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Original Article

Role of Silica Nanoparticles

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Abstract:

The unique, adaptable, and advantageous physiochemical properties of functionalized silica nanoparticles (SiO2 NPs) have garnered a lot of interest. These improved characteristics make these functionalized nanoparticles very suitable for a variety of uses. There aren't many reviews in the literature that provide an overview of how these nanomaterials are made and how they are used in various contexts. In agriculture, silica nanoparticles (SNPs) can be applied as nanofertilizers, nanopesticides, and nanoherbicides, all of which are advantageous for plant development and productivity. The absorption and delivery of SNPs in plants, as well as their function and mechanisms in boosting plant growth and strengthening plant resilience against biotic and abiotic stressors, are reviewed in this article.

Keywords: Nano Particles, Silica, Plant, Characteristics.

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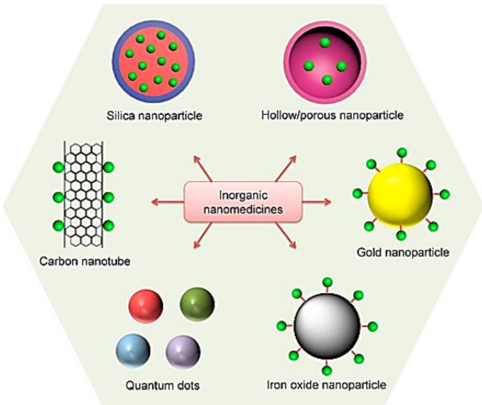
Introduction:

One of the most prevalent elements of the Earth's crust, silica is naturally created from a variety of sources, including bamboo stems and leaves, sugarcane, groundnut shell, corn cobs, wheat straw, rice husk and straw, barley, quartz, and olivine. Reusing, reducing, and minimizing the harmful effects of such agricultural wastes on the environment has thus been the focus of numerous studies. Some are used extensively as raw materials in a variety of fields, including low-cost reinforced filler, filter materials, adsorbents in environmental approaches, and cement additives in structural materials. Recently, due to the unique proper ties of silica and its compounds, many works demonstrating the various applications of silica and silica-based materials in different strategic fields have been published (Freitas *et al*., 2022). Nanomaterial technologies have garnered significant attention over the past few decades because of their numerous applications in diverse fields. These days, because of the advancements in unique. features of microscopic particles, nanotechnologies are essential to all fields of science, engineering, and medicine. Recently, nanoscale silica particles have gained significant significance. For a variety of applications, including optoelectronic sensing, agricultural fields, food industries, medication transport, therapeutic/health, and catalytic technologies, the potential qualities of nanomaterials have drawn significant interest. On the other hand, nanooxides have significant uses in a variety of industries, such as consumer goods, electronics, pharmaceuticals, cosmetics, food, and filler applications. Silica nanoparticles are also considered important nanomaterials having significant applications, which have increased drastically during the last years, have attracted extensive attention, and are widely used due to their greater advantages over conventional nanoparticles; their projected market reached about $8.8 billion in 2020. Many techniques are used to prepare silica nanoparticles (SiO2 NPs), such as plasma manufacturing, chemical vapor deposition, microemulsion synthesis, combustion processing, sol–gel synthesis, and hydrothermal processes, where such fabricated silica nano particles are classified into mesoporous and nanoporous nanoparticles. The sol–gel method is considered one of the most important and widely applied techniques utilized to prepare nanoparticles (Purcar *et al*., 2021). This method has many advantages, such as synthesis that may be carried out at lower temperatures and desired pH to produce high purity, and the kinetics of their reactions may be controlled by changing the compositions of the reaction mixtures. During the last decades, mesoporous materials, such as MSNs, have gained great attention from researchers, where it has been considered as one of the most remarkable materials to participate in advanced nanocatalysts, nanosorbents, nanomedicine, and other nanocompounds. Mesoporous silica nanoparticles (MSNs) shapes are categorized by the IUPAC system as particles with pore diameters ranging from 2 to 50 nm and functionalized with various supplementary groups. Because of their distinct advantages, MSNs have received particular attention in recent years. These nanoparticles are extremely appealing in a variety of advanced applications due to their promising attributes, which include favorable morphological traits, uniform and controllable pore size, porosity, highly chemical stabilities, and appealing physicochemical aspects. Additionally, because MSNs are biocompatible and have a large surface area, pore volume, and significant surface reactivity, these particles have evolved into appealing classes of novel biomaterials (Kankala *et al*., 2020).

Silica-based Nanomaterials and its Applications:

Nanosized materials have undoubtedly garnered a lot of attention because of their potential uses, where their exceptional qualities pave the way for novel technologies and uses. As a result, the latest developments in nanomaterial technologies hold promise for overcoming numerous obstacles in the application of cutting-edge sciences. Advanced catalysis, drug delivery and medicinal applications, environmental cleanup, and wastewater treatment are just a few of the uses for silica nanoparticles. As a result, silica nanomaterials are regarded as one of the most widely used nanomaterials; in 2016, the demand for these nanoparticles grew by 5.6% annually to around 2.8 million metric tons. The most popular methods for creating silica nanoparticles are chemical and biogenic synthesis. For commercial-scale syntheses, biogenic procedures are more affordable, energy-efficient, and environmentally benign than the chemical route, which has certain unfavorable features like producing some hazardous substances, being costly, and consuming a lot of energy. When silica nanoparticles are made with one-, two-, and three-dimensional structures, their size and dimension play essential roles that determine their potential properties. Other forms of silica nanomaterials that draw a lot of interest are silica nanotubes, hollow silica nanotubes, and silica nanofibers, which have unique characteristics including being incredibly stable and less poisonous. As a result, it may find use in a variety of fields, including advanced catalysis, biomedical sciences, medication delivery, food technology, wastewater treatment, and energy storage/conversion.



Silica-based Nanomaterials in Advanced Catalysis:

Many new solid catalysts have been used in recent decades to improve the green synthesis of numerous compounds. Silica-based nanoparticles functionalized with various catalytic species have been reported in a number of fields with an eye toward nanomaterials suitable for use in nanocatalysis. Catalytic processes frequently employ the core-shell structure of catalysts with micro/mesoporous size distributions. The metals nanoparticles coated with $SiO2$ become one of the most significant catalysts of these kinds employed in various fields because of the promising qualities of silica, such as controlled porosity, thermal stability, and chemical inertness (Lazaro *et al*., 2015). Recently, designing novel reactions, synthesis, and modification strategies in modern synthetic organic chemistry have gained great interest in both academic and industrial studies to improve the synthesis and fabrication of active materials with potential applications. Due to the specific physicochemical characteristics of various strategic materials such as platinum (Pt), cobalt (Co), copper (Cu), palladium (Pd), and gold (Au), they are extensively utilized in many modification and synthetic strategies in modern organic synthesis, especially in catalytic activities. The preparation of a novel bifunctional heterogeneous catalyst using mesoporous silica of type SBA-15 (Pt2+/SBA–APTE–SA) was investigated by chen *et al*. (2020). The catalyst was finished by functionalizing silica with succinic anhydride (SA), (3-aminopropyl) triethoxysilane (APTES), and a partially positively charged Pt2+. When it comes to the hydro-silylation of 1,1,1,3,5,5,5-heptamethyltrisiloxane (MDHM) with allyloxy polyethylene glycol (APEG), the developed catalyst has better catalytic activity than a heterogeneous Pt-catalyst. Additionally, the prepared (Pt2+/SBA APTE–SA) exhibits good stability over five cycles and appropriate activity in the hydrosilylation of various alkenes. This catalyst has potential use in the industry as a green hydrosilylation process. The click synthesis technique has been used to prepare the heterogeneous nanocatalyst via the immobilization of copper on magnetic silica nanoparticles modified with triazine den drimer (FMNP@TD–Cu(II)). Two classes of catalysts were prepared by immobilizing iron porphyrins on mesoporous silica of SBA-type to oxidize hydro carbons. These processes illustrated the crucial role of the silica surface to develop biomimetic catalysts and improve the activities. The first class was prepared via the immobilization 5,10,15,20-tetrakis(pentafluorophenyl)porphyrin iron(III) chlo ride (FeP) on SBA-15 structures modify ed with (3-aminopropyl) triethoxysilane (APTES), designated as FeP–APSBA.

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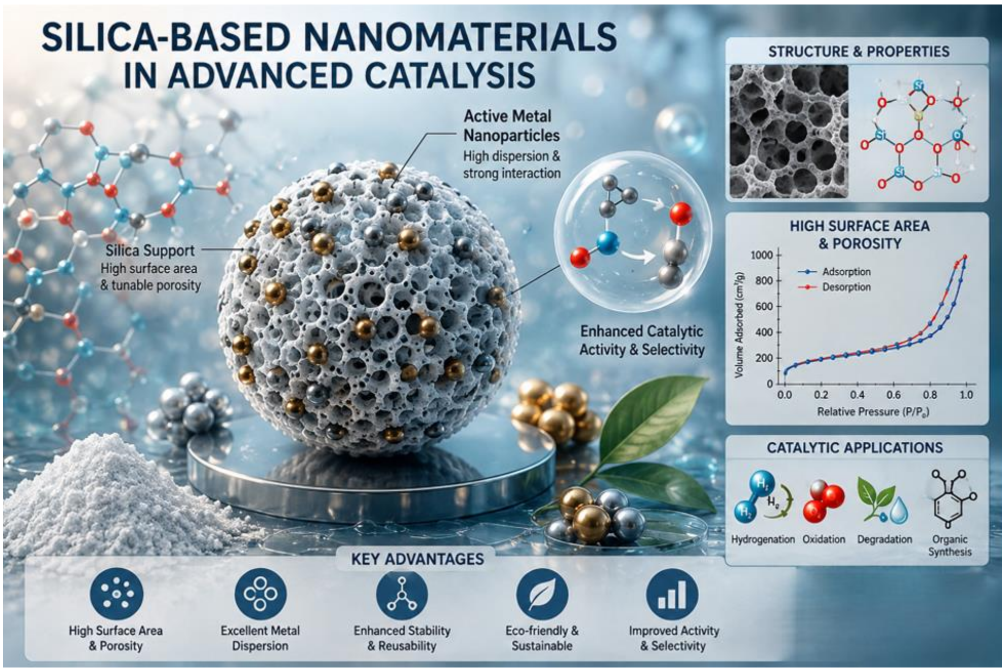

Silica-based Nanomaterial in Drug-Delivery and Biomedical Applications:

Nowadays, the development of unique nanomaterials has received considerable attention in biomedical technologies, e.g., drug delivery, gene transfections, cancer diagnosis, and therapy, Numerous therapeutic methods suffer from stability issues, failure to pass through the membrane of cells, and fast clearance in vivo. Therefore, nanomaterials can solve these issues and provide potent tools for delivering and releasing drugs, where the biosafety of these nano particles is considered as an important requirement for the use of NPs in drug delivery systems. MSNs have drawn a lot of interest in the biological and medical fields as carriers for various therapeutic medicines because of their promising features, such as their unique morphology, geometry, and the capacity of the nanoparticles to distribute and target specific organs/tissue. The huge pores of MSNs serve as reservoirs to transport therapeutic medications and surface functionalization to provide sufficient control of drug release; surface modification can also improve their biocompatibility. Additionally, compared to other drug delivery methods, the medication can be uniformly disseminated through MSNs' matrix systems because of their porosity architectures. As a result, numerous efforts have been made to functionalize drug-loaded MSNs by focusing on ligands and stimuli-sensitive materials. MSNs that react to multiple stimuli can then carry anti-cancer medications to their targets. MSNs are also thought to be a viable gene delivery vehicle. Therefore, several approaches are established to create specific multifunctional nanocarriers;

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consequently, a unique drug design technique based on nanomaterials and associated nanostructures for operative drug transport is of differentiated significance in future medical treatment. It is clear from comparing MSNs with other drug delivery methods that their porous architectures have larger drug loading capacities and offer uniform drug distributions through matrix systems. Furthermore, it is not genotoxic and does not cause hemolysis of red blood cells. As a result, they are regarded as biologically safe drug delivery vehicle (Tuncel *et al*., 2021).

Silica-based Nanomaterials in Environmental Remediation Applications and Wastewater Treatment:

Water scarcity in arid regions has increased over the past ten years as a result of environmental and water pollution, which is becoming a serious problem for all cultures today. This has led to environmental retardation and extremely dangerous health problems for humans and animals. As a result, various environmentally friendly nanomaterials have been created and synthesized to treat and cleanse certain kinds of waste. A novel composite of mesoporous silica particles coated with magnetic (DyxMnFe2xO4) nanoparticles was created and extracted from various organic contaminants. The mesoporous qualities of this synthetic composite are responsible for its inexpensive, eco-friendly, and effective catalytic properties. The photocatalytic activities of Dyx MnFe2 xO4 nanoparticles on them also decomposed the residual dye contents. The photocatalytic activity and adsorption of environmental waste treatment are significantly enhanced by this studied composite (Baig *et al*., 2021). The thermal breakdown of metal precursors in MSNs and subsequent methane CVD were used to create magnetic silica nanoparticles coated with FeCo/graphitic carbon shell nanocrystals (FeCo/GC NCs@MSNs) to interact with heavy metals and organic dyes. The graphitic carbon shields the nanoparticles from cooperative non-covalent, hydrophobic interactions with organic dyes as well as oxidation and acid leaching in strong hydrochloric acid. FeCo/GC NCs@MSNs can form bonds with organic dyes and Hg2+ ions by further functionalizing their surface with thiol groups.

Conclusion:

This study demonstrates the numerous intriguing studies and investigations that have been conducted to enhance the characteristics of functionalized silica nanoparticles (SiO2 NPs) and expand their uses. SiO2's superior features, including its nanoscale size, high surface area, extensive porosity, high stability, and excellent biocompatibility, make it the best nanomaterial to use in a variety of fields.

However, its most valuable property is its ability to be effectively combined with other materials (modifiers) for potential applications. To illustrate the significance of the surface modification stage in the different capabilities of the silica surface, five significant applications were chosen: improved catalysis, drug delivery, biomedical applications, environmental remediation applications, and wastewater treatment.

References:

1. Freitas, A. I., Domingues, L., & Aguiar, T. Q. (2022). Tag-mediated single-step purification and immobilization of recombinant proteins toward protein-engineered advanced materials. *Journal of Advanced Research*, *36*, 249-264.
2. Hafidh, A., Touati, F., & Sediri, F. (2020). Synthesis, charaterization and optical properties of nanostructured silica hybrid materials obtained by soft chemistry from perhydropolysilazane/1, 2, 4-triazole precursors. *Journal of Molecular Structure*, *1218*, 128496.
3. Purcar, V., Răditoiu, V., Nichita, C., Bălan, A., Răditoiu, A., Căprărescu, S., ... & Jecu, L. (2021). Preparation and characterization of silica nanoparticles and of silica-gentamicin nanostructured solution obtained by microwave-assisted synthesis. *Materials*, *14*(8), 2086.
4. Kankala, R. K., Han, Y. H., Na, J., Lee, C. H., Sun, Z., Wang, S. B., ... & Wu, K. C. W. (2020). Nanoarchitectured structure and surface biofunctionality of mesoporous silica nanoparticles. *Advanced materials*, *32*(23), 1907035.
5. Lazaro, A., Benac-Vegas, L., Brouwers, H. J. H., Geus, J. W., & Bastida, J. (2015). The kinetics of the olivine dissolution under the extreme conditions of nano-silica production. *Applied Geochemistry*, *52*, 1-15.
6. Chen, W., Xie, Z., Liang, H., Zhou, X., Hu, W., & Shu, X. (2020). Partially charged platinum on aminated and carboxylated SBA-15 as a catalyst for alkene hydrosilylation. *RSC advances*, *10*(6), 3175-3183.
7. Tüncel, Ö., Kahraman, E., Bağci, G., Atabey, N., & Özçelik, S. (2021). Engineered silica nanoparticles are biologically safe vehicles to deliver drugs or genes to liver cells. *Materials Science and Engineering: C*, *119*, 111585.
8. Baig, M. M., Zulfiqar, S., Yousuf, M. A., Shakir, I., Aboud, M. F. A., & Warsi, M. F. (2021). DyxMnFe2-xO4 nanoparticles decorated over mesoporous silica for environmental remediation applications. *Journal of Hazardous Materials*, *402*, 123526.