Silica from Natural Sources: a Review on the Extraction and Potential Application as a Supporting Photocatalytic Material for Antibacterial Activity

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Abstract
Silica has become a popular material due to its high abundance and many advantages in various fields. This material can be produced synthetically and extracted from nature with resultant advantages in the application of green production. Therefore, this article deals with the form of silica extracted from quartz sand, leaves, and agricultural wastes found in nature. The extraction process from various sources would be described using thermal, biological, and chemical methods. This review also highlights the potential application of silica as a photocatalytic antibacterial-supporting material and discusses its role in increasing the effectiveness of the process. The discussion was continued with research on this procedure, where synthetic auxiliary materials were compared to the extracted silica. Furthermore, results obtained indicated that the extracted material had very good potential as a photocatalyst adjunct in its application in the antibacterial field.

Keywords
Antibacterial, Extraction Method, Silica, Support Material, Photocatalyst

1. INTRODUCTION
Silica (SiO₂) which is a constituent of silica sand and mining products, is the most occurring oxide on the planet (Lutgens and Tarbuck, 2000) after oxygen in terms of its composition (Matichenkov and Calvert, 2002). The formation of silica sand is due to the weathering process of rocks containing quartz and feldspar (Bernstein and Carpi, 2015). In addition, silicones can be produced in amorphous and crystalline forms. The center of this structure is developed from atoms containing four oxygen fused to a tetrahedral angle site close to the silicon molecule by covalent bonds (Bernstein and Carpi, 2015; Julia, 2002). Consequently, this tetrahedral structure bonds with each other and forms a large silica matrix (Salih, 2011).

The bond angle around O-Si-O is 109.5°, which is a tetrahedral angle and varies in length between 1.54-1.69 A. Meanwhile, the oxygen bridge (Si-O-Si) gives silica its unique properties resulting in a very wide industrial application due to the different shapes and compositions of silica (Rayner-Canham and T., 2015).

Most silica is currently obtained from the extraction of natural materials such as waste from agriculture which is usually disposed of or burned without prior treatment and can cause pollution (Ferronato and Torretta, 2019). The large amount of waste produced each year from harvesting due to the increase of agricultural products to fulfill human needs is cause for great concern. Therefore, to reduce this problem, researchers have worked to put a use value on agricultural waste. This is widely used as a source of silica extract for further application (Rayner-Canham and T., 2015; Liang et al., 2020). The increase in waste is influenced by increased production of agricultural materials. FAO statistics show a significant increase in agricultural products each year.

There have been many discussions regarding the function-
alization of silica, especially in the field of renewable energy. In the industrial world, they are found in tires, rubber, glass, cement, concrete, ceramics, textiles, paper, cosmetics, electronics, paints, films, toothpaste, health, and other industries are widely used (Setyoningrum et al., 2020). This review article will discuss more intensely the function of silica as a support material in the field of photocatalysis which has been proven to improve its performance and potential as antibacterial agents. Furthermore, this article discusses extraction methods and sources of silica from waste and its characteristics as a support material. The discussion functions to improve the study of silica sources and their use as a support material. Also, it summarizes the optimal results from the research on silica producers obtained from the nature of fabrication and its relevance in various fields.

2. RESULTS AND DISCUSSION

2.1 Source of Silica

Silica can be manufactured synthetically and extracted from the abundant amounts found in nature. This compound is also a part of the prospective minerals selected for development and application in various industrial fields (Kim et al., 2016; Lee and Yoo, 2016; Elma et al., 2020). Various studies have been conducted using natural materials, such as beach sand and agricultural waste to produce high purity silica extracts. This beach sand has a more dominant silica concentration than other oxides (Ismail et al., 2020; Eddy et al., 2015; Okereafor et al., 2020). Several studies have shown the results of high purity silica extraction in different sand extraction areas.

2.1.1 Sand

Mining products, including silica sand, are widely used in various industries, and this material is commonly known as quartz or white sand is usually found in the lowlands. It is produced from the weathering process of rocks which contain the main minerals, such as quartz and feldspar (Bernstein and Carpi, 2015). The availability of silica sand in Indonesia is very abundant (Ishmah et al., 2020), reaching 55.80-99.87 % in 2017. Therefore, this provides benefits from various sectors in increasing its use-value (Sumarno, 2015). This material is not found in pure form but as a mixture, hence necessitating an extraction process first to obtain pure silica. Extraction is a process of separating substances from the mixture (Eddy et al., 2015). This substance has various uses in the industrial sector and usually acts as a doping or composite support or additional raw material for the manufacture of various materials. These include cement, ceramics, tiles, cast/precast, paint, cosmetics, refractory bricks, petroleum or mining, hardener in the rubber industry, and others (Madina et al., 2017).

Ishmah, 2019 succeeded in extracting silica from the sand on the beaches of Bengkulu, Indonesia. This research produced amorphous silica with a very high purity of 97.3 % and was applied as a supporting photocatalyst material to remediate phenol waste. Setyoningrum et al., 2020 also succeeded in adding to the economic importance of determining silica based on its purity and the extract used was obtained from the Kokap area, Kulonprogo. According to the experimental results, the particle size reduced with an increased conversion while the increase in the amount of extracted silica was directly proportional to the NaOH concentration. Consequently, silica gel was the product generated from this research.

2.1.2 Agricultural Waste

- Rice Husk

Silica exists as nanoparticles and is the major inorganic constituent of rice husks (85-95 %) which is a derivative obtained from rice milling and husk ash through burning in a distinct boiler (Hossain et al., 2018). The ash form is an agricultural waste, hence various studies including the extraction of trapped silica, have been conducted to promote its economic value.

Klankaw et al., 2012 extracted SiO₂ from rice husks coated together with TiO₂ on a thin film, which was prepared on a sliding glass by using the dipping method. The best function for the photocatalytic decolorization of MB dye with a total efficiency of 81 % was delivered by a thin film that consists of SiO₂:TiO₂ with values of 20:80. Furthermore, biogenic SiO₂ with high purity and surface area have been previously extracted from rice husks to prepare SnO₂/SiO₂ composites. The resulting silica has an amorphous form and is obtained from the acid pathway method, where inefficient SiO₂ extraction produces high purity biogenic SiO₂ on the nanometer
scale (Ferreira et al., 2015).

The chemical method for synthesizing amorphous silica nanoparticles from burnt rice straw was conducted by hydrolysis with acid-base treatment. In this case, the resulted silica particles ranged in size from 60–90 nm and obtained a total yield of 76.43 % through physiological observations (Uda et al., 2021). Furthermore, research involving the extraction of silica has been conducted through an environmentally friendly chemical treatment approach and those with a yield of 98.08 ± 0.11 % were extracted from RHA. The characterization studies indicated that the difference between the commercial-grade silica (19.49 ± 13.03 nm) and mean particle size of the extracted SiO₂-NPs (17.71 ± 7.53 nm) was insignificant (Nayak and Datta, 2021). According to Motlagh et al., 2020, extract silica and activated carbon simultaneously formed the two value-added chemical products from rice waste, where the results indicated that more silica was obtained from the straw (83 %) than from the husks (66 %).

- Fly Ash Waste
Fly ash is an intricate derivative obtained from burning a variety of mineral coals (Yao et al., 2015), with an SiO₂ content of 45–60 % (Wang et al., 2020). This material is considered to be less dense than cement and to contain spherical vitreous particles with sizes ranging from 8 to 20 mm. Besides, the synthesis of mesoporous silica, fly ash has attracted attention because of the characteristics of its resulting material (Miricioiu and Niculescu, 2020; Mehmood et al., 2017) which is rich in metal oxides, mainly silica. This substance can harm the environment by interacting with water and soil which causes groundwater pollution with heavy metals, such as Cr, V, Ni, Cd, and Pb (Miricioiu and Niculescu, 2020). In addition, silica-rich fly ash acted as renewable source material for silica synthesis (Yadav et al., 2020).

Furthermore, nanoporous substances, such as zeolite or mesoporous silica are produced from fly ash which is used as a possible precursor due to its high silica content. These mesoporous substances, such as MCM-41 or SBA-15, are obtained from materials with a great deal of silica content and used to remove or capture CO₂ from emissions or for wastewater treatment (Miricioiu and Niculescu, 2020).

Research conducted by Yadav et al., 2020 used a simple, efficient, and cost-effective alkaline fusion process for the production of nano-silica which measured 10 to 60 nm in spherical and aggregate shapes from fly ash-based tiles. Several studies aimed to minimize the danger of environmental ash stockpiles by reusing fly ash from biomass power plants to produce silica material. According to a previous study, the synthesized amorphous silica was successful with a purity of 44.41 % to 93.63 % and a yield of 20.45 %. The size of the agglomerate particles ranged between 380.9 nm to 178.8 nm, when the ash was converted into spherical silica (Liang et al., 2020).

- Cassava Waste
Multiple studies have been performed to increase the economic value of cassava waste because the result obtained is usually disposed of carelessly or burned (Adebisi et al., 2018; Adebisi et al., 2019; Farirai et al., 2021). Studies on the amorphous silica nanoparticles from the cassava periderm were successfully conducted using the modified sol-gel method. These results showed that the ethylene glycol-modified silica was less agglomerated with a higher yield and a lower particle size. In this study, silica nanoparticles were used as a precursor for the synthesis of silicon nanoparticles (Adebisi et al., 2017).

- Palm Ash Waste
Also, oil palm ash and other agricultural wastes are used in the synthesis of silica (SiO₂) as a renewable source of energy (Imoisili et al., 2020; Razak et al., 2019; Faizul et al., 2014; Faizul et al., 2013; Pa et al., 2016). The result, in this research, showed that silica with a purity of more than 90 % could be extracted from palm ash (Pa et al., 2016).

- Palm shells
Silica nanoparticles obtained through the use of the modified sol-gel extraction technique have been successfully formed from palm shell ash. Furthermore, the microstructural analysis showed that the unit size of the extracted materials was between 50–98 nm, with a very high specific surface area of 438 m² g⁻¹ (Imoisili et al., 2020).

- Coconut Husk Ash
Generally, coconut husks are disposed of as waste material, either by combustion or in a waste disposal site while its fruit is used globally as a source of nutrition, drink, or other products. Therefore, this material causes various environmental and health problems without proper processing or disposal methods (Anuar et al., 2020).

Research has been conducted to explain the synthesis, optical and physical properties of silica obtained from coconut coir waste, and its possible use in optical applications. Furthermore, prior to the utilization of the green synthesis method in the extraction of silica from ash after treatment with sulfuric acid, this material was burned at a temperature between 500–700 °C to produce coconut coir ash (CHA). Subsequently, the weight of the coconut husk particle size distribution was reduced from 200–750 nm to 200–410 nm at temperatures ranging between 221–360 °C (Anuar et al., 2020).

- Olive Seed
Investigation of silica extract from olive seeds using the alkaline leaching extraction method conducted by Naddaf et al., 2020 was successful. According to the results, the extracted powder consisted of 15–68 nm porous nanoscale silica with several hundreds of nanometer-sized particles. The resulting material which has been used for biological applications was amorphous silica which turned into a crystalline phase known as cristobalite, after sintering at 900 °C.

Silica extraction from natural materials and agricultural waste byproducts are much in demand because it provides advantages compared to other conventional methods, the advantages of this method include simple, lower costs, higher safety margins and lack of pollution produced during the synthesis process (Mor et al., 2017).
2.2 Characteristic of Silica
Silicon dioxide or silica (Figure 2) is the most abundant oxide compound form of silicon on earth with the chemical formula SiO$_2$. The center of this structure is developed from atoms containing four oxygen fused to a tetrahedral angle site close to the silicon molecule by covalent bonds (Bernstein and Carpi, 2015; Julia, 2002). Consequently, this tetrahedral structure bonds with each other and forms a large silica matrix (Salh, 2011).

Silica material has a pore size between 5-3000 Å and can either be amorphous or quartz, which is more stable as shown in Figure 3. The bond angle around O-Si-O is 109.5° which is a tetrahedral angle and varies in length between 1.54-1.69 Å. The angle of the Si-O-Si (siloxane) bond varies between 120-180° which is influenced by changes in bond energy, hence allowing it to rotate freely and easily and to form amorphous or irregular structures (Julia, 2002; Yao et al., 2015; Sun et al., 2017).

This oxygen bridge (Si-O-Si) and its different shapes and compositions give silicon dioxide its unique properties. In addition, the industrial application of silica is very wide (Rayner-Canham and T., 2015) due to these physical properties (Haynes, 2011):

- Chemical formula : SiO$_2$
- Molar mass : 60.08 g/mol
- Density : 2.648 ($\alpha$-quartz), 2.196 (amorphous) g·cm$^{-3}$
- Melting point : 1,713 °C (amorphous)
- Boiling point : 2,950 °C
- Magnetic susceptibility : -29.6·10$^{-6}$ cm$^3$/mol

Silica is naturally crystalline, hence it is necessary to synthesize it by certain methods to obtain an amorphous form (Julia, 2002; Yao et al., 2015). The crystalline form of silica is quite diverse and the shapes are known as polymorphs.

2.3 Extraction Methodologies
The silica extraction method is concerned with removing impurities or unexpected substances from the natural materials used. This substance can be extracted using several methods, including thermal and microbial processing (Uda et al., 2021).

2.3.1 Thermal Method
The thermal method involves heating in the form of calcination or pyrolysis. According to Venkateswaran et al., 2018, the extraction of silicon from rice husks was conducted through a thermal method that functions to remove most of the organic substances. In this study, the heating temperature was varied to see its effect on the percent Si obtained. Furthermore, after dehydration with sodium hydroxide solution, the acid-treated rice husks are used for the direct extraction of silica. Subsequently, silica is obtained from the resultant sodium silicate through the addition of an appropriate amount of mineral acid for 5–6 hours to acquire the rice husk ash (RHA) by RH pyrolysis at temperatures between 500 °C to 850 °C in a muffle furnace. The results showed that the percentage of silicon obtained increases with the calcination temperature, where absorption peaks and wavelengths of around 300–310 nm are present at 850 °C. The results in this case, where the silicon powder had a pure phase formation, high purity, and good absorption peak were better than other investigations.

2.3.2 Biological methods
This method makes use of living things such as animals, bacteria, and fungi. Estevez et al., 2009 reported the use of California worms to extract silica from rice husks which were moistened and digested in their mouth using enzymatic fluids containing lipase, amylase, trypsinogen, etc. However, the structure of silica, which can only be completely dissolved with hydrogen hydrofluoric acid, makes the enzymes unable to react with silica. The rice husk enters the pharynx which is located in ring 6, crushing and sucking the food and sending it to the oesophagus where the pH is neutralized using CaCO$_3$. In-ring 20, the intestine begins the process of digestion and absorption, during which the strong action of the muscles in the intestinal wall destroys food while the endocrine, pharyngeal and calciferous glands provide enzymes, such as amylases and proteases that produce degradation of organic matter. However, the mechanical work is produced by the movement of the muscles in the intestines of the worms grinding the fine silica. The
humus is dried at room temperature, pulverized to 210 μm, and stored for a week in a secure plastic bag. Subsequently, this is calcined at different temperatures and the undigested sample rinsed with distilled water until a neutral pH was obtained and dried. This research produced high purity silica with nano-size distribution and spherical shape.

2.3.3 Chemical method
This method involves chemicals such as acids, bases, and other agents which are used to remove impurities and increase the purity of the silica contained in it. Apart from this, acid leaching can convert impurities into ions that are capable of dissolution (Vaibhav et al., 2015). The effect of acids in removing metal impurities from rice husks was demonstrated through the use of HCl, which was more effective when compared to H₂SO₄, and HNO₃ (Chakraverty et al., 1988).

According to Gao et al., 2019, the silica extraction from rice husks was conducted through chemical methods, where HFA was dissolved with 15 % (1:4.5) sodium hydroxide solution by weight and stored at 100 °C for 2 hours, then filtered. Furthermore, NaOH was added to separate the silica from impurities and to form a sodium silicate solution, which was transferred to hydrogel silica by adjusting the pH to 6 or 7 with the HAc solution through an ultrasonication assisted process. Consequently, the effect of pH on silica purity was produced and the powdered SiO₂ was obtained after dehydrogenation gelation and drying. Kamath and Proctor, 1998 reported the solubility of amorphous silica to be low at pH <10, hence a more alkaline pH is excellent in producing a material of high purity. The recent extensive application of this form of nano-silica in areas, including chromatography, pharmaceuticals, adsorbent materials, electronic components, drug delivery systems, catalysts, and dyes has resulted in its increasingly high demand.

Several studies were conducted using chemical methods which are widely used due to their simplicity when compared with other processes. Adebisi et al., 2017 also used this method to obtain nano-sized silica from the cassava periderm using three different routes. The acid treatment pre and post calcination are effective in reducing or removing soluble metal impurities. Furthermore, silica obtained from the pre-treatment, post-calcination process, and the ethylene glycol-modified sol-gel method was discovered to produce particles of higher purity that were in the nano range from 3.12 to 50.75 nm (Adebisi et al., 2017). Table 1 shows current research in silica extraction from natural materials.

The extraction of silica from natural materials produces different particle sizes. Particle size and size distribution are the most important characteristics of the nanoparticle system due to its influence on the properties of the material and the stability of particles. Nanoparticle-sized silica (1-100 nm) provides better activity. This is because nanoparticles have a relatively higher intracellular absorption compared to microparticles and are available for a wider range of biological targets due to their small size and relative mobility. In addition, smaller particles have a larger surface area and nanoparticle surface characteristics can be easily modified to produce certain properties (Li et al., 2020). Based on this, extraction methods that take into account the size of nanoparticles, eco-friendly extraction and can be widely used in most natural materials or waste is a chemical method. This method is quite simple and relatively inexpensive as well as produces good results. Nonetheless, this method needs to be adapted to the 12 principles of green chemistry to support eco-friendly and harmless for the surrounding environment.

2.4 Extract Silica as a Supporting Material in Antibacterial Photocatalysis
Silica has various applications, which include its role as a supporting material for a photocatalyst in the photocatalytic process. This procedure is a combination of chemical reactions that requires light elements and photocatalysts to accelerate chemical transformations (Effendy, 2010). This compound is generally a semiconductor because it has a bonding and an antibonding band separated by bandgap energy (Jal et al., 2004; Holleman A. and Wiberg, 2001). Figure 4 demonstrates this phenomenon in semiconductor materials.

Table 2 shows the difference particle size in the extraction product. In photocatalyst, particle size become an important factor that is able to influence the activity of photocatalysts. The surface structure and shape of crystals can be affected by
The increase in particle size causes a decrease in the rate of with the appropriate energy, causing electrons (e⁻) in the va-

cence band to be excited towards the conduction band and leaving a positive hole which is abbreviated as h⁺, in the va-

cence band.  

- The e⁻ and h⁺ pairs will undergo recombination, either on the surface or in the bulk particles. Subsequently, the hole (h⁺) will initiate an oxidation reaction and the electron (e⁻) will initia-

te a chemical reduction reaction around the semiconductor surface.

- Products resulting from a redox reaction with the environ-

ment will form radicals that have high oxidation-reduction power.

Compounds that primarily kill or retard the development of bacteria, without generally poisoning the adjacent tissue possess antibacterial action (Hajipour et al., 2012). Its mechanisms of action include inhibiting cell wall growth, resulting in changes in cell membrane permeability, inhibiting protein synthesis, and inhibiting cell nucleic acid synthesis (Ferronato and Torretta, 2013). The mechanism behind nanoscale activity in bacteria has

| Starting material | Method | Products | Particle size (nm) | References |
|-------------------|--------|----------|-------------------|------------|
| Sand              | Chemical | Silica | -                 | (Triwikantoro D and Zainuri, 2015) |
|                   | Chemical | Silica | Pore Size 15-68 nm | (Vaibhay et al., 2015) |
|                   | Chemical | SiO₂ | Macrometer        | (Ishmah, 2019) |
|                   | Chemical | Silica Gel | 150 mesh | (Ismaiil et al., 2020) |
|                   | Sol-gel | SiO₂ | ~200 nm           | (Klankaw et al., 2012) |
|                   | Chemical | Silica Gel | 150 mesh | (Seyyoningrum et al., 2020) |
| Rice Husk         | Biotransformation | Silica | 132-254 nm        | (Espindola-Gonzalez et al., 2010) |
|                   | Acid Pre-treatment | Silica | 6 nm              | (Rafiee et al., 2012) |
|                   | Hydrolysis | Amorphous Silica | 50-200 nm | (Zemmukhova et al., 2015) |
|                   | Leaching Calcination | Silica | 181.2-294.7 nm    | (Carmona et al., 2013) |
|                   | Pyrolysis | Silica | 70-100 nm         | (Mollah et al., 2020) |
|                   | Acid Leaching | - | Nanoparticle Silica Amorphous | 17.71 ± 7.53 nm | (Nayak and Datta, 2021) |
| Palm Ash Ash      | Acid Leaching | Sol-gel | Nanoparticle Silica | 50–98 nm | (Pa et al., 2016) |
| Fly Ash Waste     | Thermal | SiO₂ Mesopore | 8-20 nm | (Permatsar et al., 2016) |
|                   | Alkaline | Nanoparticle Silica Amorphous | 10-60 nm | (Yadav et al., 2020) |
|                   | Alkaline | Nanoparticle Silica | Nanosize | (Wang et al., 2020) |
|                   | Alkaline | Silica Amorphous | 380.9 nm-178.8 nm | (Liang et al., 2020) |
|                   | Acid-base | Nanoparticle Silica Amorphous | 60-90 nm | (Uda et al., 2021) |
| Coconut Husk Ash  | Green Synthesis | Orthorhombic Tridymite (silica) | 200–750 nm | (Aminar et al., 2020) |
| Maize Stalk       | Green Production | Silica Nanoparticles | - | (Adebiyi et al., 2019) |
| Olive Stones      | Alkaline Leaching Process | Nano-silica | Nanosize | (Naddaf et al., 2020) |
| Traditional Chinese Joss Paper | Alkaline Treatment | Silica | Nanosize | (Ramanathan et al., 2020) |
| Sugarcane Bagasse Ash | Alkaline Leaching Process | Silica Microparticles | Microsize | (Adebiyi et al., 2017) |
| Cassava Waste     | Sol-gel | Silica Amorphous | Nanosize | (Adebiyi et al., 2017) |
| Bamboo Leaves     | The Box Behnken Design | Amorphous Nano-silica | - | (Olawale, 2020) |
| Corn Cobs Husks   | Biotransformation | Silica Nanoparticles | ~40 and ~70 nm | (Piel et al., 2020) |
not been fully elucidated. The three most common mechanisms of toxicity proposed to date include the (Asharani et al., 2008):

- DNA replication and disruption of ATP production prior to the absorption of free ions
- Nanoparticles and ion generation ROS, and
- Nanoparticles direct damage to cell membranes.

Asharani et al., 2008 suggested that the concentration of $h^+$ is important in the reactions that occur within the mitochondria of eukaryotic cells. Likewise, when there is a proton motive force in the cell membrane, a similar mechanism can occur. ROS works against bacteria through multiple methods, including the interaction with the thiol group of enzymes and proteins which are essential for bacterial respiration. Also, by relating with the transport of essential substances across cell membranes (Cho et al., 2005), and binding to bacterial cell walls and, altering its cell membrane functions (Percival et al., 2005).

Overall, the potential of silica as supporting material for antibacterial photocatalysts can be proven by its role in increasing the produced ROS. Therefore, the review of silica application in the field of photocatalyst as a supporting material is necessary. There have been many studies discussing the effectiveness of photocatalyst performance after adding silica.

Klankaw et al., 2012 succeeded in making $\text{TiO}_2$-$\text{SiO}_2$ thin film with the extracted silica for dye degradation. This thin film is made through the self-assembly method by mixing a solution of $\text{SiO}_2$ with titanium precursor and allowed to stand for precipitation together with silica and titanium crystals. The results showed the photocatalytic decolorization of methylene blue dye (MB) reached 81 %, where the advantages of $\text{SiO}_2$ include; (1) the increase of the film absorbency and (2) the provision of hydroxyl radicals to promote the photocatalytic reaction. The photocatalytic reactivity of thin films for decolorization of MB dye depends on the increase in the specific surface area and chemical structure of the photocatalyst (Figure 7).

Mohamed et al., 2019 reported biogenic silica as the supporting material for nano polyacrylonitrile in the degradation of malachite green (MG) dye. An investigation was conducted on the multiple factors affecting the degradation of this color, including solution pH, dye concentration, and irradiation time and on its photocatalytic performance under visible light in an aqueous solution. The results from the studied nanocomposite fiber demonstrated an exceptional photodegradation performance with a 98 % maximum efficacy in less than 10 minutes for Malachite green. Furthermore, the fabricated fiber is used in continuous operating modes, such as fixed-bed columns because of its flexibility.

Sarkar et al., 2017 explained that doping or composite manufacturing is an active method of diffusing light absorption into the visible region. The study describes the extraction procedures for nano-silica from rice husks and the sol-gel preparation of titania-nano-silica composites for photocatalytic and photovoltaic applications. Furthermore, the extracted nano-
The results showed that the growth of 28 Staphylococcus aureus was severely stunted within 3 hours. Research on SiO$_2$ (Nilchi et al., 2010; Hou et al., 2018; Shaban et al., 2020). This also encourages the assumption that more ROS will be produced, which has a very important role in the inactivation of bacteria as previously described (Marambio-Jones and Hoek, 2010; Kim et al., 2011; Hou et al., 2018).

So far, a great deal of research have been conducted on silica as a supporting material for antibacterial photocatalysis (Zemnukhova et al., 2015; Carmona et al., 2013; Permatasari et al., 2016; Ramanathan et al., 2020; Olawale, 2020; Piela et al., 2020). However, the silica used was synthetic as was conducted by Hou et al., 2018, in making SiO$_2$ mesoporous spherical particles that were coated separately with Ag$_2$O, Cu$_2$O, CeO$_2$, and NiO nanoparticles and used for 26 antibacterial applications. Synthesis of CuO$_2$@SiO$_2$ as an antibacterial is also performed by Li et al., (2018) to achieve percent inactivation bacteria reached 99.9%.

The bactericidal effect of the composites was tested against 27 Staphylococcus aureus in dark or LED lighting conditions. The results showed that the growth of 28 Staphylococcus aureus was severely stunted within 3 hours. Research on SiO$_2$ produced from chemical synthetic materials has been conducted and proven to be able to be a good supporting material. Research conducted by Tan et al., (2016) showed antibacterial activity of AgCl and AgCl@SiO$_2$ nanoparticles on E. Coli and explain about the role of SiO$_2$. Researchers have successfully synthesized AgCl@SiO$_2$ nanoparticles with a porous shell-shaped SiO$_2$ that show improved stability compared to Ag(I) samples. Silica shell protection makes nanoparticles resistant to light irradiation and can be used repeatedly. The application of SiO$_2$ as supporting material TiO$_2$ for antibacterial in textiles application has been done by Kartini et al., 2010. The result of this study is the increased antibacterial activity of TiO$_2$/SiO$_2$ in layered cotton which explains that the presence of SiO$_2$ is able to increase antibacterial activity. Researchers explained the possibility of increased antibacterial activity due to the increase in coating sole adhesive to cotton fibers.

Manoharan et al., 2018 also successfully synthesized nanocomposite ZnO/TiO$_2$/SiO$_2$ as antibacterial agents in cotton fabrics against E. coli bacteria (Gram negative) and Staphylococcus aureus (Gram positive) are very significant. Strong bactericidal effects observed for nanocomposite-coated clothing for both bacteria strains had an inhibitory zone of 19 mm observed for S. aureus and 18 mm for E. coli.

The advantages of the hydrophobic properties of SiO$_2$ in its antibacterial activity are explained in Zhao et al., 2020 research. In this study the fabrication of MoO$_3$-SiO$_2$-Ag$_2$O was done by distributing a small amount of Ag$_2$O separately in the amorphous SiO$_2$ matrix. The desired antimicrobial activity to inactivate Escherichia coli, Salmonella Typhimurium and Staphylococcus aureus can be achieved due to the presence of this layer of surface hydrophobicity in SiO$_2$, and other reasons such as the release of Ag$^+$ ions, surface acid reactions and photocatalytic activity, which can be used to reduce hospital-acquired infections.

Hoang et al., 2016 showed E.coli inactivation under UV-C irradiation using photocatalysts TiO$_2$ (Degussa-P25), TiO$_2$-SiO$_2$ or 1% Ag-TiO$_2$-SiO$_2$ for 30 minutes. SiO$_2$ is signifi-
Therefore, it can be concluded that the material has the potential as supporting material for antibacterial photocatalysts.

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REFERENCES

Adebisi, J., J. Agunsoye, S. Bello, I. Ahmed, O. Ojo, and S. Hassan (2017). Potential of producing solar grade silicon nanoparticles from selected agro-wastes: A review. Solar Energy, 142; 68–86

Adebisi, J., J. Agunsoye, S. Bello, M. Haris, M. Ramakokvhu, M. Daramola, and S. Hassan (2018). Extraction of silica from cassava periderm using modified sol-gel method. Nigerian Journal of Technological Development, 15(2); 57–65

Adebisi, J. A., J. O. Agunsoye, S. A. Bello, F. O. Kolawole, M. M. Ramakokvhu, M. O. Daramola, and S. B. Hassan (2019). Extraction of silica from sugarcane bagasse, cassava periderm and maize stalk: Proximate analysis and physicochemical properties of wastes. Waste and Biomass Valorization, 10(3); 617–629

Anuar, M. F., Y. W. Fen, M. H. M. Zaid, K. A. Mator, and R. E. M. Khaidir (2020). The Physical and Optical Studies of Crystalline Silica Derived from the Green Synthesis of Coconut Husk Ash. Applied Sciences, 10(6); 2128

Asharani, P., Y. L. Wu, Z. Gong, and S. Valiyaveettil (2008). Toxicity of silver nanoparticles in zebrafish models. Nanotechnology, 19(25); 1–8

Bapat, G., C. Labade, A. Chaudhari, and S. Zinjarde (2016). Silica nanoparticle based techniques for extraction, detection, and degradation of pesticides. Advances in Colloid and Interface Science, 237; 1–14

Bernstein, R. and A. Carpi (2015). Properties of Solids. Vision-learning

Castellote, M. and N. Bengtsson (2011). Principles of TiO2 photocatalysis. Applications of Titanium Dioxide Photocatalysis to Construction Materials, 5; 5–10

Chakraverty, A., P. Mishra, and H. Banerjee (1988). Investigation of combustion of raw and acid-leached rice husk for production of pure amorphous white silica. Journal of Materials Science, 23(1); 21–24

Chatterjee, A., S. Shamim, A. K. Jana, and J. K. Basu (2020). Insights into the competitive adsorption of pollutants on a mesoporous alumina–silica nano-sorbent synthesized from coal fly ash and a waste aluminium foil. Royal Society of Chemistry Advances, 10(26); 15514–15522

Cheng, H., W. Wang, B. Huang, Z. Wang, J. Zhan, X. Qin, X. Zhang, and Y. Dai (2013). Tailoring AgI nanoparticles for the assembly of AgI/BiOI hierarchical hybrids with size-dependent photocatalytic activities. Journal of Materials Chemistry A, 1(24); 7131–7136

Cho, K.-H., J.-E. Park, T. Osaka, and S.-G. Park (2005). The study of antimicrobial activity and preservative effects of nanosilver ingredient. Electrochimica Acta, 51(5); 956–960

Eddy, D. R., F. N. Puri, and A. R. Noviyanti (2015). Synthesis and photocatalytic activity of silica-based sand quartz as the supporting TiO2 photocatalyst. Procedia Chemistry, 17; 55–
Effendy (2010). Logam, AlOi, Semikonduktor, dan Superkonduktor. Malang: Bayumedia 514 Publishing
Elma, M., E. L. Rampun, A. Rahma, Z. L. Assyaiﬁ, A. Sumardi, A. E. Lestari, G. S. Saputro, M. R. Bilad, and A. Darmawan (2020). Carbon templated strategies of mesoporous silica applied for water desalination: a review. Journal of Water Process Engineering, 38; 101520
Espindola-González, A., A. Martínez-Hernández, C. Angeles-Chávez, V. Castano, and C. Velasco-Santos (2010). Novel crystalline SiO2 nanoparticles via annelids bioprocessing of agro-industrial wastes. Nanoscale Research Letters, 5(9); 1408–1417
Estevéz, M., S. Vargas, V. Castano, and R. Rodríguez (2009). Silica nano-particles produced by worms through a biodigestion process of rice husk. Journal of Non-crystalline solids, 355(14–15); 844–850
Faizul, C. P., C. Abdullah, and B. Fazlul (2013). Extraction of silica from palm ash using citric acid leaching treatment: Preliminary result. Advanced Materials Research, 795; 701–706
Faizul, C. P., A. Chik, M. Bari, H. J. Noorina, et al. (2014). Extraction of silica from palm ash using organic acid leaching treatment. Key Engineering Materials, 594; 329–333
FAOSTAT (2021). Agriculture and Consumer Protection. Food and Agriculture Organization
Farirai, F., M. Ozonoh, T. C. Aniokete, O. Eterigho-Ikelegbe, M. Mupa, B. Zeyi, and M. O. Daramola (2021). 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(1); 57–78
Ferreira, C. S., P. L. Santos, J. A. Bonacin, R. R. Passos, and L. A. Pocrifka (2015). Rice husk reuse in the preparation of SnO2/SiO2 nanocomposite. Materials Research, 18(3); 639–643
Ferronato, N. and V. Torretta (2019). Waste mismanagement in developing countries: A review of global issues. International Journal of Environmental Research and Public Health, 16(6); 1060
Gao, Q., J. Xu, and X.-H. Bu (2019). Recent advances about metal-organic frameworks in the removal of pollutants from wastewater. Coordination Chemistry Reviews, 378; 17–31
Hajipour, M. J., K. M. Fromm, A. A. Ashkarran, D. J. de Aberasturi, I. R. de Larramendi, T. Rojo, V. Serpooshan, W. J. Parak, and M. Mahmoudi (2012). Antibacterial properties of nanoparticles. Trends in Biotechnology, 30(10); 499–511
Haynes, W. M. (2011). CRC Handbook of Chemistry and Physics (92nd ed.) ISBN 551 1439855110. Boca Raton FL: CRC Press
He, X. and C. Zhang (2019). Recent advances in structure design for enhancing photocatalysis. Journal of Materials Science, 54(12); 8831–8851
Hoang, N. T.-T., A. T.-K. Tran, N. Van Suc, et al. (2016). Antibacterial activities of gel-derived Ag – TiO2 – SiO2 materials under different light irradiation. AIMS Materials Science, 3(2); 339–348
Holleman A., F. and E. Wiberg (2001). Inorganic Chemistry, translated by Eagleson, Mary, Brewer, William. San Diego/Berlin: Academic Press/De Gruyter
Hossain, S. S., L. Mathur, and P. Roy (2018). Rice husk/rice husk ash as an alternative source of silica in ceramics: A review. Journal of Asian Ceramic Societies, 6(4); 299–313
Hou, Y.-x., H. Abdullah, D.-h. Kuo, S.-j. Leu, N. S. Gultom, and C.-H. Su (2018). A comparison study of SiO2/nano metal oxide composite sphere for antibacterial application. Composites Part B: Engineering, 133; 166–176
Hwang, Y. J., S. Yang, and H. Lee (2017). Surface analysis of N-doped TiO2 nanorods and their enhanced photocatalytic oxidation activity. Applied Catalysis B: Environmental, 204; 209–215
Imoisili, P. E., K. O. Ukoba, and T.-C. Jen (2020). Green technology extraction and characterisation of silica nanoparticles from palm kernel shell ash via sol-gel. Journal of Materials Research and Technology, 9(1); 307–313
Ishmah, S. N. (2019). Ekstraksi Silika Pasir Pantai Bengkulu Sebagai Pendukung Fotokatalis Titanium Dioxide Dalam Remediasi Limbah. Univeristas Padjadjaran
Ishmah, S. N., M. D. Ferman, M. L. Firdaus, and D. R. Eddy (2020). Extraction of Silica from Bengkulu Beach Sand using Alkali Fusion Method. PendIPA Journal of Science Education, 4; 1–5
Ismail, A., A. L. Widyaningsytas, B. H. Susanto, and M. Nasikin (2020). Facile Synthesis Silica Nanoparticles from Indonesia Silica Sand and their Physico-Chemical Properties. Key Engineering Materials, 862; 35–39
Jal, P., M. Sudarshan, A. Saha, S. Patel, and B. Mishra (2004). Synthesis and characterization of nanosilica prepared by precipitation method. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 240(1); 173–178
Joni, I., L. Nulhakim, M. Vanitha, and C. Panatarani (2018). Characteristics of crystalline silica (SiO2) particles prepared by simple solution method using sodium silicate (Na2SiO3) precursor. Journal of Physics: Conference Series, 1080(1); 12006
Julia, D. L. (2002). Silica-Titania Composite for Water Treatment. University of Florida, USA
Kamath, S. R. and A. Proctor (1998). Silica gel from rice hull ash: preparation and characterization. Cereal Chemistry Journal, 75(4); 484–487
Kartini, I., E. S. Kunarti, E. T. Wahyuni, I. Purwantini, C. Wiedyaningsih, and R. Listyawati (2010). Antibacterial Coating Of Titania-Silica Nanosols On Cotton Fabrics. The 2nd International Conference on Chemical Sciences Proceeding, ISSN NO. 1410-8313
Khan, K., M. F. Ullah, K. Shahzada, M. N. Amin, T. Bibi, N. Wahab, and A. Aljaafari (2020). Effective use of micro-silica extracted from rice husk ash for the production of high-performance and sustainable cement mortar. Construction
Kim, M.-K., J.-A. Lee, M.-R. Jo, and S.-J. Choi (2016). Bioavailability of silica, titanium dioxide, and zinc oxide nanoparticles in rats. *Journal of Nanoscience and Nanotechnology, 16*(6); 6580–6586

Kim, S.-H., H.-S. Lee, D.-S. Ryu, S.-J. Choi, and D.-S. Lee (2011). Antibacterial activity of silver-nanoparticles against Staphylococcus aureus and Escherichia coli. *Microbiology and Biotechnology Letters, 39*(1); 77–85

Kim, Y. H., D. K. Lee, H. G. Cha, C. W. Kim, and Y. S. Kang (2007). Synthesis and characterization of antibacterial Ag–SiO$_2$ nanocomposite. *The Journal of Physical Chemistry C, 111*(9); 3629–3635

Klankaw, P., C. Chawengkijwanich, N. Grisdanurak, and S. Chiarakorn (2012). The hybrid photocatalyst of TiO$_2$–SiO$_2$ thin film prepared from rice husk silica. *Superlattices and Microstructures, 51*(3); 349–352

Lee, D. W. and B. R. Yoo (2016). Advanced silica/polymer composites: Materials and applications. *Journal of Industrial and Engineering Chemistry, 38*; 1–12

Li, D., H. Song, X. Meng, T. Shen, J. Sun, W. Han, and X. Wang (2020). Effects of particle size on the structure and photocatalytic performance by alkali-treated TiO$_2$. *Nanomaterials, 10*(3); 546

Li, X., M. Liang, S. Jiang, S. Li, Y. Gao, J. Liu, Q. Bai, N. Sui, and Z. Zhu (2021). Pomegranate-Like CuO$_2$@SiO$_2$ Nanospheres as H$_2$O$_2$ Self-Supplying and Robust Oxygen Generators for Enhanced Antibacterial Activity. *ACS Applied Materials & Interfaces, 13*(19); 22169–22181

Liang, G., Y. Li, C. Yang, C. Zi, Y. Zhang, X. Hu, and W. Zhao (2020). Production of biosilica nanoparticles from biomass power plant fly ash. *Waste Management, 105*; 8–17

Lin, H., C. Huang, W. Li, C. Ni, S. I. Shah, and Y.-H. Tseng (2006). Size dependency of nanocrystalline TiO$_2$ on its optical property and photocatalytic reactivity exemplified by 2-chlorophenol. *Applied Catalysis B: Environmental, 68*(1-2); 1–11

Lunt, A. J., P. Chater, and A. M. Korsunsky (2018). On the origins of strain inhomogeneity in amorphous materials. *Scientific Reports, 8*(1); 1–8

Lutgens, F. K. and E. J. Tarbuck (2000). *Essentials of Geology, 7th Ed.*, Prentice-Hall

Madina, F. E., R. Elvia, and I. N. Candra (2017). Synthesis of Silica from The Sand of Panjang Beach and Its Application for Rhodamine B Adsorption. *Jurnal Pendidikan dan Ilmu Kimia, 1*(2); 98–101

Manoharan, C., V. Rajendran, and R. Sivaraj (2018). Synthesis, characterization and applications of Zno/TiO$_2$/SiO$_2$ nanocomposite. *Ortogonal Journal of Chemistry, 34*(3); 1333

Marambio-Jones, C. and E. M. Hoek (2010). A review of the antibacterial effects of silver nanomaterials and potential implications for human health and the environment. *Journal of Nanoparticle Research, 12*(5); 1351–1551

Matichenkov, V. and D. Calvert (2002). Silicon as a beneficial element for sugarcane. *Journal American Society of Sugarcane Technologists, 22*(2); 21–30

Mehmood, A., H. Ghafar, S. Yaqoob, U. F. Gohar, and B. Ahmad (2017). Mesoporous silica nanoparticles: a review. *Journal of Drug and Research Development, 6*(2)

Miricioiu, M. G. and V.-C. Niculescu (2020). Fly ash, from recycling to potential raw material for mesoporous silica synthesis. *Nanomaterials, 10*(3); 474

Mohamed, A., M. M. Ghobara, M. Abdemaksoud, and G. G. Mohamed (2019). A novel and highly efficient photocatalytic degradation of malachite green dye via surface modified polyacrylonitrile nanofibers/biogenic silica composite nanofibers. *Separation and Purification Technology, 210*; 935–942

Mor, S., C. K. Manchanda, S. K. Kansal, and K. Ravindra (2017). Nanosilica extraction from processed agricultural residue using green technology. *Journal of Cleaner Production, 143*; 1284–1290

Motlagh, E. K., N. A. Kolur, S. M. Sharifian, and A. E. Pirbazari (2020). Effect of Silica Extraction on the Porous Structure and Surface Area of Activated Carbon Prepared from Rice Wastes. *Irish Centre for High-End Computing; 15–17

Naddaf, M., H. Kafa, and I. Ghanem (2020). Extraction and characterization of Nano-silica from olive stones. *Silicon, 12*(1); 185–192

Nayak, P. and A. Datta (2021). Synthesis of SiO$_2$-nanoparticles from rice husk ash and its comparison with commercial amorphous silica through material characterization. *Silicon, 13*(4); 1209–1214

Nilchi, A., S. Janitabar-Darzi, A. Mahjoub, and S. Rasoulifar-Garmarodi (2010). New TiO$_2$/SiO$_2$ nanocomposites-Phase transformations and photocatalytic studies. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 361*(1-3); 25–30

Okerefor, U., M. Makhatha, L. Mekuto, and V. Mavumengwa (2020). Gold Mine Tailings: A Potential Source of Silicon Sand for Glass Making. *Minerals, 10*(5); 448

Olawale, O. (2020). Bamboo leaves as an alternative source for silica in ceramics using Box Benhken design. *Scientific African, 8*; 418

Otero-González, L., I. Barbero, J. A. Field, F. Shadman, and R. Sierra-Alvarez (2014). Stability of alumina, ceria, and silica nanoparticles in municipal wastewater. *Water Science and Technology, 70*(9); 1533–1539

Pa, F. C., A. Chik, and M. F. Bari (2016). Palm ash as an alternative source for silica production. *MATEC Web of Conferences, 78; 1062

Percival, S. L., P. Bowler, and D. Russell (2005). Bacterial adsorption of mesoporous silica. *Journal of Drug and Research Development, 6*(2); 8–17

Permatasari, N., T. N. Sucahya, and A. B. D. Nandiyanto (2016). Agricultural wastes as a source of silica material. *Indonesian Journal of Science and Technology, 1*(1); 82–106

Piela, A., E. Żymańczyk-Duda, M. Brzezińska-Rodak, M. Duda, J. Grzesiak, A. Saeid, M. Mironiuk, and M. Klimek-Ochab (2020). Biogenic synthesis of silica...
nanoparticles from corn cobshusks. Dependence of the productivity on the method of raw material processing. Bioorganic Chemistry, 99; 103773

Qi, K., B. Cheng, J. Yu, and W. Ho (2017). Review on the improvement of the photocatalytic and antibacterial activities of ZnO. Journal of Alloys and Compounds, 727; 792–820

Rafiee, E., S. Shahebrahimi, M. Feyzi, and M. Shaterzadeh (2012). Optimization of synthesis and characterization of nanosilica produced from rice husk (a common waste material). International Nano Letters, 2(1); 1–8

Rahman, S., L. Rahman, A. T. Khalil, N. Ali, D. Zia, M. Ali, and Z. K. Shinwari (2019). Endophyte-mediated synthesis of silver nanoparticles and their biological applications. Applied Microbiology and Biotechnology, 103(6); 2551–2569

Ramanathan, S., S. C. Gopinath, M. M. Arshad, P. Poopalan, P. Anbu, T. Lakshmipriya, and C.-G. Lee (2020). Alkalized extraction of silica-alumina nanocomposite from traditional Chinese joss paper: optical characterizations. Materials Chemistry and Physics, 243; 122621

Rattanaudom, P., B.-J. Shiau, U. Suriyapraphadilok, and A. Charoensaeng (2020). Effect of pH on silica nanoparticle-stabilized foam for enhanced oil recovery using carboxylate-based extended surfactants. Journal of Petroleum Science and Engineering, 192; 107729

Rayner-Canham, G. and O. T. (2015). Descriptive Inorganic Chemistry, 1st ed. New York: W. H. Freeman and Company

Razak, H., N. Abdullah, H. Setiabudi, C. Yee, and N. Ainirazali (2019). Influenced of Ni loading on SBA-15 synthesized from oil Palm ash silica for syngas production. IOP Conference Series: Materials Science and Engineering, 702(1); 12024

Salhi, R. (2011). Defect related luminescence in silicon dioxide network: a review. InTech Rijeka

Sarkar, P., S. A. Moylez, A. Dey, S. Roy, and S. K. Das (2017). Experimental investigation of photocatalytic and photovoltaic activity of titania/rice husk crystalline nanosilica hybrid composite. Solar Energy Materials and Solar Cells, 172; 93–98

Sellapan, R. (2013). Mechanisms of Enhanced Activity of Model TiO2/Carbon and TiO2/Metal Nanocomposite Photocatalysts. Chalmers University

Seytongrung, T. M., S. W. Murni, and W. W. Nandari (2020). Extraction of Silica from Kalirejo Minerals, Kokap, Kulonprogo, Yogyakarta. Proceeding of LPPM UPN “Veteran” Yogyakarta Conference Series 2020-Engineering and Science Series, 1(1); 269–276

Sevinç, A. H. and M. Y. Durgun (2020). Properties of high-calcium fly ash-based geopolymer concretes improved with high-silica sources. Construction and Building Materials, 261; 120014

Shaban, M., A. Hamd, R. R. Amin, M. R. Abukhadra, A. A. Khalek, A. A. P. Khan, and A. M. Asiri (2020). Preparation and characterization of MCM-48/nickel oxide composite as an efficient and reusable catalyst for the assessment of photocatalytic activity. Environmental Science and Pollution Research, 27(26); 1–13

Sirimahachai, U., N. Ndiege, R. Chandrasekharan, S. Wongnawa, and M. A. Shannon (2010). Nanosized TiO2 particles decorated on SiO2 spheres (TiO2/SiO2): synthesis and photocatalytic activities. Journal of Sol-gel Science and Technology, 56(1); 58–60

Sumarno, S. (2015). Pemurnian Pasir Silika dengan Metode Leaching Asam dan bantuan Sonikasi. Seminar Nasional Teknik Kimia Kejanganan; 1–3

Sun, J., Z. Xu, W. Li, and X. Shen (2017). Effect of nano-SiO2 on the early hydration of alite-sulphoaluminate cement. Nanomaterials, 7(5); 102

Trivikantoro D, M. and M. Zainuri (2015). Synthesis of SiO2 nanopowders containing quartz and cristobalite phases from silica sands. Materials Science-Poland, 33(1); 47–55

Uda, M., S. C. Gopinath, U. Hashim, N. Halim, N. Parmin, M. Afnan Uda, and P. Anbu (2021). Production and characterization of silica nanoparticles from fly ash: conversion of agro-waste into resource. Preparative Biochemistry & Biotechnology, 51(1); 86–95

Vaibhav, V., U. Vijayalakshmi, and S. M. Roopan (2015). Agricultural waste as a source for the production of silica nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 139; 515–520

Venkateswaran, S., R. Yuvakkumar, and V. Rajendran (2013). Nano silicon from nano silica using natural resource (RHA) for solar cell fabrication. Phosphorus, Sulfur, and Silicon and the Related Elements, 188(9); 1178–1193

Wang, J., M. Liu, Y. Wang, Z. Zhou, D. Xu, P. Du, and X. Cheng (2020). Synergistic effects of nano-silica and fly ash on properties of cement-based composites. Construction and Building Materials, 262; 120737

Waseem, M., S. Mustafa, A. Naem, and K. Shah (2009). Synthesis and characterization of silica by sol-gel method. Journal of Pakistan Materials Society, 8(1); 19–21

Yadav, V. K., R. Suriyaprabh, S. H. Khan, B. Singh, G. Gnanamoorthy, N. Choudhary, A. K. Yadav, and H. Kalasariya (2020). A novel and efficient method for the synthesis of amorphous nanosilica from fly ash tiles. Materials Today: Proceedings, 26; 701–705

Yang, S.-J., X. Chen, B. Yu, H.-L. Cong, Q.-H. Peng, and M.-M. Jiao (2016). Self-cleaning superhydrophobic coatings based on PDMS and TiO2/SiO2 nanoparticles. Integrated Ferroelectrics, 169(1); 29–34

Yao, Z. T., X. S. Ji, P. Sarker, J. Tang, L. Ge, M. Xia, and Y. Xi (2015). A comprehensive review on the applications of coal fly ash. Earth-Science Reviews, 141; 105–121

Zemmukhova, L. A., A. E. Panasenko, A. P. Artém’yanov, and E. A. Tsoy (2015). Dependence of porosity of amorphous silicon dioxide prepared from rice straw on plant variety. BioResources, 10(2); 3713–3723

Zhao, Y., J. Xu, Z. Li, T. Fu, and S. Jiang (2020). In vitro antibacterial properties of MoO2/SiO2/Ag2O nanocomposite coating prepared by double cathode glow discharge technique. Surface and Coatings Technology, 397; 125992