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Bio-based Synthesis and Applications of SnO_2 Nanoparticles - An Overview

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Abstract

Incorporation of biosynthesis technique into nanotechnology is a significant step in nanoscience research because this green protocol of synthesizing nanoparticles is cost effective, quite safe and eco-friendly compared to the conventional chemical and physical methods. For these reasons, in recent years, this green and bio-based route for the preparation of nanoparticles has gained much attention, and many metal and metal oxide nanoparticles have been prepared by using this method in which plant source, bacteria, fungus and some biological materials are used. Among other metal oxide nanoparticles, tin oxide nanoparticles have attracted attention of researchers because of their wide applications in different fields like catalysis, energy storage, sensors, dye-sensitized solar cells, medicine, and optoelectronics. This review provides an overview of various reports of synthesis of SnO_2 nanoparticles by biological means and also focuses on the properties of these green synthesized SnO_2 nanoparticles like photocatalytic activity, gas sensing ability and different biomedical activities.

1. Introduction

Nanoscale oxide semiconductors have been studied enormously for their distinctive optical, electronic, magnetic, catalytic and medicinal properties as compared with the traditional and commercial bulk materials [1-3]. These unique properties generated researchers' interest in the synthesis of nanoscale materials with different sizes, shapes, and compositions. For this purpose, during the last two decades, a vast number of physical and chemical synthetic routes have been established. In recent years, for reducing or removing the use of toxic chemicals, the comparatively new and largely unexplored bio-mediated green synthesis technique has been developed. This biogenic synthesis of nanoparticles depends on the source materials [4-10] such as plants and plant parts, bacteria, fungus and other bio-based molecules (protein, vitamin, molecules etc.) used in the procedure. The plant phytochemicals which have antioxidant property is mainly responsible for the preparation of metal and metal oxide nanoparticle. Besides, many biological components have abilities to act as templates in the synthesis and help to produce a self assembled nanoscale material [11, 12]. So a novel and economically beneficial bio-based green synthesis method may be a better alternative choice for the synthesis of metal oxide nanoparticles compared to commonly used chemical and physical methods. Among the semiconducting nanoparticles, Tin oxide (SnO_2) has been studied intensely because of its potential applicability to lithium-ion batteries [13], transparent conducting electrodes in ionic devices [14], anti-reflective coatings [15], solid-state gas sensors [16], solar cells [17], catalytic support materials [18], energy storage [19], medicine [20] etc. A large number of physical and chemical methods have already been reported in the literature to fabricate different types of SnO_2 nanostructures such as hydrothermal method [21], solvothermal [22], microwave synthesis [23], co-precipitation method [24], sol-gel [25], spray pyrolysis [26], chemical vapor deposition [27], thermal evaporation of oxide powders [28], rapid oxidation of elemental tin [29], micro emulsion [30] etc. However, due to many disadvantages of these routes like toxicity of the chemicals, expensive equipment, energy waste and environmental pollution developing facile and green methods for synthesizing tin oxide nanoparticles has drawn much importance in the recent years and still, research is going on upon it. This review briefly summarizes the recently reported biogenic synthesis of SnO_2 nanoparticles (Nps) using plant extracts and

biotemplates, including bacteria, amino acids, vitamin C etc. and also focuses on the properties of these green synthesized SnO_2 Nps like photocatalytic activity, gas sensing ability and different biomedical activities.
As green synthesis of SnO_2 Nps becomes an interesting area of research, a number of works have been carried out using biological organisms like bacteria, a variety of plant and plant based products, and also by some other bio-based molecules. A list of such works is summarized in Table-1 and discussed below:

Table 1: Various sources and morphological studies of SnO_2-Nps.

Green parts	Name of the source	Morphology	Size (nm)	Particle size determination from:	References
Bacterial cells	*Erwinia herbicola*	mostly spherical	10-42	TEM	[31]
Plant parts: Leaf	*Aloe barbadensis Miller*	spherical	50 -100	SEM	[32]
Leaf	*Aspalathus linearis*	quasi-spherical	2.5-11.40	TEM	[33]
Leaf	*Brassica oleracea L. var. botrytis*	agglomerated quasi-spherical; & spherical	3.55–5.8; & 5.28–6.34	TEM	[34]
	Camellia sinensis	spherical	5 to 31	HR-TEM	[35]
Leaf	*Cleistanthus Collinus*	irregular	20-40	SEM	[36]
Leaf	*Daphne alpina*	Elongated shaped	19.5 to 27.2	SEM	[37]
Leaf	*Ficus carica*	agglomerated spherical	128	particle size analyzer	[38]
Leaf	*Plectranthus amboinicus*	clustered structure	63	particle size analyzer	[39]
Leaf	*Tamarindus indica, Ficus bengalhensis, Baringtoria acutagularis, Annona Squamosa Linn, Cyclea peltata*	Irregular, spherical	27	XRD	[19]
Flower	*Nyctanthes arbor-tristis*	granular	2-8	Particle size analyzer	[40]
Flower	*Saraca indica*	spherical	2.2-18.2	HRTEM	[41]
Fruit	*Cyphomandra betacea*	spherical	20-50	TEM	[42]
Fruit	*Punica granatum*	irregular, spherical, rectangular	2.2-42.4	TEM	[43]

Fruit peel	*Annona squamosa*	spherical	27.5	TEM	[44]
Seed	*Persia Americana*	flake- like	4	XRD	[45]
Seed	*Piper nigrum*	mostly spherical	5-30	TEM	[46]
Seed	*Trigonella foenum-graecum*	mostly spherical	2.6–20	TEM	[47]
Root bark	*Catunaregam spinosa*	spherical	47 ± 2	TEM	[48]
Egg shell membrane	Chicken egg	spherical or rectangular	5-12	TEM	[49]
Carbohydrate	Starch	Mostly spherical	13	XRD	[50]
Pectin	*Cicer arietinum* L	spherical	~10	TEM	[50]
recombinant silicatein-*α*	Marine sponge	spherical	50	TEM	[51]
Amino acid	Arginin	Spherical	~ 4-5	TEM	[52]
Amino acid	Aspartic acid	Spherical	~ 2.6	TEM	[53]
Amino acid	glutamic acid	spherical	~1.6	TEM	[53]
Amino acid	glycine	Spherical	~6–33	TEM	[54]
Amino acid	L-lysine monohydrate	spherical	~4–17	TEM	[55]
Amino acid	serine	spherical	~ 4	TEM	[56]
Amino acid	Tyrosine	Nearly spherical	~15-20	TEM	[57]
Vitamin C	Ascorbic acid	spherical	30	TEM	[58]
Glucose	Glucose	granular	~2-8	HRTEM	[59]

2. Green Synthesis of SnO_2 Nanoparticle

2.1. Bacterial cell mediated synthesis

Different bacterial species have been used for the synthesis of various metal and metal oxide nanoparticles [60]. Researchers reported that the presence of proteins, enzymes, and the biochemical reaction pathways are responsible for metal ion reduction [61]. The main benefit of using bacteria for the synthesis of nanoparticle is that the large scale synthesis can be done with the minimal use of hazardous and expensive chemicals [60, 62]. This bacteria mediated synthesis process has some drawbacks also: bacterial culture techniques are time consuming and the size, shape, and crystallinity of the nanoparticles can not be controlled properly [63]. Srivastava et al. [31] synthesized stable SnO_2 Nps using fresh and clean *Erwinia herbicola* bacterial cells and aqueous Tin(II) chloride solution. The sizes of the as-synthesized SnO_2 Nps were observed in the range of 3−18 nm. It was also seen that the sample annealed at 150˚C for 2h produced mostly spherical shaped SnO_2 nanoparticles with sizes in the range of 10−42 nm. It was stated that the biosynthesized SnO_2 Nps were capped or covered by the amino acids, proteins, or other biomolecules involved in the reaction, providing natural support and stability.

2.2. Plant source-mediated synthesis

Biosynthesis of metal oxide nanoparticles from plant biomass or extracts has been considered as a green route and is under thorough research. Although the proper mechanism for the synthesis of metal oxide nanoparticles is not clearly known, several hypothetical mechanisms have been proposed by researchers [34-35, 64-65]. From literature study, it can be said that phytochemicals present in plants are responsible for the formation of metal oxide nanoparticle. It is believed that several bioactive agents which are present in plant extracts such as alkaloids, phenolic acids, polyphenols, proteins, sugars, and terpenoids have an important role in the reduction of metallic ions [66, 67]. The reduced metal ions may then be attached with atmospheric oxygen or with the oxygen coming from the degrading phytochemicals to form metal oxide nanoparticles. Moreover, phytochemicals present in the system help to prevent agglomeration between the particles [35, 60, 66, 67, 68]. Several Researchers synthesized SnO_2 Nps by using extract of different plant parts of various plants which are summarized below:

2.2.1 Using Leaf extract

Gowri et al. [32] utilized aqueous extract of *Aloe barbadensis Miller* (aloe vera) leaf for preparing tin hydroxides from $SnCl_2.2H_2O$ and finally it was converted to crystalline SnO_2 Nps by heat treatment at the temperature of 450˚C for 3 hours. In this method homogenous and agglomerated spherical shaped granules were formed with the size ranging from 50 to 100 nm. Dried leaf extract of *Aspalathus linearis* (Rooibos) plant was used by Diallo et al. [33]. They found that both the particle size and crystallinity of the sample increased with the annealing temperature and the average diameter of the quasi-spherical nanoparticles was found to vary in the range of~2.5 to 11.40 nm. The bioactive components (aspalathin, nothofagin, aspalalinin etc.) present in the leaf extract are believed to act as chelating agents. Osuntokun et al. [34] performed an experiment using fresh *Brassica oleracea L. var. Botrytis* (cauliflower) leaf extract reacting with Tin(II) chloride. It was reported that antioxidants like polyphenols and flavonoid which are present in the cauliflower extract acted as chelating agents and responsible for the reduction of Sn^{2+} ion to Sn^0 metal. The size of the particles produced by annealing at 300˚C (S1) and 450˚C (S2) were found to be in the range of 3.55–5.8 and 5.28–6.34 nm respectively and the morphological pattern of the particles (S1) exhibited quasi-spherical shape with high agglomeration, while the particles (S2) were spherically shaped. Selvakumari et al. reported the formation of SnO_2 Nps using the leaf extract of *Camellia sinensis* (Green tea) [35]. The polyphenols present in the leaf extract acts both as a capping and stabilizing agent. The phenolic compounds capped Sn^{2+} is then reduced to Sn^0 nanoparticles via hydroxyl (–OH) groups of polyphenols inside the nanoscopic templates and finally converted to SnO_2 Nps with aerial oxidation. It was observed that agglomerated spherical nanoparticles were formed with sizes varying from 5 to 31 nm. The plant leaf extract of *Cleistanthus Collinus* was used for the synthesis of SnO_2 Nps [36] and the particles sizes were found to vary within 20-40 nm. Leaves of Daphne alpina were used to prepare mesoporous SnO_2 Nps [37] from $SnCl_4.5H_2O$ precursor. It was observed from SEM images that the synthesized slightly elongated shaped SnO_2 particles were uniformly distributed having size in the ranges from 19.5 to 27.2 nm. J. Hu [38] synthesized SnO_2 Nps from an aqueous mixture of *Ficus carica* (Fig) leaf extract and Tin(II) chloride solution. Volatile essential oil and flavonoids present in the leaf extract was said to be acted as capping agent on the SnO_2 Nps. An average particle size of about 128 nm was obtained. Fu et al. [39] performed the experiment with aqueous leaf extract of *Plectranthus amboinicus* and found that the biosynthesized SnO_2 Nps (average diameter of 63 nm) exhibited agglomerated clustered structure. Sudhaparimala et al. [20] reported the synthesis of Tin (IV) oxide nanoparticles by trituration of tin metal with five plants extract namely *Tamarindus indica*, *Ficus bengalhensis*, *Baringtoria acutagularis, Annona Squamosa Linn*, *Cyclea peltata* followed by calcination. They noticed that the impact of repeatedly grinding with plant extracts helped to reduce the particle size. An average crystallite size of 27 nm was achieved. They found the presence microscopic level of Ca, P, Na, Mg and Fe elements at the surface of the nano crystallite and also the presence of oxygen deficiency in the crystal lattice which occurred due to non-stoichiometry in the crystal lattice.

2.2.2 Using Flower extract

Gandhi et al. [40] synthesized SnO_2 Nps with an average size ranging from 2-8 nm using flower extract of *Nyctanthes arbor-tristis* (Parijataka). Extracts of another flower, *Saraca indica* (Ashoka), was used to synthesize SnO_2 Nps by Vidhu et al. [41]. They studied the influence of reaction parameters like volume of extract and temperature on the formation of tin oxide nanoparticles and found to vary the particles size from 2.2 nm to 18.2 nm.

2.2.3. Using Fruit extract

Spherical shaped SnO_2 Nps having an average size of 20-50 nm were synthesized using methanolic extract of *Cyphomandra betacea* (*tamarillo*) fruit [42]. Kumari et al. [43] prepared SnO_2 Nps using juice of ripe *Punica granatum* (pomgranate) fruit and noticed that the particle size and crystallinity of the sample varied with the variation of concentration of extract and also with increasing annealing temperature. TEM images showed that as synthesized particles were irregularly shaped whereas the annealed samples at higher temperature were non agglomerative, spherical or rectangular in shape. The average particle size was found to vary within the range of 2.2 to 42.4 nm.

2.2.4. Using Fruit Peel extract

Dried peel extract of *Annona squamosa* (sugar apple) fruit was used to synthesize stable SnO_2 Nps with an average size of 27.5 nm [44]. Water-soluble compounds containing hydroxy (-OH) functional groups present in aqueous peel extract were said to be responsible for the stabilization of SnO_2 Nps.

2.2.5. Using Seed extract

Elango et al. [45] prepared SnO_2 Nps (average size~ 4 nm) using methanolic extract of *Persia Americana* (avocado) seed and aqueous stannous chloride solution. Tammina et al. [46] synthesized tetragonal SnO_2 Nps having different sizes using *Piper nigrum* (black pepper) seed extract at different calcination temperatures. The size of the particles was found to vary from 5-30 nm depending on the calcination temperature. An extract of *Trigonella foenum-graecum (*fenugreek) seed was used to produce mostly spherical shaped SnO_2 Nps with size in the range 2.6–20 nm [47]. It was reported that the crystallite size of SnO_2 Nps decreases with increasing the quantity of seed extract during synthesis. .

2.2.6. Using Root bark extract

Haritha et al. [48] reported to use root bark extract of *Catunaregam spinosa* plant for the synthesis of SnO_2 Nps. The phytochemicals present in the root bark extract act as a capping agent for the formation of nanoparticles and helped to prevent agglomeration.

2.3. Using other bio-based sources

Egg shell membrane of the fresh chicken egg was used by Sangami et al. [49] during the synthesis of SnO_2 Nps. They used tin oxalate as the precursor material. The formation of non-agglomerative, spherical or rectangular shaped nanoparticles with size range from 5-12 nm was observed. The pores exist in between the interwoven fibers (collagen and glycoprotein) of egg shell membrane controls the movement of the ions and in this way, it helps to control the particles size of the product. .

Gattu et al. [50] synthesized SnO_2 nanoparticles by using carbohydrate (starch). It was suggested that the carbohydrates within the extract acted like an organic template which could bind several metal cations through their functional groups (carboxyl, hydroxyl) and hence a uniform dispersion of the cations was observed. The average size of particles was found to have 13 nm. In some other experiments [69-71] they used remnant water collected from soaked Bengal gram beans (*Cicer arietinum* L.) for preparing pure and Ni, Fe and Au-doped SnO_2 Nps. Pectin, present in the extract as the natural bio-molecule was said to be responsible for biosynthesis of SnO_2 Nps. The average crystallite size of the spherically shaped pure, Ni and Au-doped SnO_2 Nps were found to be ~11 nm, 6 nm and 25 nm, respectively. In another study [71] they found that the green synthesized pure and Fe-doped spherical particles had an average size 6 nm and 5.8 nm respectively. The morphological patterns of both the pure and Ni-doped SnO_2 Nps (calcined at 600˚C) were found to be spherical in shape. André et al. [51] reported that recombinant silicatein-α could mediate the formation of nanostructured crystalline SnO_2 at room temperature. TEM images indicate the formation of spherical agglomerates with an average size of 50 nm. It was said that agglomeration of the protein on the newly formed crystals helped to form smaller size particles and the synthesized SnO_2 Nps were stabilized by surface binding of silicatein through its functional (amino and/or carboxylate) groups.

Several amino acids like arginine [52], glycine [54], lysine [55], serine [56], Tyrosine [57], glutamic acid and aspartic acid [53] were also used for the synthesis of SnO_2 Nps as amino acid has a good complexing or capping ability. Researchers explained that the formation of SnO_2 Nps by using amino acids may take place through the consecutive steps: adduct formation (with amino acid), hydrolysis of the adduct, condensation and calcination. Amino acid mediated synthesis provides elimination of toxic chemicals and solvents during the synthesis. The

particles size was found to vary within ~4-5nm, ~6–33 nm, ~4–17 nm, ~4 nm, ~15-20 nm, ~1.6 nm, ~2.6 nm for arginine, glycine, lysine, serine, tyrosine, glutamic acid and aspartic mediated synthesis.

The green synthesis of SnO_2 Nps by using vitamin C was described by Yang et al [58]. The average size of spherical SnO_2 Nps was found to have ~ 30 nm. Vitamin C reported to act both as a reducing agent and also a capping agent during the synthesis of SnO_2 Nps. Manjula et al. [59] successfully synthesized well-defined porous SnO_2 nanospheres at low temperature using glucose as the reducing and structure directing agent. Monodispersed and uniform-sized porous nanospheres of 50 nm consisting of a few hundred nanoparticles of ~ 2−3 nm in diameter were found to form. It was observed that though the smaller particles within the nanosphere tend to agglomerate with calcination (size became larger ~8 nm), the overall size of the nanosphere did not change.

3. Applications

3.1. Photocatalytic activity

Nanostructured semiconductor SnO_2 acts as an excellent photocatalyst in the degradation of some common textile dyes. Biosynthesized SnO_2 nanoparticles was found to exhibit excellent photocatalytic responses for Methylene blue (MB) and Eosin Y dye [33,42]. Diallo et al. [33] noticed that smaller size SnO_2 nanoparticles based solutions can degrade several dyes (MB, Eosin Y dye and Congo red) more effectively with a faster rate. Another study [34] also reported about the photocatalytic activities of biosynthesized SnO_2 Nps using MB under ultraviolet light irradiation. It was found that after 180 min the degradation of MB was completed 91.89 and 88.23% by SnO_2 Nps annealed at 300˚C (S1) and 450˚C (S2) respectively and the variation of degradation efficiency was explained by the size variation of nanoparticles. The smaller size of S1 compared to S2 and relatively high surface to volume ratio is responsible for exhibiting better photocatalytic activity. Haritha et al. [48] studied the degradation of toxic congo red dye by using bio-synthesized SnO_2 Nps, and observed the higher percentage of degradation of the dye with the K value of 0.9212 which obeys pseudo-first order reaction kinetics. Catalytic degradation of another organic dye, phenolsulfonphthalein (phenol red), by biosynthesized SnO_2 Nps was observed by Elango et al. [45]. It was noticed that SnO_2 Nps exhibited higher degradation activity by the catalytic action of long UV at 365 nm. Fu et al. [39] measured the photodegradation rate of rhodamine B (Rh B) in aqueous solution under visible light by applying both the biosynthesized SnO_2 Nps (S1) as well as commercial SnO_2 (S2) and compared their photocatalytic efficiency. They found that the biosynthesized SnO_2 Nps exhibited a much higher performance than commercial SnO_2. It was observed that S1 could degrade more than 95% of RhB whereas S2 could degrade 42.7% after 120 min visible light irradiation at a wavelength of 553 nm. They calculated the apparent rate constant of commercial SnO_2 and biosynthesized SnO_2 Nps and found 0.0015 and 0.0121/min, respectively. The strong interaction between SnO_2 Nps and rhodamine-B dye was also observed by Sangami et al. [49]. It was found that synthesized SnO_2 nanoparticles exhibited better photocatalytic responses towards the degradation of rhodamine-B dye at a pH value of 9 in comparison with at pH 4 and 7. They explained that the loss of aromaticity of pyrilium ring of the xanthene chromophore is taking place with the addition of base to Rh-B and hence, it could degrade easily. In the acidic condition, the stability of the moiety was enhanced which was responsible for the reduction of degradation capability. It was found that maximum 94.48% degradation of Rh-B could be achieved upon exposure to UV light for 60 min. Srivastava et al. [31] examined the photocatalytic activity of the biosynthesized SnO_2 Nps and found that approximately 93.3, 97.8, and 94.0% degradations of methylene blue, eriochrome black T, and methyl orange dyes occurred in the photocatalytic degradation process, respectively. They explained that the synthesized SnO_2 nanoparticles showed more pronounced photocatalytic activity due to their high specific surface area, which provides maximum exposure for reactant to the active site. Bhattacharjee and coworkers [52, 53, 56] reported degradation of some common dyes like methylene blue, eosin Y, methyl violet 6B, etc. under solar irradiation. The method is a very cost effective method and scalable to large extent compared to common UV assisted photo degradation technique. Begum et al. [55] also studied the dye removal using lysine mediated green synthesized 5 nm SnO_2 nanoparticles. They observed the photocatalytic property of SnO_2 Nps in the degradation of malachite green oxalate and Victoria blue dyes from aqueous phase under direct sunlight within 120 min. It was reported that pseudo first order reaction was followed for both the dyes and the rate of the constant (k) of photodegradation of malachite green oxalate dye and Victoria blue was found to be 1.6×10^{-2} min^{-1} and 1.06×10^{-2} min^{-1}, respectively. Manjula et al. [59] found the potentiality of green synthesized SnO_2 Nps towards the complete degradation of another dye, methyl orange. The activity of SnO_2 Nps towards the photocatalytic degradation of Violet 4 BSN dye was investigated under 125W UV lamp (Hg lamp, λmax 254nm) by Tamina et al. [57]. From experimental study, they found that the time required for complete degradation of dye decreased with the

increase in catalyst dosage whereas the increasing the dye concentration led to the decrease in degradation efficiency to 96%.

3.2. Catalytic Property for reduction of aromatic compounds

Researchers [55, 72] utilized SnO_2 nanoparticles for the reduction of p-nitrophenol into p-aminophenol in aqueous medium and found that SnO_2 Nps can act as an efficient catalyst for the reduction of p-nitrophenol in presence of $NaBH_4$. It was proposed that in the catalytic reduction, the SnO_2 Nps act as catalysts to transfer electrons from BH_4^- ion to the p-nitrophenol. Begum et al reported that at particular concentrations of the materials 27 min was required for the completion of reduction process of 4-nitrophenol [55] whereas in the absence of the catalyst, the reduction did not start even after 5 h. The investigation revealed that the kinetics of the reduction followed the pseudo first order reaction with a rate constant (k) 9.3×10^{-4} s^{-1}.

3.3. Gas sensing property

Selective detection of various gases is very important for monitoring environmental pollution. Gas sensors are used to detect various gases for monitoring the changes in the ambient gas atmosphere. Metal oxide based gas sensors devices are in the use for the last couple of decades [69-72]. Gattu et al. [50] found the promising NH_3 gas sensing property of biosynthesised SnO_2 Nps thin film at room temperature. They [69, 70] also observed the gas sensing property of biosynthesized Ni and Au-doped SnO_2 nanoparticles for NO_2 gas. It was noticed that NO_2 gas sensing response was relatively higher for biosynthesized Ni-doped SnO_2 compared to chemically synthesized Ni-doped SnO_2. The efficiency of the sensor was found to increase with Ni doping for both the samples (biosynthesized and chemically synthesized). The reason for that may be the decrease of particle size with Ni doping, which exposed larger surface area for adsorption of NO_2 gas [73]. They also compared the gas sensing properties of Ni doped SnO_2 towards other gases like NH_3, LPG and H_2S. It was found that the gas sensor of 'Ni-doped SnO_2' exhibited excellent selectivity to NO_2 gas when compared to other gases. Gas sensors based on the biosynthesized Ni-doped SnO_2 showed gas response of 40 at 100 ppm of NO_2 gas. It was also found that Gas sensor based on the Au-doped SnO_2 showed the gas response of ~30% for 100 ppm of NO_2 gas [70]. In another study [71] Gattu et al. examined the gas sensing properties of biosynthesized pure and Fe-doped SnO_2 Nps for NH_3 gas. They found that the response for 100 ppm NH_3 gas was to be 28% for pure SnO_2 and 46% for Fe-doped SnO_2 nanoparticle thin film. Li et al. [74] found that the green synthesized SnO_2 materials exhibited highly sensitive, fast-responding and size selective sensing behaviours. They observed that the gas-sensor properties are strongly structure-dependent. It was seen that in comparison with the mesoporous SnO_2 layers sensors the response of the SnO_2 nanocrystallites having microporous structures toward H_2 is much larger than the response to CO. Manjula et al. [59] found that the green synthesized SnO_2 materials exhibited excellent gas sensing capabilities. They investigated that the incorporation of 0.5 wt % Pd into SnO_2 matrix increased the sensitivity and made it highly selective for low temperature hydrogen detection. It was also reported that with a response time of 10 s the material was able to respond to even 50 ppm H_2 in N_2 at room temperature.

3.4. Cd^{2+}, Hg^{2+} sensor

Haq et al. [37] performed the sorption studies of Cd^{2+} ions by biosynthesized SnO_2 Nps at pH 4 and 6. It was found that with the increase in both pH of the solution and also with the temperature adsorption of the Cd^{2+} ions was enhanced. Junjie Hu [38] successfully used the biosynthesized SnO_2 Nps as electrode modifier for electrochemically detection of Hg^{2+}. It was found that the SnO_2/GCE exhibited a linear relationship within the Hg^{2+} concentration range from 0.001 to 1.5 μM.

3.5. Antibacterial activity

Vidhu et al [41] studied the antibacterial activity of the SnO_2 Nps against gram negative *Escherichia coli* bacteria. It was observed that the bactericidal potency was enhanced with the increase in concentration of nanoparticles and hence, it was stated that higher concentration of SnO_2 Nps was significant in bactericidal effect. Due to the large surface area the activity of the nanoparticles increases, therefore SnO_2 Nps react efficiently with the cell membrane and inactivate the bacteria [75]. Kamraj et al. [36] also investigated the antibacterial activities of SnO_2 Nps against a gram negative strain, *E.coli* and compared the activity with a gram positive strain, *S.aureus.* They observed that *E.coli* showed more significant activity than *S.aureus* and explained the phenomenon as the cell wall is absent in *E.coli* but it is present in *S.aureus*, hence the nanoparticles could easily be entered into the *E.coli* causing more cell damage than that of *S.aureus*. Kumari et al. [43] studied the antibacterial activity of as prepared SnO_2 Nps on microorganism *E.coli* and found that the

growth inhibition zone on *E.coli* was increased with increase in concentration of nanoparticles. Gowri et al. [32] also noticed the antibacterial activity of biosynthesized SnO_2 Nps towards both the *S.aureus and E.coli.* They found that SnO_2 nanoparticles exhibited more inhibition with *S.aureus*, a gram positive strain compared with *E.coli*, a gram negative strain.

3.6. Antioxidant activity

The antioxidant activity of biosynthesized SnO_2 Nps was examined by monitoring the ability of quenching of the stable 1,1-diphenyl-2-picryl hydrazyl (DPPH) radical (deep violet colour) into nonradical form (yellow colour) [41]. It was observed that the colour of DPPH gradually changed from deep violet to pale yellow in the presence of SnO_2 Nps which indicate the scavenging action and conversion of DPPH to DPPH-H. It was reported that the radical scavenging efficiency depends on various factors such as particle size, morphology and defects. The scavenging activity of the annealed sample was found to decrease in comparison to that of the as prepared sample. Kamraj et al. [36] observed the significant DPPH scavenging activity of the biosynthesized SnO_2 Nps. The antioxidant activity was found to increase with the increase of the concentration of synthesized nanoparticles and also with reaction time. Sudhaparimala et al. [20] also examined the antioxidant property of biosynthesized nanoscale SnO_2. They calculated the free radical equivalent of DPPH radical of the sample and found that it was 0.8026 for per mg of the sample. Kumari et al. [43] determined the radical scavenging activity of SnO_2 Nps using DPPH assay and noticed that the annealed sample exhibited a lower scavenging activity in comparison to the as-prepared sample. The decrease in activity with the increase in annealing temperature might be due to the decrease in surface area to volume ratio due to increased crystallite size. They also found that the antioxidant activity increased with the increase in sample dosage.

3.7. Anti cancer activity

Tamina et al. [46] had studied the cytotoxic effect of size specific SnO_2 Nps on colorectal (HCT116) and Lung (A549) cancer cell lines. It was found that the generated *Reactive oxygen species (*ROS) was responsible for cytotoxicity of SnO_2 Nps to the studied cancer cells. They also observed that smaller size Nps exhibited higher cytotoxicity over larger size Nps due to the generation of more ROS in the former case. Roopan et al. [44] found the cytotoxic effect of biosynthesized SnO_2 Nps on hepatocellular carcinoma cell line (HepG2). It was reported that with the increase of concentration of SnO_2 Nps (upto 500 μg/mL) cytotoxicity of SnO_2 Nps on hepatocellular carcinoma cell line (HepG2) was also increased. The calculated IC50 value of SnO_2 particles was found 148 μg/mL.

3.8. Body weight increasing

Yang et al. [58] studied the effect of vitamin-C stabilized SnO_2 Nps on the body weight of neonatal rats and observed that the vitamin-C stabilized SnO_2 Nps promoted a higher body weight gain compared to raw SnO_2 Nps. It was said that when vitamin-C stabilized SnO_2 entered into the body system of rats, vitamin-C capped on the surface of SnO_2 Nps acted as an antioxidant and reduced the oxidative stress caused by SnO_2 Nps on cells, resulting in reduced weight loss in the rats.

Conclusion

The green biosynthesis method is an economically beneficial and easy process which could eliminate several problems associated with the use of toxic reagents in the chemical synthesis procedure. The present review summarises the literature for an understanding of the synthesis of SnO_2 Nps by using different biological sources. It can be seen that several scientists worldwide have been extending their knowledge in the development of eco-friendly bio-based routes for synthesis of nanomaterials, with desired shapes and controlled sizes and focuses on their potential applications in various fields, however, in order to utilise maximum potential of this system the role of functional groups in synthesis of nanoparticles should be studied in detail in future. This review may be helpful for researchers to plan their future research work on the green synthesis of SnO_2 Nps and focusing on their application in the said fields.

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