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ORIGINAL PAPER

# Multifaceted Application of Silica Nanoparticles. A Review

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## Abstract

Nanoparticles have immense industrial, biotechnological, and biomedical/pharmaceutical applications due to their pliability in structure, size, biocompatibility, high surface area, and versatile functionalization, which have led to their ubiquitous application in diverse areas Advancement of the science in the research field has revolutionized our lifestyle and health care from medicine to the agricultural field but there were also some negative impacts of this development apart from the benefits. Nanotechnology has been one of the ladders responsible for this revolution which has to some extent decreased the adverse effects. Among various types of nanoparticles, silica nanoparticles (SiO2 NPs) have become favoured as nanostructuring, drug delivery, and optical imaging agents. Silica nanoparticles are immensely stable, less toxic. Mesoporous silica materials with pore sizes in the range between 2 and 50 nm have attracted widespread attention due to their precisely tuneable macroscopic form, chemical functionality, and mesoporous structure. Silica has been also applied for the remediation of the environment pollutants like to carry out enhanced oil recovery to reduce the liberation of brine, heavy metals and radioactive compounds into water, removal of metals, non-metals and radioactive elements,water purification. This article reviews the important applications of silica nanoparticles from the medicine, agricultural field to the environmental bioremediation.

**Keywords** Silica nanoparticles · Insecticides · Biocompatibility · Diagnostics · Drug delivery · Medical imaging · Bio-functionalization · Bioremediation

## Abbreviations

| | |
|---|---|
| MSNs | Mesoporous silica nanoparticles |
| DDS | Drug delivery system |
| SNPs | Silica nanoparticles |
| NPs | Nanoparticles |
| QDs | Quantum dots |
| hMSCs | Human mesenchymal stem cells |
| MRI | Magnetic resonance imagining |
| MDR-TB | Multi drug resistance tuberculosis |
| HRP | Horseradish peroxide |
| GI | Gastro intestinal |
| NPV | Nuclear polyhedrosis virus |

## 1 Introduction

Nanotechnology encompasses science, engineering, and technology involve imaging, measuring, modelling, and manipulating of matter at the nanoscale. The development of unique nanoscale particles has the immense potential to revolutionize the industry, including electronics, medicine, and consumer products. In the recent years, application of silica nanoparticles has increased drastically. Starting from the agricultural field, food industry, drug delivery, and industrial applications silica nanoparticles have been used widely due to its greater advantage over the conventional nanoparticles. In general, the nanoparticles synthesis are usually classified into: The "physical and chemical", "bottom-up" and "top-down" techniques The Physical synthetic methods such as inert gas condensation, severe plastic deformation, ultrasonic shot peeling,high-energy ball milling, grinding process and pyrolysis can be used to synthesize metallic nanoparticles [1] Chemical methods involve the reduction of chemicals [2] electrochemical procedures [3] and reduction of phytochemicals [4] microemulsion, chemical coprecipitation, chemical vapor condensation, pulse electrodeposition. Bottom-up reaction take up, from atomic level through forming molecules, and

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in top-down" the scale of the product nanoparticles is larger, so that a mechanical process or the addition of acids is needed to reduce the particle size [5]. However the chemical methods used for the synthesis of nanoparticles are too costly and also involved with the use of toxic and hazardous chemicals that are responsible for various biological and environmental risks [6] The evolution, of green processes as green nanotechnology for the synthesis of nanoparticles has been unrolling into an important branch of nanotechnology deals with the safe and eco- friendly methods for nanomaterials fabrication which is considered as an alternative for the conventional physical and chemical methods. Green nanotechnology uses,micro-organisms fungi, algae and bacteria, plant extracts (Biomolecules in plants such as proteins/enzymes, amino acids, carbohydrates, alkaloids, terpenoids, tannins, saponins, phenolic compounds, reducing sugar and vitamins) for bioreduction, bioleaching, formation and stabilization of nanoparticles [7]. Green nanotechnology is replacing the other convenient methods such as "physical and chemical", "bottom-up" and "top-down" due to the elimination of hazardous chemical reagents and bestows the effective synthesis of desired products in an inexpensive manner [4]. Silica nanoparticles are synthesized from alcohol solution of silicon alkoxides in presence of a catalyst ammonia this gives rise to various size of silica nanoparticles ranging from 50 nm-1 μm. This same method is modified for various applications of silica nanoparticles.

In nanoscience and material science metal oxides also play a major role in many areas. Metal oxide nanoparticles have eccentric physical and chemical properties due to their restricted size and high density. Particle size is expected to influence three important parameters in any material that is structural characteristics, namely the lattice symmetry and cell parameters, second important effect of size called as quantum size or confinement effects which arises from the existing of discrete, atom-like electronic states, the third group of properties influenced by size of the oxide particle Many oxides have wide band gaps and a low reactivity in their bulk state [8]. However decrease in the average size of an oxide particle do in fact change the magnitude of the band gap [9], which strongly effects in the conductivity and chemical reactivity of the metal oxide. Surface properties are essential for any material due to their importance in chemistry because most of the solid-gas or solid-liquid chemical reactions are mostly confined to the surface and/or sub-surface regions of the solid [10]. Metal Nanostructures have been prepared for many oxides such as AlO3, MgO, ZrO2, CeO2, TiO, ZnO,Fe, Sn and TiO2. Metal oxides can attain a vast number of structural geometries which can be exploited for fabrication of, sensors, piezoelectric devices, fuel cells, coatings for the passivation of surfaces against corrosion, and encapsulation of agrochemicals for controlled release engineered NPs based products, (nanofertilizers, nanofungicides, nanopesticides), and as catalysts [11]. Due to their strong magnetic properties the iron oxide NPs were used in biology and in medicine for the magnetic separation of biological products,cells as well as magnetic guidance of particle systems for site-specific drug delivery, and also used in gene transfer (crop improvement), Nanosensors, nanofood, encapsulation, food packing, nanocoating's, precision farming (remote-sensing devices) [12], Current research on metal oxides affirms that most of their physico-chemical properties unveil notable significance in chemistry are mostly related to the industrial use of oxides as ceramics, sensors, absorbents and/or catalysts [13].

Mesoporous silica nanoparticles (MSNs) have captivate serious recognition over the last decade due to their distinctive and versatile physiochemical properties [14]. Mobil researchers in 1992 first synthesized MSNs and were called Mobil crystalline materials (MCM) [15]. Silica is one of the most complex and most abundant families of materials, which can exist as a compound of several minerals and as synthetic product. Some examples include fused - quartz, fumed- silica, silica - gel, and different kinds of aerogels. Inside the majority of silicates, the Si atom shows a tetrahedral coordination, consisting of four oxygen atoms surrounding a central Si atom. The most common example is seen in certain quartzite polymorph [16]. Silica NPs are broadly divided as mesoporous and nanoporous in which size of both the nanoparticles can be controlled by changing the composition of the surfactants during the synthesis of nanoparticles [17]. Silica nanoparticles are used widely in various applications, because of their easy and low-cost large-scale preparation hydrophilic nature, good biocompatibility, large specific surface area, pore volume and controlled particle size [18, 19]. Silica nanoparticles are also thought to be the safest non-toxic particles for DNA-conjugation and drug delivery [20]. Silica nanoparticles due to its smaller size, chemical nature, surface area and greater absorption capacity by the plant cells, it has been used in increasing the seed viability of the maize plant. Enzyme activity is a main concern in biochemical studies and it plays an important role in the use of enzymes in drug discovery, food chemistry, and biofuels from enzymatic biomass processing. The hydrolysis and formation of esters catalysed by lipase are research topics in organic biosynthesis. The immobilization of the enzymes on the nanoparticles is also focused field currently in nanotechnology [21]. silica plays a vital role as ingredients in food, pesticides and personal care products; as fillers in plastics, rubbers, and coatings; and as staring materials for semiconductors, silicates and ceramics. Silica applications has also recently explored in the biomedical field. Researchers have successfully worked on the utilization of these nano carriers for loading multifarious of cargo ranging from drugs to macromolecules [22]. Such as DNA, proteins and RNA [23]. All-inclusive literatures are available and research is still going in evaluating new ventures for the use of MSNs in drug delivery. Several reviews related to silica nanoparticles in improving the compatibility of the drug [24, 25] as controlled/sustained drug delivery system, applications in biomedicine [26, 27] have been published. The oil spillage occurring from exploration, transportation, storage and refining of crude oil is a frequent phenomenon. The accidental oil spillage of crude oil from tankers and ships leads to spreading of oil over a large surface area of the ocean and has major impact on coastal shoreline and oceanic ecosystem. The silica nanoparticles has been used the starting filtration and absorption material in many bioremediations [28].

### 1.1 Chemical Synthesis of Silica Nanoparticles

Silica nanoparticles where produced from the long date ago by different methods such as reverse micro emulsion, stober's methods, flame synthesis and widely utilized sol-gel method. There are also some novel methods evolved during the time to synthesize the silica nanoparticle. The chemical synthesized silica nanoparticles are widely used as chemical route is easy to follow and we have options of modification of the different parameters of the silica nanoparticle, in reverse micro emulsion, the spherical miscelles are formed by the dissolving surfactants molecules in the presence of water, the polar head groups assigns themselves to form the reverse micelles (micro cavities containing water) [29]. The major catch of this method are high cost and difficulties in removal of surfactants in the final products. But this method was successfully used for the coatings of nanoparticles to attach different functional groups for ample applications [30, 31].

The high temperature flame decomposition of metal-organic precursors are also popular method for the synthesis of silica nanoparticles which is also called as chemical vapour condensation (CVC) [32]. The CVC process synthesize the nanoparticles by reacting hydrogen and oxygen with silicon tetrachloride ($SiCl_4$).the main disadvantage of this method is the controlling the particle size, morphology, and phase composition [33]. However this method has been used widely in commercial synthesis of silica nanoparticles in powder form.

Sol-gel method for the synthesis has been used since decades for the production of silica,glass, and ceramic materials due to its propensity to form pure and homogeneous products at clement state. This method involves hydrolysis and condensation of metal alkoxides such as TEOS,TMOS, or inorganic salts as sodium silicate in the presence of mineral acid (e.g., HCl) or base (e.g., NH3) as catalyst [34, 35]. The formation of the silica particles from the TEOS are in the below reaction. The hydrolysis lead to the formation of silanol groups from TEOS molecules followed by the condensation/polymerization between the silanol groups (Si–O–Si) that form entire silica structure.

The Werner Stöber frontiersman of the stober's method synthesized the spherical and monodispersed silica particles with the size ranging from 5 to 2000 nm from silica alkoxides aqueous alcohol solution in the presence of catalyst ammonia [36]. The stober's method was evolved with the time as many contemporary research works has been done on the synthesis of silica nanoparticles with this method. The main edge of the stober's method is the capability to form monodispersed spherical silica nanoparticles with wide range of size as compared to acid catalyzed systems which usually produces gel structures. Alexander Liberman et al. have depicted in (Fig. 1) the Common techniques in silica nanoparticle synthesis. The chemical approach silica nanoparticles are proven to more toxic, economically costly, high energy consumption, which led the emergence of biogenic route of synthesis biogenic synthesis and Biosilification is an economically viable, energy saving and green approach for the commercial scale synthesis of oxide nanomaterials [31].

### 1.2 .Biogenic Synthesis of Silica Nanoparticle

The biological synthesis of nanoparticles using bacteria, fungi, algae (biomass), plant compounds (extract and metabolites) have become a recent trend [37]. Biosilicification the biological synthesis of silica through silicatein and silaffin has resulted in the design of synthetic cationic polypeptides that mimic the behaviour of silicatein. Diatoms and fungi has also been investigated in the formation of silica by hydrolysis of silicon. Through a detailed study of the reaction of the fungus Fusarium oxysporum with aqueous a anionic complex of $SiF_6^{2-}$ resulting in their protein-mediated hydrolysis and room temperature synthesis of silica [38, 39]. .They accumulate the inorganic metallic ions present in the environment and convert it to metal nanoparticles [40]. Silica nanoparticle or nanosilica have a wider application because of their stable nature, low toxicity and are surface functionalized by using bonding molecule and polymers. The silica nanoparticles are synthesized using sugarcane bagasse, rice husk,rice straw [41, 42] are some by-products considered as waste material. The silica present in the waste materials isolated using sodium hydroxide as a precursor to form sodium silicate solution [43]. PH, temperature, concentration and time influences the synthesis of the nanoparticles [44].

The purpose and preference of biological synthesis over physiochemical synthesis is because of their low-toxicity, rapid and easy isolation, eco-friendly nature and safe, affordable and controlling the characterization of the NPs like size [40]. The source containing silica (Rice Husk, rice straw, sugarcane bagasse) were washed with distilled water to remove the impurities like dust, sand and dried in hot-air oven at 60 °C for a day. The silica were synthesized with or without acid leaching, followed by combustion. The pre-treatment's includes water treatment Water pre-treatment of raw RH to washout adhering some metal cations soil, and dust, acid treatment such as HCl, was one of the simplest pre-treatment's to obtain high quality RH silica [45–48]. There has been lot of efforts has been made to minimize the metal and carbonaceous impurities to produce high quality silica, there are many minerals present in bio

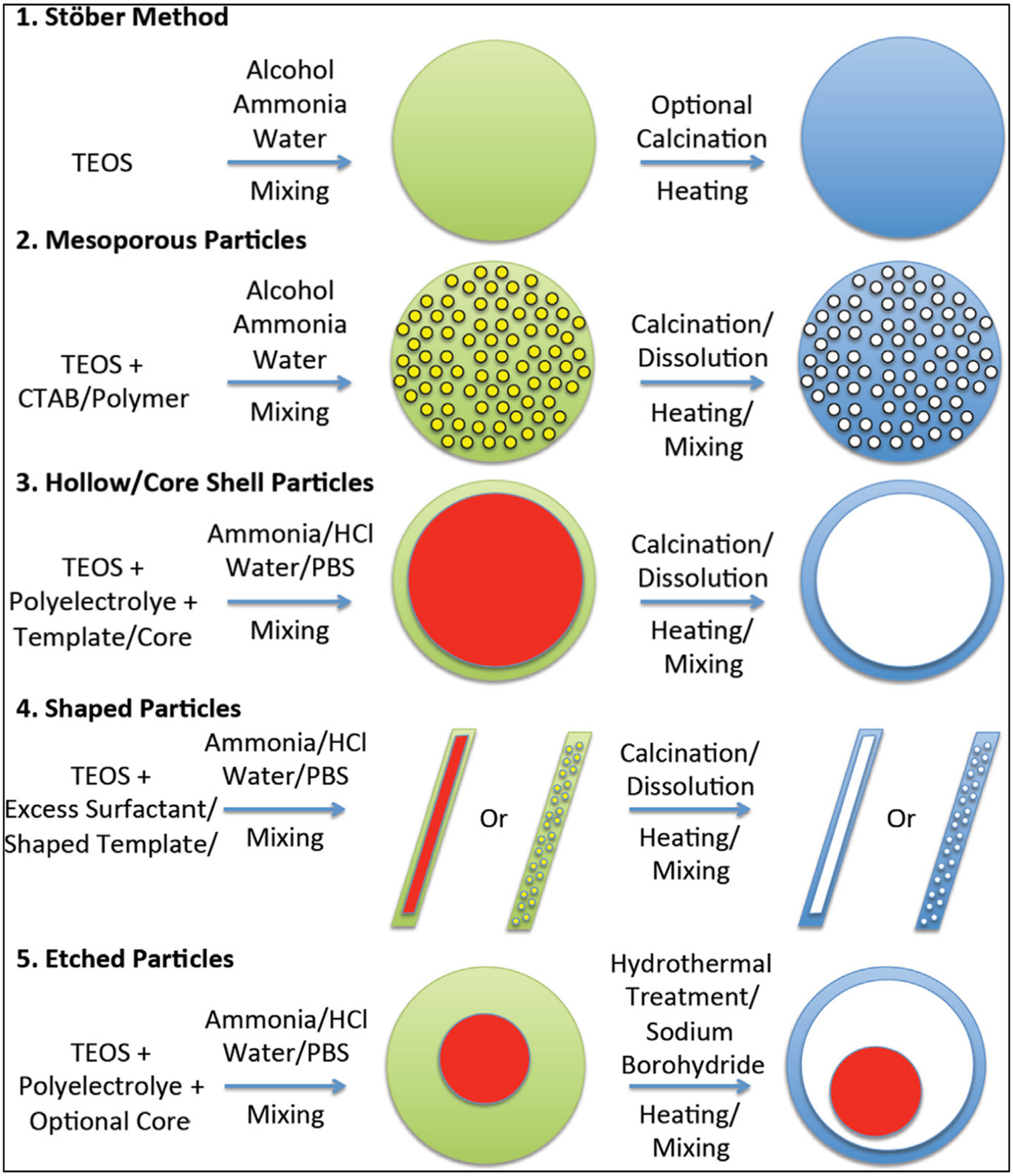

**Fig. 1** Common techniques in chemical synthesis of silica nanoparticle [31]

products such as K, Na, Ca, P, and Al, etc. were found responsible for residual carbon and crystallinity in the synthesized silica. Acid leaching is widely used before calcination to effectively remove metal impurities. HCl has been widely used for the acid treatment besides HCl other acids including $H_2SO_4$ and HBr etc. [49–52] have been used to treat RH to produce high quality silica. The base or salt treatments have been also explored in case of rice husk to remove metal impurities sodium hydroxide (NaOH) was mostly used [40]. Salts, has also been used for pre-treatment RH such as KMnO4 [52].

The silica has also been synthesized directly by calcination of the RH, The morphology and property of the synthesized silica critically depends on the degree of calcination.shen.et al conducted thermal treatment of raw RH for 0.5–3.5 h with air [53] to study the effect of calcination temperature, duration, atmosphere, and instrument. The silica obtained from calcination of RH at 600c was amorphous and at 700 c was both amorphous and crystalline. With the increase of the temperature the amorphous nature of the silica diminished and crystallinity increases. Direct calcination is the simple and straightforward method but the silica usually contains good amount of metallic and other impurities that is because most of researchers opt for the treatment of acids or bases for the synthesis of biogenic silica from the bio products. As most of the common crystalline SiO2 particles are not in the nanometer-size region, given below (Table 1) are the various detailed processes for the green synthesis of amorphous silica nanoparticles (aSNPs). Suriyaprabha Rangaraj and Rajendran Venkatachalam highlights the feasibility for the mass production of silica nanoparticles from bamboo leave waste rather using chemical precursor of silica for drug delivery and other medical applications [50]. The Fig. 2 shows the chemical and biogenic synthesis of synthesis of silica nanoparticles.

### 1.3 Chemical Applications of Silica Nanoparticles

Silica nano particles advantageous properties allows variety of moieties functionalized with ease in different regions of the particle. The structure of MSNs has three specific sites of function-alization that are mainly focus, namely: the pore walls,,entrance to the pores and the interior/ exterior surfaces of the particles. The particle surface Functionalization allows for specific and unique applications of that would other-wise be inaccessible [16]. Mainly the functionalizations are done using organo-substituted trialkoxysilanes during the synthesis of the material by co- condensation or by post-synthesis grafting [31]. The major advantage of introducing any functionality within the pore walls of MSN is that the non-siliceous group will not partially block the mesopores. Alkoxysilanes are bind forming at 1–3 Si–O–Si links to the surface in a condensation reaction with the surface silanol groups. Different metals have also been incorporated into the walls of mesoporous silica materials. Aluminium is one of the most common element incorporated into the mesoporous silica matrices, which has been employed for various catalytic processes. Zhai and co-workers prepared Mesoporous aluminosilicate nanoparticles using polyethylene glycol to surround the formed particles thereby ensuring the obtention of particles as small as 20 nm [58]. Shi and co-workers synthesised a layer of mesoporous silica on a hematite nanocore to obtain magnetic MSN that were used to load and release ibuprofen as a model drug [59]. Hyeon and co-workers prepared MSN with quantum dots (CdSe/ZnS) and magnetic nanoparticles embedded in the matrix of the material [60]. Yamashita and co-workers prepared iron oxide and titanium oxide-embedded MSNs, and used them for catalytic oxidation reactions [61]. An exclusive characteristic of mesoporous silica nanoparticles is that they have two designated surfaces: an internal and an external one these two surfaces differences have proven to be relevant for a variety of phenomena one is concept of “gatekeeping” in mesoporous silica. Lin et al. immobilized an amine reactive fluorophore in the internal surface by growing a dense polymer on the external surface of the particles, and by, selectivity could be induced for the detection of neurotransmitters [62].

Combination of Monofunctionalized MSN can also be used for one-pot synthesis of multistep reactions that do not require proximity between the groups. The main advantage of this is when the catalytic groups are chemically incompatible. Lin et al. demonstrated this ability by functionalizing one MSN with a Brønsted acidic group (4-ethylphenylsulfonic acid) and another one with a basic group (3-aminopropyl). Both MSNs were used to catalyze in a single pot the sequential conversion of 4-nitrobenzaldehyde methyl acetal into its corresponding aldehyde, and the immediate coupling of this intermediate with nitromethane to yield (E)-1-nitro-4-(2-nitrovinyl)benzene. The reaction gave 97.7% yield in the presence of the MSN catalysts, Remarkably, the MSN catalysts allowed the two incompatible species to act without neutralizing each other despite being set simultaneously in the same reactor [63]. Functionalization at the pore entrances was a pioneer work done by Fujiwara and co-workers proposed the use of the voids of mesoporous silica as reservoirs to load and release molecules in a controlled fashion based on the observation that the short time grafting of silanes on MCM-41 that still contained surfactant produced a dense functionalization at the pore entrances [64].

### 1.4 Biotechnological Applications of Silica Nanoparticles

Nanotechnology to nanomedicine, nanoparticle drug delivery is the significant step, to supervise, restore, edifice, and control of human biological systems at the micro level, using engineered nanostructures and nanodevices. The main paradigm of this novel technology is the distribution of drugs, target delivery and other therapeutic agents within a patient’s body. Because of their ability of fine delivery and target particular organs/tissue, to act as carriers of oligonucleotides in antisense therapy, and to deliver drugs, proteins, and peptides. In past 20 years, mesoporous silica nanoparticles (MSNs) have enticed more and more recognition for their potential biomedical applications. Because of their customized mesoporous structure and high surface area, MSNs as drug delivery shuttle show significant advantages over traditional drug nanocarriers. In recent times much focus has been paid on the silica nanoparticles (SiO2 NPs) as promising carriers for controlled drug delivery [65, 66]. Aughenbaugh et al. 2001 conducted the research to investigate the controlled release of drugs and the role of $SiO_2$ xerogels as carriers. Hydrophobic drugs are not much effective due to poor water solubility which results in low absorption during oral dose [67, 68]. The silica nanoparticle entrapment of drug enhances drug delivery, absorption and also reduces the toxicity of the free drug in the body. Thus the therapeutic index is increased due to this Silica nanoparticles to improve the dissolution and absorption of hydrophobic drugs during oral administration [19]. These nanoparticles have high biocompatibility, high drug loading capacity and even simple modification of a functional group

**Table 1** Biogenic synthesis of amorphous silica nanoparticles (aSNPs)

| Experiments | Methods | Result obtained | References |
|---|---|---|---|
| Green synthesis of silicon nanoparticles using rice husk | Method 1<br>• Rice husk was boiled for two hours in 10 wt% HCl, then washed using deionized water and dried<br>• Pyrolyzed at 700 C for 2 h and ultrasonicated and stirring in 0.20 M, KN03<br>• Sample filtered and dried at 800 for 4 h | Semi crystalline porous silica nanoparticle | [54] |
| | Method 2<br>• rice husk was rinsed with deionized water several times and then dried overnight in the oven at temperature 90 °C.<br>• grounded into powder and mixed with ionic liquid resulted in the extraction of lignocellulose 15:1<br>• stirred and heated in the oil bath at 100 C for 12 h<br>• then centrifuged precipitated lignocellulose was collected and washed with deionized water, and dried overnight at 90 C<br>• dried lignocellulose was pyrolyzed for 2 h at 700 C in order to produce silica nanoparticles | Silica nanoparticle | [55] |
| | Method 3<br>• rice husk was treated using 30 wt% sulfuric acid and 10% hydrochloric acid solutions calcinated in muffle furnace at 600 C for a period of 4 h<br>• husk ash was acid leached with 10% HCl followed by addition of 30 wt% sulfuric acid solution was added at a temperature of 100 C<br>• mixture was kept for 2 h in pyrex three-neck round bottom flask that had a reflux condenser in the hemispherical heating mantle<br>• slurry obtained was filtered and washed with distilled water many times till the pH value of 7 was achieved | Silica nanoparticle | [56] |
| Green synthesis of silica nanoparticles using sugar beet bagasse | • sugar beet bagasse was calcinated at 500 °C for a period of 12 h.<br>• Treated with concentrated $HCl:HNO_3$ 1:3 (*v*/v) at 35 °C for 2 h and then dried in the oven at 60 °C<br>• residue was obtained, 50 ml water was added concentrated NaOH was added (pH 13–14)<br>• solution was kept overnight and was neutralized using HCl then filtered with the help of a 0.22 μm | | [57] |

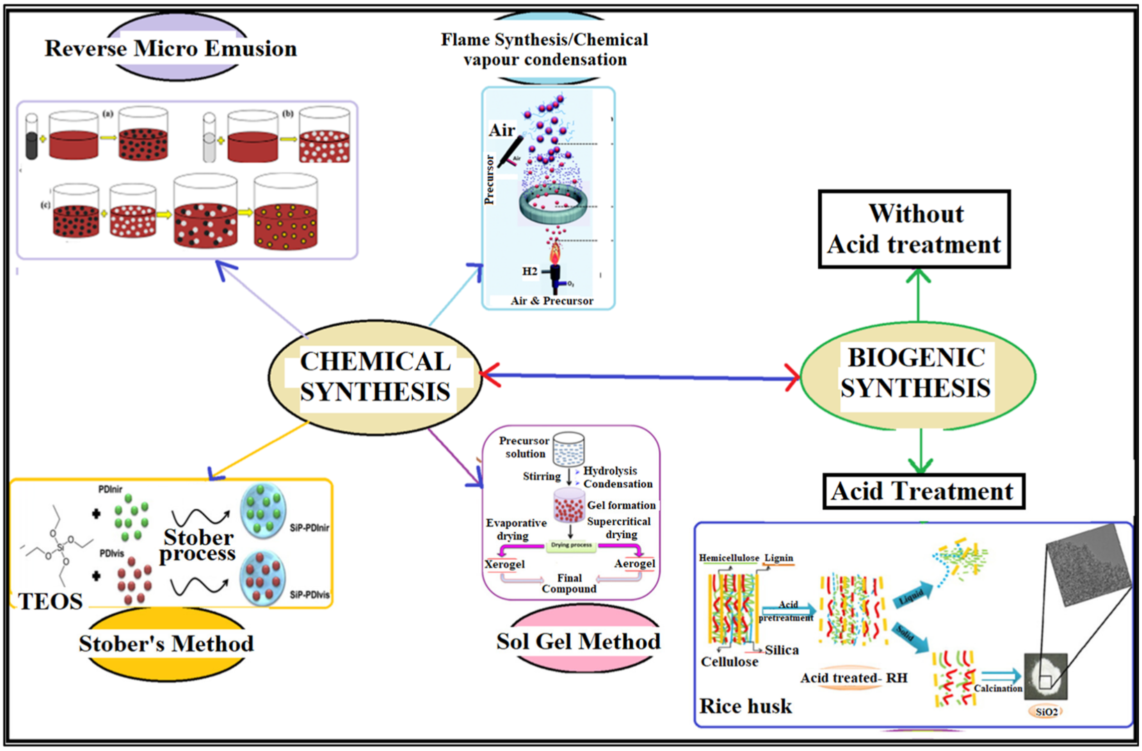

**Fig. 2** Schematic illustration of the chemical and biogenic synthesis of silica nanoparticles

of silica nanoparticles are responsible for controlled drug release [69]. The surface of silica nanoparticles is negatively charged which renders the positively charged hydrophobic drug molecule and makes it electrostatically compatible with the drug release [20, 70]. Zhang et al. investigated the effect of silica nanoparticles as oral administration delivery system for a hydrophobic drug telmisartan. Their study showed that the silica nanoparticles significantly improved the permeability of the drug [71]. Curcumin a potent bioactive compound is having wide application in the therapeutics such as anticancer agent but poor bioavailability is the major problem for the poor efficiency of curcumin. Considering this Gangwar coworkers conjugated curcumin with silica nanoparticles and studied its cytotoxic effect against HeLa cell lines and normal fibroblast cell lines. They found that the curcumin conjugated silica nanoparticles have increased potential as an anticancer agent rather than curcumin alone [72]. Lein and colleagues prepared magnetic and thermosensitive nanoparticles grafted with (PNIPAM) thermosensitive poly (N-isopropylacrylamide) on the surface of silica (SiO2)-coated Fe3O4 nanoparticles with the particle size of 18.8 ± 1.6 nm. Bovine serum albumin (BSA) adsorption and desorption behaviour on the surface of PNIPAM-grafted SiO2/Fe3O4 nanoparticles designate that the fabricated nanoparticles are suitable for controlled drug delivery [73]. The new category of surface-modified silica nanoparticles has been synthesized for dormant approach in boron neutron capture therapy. Eric and group used a modified Stöber method synthesized Sub-50 nm silica particles and applied in surface-initiated atom transfer radical polymerization of two biocompatible polymers, poly(2-(methacryloyloxy) ethyl succinate) and poly(2-(hydroxyethyl)methacrylate) functionalized with carboranyl clusters in high yields acts as boron source proved very stable and non-toxic under biological conditions [69]. Hanif, Huzaifa, et al. presented MSNPs system a reliable method for targeted delivery of monastrol into the cancer cells in vitro [74] (Fig. 3).

Silica nanoparticles are thought of functioning as a cap on the surface which causes the controlled release of the encapsulated drug. Additionally, these nanoparticles are photo absorber which absorbs the optical energy and convert it into heat energy to treat cancer. Yao and colleagues used this property of silica nanoparticles and constructed the quantum dots capped magnetic mesoporous silica nanoparticles as a photothermal therapy. These nanoparticles effectively capped the surface thus there was controlled drug release in an acidic environment. The hydroxy, epoxy group on quantum dots functionalized silica nanoparticles making it pH-responsive [75]. It is believed that the monodentate carboxylate coordination allows triggered drug release by ligand exchange in the cells in the low pH [76].

### 1.5 Biomedical Applications of Silica Nanoparticles

Biomarkers should be very specific towards the biomolecules to detect and should have stable signal transducer. Nanoparticles due to their small size and large surface area to volume ratio are used to detect even the minute

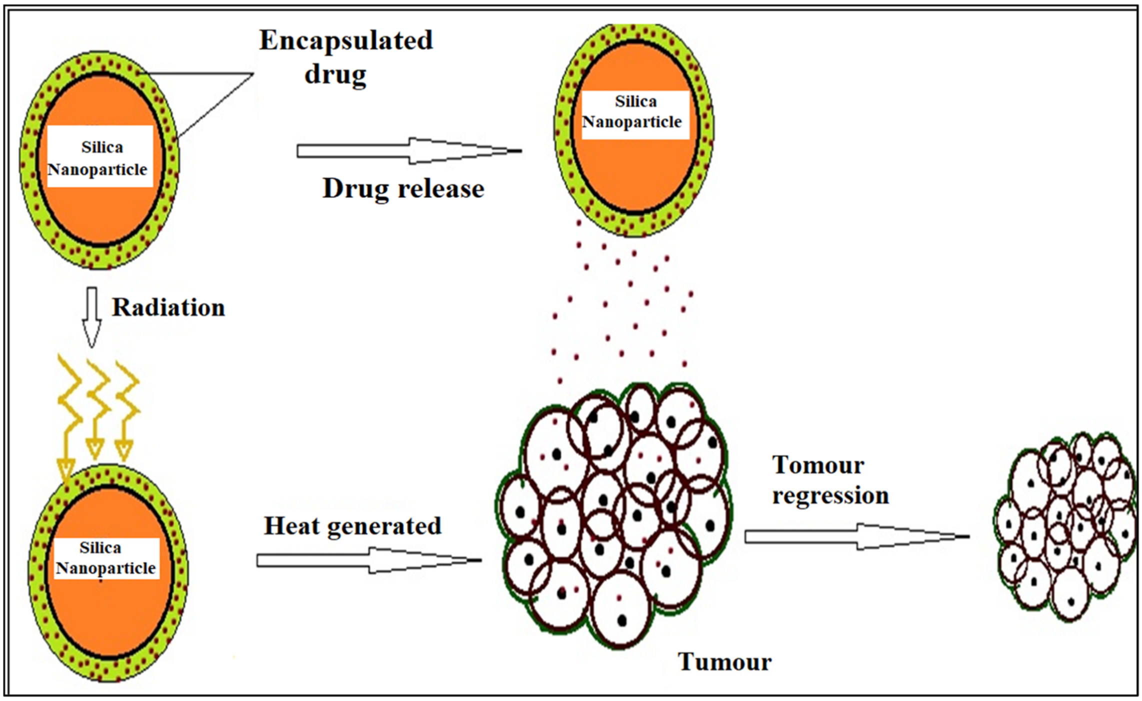

**Fig. 3** Drug delivery mechanism silica nanoparticle functioning as a cap on the surface which causes the controlled release of the encapsulated drug and shows photo absorbing property which absorb the optical energy and convert it into heat energy to treat cancer [74]

biomolecules with specificity. Currently, Quantum dots are the most important nanoprobes used in imaging. Although Quantum dots (QDs) are widely used in the biomedical application there is a huge concern about the toxicity of heavy metal like cadmium, lead present in QD which may harm the cells. Also, QD are insoluble in water thus they have to be linked with some polymer for using it in aqueous biological condition. Thus alternative nanoparticles are used for bioimaging which will be less toxic. Studies show that by covalently linking the fluorophores in the core of silica nanoparticle improves the fluorophore property. Choi coworkers synthesized C dots by covalently linking the as tetramethyl rhodamine isothiocyanate dye in the core shell of silica nanoparticles. These C dots showed an increase in brightness and stability of the dye. Also, they were water-soluble in nature and most importantly since they consist of silica which is biologically inert they are non-toxic to the biological environment compared to QDs [77, 78]. The surface of core-shell of silica nanoparticles has the high adhesive strength to hydrogels and tissues. Thus silica nanoparticles are used to design as a glue which is clearly visualized by imaging. This process is less invasive as compared to the cyanoacrylate adhesive which is a common tissue adhesive [69]. Silica nanoparticles are also shown to differentiate cells. They are known to show osteogenesis of the hMSCs. As the osteogenesis and adipogenesis are inversely related the silica nanoparticles decrease the adipogenic differentiation. This property of silica nanoparticles can be used in the treatment of obesity [79].

Yoshio Kobayashi et al. proposes preparation methods for quantum dot/silica (QD/SiO2) core–shell particles that immobilize Au nanoparticles (QD/SiO2/Au) with an average size of 47.0 ± 6.1 nm was prepared by a sol–gel reaction of tetraethyl orthosilicate in the presence of the QDs with an average size of 10.3 ± 2.1 nm. was found to have dual functions, (Fig. 4) i.e., fluorescence emission and X-ray absorption in vivo, which makes it suitable to function as a contrast agent for dual imaging processes [81].

Both the inner and external surface of mesoporous silica nanoparticles can be functionalized with different functional groups. Recent studies have shown that the development of fluorinated mesoporous silica nanoparticles can act as a dual probe. Fluorine Nucleus (19F) nucleus is very sensitive, abundantly present in nature, can be used in ionization radiation-free imaging and has nearly same resonating frequency that of 1H.Additionally, as it is present in traces in biological tissues the probes of 19F can detect very minute details with strong signal to background noise ratio. However, it is challenging to develop probes containing appropriate fluorine for detection in 19F MRI. Thus the probes of fluorine groups can be grafted on the surface or in the core of silica nanoparticles for imaging [82]. Marine Perrier and co-workers prepared an original fluorophore engineered for two-photon excitation or a porphyrin derivative were entrapped in the silica shell of magnetic porous silica nanoparticles during the synthesis of the silica moiety without damaging the structure of the organic part and they grafted mannose on the surface of the nanoparticles to

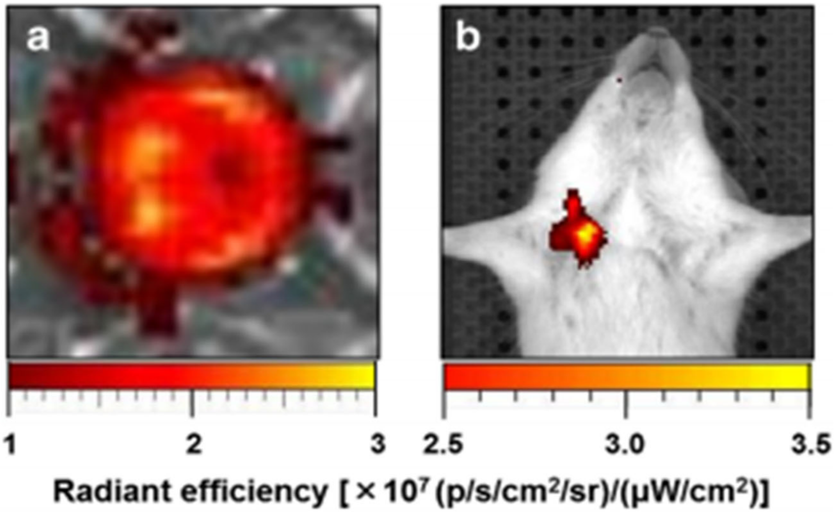

**Fig. 4** IVIS images of a the QD/SiO2/Au particle colloid solution and b a mouse after the colloid solution was injected into its chest wall [80]

target MCF-7 breast cancer cells Nano-objects designed with the two-photon fluorophore were efficient for two-photon imaging of MCF-7 cancer cells, whereas the nano-objects with the photosensitizer efficiently killed cancer cells [83].

Medical diagnosis and research have become more precise on the analysis and detection of single chemical interactions of small targets like DNA, mRNA, proteins, cells, peptides. To detect such a small molecules probes of similar size have been developed which brings nanotechnology into the limelight of medical research [75]. In past couples of years, nanoparticle-based techniques have shown promising results in ultrahigh-throughput screening, microchip technology, diagnostics, drug, delivery, medical imaging, treatment of cancer, diabetes, allergy, infection and many more [79, 81]. Investigation of enzymatic hydrolysis of quinizarin diester adsorbed in silica nanoparticle and dispersed in the surrounding medium, respectively, shows good immobilization of quinizarin diester in silica nanoparticles [80]. Wab and co-worker study describes the formation and properties of a silica nano colloid drug delivery system synthesized using micelle formation method earlier they have reported the feasibility of using the same approach to entrap colourless water-soluble drug (isoniazid).SiNPs (mesoporous NPs and surface functionalized NPs) have been designed to be carrier systems for drugs and genes which has pushed the boundaries in medicine field [21].

Generally, antibiotics are the releasing antibacterial agents in the surroundings to kill bacteria. However, there is depletion of the antibacterial agent after a point and undesirable toxic substances are released into the environment. On the other hand, there are some antibacterial agents which kill the bacteria by contact. Quaternary ammonium compound is a type of contact killing antibacterial agent. Synthesized silica nanoparticles which are cross-linked to the photosensitive contact killing the antibacterial agent. These were then used as a UV-curable antibacterial coating. These particles possess high mechanical properties, optically transparent and are chemically inert [84]. Major challenges in developing new antibiotics are the antibacterial poorly penetrates into the bacteria and has toxicity in the surrounding environment. To overcome this, silica nanoparticle encapsulated peptide which is effective against *Pseudomonas aeruginosa* in the lung infection. The silica nanoparticle which is biodegradable protected the peptide from its release before reaching the target site [85]. The rise in multi-drug resistant tuberculosis has developed huge loss in the pharmaceutical industry. As the high cost of production of new antibiotic has to be sold out for a low price and should be produced in bulk. To overcome this Valetti and co-workers refurbished the clinically tested drug clofazimine. It is active against MDR –TB but has inconsistent therapeutic activity. Also it is poorly soluble in GI tract and is not absorbed well in GI tract. The encapsulation of this drug by silica nanoparticles stabilized the molecule in amorphous form and increased its solubility [86]. The silica nanoparticles gentamicin nanohybrid has been successfully prepared for the controlled in vitro release of the antibiotic gentamicin as a targeted bacterial growth inhibitor for various gram-negative bacteria promising antimicrobial administration of the nanohybrids in bone applications [87]. The other nanoparticles have also a wide range of antimicrobial activity but due to their toxicity have limited use. The nanocomposites of silica nanoparticles with those nanoparticles have emerged the option of less toxic nanocomposites with antimicrobial activity [88, 89]. Silica nanoparticles can be promising antibacterial with least toxicity in future.

## 2 Application of Silica Nanoparticles in Agricultural Field

The unrestorable damage agriculture has had to face because of numerous facets like fungi, weeds, and insects from decades, leading to the exhaustive decrease in yields. This problem has been highly controlled by the institution of the chemical pesticides in the agricultural field. But due to the heavy usage of chemical pesticides and eventual uninhibited application of them has warranted for alternatives mainly for health and environmental concerns. Degraded soils and ground water pollution has resulted in nutritionally imbalanced and unproductive lands. There is an increasing concern of public health about the use of chemical pesticides because they are associated with different types of neurologic pathologies, cancers, respiratory symptoms and hormonal and reproductive abnormalities, according to some epidemiological studies therefore, an eco-friendly insecticides are in the main focus in the current scenario. In the stored food commodities the stagnation, is mainly caused by these factors like. Fungi, insects, and rodents under different conditions of storage. The estimates of yield losses by insects and diseases range from 5 to 10% in temperate regions and 50–100% in tropical regions [90]. Torney, Francois, et al. synthesized a honeycomb mesoporous silica nanoparticle (MSN) system of 3-nm pore size act as a nano carrier for genetic material and chemicals into intact leaves and isolated plant cells. They loaded the MSN with the gene and its chemical inducer and capped the ends with gold nanoparticles to keep the molecules from leaching out. Further developments of these MSNs such as pore enlargement and multi-functionalization may offer new possibilities in target-specific delivery of proteins, nucleotides and chemicals in plant biotechnology. When maize seeds were pre-treated with silica nanoparticles, the seed showed greater resistance from fungus attack [91]. This nature is attributed due to the formation of organic compounds in the cell wall of the maize seeds. Also, pre-treated seeds with silica nanoparticles had increased nutritional content due to the absorption capacity and had greater germination rate when compared to any other silica-based source [92]. Siddiqui and Al-Whaibi also claimed about the increased germination rate, seed germination index and mean germination time [93]. The concentration of silica nano-particles used was 8 g L-1 that resulted in the increase in germination rate by 22.16%. Survival of the plants during stress conditions like increased salinity is very less. The only way to raise the survival of the plant during these stress conditions was by introducing a gene that codes for a protein which helps to withstand even during higher salinity conditions. But introducing these genes into the plant is a costly, time consuming and a tedious process. Lately, application of silica nanoparticles has proven a means to reduce the workload of gene introduction. Kalteh and his colleagues treated Basil (Ocimumbasilicum) plants with silica nano-particles which were planted in an increased salinity condition. The results indicated a positive effect of silica nano-particles during stress conditions by increasing the proline content and the chlorophyll a content. Increased proline content helps the plant to withstand the stress. Silica nanoparticles reduced the sodium toxicity by decreasing the absorption of sodium content. Also, usage of water in the plant was efficient by regulating humidity of xylem and water translocation due to silica nanoparticles treatment [94]. In contrast to Kalteh's experiment, treatment of silica nanoparticles to algae, *Scenedesmus obliquus*, showed opposite effect. The chlorophyll content in *S. obliquus* decreased when treated with higher levels of silica nanoparticles (100 mg L-1 and 200 mg L-1) [95]. However, at a moderate concentration of 50 mg L-1, algae were able to resist the stress environment by regulating homeostatic mechanism [96]. Table 2 shows some important application of silica nanoparticles in agriculture sector. One of the advantages of using silica nano-particles is they do not cause any adverse effect on the plant and instead it improves the strength and structural rigidity of the plants [104].

## 3 Entomotoxic Application of Silica Nanoparticles

Nuclear Polyhedrosis Virus (NPV) is a double-stranded DNA virus that infects insects and has been reported to cause problems in the silk production industry [105]. Nano-silica with surface modification having hydrophobic and hydrophilic groups was effective against NPV, Similarly, hydrophilic silica nanoparticles were more effective when compared to hydrophobic and its bulk counterpart [98]. Concentration of 1 g $kg^{-1}$ could kill 89% of *Sitophilus oryzae* in 2 days and subsequently, the infestation did not occur for more than 2 months after mixing the rice with silica nanoparticles. Use of nano-silica in pesticide has been the most effective method in agricultural filed to decrease the insects infestation [100, 106]. A report suggests *Aphis gossypii* and *Callosobruchus maculates* causes damage to the tomato plants and were treated with pesticide containing nano-silica and the results obtained showed significant decrease in the number of eggs laid per female. Hence there was the reduction in the number of progenies and caused less damage to the plants [107]. The effect of nano-silica particles was more in case of adults when compared to larvae by reparation of the digestive tract leading to dehydration, blockage of spiracles and trachea. Also, the cuticle layer of the insect was damaged that led to the death [97, 101]. Similarly, the longevity and nymph production of *Spodopteralittoralis* was affected by the treatment of silica nanoparticles and therefore recommended as one of the best pest management strategy [108] .Figure 5, depicts entomotoxic effects of silica nano-particles silica nanoparticle dehydrated the digestive tract of *aphis gosypii* and blocked the tacheole also has damaged the outer cuticle layer which shows perforations. Silica nanoparticles at concentration of 112.5 ppm were able to eradicate the mosquito vectors by affecting larval stage, pupa stage and interfering with growth of the mosquito [97]. The Major advantage of using silica

**Table 2** Shows some important application of silica nanoparticles in agriculture sector

| Serial number | Nanoparticle Size(nm) | Concentration of Nano-silica | Applications | References |
|---|---|---|---|---|
| 1. | 20–40 | – | Increased seed viability | [92] |
| 2. | 12 | 8 g L$^{-1}$ | Increased germination rate, seed germination index and mean germination time | [93] |
| 3. | 15 | 112.5 ppm | Insecticide (Mosquito control) | [97] |
| 4. | 10–20 | 200 mg ml$^{-1}$ | Growth inhibition and decreased chlorophyll content in *Scenedesmus obliquus* | [95] |
| 5. | 15–30 | 2 g Kg$^{-1}$ | Entomotoxic effect against *Sitophilus oryzae* | [98] |
| 6. | 23–33 | 0.5 mg cm$^{-2}$ | Entomotoxic effect against Spodopteralitura | [99] |
| 7. | 50 | 155 ppm | Nanopesticide against Tutaabsoluta | [100] |
| 8. | 20–60 | 2.06 g Kg$^{-1}$ | Insecticidal effect against Callosobruchus maculates | [101] |
| 9. | 80 | – | Controlled delivery system for water-soluble pesticide | [102] |
| 10. | 70–100 | – | Controlled release of avermectin | [103] |

nanoparticles is that they do not develop resistance to silica nano-particles because the damage is done physically and not at the molecular level [99].

There are many other eco-friendly safe pesticides such as biopesticides which are also effective against the pests but they are less efficient bioavailable for insects and have very less biocompatibility to be stable in the normal environmental conditions such as temperature, humidity, pH, pressure etc. [109]. Silica nanoparticle is the possible option for these eco-friendly pesticides which can make these pesticides highly effective against by conjugation or encapsulation of these biopesticides. Hence the silica nanoparticle can be used as the pesticides carrier. In order to transfer the pesticides in a field, silica nanoparticles are used as a controlled delivery system. Validamycin, a water-soluble pesticide, was entrapped in porous silica nanoparticles and a controlled release of the pesticide was evaluated. Alongside, parameters such as pH and temperature play the crucial role in the release of entrapped pesticide. Higher the pH and temperature, greater was the release of pesticide from the conjugate of pesticide-PHSN (Porous hollow silica nano-particles) [102, 103]. The release of the pesticide depends chiefly on the surface area rather than pore size of the nano-particles The adsorption and release of an agricultural biocide (imidacloprid) by the mesoporous silica nanoparticle demonstrated the more effectively controlled and targeted delivery for other biomolecules [110] .There is a huge scope in the development of the biopesticides with the application of silica nanoparticle.

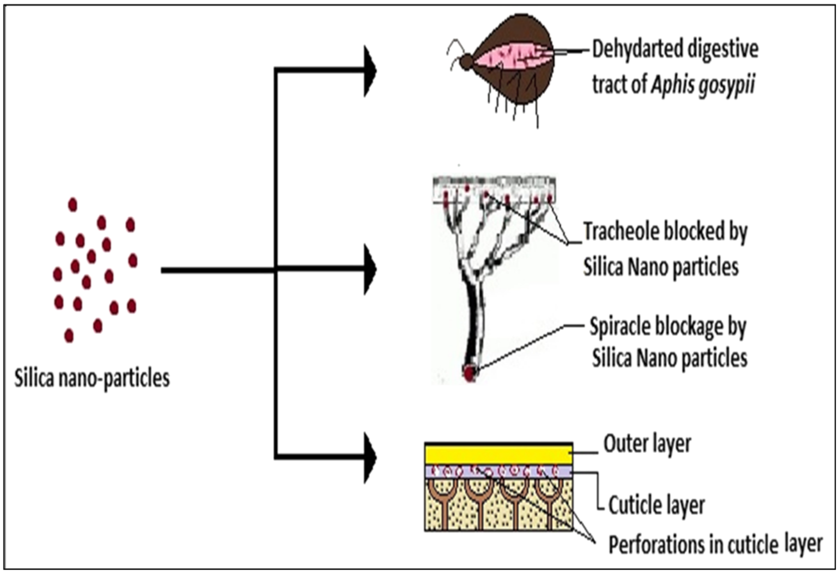

**Fig. 5** Entomotoxic effects of silica nano-particles silica nanoparticle dehydrated the digestive tract of aphis gosypii and blocked the tacheole also has damaged the outer cuticle layer which shows perforations [97].

### 3.1 Applications of Silica Nanoparticles in Fruit Preservation Industry

The induction of nanomaterials in food packaging provides an edge to safety and functionality that potentially increases the shelf life of foods [111]. In a novel approach, chitosan / nano-silica hybrid films were used to coat longan fruits (*Dimocarpuslongan Lour. cv shijia*) to increase shelf life [112]. Apart from increased shelf life, the hybrid film also showed decreased levels of peroxidase activity, browning effect and weight loss that led to improved way to preserve the fruit. Similarly, Loquat (*Eriobotrya japonica Lindl.*) fruit was coated with chitosan / nano-silica hybrid films and not only the shelf life was increased but it also increased levels of reducing sugars such as glucose and fructose by improving the activities of various enzymes like catalase, superoxide dismutase and ascorbate peroxidase [113]. Figure 6, shows application of Nano-silica in fruit preservation chitosan / nano-silica hybrid film increases shelf life., the hybrid film also showed decreased levels of peroxidase activity, browning effect and weight loss owing to their availability, low cost and relatively simple processed clay and silicates have attracted focus of researchers as potential nanoparticles. The layered silicates, about 1 nm thick to a few microns long are usually employed in nanocomposites in their two-dimensional structure. The combination of silicates and polymers impart excellent barrier properties. This combination enhances the diffusive path for an infiltrate molecule [114, 115]. Silica has immense potential as the packaging materials combined with other materials for the best results there is a huge gap in the research involved in the production of packaging materials as the polythene bags and plastic materials are huge threat to our environment the silica nanoparticle can fill that gap with combination with other biodegradable polymers.

## 4 Industrial Applications of Silica Nanoparticles

Industrial applications of silica nanoparticles have increased ever since it has been introduced in various fields. Biosensors were developed using mesoporous silica-based nano-fibers for the immobilization of Horseradish peroxide (HRP) [116]. Mesoporous silica-based nano-fibers were used as a matrix for encapsulation of HRP and its activity was measured, results indicated the presence of HRP in its native state and did not lose its activity. Greater surface area, small diameter and excessive porosity of mesoporous silica nano-fibers lead to the encapsulation of HRP enzyme and similarly, other enzymes can be encapsulated using the same technique. In the same way, Takeshi Yamauchi and his colleagues immobilized capsaicin on the surface of silica nano-particle using poly

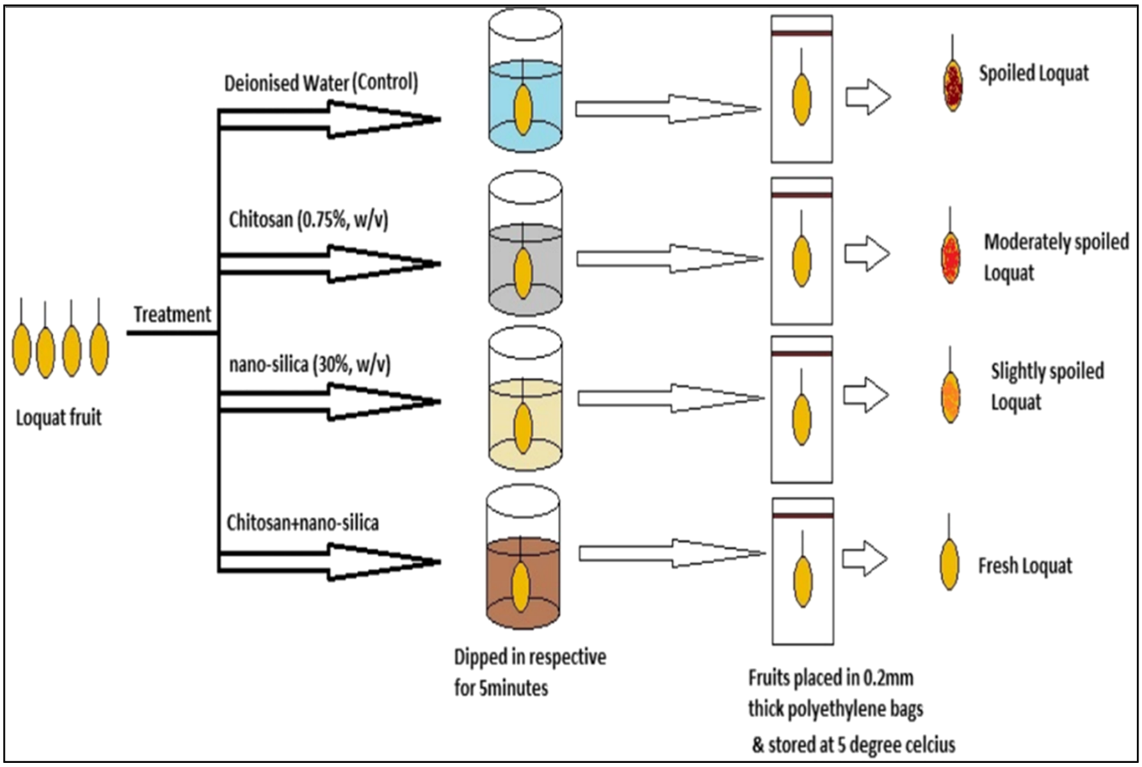

**Fig. 6** Application of Nano-silica in fruit preservation chitosan / nano-silica hybrid film increases shelf life., the hybrid film also showed decreased levels of peroxidase activity, browning effect and weight loss [114]

(amidoamine) (PAMAM) and its stimulus activity was determined [116, 117]. The advantage of performing the experiment was that encapsulated capsaicin had increased stimulus activity when compared to capsaicin alone.

Conventionally prepared molecularly imprinted polymers (MIPs) has a disadvantage of having irregular shapes, sizes and altered distribution of binding sites, therefore nano-silica based MIP nanoshell were prepared for determination of rhodamine B (RhB) [118]. Silica-based MIP had higher binding kinetics, increased recognition of RhB and elevated affinity due to the electrostatic force and hydrogen bonding between the template and MIPs. Silica nanoparticles were reported to increase the toughness of hybrid polymer when combined with the epoxy polymer that can be used as electronic encapsulating resins, adhesives and composite matrices [119]. Composite of alumina and silica nanoparticles were prepared that had greater anti-friction and anti-wear properties when evaluated against pure alumina and silica nanoparticles [120]. Recent advances in the synthesis and production of nanoparticles have enabled the production of environmentally responsive surface-modified nanoparticles with both hydrophilic and hydrophobic surface groups which enhance the recovery of oil. Environmentally responsive surface-modified colloidal nanoparticles coated with, at least, two physio chemically distinct surface groups which can decrease the Oil–water interfacial tension and water surface tension. Abed Behzadi and Ali Asghar Mohammadi synthesized and used environmentally responsive surface-modified silica nanoparticles silica nanoparticles with polyethylene glycol chains as hydrophilic agent and propyl chains as hydrophobic agent for enhancement of oil recovery [121, 122]. Due to their effectiveness in very harsh environments silica Nanoparticles are a promising, substitute to the chemical surfactants to stabilize emulsions or foams in enhanced oil recovery (EOR) processes in oil industry. Size-dependent properties of silica nanoparticles pickering the stabilization of emulsions and foams which helps in enhanced oil recovery [123].

## 5 Application of Silica in Environmental Remediation

Silica nanoparticles are used to carry out enhanced oil recovery to reduce the liberation of brine, heavy metals and radioactive compounds into water. If there is a leak, the affected water is pushed underground; this causes water flooding which benefits oil recovery. The nanoparticles may not be that balanced in high salinity water which is where the oil is extracted from and this poses an obstruction in their use. Hence the need to change the nanoparticle functionality to support the extraction is a necessity. This was tested [124] where H+ protection was given to silica nanoparticles in sea water under lab conditions showing that HCl added to nanoparticle and seawater solution serves the shielding act. Surface treated nanoparticles can move across rocks holding the oil through reversible adsorption and with the use of viscosity enhancers the transportation issue was also resolved by experimentation. Behaviour of silica nanoparticles in sandstone, dolomite, and limestone was also studied [125]. One such study involves commercial silica with a size of twenty nanometre using sandstone core as the reserve. Different concentrations of silica nanocomposites were used. The maximum oil recovery was achieved at optimum silica nanoparticles concentration of 0.1 weight percentage [126]. SiNPs steady CO2 foam from oil and remain stable during oil displacement, this increases oil recovery helps in lowering carbon footprint due to carbon dioxide [127]. Various new studies in nanotechnology have shown that incorporation of nanoparticles in the polymer helps with the flooding process improving the oil recovery factor. The Nano silicates increase the recovery factor up to 10% and this is because of the viscosity of the injected fluid [128].

The removal of lead metal by adsorption on silica nanoparticles was studied under the condition that two lead polluted plants connected to electrically charged SiNP were analysed under ICP-MS. They worked better, adsorbing more lead from the atmosphere than normal SiNP did as the control [129]. The barrier to commercial application is the cost factor along with a detailed research of interaction and pathway of the nanoparticles in the environmental remediation process [130]. In 2015 meso-porous SiNP (MCM-41) was developed with greater surface area supported with larger sized pores. This was used to remove trace mercury from aqueous solutions and medicine. It was effective and did not negatively impact the components in the medicine [131]. To remove Boron- a non-metal which essential in trace but harmful in excess, mesoporous SiNP infused with cellulose acetate matrix were developed with 150 nm diameter and two hydroxyl group members were added which combined with boron covalently. This caused boron removal in acid form till 93%. Such setups could be appropriately implied in multi-stage filtering procedures. It will be cheap, efficient and simple for scavenging roles [132]. To avoid accumulation of biocides by uptake through soil which is not good for both humans and their surroundings, their activities have to be highly productive. This is achieved by preserving them in polymer encapsulation. Silica-based supports have also been used for the same purpose so as to prevent leaching from occurring. Use of silica obtained from natural sources as a medium for carrying neem extract of biocide ability combined with poly-carboxylic acid was researched by [133] and the result was favourable with more biocide loading intent availability and more thermal stability than the control which was not loaded with 50% elimination of DPPH free radicals. Silica nanoparticle (SiNPs) can be used to capture atmospheric lead due to the large surface and the negative-charged groups in the SiNPs which combine with the positively charged Pb. A class of adsorbents - Nano-sized super paramagnetic zirconia (SPMZ)ZrO2/ SiO2/Fe3O4 is used for the removal of fluoride selectively from a system with a variety of metal and non-metal pollutants [134]. For removal of radioactive components from nuclear sites, a process called decontamination is followed; this prevents the potential escape to the environment. This process utilizes foam which should be preferably stable when cleaning equipment and contaminants. It tends to decrease the secondary waste. For this purpose silica NP were altered using dimethyl dichloro silane to establish foam stability by checking volume. More stable foam was generated as the hydrophobicity increased with increased modified silica particle-DMDCS combination [135].

## 6 Application of Silica Nanoparticles in Water Purification

Due to extensive study regarding the effect of nanoparticles on living organisms of land or of aqueous bodies, it has been concluded that their reactivity causes deterioration in the life span. This has been concluded by evidence of movement of toxic products of such reactions into the cells impairing their mechanism. Hence this development can be used to establish their release into waste water managing stream to eradicate or lower the Biological oxygen demand. It is more efficient than conventional setups which don't involve the usage of nanoparticles. Usually silica (SiO2) nanoparticles are exercised for bio-removal purpose [136]. Another study conducted presented that the antiviral strength of Silver nanoparticles coupled with silica nanoparticles when tested against bacteriophage MS2 and murine norovirus (MNV) found in deionised, ground, surface and tap water, was stronger for MNV than MS2in all four types of water. Antimicrobial capability of (Ag30-SiO2) particles was impacted by levels of temperature and organic matter content. These particles can be modified to purify water by removing viruses with ill effect on surroundings [137]. An experiment involving formation of PDMS thin film on silica nanoparticles using CVD through controlled pressure resulted in a steady mixture of oil and PDMS which was hydrophobic and was used for carefully choosing oil to remove from oil-water mixture. This is an environmental concern which usually results from accidental oil spills from ship carriers in the sea. To prevent oil diffusion and its removal is important as this could also contaminate rivers with additive effect of oil release by wastewater from industries [138]. The harmful chemical nature of the dyes from industries is troublesome to the humans and aqueous life forms. Hence before discarding the to the surrounding environment waters, the waste must be treated. In this study, the aim was to synthesise meso-structured SiNP with 3-aminopropyl triethoxysilane (APTES) to enhance adsorption due to pore expansion. This was implemented to check for acceptance of Methylene blue a staple dye used most in the dyeing wood, cotton and silk industry but is responsible for causing jaundice, quadriplegia or vomiting depending on exposure levels. The experiment was successful in giving satisfactory outcomes in terms of removal [139]. Methyl red is an azo dye with N-N bonding that is used in textile and paper industry, it can cause irritation in the eye, digestive tract and skin if one comes into contact with them. To remediate them silica nanoparticles were studied were found to show photo catalytic activity for MR dye breakdown. The control and SiO2 NPs doped with silver and gold nanoparticles were synthesised respectively. The results presented an inclination of catalytic degradation the most for control SiO2 NPs, then SiO2 NPs coated with gold nanoparticles and lastly for silver nanoparticles\ [140]. The dyes in wastewater are aesthetically pleasing but also affect photosynthetic activity of algae and aquatic plants, impacting their overall life. The need for alternatives arises from lack of recyclability and less adsorption capacity [141]. Das, Sujoy K., et al. successfully prepared the Nano-silica fabricated with silver nanoparticles as an antifouling adsorbent for efficient dye removal, and effective water disinfection and biofouling control [141].

## 7 Conclusion and Outlook

This review paper provides a current perspective on the potential of Silica nanoparticles applications. Silica nanoparticles have been extensively developed since the discovery of mesoporous materials due to their unique features such as large surface area, tuneable pore diameter, controlled particle size and morphology, excellent biocompatibility, offer great advantage. Contributions in the biomedical field, agricultural, food industry, and catalytical field have been made silica nanoparticles like magic bullets. The encapsulation of the different bioactive molecules for a wide range of application has made it a ubiquitous material which increases the efficiency, specificity, target delivery, bioavailability, and biocompatibility of different bioactive compounds. The silica nanoparticles have evolved from the field of nanotechnology to different fields of science and engineering. The silica nanoparticles have a wonderful approach for the application in the different field like diagnostic, imaging agent, and target drug delivery in the treatment of cancer. One of the most valuable features of silica nanoparticles is to use them to merge with different materials, to combine various functionalities, which will act as a basis to obtain multifunctional medicine dedicated nano platform enabling multimodal imaging and simultaneous diagnosis and therapy. MSNPs are promising nanocarriers to efficiently transport and site-specifically deliver highly toxic drugs, like chemotherapeutic agents with site-specific characteristics to kill only tumor cells. Mesoporous silica nanoparticles have also become excellent nano vehicle to design smart drug delivery systems for biomedical applications. The silica nanoparticles have also contributed a huge development in the smart pesticides and mineral carriers for the plants in the agricultural field. Thanks to the versatility and robustness of silica nanoparticles, multifunctional systems, and smart materials have been proposed employing the platform of mesoporous silica nanoparticles for the purpose of the delivery carrier with different biomolecules for this purpose. Insect pests and fungi cause heavy losses to stored grains including pulses, especially in humid and warm areas of the world Biopesticide or biological pesticides and fungicides based on plant principles specific to a target pest offer an ecologically sound and effective solution to pest and fungi problems. They pose less threat to the environment and to human health. But the bioavailability stability of the bioactive compounds remains a major concern. Silica nanoparticle is the possible option for these eco-friendly pesticides which can make these pesticides highly effective against these pesticides by conjugation or encapsulation of these Biopesticides by providing bioavailability, stability, and efficiency of these bioactive compounds as insecticide and fungicide. Silica Nanoparticles can serve as ‘magic bullets’, containing herbicides, chemicals, or genes, and for water purification, bioremediation of environmental pollutants.

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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that there is no conflict of interests regarding the publication of this paper.

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