilian industry. J. Braz. Chem. Soc. 30 (7), 1524–1533.

Sapawe, N., 2018. Production of silica from agricultural waste. Arch. Org. Inorg. Chem. Sci. 3, 2.

Sarawade, P.B., Kim, J.K., Hilonga, A., Kim, H.T., 2010. Preparation of hydrophobic mesoporous silica powder with a high specific surface area by surface modification of a wet-gel slurry and spray-drying. J. Power Tech. 197, 288–294.

Seyed, N.A., Ahmad, R.D., Amir, J., 2013. Synthesis and characterization of LTA Nano zeolite using barley husk silica. Mater. Res. Bull. 48, 1753–1759.

Sharma, C.K., Sharma, M., Panwar, A., 2017. Biomedical applications of green synthesized nanoparticles. In: Communication and Computing Systems - Proceedings of the International Conference on Communication and Computing Systems, ICCCS 2016.

Silva, G.A., 2004. Introduction to nanotechnology and its applications to medicine. Surg. Neurol. 61, 216–220.

Singh, S.P., Endley, N., 2020. Fabrication of nano-silica from agricultural residue and their application. In: Nanomaterials for Agriculture and Forestry Applications. Elsevier, pp. 107–134.

Soemphol, W., Charee, P., Audtarat, S., Sompech, S., Hongsachart, P., Dasri, T., 2020. Characterization of a bacterial cellulose-silica nanocomposite prepared from agricultural waste products. Mater. Res. Express 7 (1), 015085.

Soni, M., Mehta, P., Soni, A., Goswami, G.K., 2018. Green nanoparticles: synthesis and applications green nanoparticles: synthesis and applications. IOSR J. Biotechnol. Biochem. 4 (3), 78–83.

Stöber, W., Fink, A., Bohn, E., 1999. Controlled growth of monodisperse silica spheres in the micron size range. J. Colloid Interface Sci. 26, 62–69.

Surayah, O., Sapawe, N., 2019. Waste material as an alternative source of silica precursor in silica nanoparticle synthesis – a review. Mater. Today: Proceedings 19, 1267–1272.

Tzong, H.L., Chen Chen, Y., 2011. Synthesis and surface characteristics of Nano silica produced from alkali extracted Rice husk ash. Mater. Sci. Eng. 176, 521–529.

Vial, S., Reis, R.L., Oliveira, J.M., 2017. Recent advances using gold nanoparticles as a promising multimodal tool for tissue engineering and regenerative medicine. Curr. Opin. Solid State Mater. Sci. 21, 92–112.

Wang, W., Lu, K.J., Yu, C.H., Huang, Q.L., Du, Y.Z., 2019. Nano-drug delivery systems in wound treatment and skin regeneration. J. Nanobiotechnol. 17, 1–15.

Wee, N.N.A.N., Samsuri, A., Latif, M.N., Yunus, W.M.Z.W., 2019. Synthesis of silica from rice husk using acid pretreatment and its characterization. In: AIP Conference Proceedings. Vol. 2068, No. 1. AIP Publishing LLC, p. 020068.

Younesi, H., Ghasemi, Z., 2011. Preparation and characterization of nanozeolite NaA from rice husk at room temperature without organic additives. J. Nanomater. 2011, 8. https://doi.org/10.1155/2011/858961.

Yu, H., Park, J.Y., Kwon, C.W., Hong, S.C., Park, K.M., Chang, P.S., 2018. An overview of nanotechnology in food science: preparative methods, practical applications, and safety. J. Chem. 2018. https://doi.org/10.1155/2018/5427978, 5427978.

Zaky, R., Hessien, M., El-Midany, A., Khedr, M., Abdel-Aal, E., ElBarawy, K., 2008. Preparation of silica nanoparticles from semiburned rice straw ash. Powder Technol. 185, 31–35.
Zhou, Y., Tian, Y., Zhang, L., Liu, Y., Feng, L., 2018. Application of novel biochars from maize straw mixed with fermentation wastewater for soil health. In: Sustainable Technologies for the Management of Agricultural Wastes. Springer, Singapore, pp. 25–43.
Zulfiqar, U., Subhani, T., Husain, S.W., 2016. Synthesis and characterization of silica nanoparticles from clay. J. Asian Ceramic Soc. 4 (1), 91–96.

Further reading

Khatami, M., Alijani, H., Nejad, M., Varma, R., 2018. Greener synthesis using natural plant products nanoparticles. Appl. Sci. 8, 411.