Current Research in Green and Sustainable Chemistry 4 (2021) 100211

Contents lists available at ScienceDirect

Current Research in Green and Sustainable Chemistry

journal homepage: www.elsevier.com/journals/current-research-in-green-and-sustainable-chemistry/2666-0865

Plant extract mediated cost-effective tin oxide nanoparticles: A review on synthesis, properties, and potential applications

Waseem Ahmad [a,1], Agrima Pandey [a], Vishal Rajput [b], Vinod Kumar [b,c,**], Monu Verma [d,1], Hyunook Kim [d,*]

[a] Organic Chemistry Section, Department of Chemistry, Uttaranchal University, Dehradun, 248001, India
[b] Department of Life Sciences, Graphic Era (Deemed to Be University), Dehradun, Uttarakhand, 248002, India
[c] Peoples' Friendship University of Russia (RUDN University), Moscow, 117198, Federation, Russia
[d] Water-Energy Nexus Laboratory, Department of Environmental Engineering, University of Seoul, Seoul, 02504, Republic of Korea

ARTICLE INFO

Keywords:
Tin oxide nanoparticles
Green synthesis
Biosynthesis
Properties
Applications analytical techniques
Characterization

ABSTRACT

In the last few decades, nanotechnology a branch of science has become the soul of all the research and developments in the modern era of science and technology. Metal oxide nanoparticles have majorly contributed to almost all the domains working on nanoscale. In them, tin oxide nanoparticles (SnO_2 NPs) gained a lot of fame among the researchers owing to its interdisciplinary applications. There are multiple physical and chemical methods exist for the synthesis of different size and shapes nanostructures, which are now obsolete due to their energy requirements and toxic nature. Now a days, green synthesis has however taken over them and is the most used fabrication technique. In recent years, SnO_2 NPs have been synthesized via plant mediated synthesis, biomolecules and using microorganisms (referred to as biosynthesis). Various properties of the green synthesized nanoparticles have also been discovered through different analytical techniques. This review deals with the differently mediated green synthesis of SnO_2 NPs, their properties, and multidisciplinary applications.

1. Introduction

Nanotechnology, abbreviated as nanotech is the intriguingly emerging modern technique which involves the manipulation of bulk materials into nanosized materials ranging from 1 to 100 nm. Nanotechnology encompasses almost all the domains known to mankind, it be physics, chemistry, human biology, genetics, energy sciences, food industry, electronics, aviation, medicine or any other field of scientific research [1]. The scaling down of the size of materials increases its surface to volume ratio, thereby bringing about novel physical, biological, chemical, electrical, and optical properties to the material. These properties of nanomaterials and nanoparticles have led to their versatile applications. Thus, nanotechnology produce materials with light weight, higher screening, better electrical conductivity, more strength, more durability, and better reactivity with other significant traits. Many prosperous materials have micro- and nano-scale structures, and many industrial operations or processes that have been used for decades (for example, manufacturing polymers and steel) have manipulation phenomena at the nanoscale. The most advanced manufacturing process in nanotechnology is the manufacture of microelectronics, which uses thin film and photolithography techniques to create micron and nanometer-sized components on computer microcircuits. Nature abounds with such nanoscale structures, like milk (a nanoscale colloid), hemoglobin in blood, proteins that carry oxygen, cells, bacteria, viruses etc [2].

Nanoparticles (NPs) are ultrafine with many new physical, biological, and chemical properties, which depend entirely on their size, shape, and morphology. Due to its ultra-fine size, they have unique material properties; thus, can direct various fields inclusive of medicine and healthcare, engineering, textile, catalysis, and environmental remediation. NPs exist in nature and are also produced by human activities. These atoms can be of the same type or a combination of two different elements [3]. Based on origin, size, properties, and morphology, some of the most common ones are metal based NPs, carbon-based NPs, ceramic NPs, polymeric NPs, semiconductor NPs, lipid-based NPs, composites, and dendrimers, etc. [4,5]. NPs of silver provide anti-microbial affect; gold NPs helps treat cancer and cardiac illness; nickel NPs are the basis of fuel

* Corresponding author.
** Corresponding author Department of Life Sciences, Graphic Era (Deemed to be University), Dehradun, Uttarakhand, 248002, India.
E-mail addresses: vinodkdhatwalia@gmail.com (V. Kumar), h_kim@uos.ac.kr (H. Kim).
[1] Co-first authors.

https://doi.org/10.1016/j.crgsc.2021.100211
Received 23 September 2021; Received in revised form 25 October 2021; Accepted 28 October 2021
Available online 30 October 2021

cells, nanowires, textiles, coatings, copper oxide NPs possess antibiotic, antifungal and antimicrobial properties and zinc oxide NPs, Titanium oxide NPs, Cerium oxide NPs are excellent UV absorber [6].

In the recent times the NPs employed at various walks of science are generally oxides of metal owing to their high resistance to bacteria, fungus and other infection causing microbes. The metal oxide NPs generated using green synthesis show surprisingly good results and are economically and environmentally benign to produce. Among the various metal oxide NPs, SnO_2 NPs have gained much attention for they have remarkably perceptible magnetic, photocatalytic, anti-bacterial, anti-fungal properties.

Tin (IV) oxide (SnO_2) is a recognized group 14 metal oxide nanoparticle comprehending appreciable physical, chemical, optical, and medicinal properties. SnO_2 NPs present as crystallite have rutile tetragonal phase and exhibit quasispheroidal and spherical morphologies Nanostructured SnO_2 particles possess exceedingly large potential in environment remediation because of their reasonably designed structure and flexible band energy gap ranging from 3.6 to 3.8 eV. The low manufacture cost, rapid response and high sensitivity has paved the way for use of SnO_2 NPs in chemi-resistant gas sensors and can detect various gases like nitrous oxide, nitrogen dioxide, hydrogen disulphide and carbon monoxide. Alterable properties of nanostructured SnO_2 give them photocatalytic degradation efficiency towards various organic dyes, organic industrial and domestic contaminants, and other pharmaceutical compounds. Different morphologies of SnO_2 nanostructures namely, nanowires, quantum wires, nanorods, hollow spheres, nanofilms, hollow nanotubes, core-shells etc. and their ability to be tuned as metal ion doping, metal oxide-SnO_2doping, SnO_2-noble metal doping; make them potential candidates for electronic storage device making and also energy generation [7]. The high surface to volume ratio, fine particle size imparts mobility and low atom count on edge and vertex impart nano absorptivity to SnO_2 NPs and make them potent for grey water treatment, pollutant sensing and restoration of environment. Their high thermal resistivity up to 500 °C and their strong physical and chemical stability mate them viable in the manufacture of dye-sensitizing solar cells, lithium-ion batteries and photoelectrochemical cells. The strong physical and chemical hold favors the application of nanosized tin oxidized in catalysis, electrolysis, fluorescent diodes, glass coatings as well as antistatic coatings [8].

All these distinctive physiochemical properties have led to astounding research in the synthesis of SnO_2 nanostructures [9]. Conventionally, chemical, and physical methods like chemical precipitation, hydrothermal, microemulsions, sol-gel methods were employed for the synthesis of SnO_2 NPs. However, their (chemical methods) toxic effects, expenses and high energy and pressure requirements have limited their adoption. Therefore, cost effective and environment friendly methodology called green synthesis came into existence, where plant extracts, biomolecules, agriculture products etc. are used as reducing and capping agents [10].

Thereby, the current review encapsulates the comparative study of different biological and green agents used for the synthesis of SnO_2 NPs. It also successfully covers all the studies dealing with the characterization and properties of differently mediated SnO_2 NPs.

2. Synthesis of SnO_2 NPs

NPs are prepared using two approaches which are top-down approach and bottom-up approach. These approaches are applied to different modes of preparation, which are physical method, chemical method, and biological method [11].

2.1. Bottom-up method

Bottom-up or constructive method is the synthesis of bulk material from atom to clusters to SnO_2 NPs. It includes sol-gel method, spinning method, chemical vapor deposition (CVD), pyrolysis and biosynthesis. This is the widespread technique because of ease and efficiency to tune the size of the particles as and where needed.

2.2. Top-down method

Top-down or destructive method is the synthesis of SnO_2 NPs by reduction of a bulk material to nanometric scale particles. It's inclusive of mechanical milling, laser ablation, sputtering and thermal decomposition, nanolithography. One of the major drawbacks of this method is its inability to control the size of the particles. Thus, this technique is less prevalent in the nanotechnological development of matter.

2.3. Chemical and physical methods for synthesis of SnO_2 NPs

Studies show the employment of various chemical and physical technologies in the synthesis of SnO_2NPs. These include thermolysis [12], hydrolysis [13], microwave assisted method [14], sol-gel method [15], chemical decomposition [16], solid state chemical reaction method [17] and flame synthesis [18]. Chemical process was the most widespread synthesis technique used for SnO_2 NPs synthesis years ago owing to their ease of synthesis and control over shape of NPs as well as their manageable size. However, these methodologies pose environment sustainability threats and thereby limitations like cost-effectiveness, eco--toxicity and high pressure and energy requirements exist. Thus, chemically synthesized SnO_2 NPs lagged behind in mass production. It also limited their potential applications in different domains. Restricted yet acknowledgeable number of studies have been done on the side effects posed using these physiochemical methods for SnO_2 synthesis and have also discussed the disadvantages of the NPs so synthesized [19].

The thermolysis methods involves the use of precursor bis (dimethylamido) tin (II) dimer, [{Sn $(NMe_2)_2)_2\}_2$]. The synthesis proceeds by the decomposition of the dimer [{Sn $(NMe_2)_2)_2\}_2$] in a single step at a temperature around 190 °C, in a thermo-gravimetric instrument under the helium airflow. Resultant pure tin is obtained when the precursor is reduced in weight by almost 55%. The thermal oxidation of pure tin for 6 h at 200 °C, followed by heating in the presence of air for 6 h at 600 °C, leads to the formation of SnO_2 NPs [20]. During the synthesis of SnO_2 NPs through the hydrolysis of tin isopropoxide in the presence of acetylacetone and *p*-toluenesulphonic acid, and then ageing at 60 °C. This resulted in the formation of non-aggregated monodisperse spherical cassiterite-SnO_2 NPs which can be preserved at 4 °C temperature for a period of 4 months after which it destabilizes. Likewise, another appealing technique which is reported to be highly viable is microwave assisted technique. In this method a hydrated tin oxide salt aqueous solution is taken, which adds up to the formation of crystalline SnO nanoplatelets, which on annealing yields crystalline SnO_2 for temperatures corresponding to 300 °C [21].

During a study, 0.1 M tin chloride solution prepared in deionized water, which was pH adjusted using ammonium hydroxide. It was followed by washing with water till the solution was devoid of chloride ions [22]. Ethanol was then used to wash away ammonium ions. The resulting precipitate was irradiated to radiation frequency of 2.45 GHz and power 1 kW in a regular domestic microwave [23]. Mesoporous silica was immersed into prepared $Sn(acac)_2Cl_2$ precursor solution for about 5 days at room temperature (25 °C). It was then and dried under vacuum for almost 12 h. Firstly, the precursor sample was annealed for a period of 2 h at 200 °C and then exposed to oxygen rich atmosphere for 1 h. At temperature less than 500 °C, the sample turned blackish brown. On annealing at 600 °C, the color disappeared resulting in SnO_2 NPs dispersed in monolithic mesoporous silica. Although hydrothermal and microwave assisted hydrothermal process have some features in common, yet microwave assisted method have dominance over it. In the typical conventional hydrothermal method, 10 ml of $SnCl_4$–HCl stock solution is transferred to an autoclave safe Teflon1 container. An appropriate amount of liquid ammonia or urea is added to it. It is then autoclaved at 100–200 °C for 0.5–8 h. The microwave assisted hydrothermal process used 5–10 ml $SnCl_4$– HCl stock solution and base like ammonium hydroxide or urea and was exposed to a temperature range of 100–200 °C for 30 min to 4 h at 300W power [24]. During the

preparation of SnO_2 NPs used the same sol-gel methodology, conducted by varying reaction conditions as in concentration of ammonia and the reaction temperature and reaction rate. Generally, tin(IV) chloride solution with 25% ammonia solution in it is constantly stirred at a controlled rate within particular pH range and at temperatures generally between 30 and 90 °C. After magnetic stirring for almost 2 h, the sol is aged for a day. The resulting gel is washed with ethanol and dried at 80 °C, grinded and calcined at 400 °C for 2 h [25].

3. Biological synthesis of SnO_2 NPs

The chemicals methods are reported to have adverse effects on the environment as well as the place of application of the SnO_2 NPs. The conditions of synthesis like high temperature and high pressure also opposed the mass production of SnO_2 NPs and hence sidelines the applications, thus, a need for a better synthesis technique is necessary [26]. This search led to the discovery of green synthesis, and it includes the involvement of naturally available plants, plants material and microorganism as reducing agents in the fabrication of nanostructures. Various studies reported the use of aqueous or alcoholic extract derived from leaves of plants and trees, flowers, fruits, fruit peels, roots, waste plant material as well as agricultural waste for SnO_2 NPs synthesis. Moreover, various researchers also mentioned the use of other biological sources like bacteria, vitamins, proteins, and other metabolites together with some precursor for the purpose of reduction and capping. The main advantage of using biological synthesis is the cost-effectiveness, non-toxic approach which in turn ensures utilization in vivid applications in many domains (Fig. 1) [27].

4. Synthesis from plant extract

The abundance of renewable resources like plants made the green synthesis cost effective and the presence of phytochemical added to their safety and non-toxic nature. The procedure exhibited potential of being direct, handy to implement and kinetically faster. The biomolecules in the plants like the vitamins, proteins, polysaccharide, amino acids, enzymes and organic constituents like phenolic acids, citrates, flavonoids, alkaloids, tannins, carbonyls, amines, and amides are the key active components responsible for capping, reduction, and stabilization. The involvement of these high metabolites was reported widely moreover, most of the work includes the involvement of leaves extract of plants [32].

4.1. Leaves

For instance, economically biosynthesized SnO_2 NPs from aqueous leaves extract of *Aquilaria malaccensis* plant aka agarwood, in solution of tin(IV) chloride pentahydrate at room temperature following eco-friendly, non-toxic, and rapid green path. The synthesized NPs agglomerates were found to be uniformly distributed spheres showing great potential in catalysis and optoelectronic devices [28]. *Daphne Mucronata* leaves extract was employed as reducing and capping agent for SnO_2 NPs fabrication [29]. The synthesized NPs have efficiency in degradation of R6G dye and, also are effective against fungal and bacterial strains. The green synthesis of highly crystalline SnO_2 NPs using *Delonix elata* leaf extract via different synthesis techniques (sonication, microwave method and wet chemical method) [30]. Another study revealed that microwave synthesized SnO_2 NPs possess excellent crystallinity and exhibit higher surface

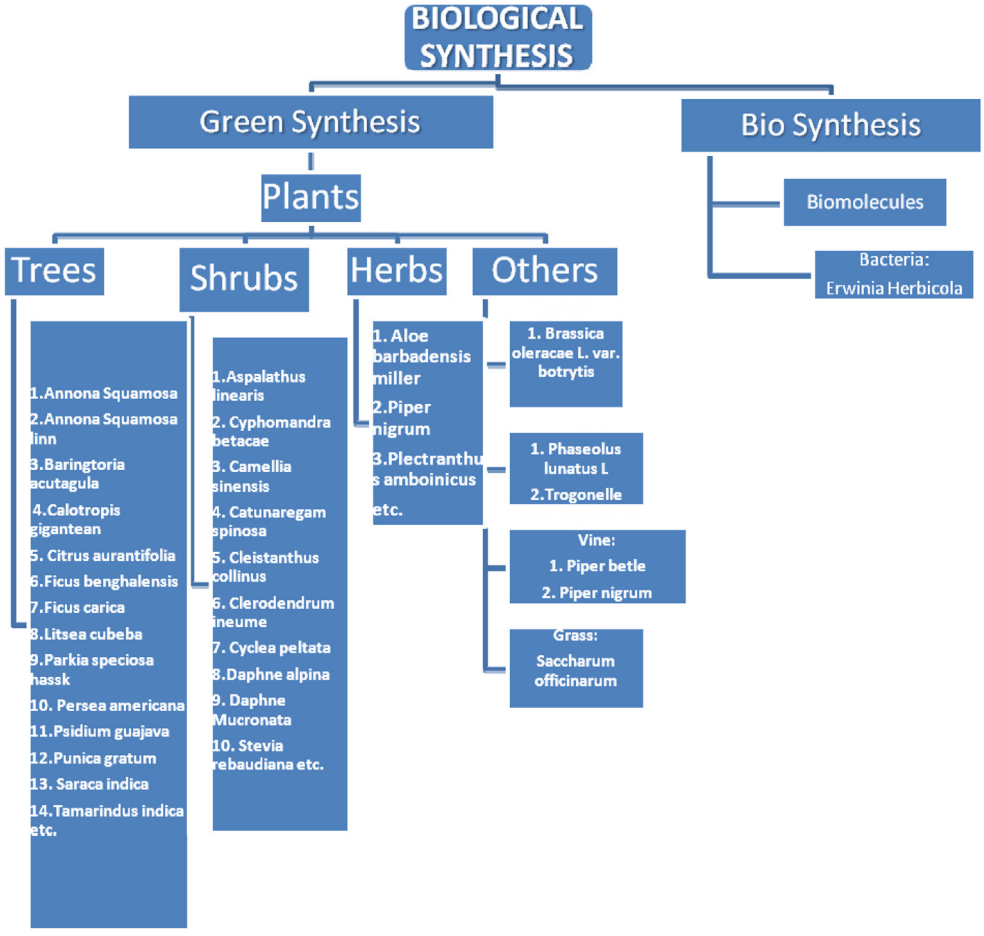

Fig. 1. Biological synthesis of SnO_2 NPs.

area 196 m^2 g^{-1} compared with the other two methods [31] by using extract of *Carica Papaya (CP), Moringa oleifera (MO), Murraya koenigii (MK) and Acalypha indica (AI)* leaves for the synthesis of SnO_2 NPs.

In another attempt, aimed to determine the anti-cancer ability of SnO_2 NPs produced using water extracts from *Limonia acidissima* and biologically derived leaves. The so furnished NPs showed 89% photocatalytic degradation proficiency against Rhodamine B organic dye [32]. To carry out the green synthesis of SnO_2 NPs in a simple, environmentally friendly, and low-cost process using guava leaf extract (*Psidium guajava*) [33]. Combining efficiency with environmental protection features, these NPs can be used for sustainable development or other industrial applications. During the furnishing of SnO_2 NPs from *piper betle* leaf extract, to remove reactive yellow dye 186 (RY-186) [34]. The use of biosynthesized SnO_2 as a heterogeneous catalyst to purify industrial wastewater to protect the environment is dealt with in this study. For the synthesis of SnO_2 NPs using *stevia rebaudiana* plant ethanol extract. The synthesis of SnO_2 NPs from the leaf extract of the *S. rebaudiana* plant is a very simple, economical, and environmentally friendly process [35]. This process can also be used to synthesize other metal nps, as the use of green synthesis methods, with non-toxic chemicals and green tea extract (*Camellia sinensis*) to efficiently synthesize SnO_2 NPs [36]. Study proposed an ecologically harmless method for synthesizing SnO_2 NPs using *aloe vera* extract. The metal salts present in aloe vera plant extract led to the formation of corresponding hydroxide [37]. For the bio-synthesized SnO_2 NPs using leaf extract of fig (*Ficus carica*) prepared using water and tin (II) chloride solution at 80 °C. The results show that the biomolecules may be used as a matrix for reducing and stabilizing NP Stannous oxide [38].

Few researchers furnished SnO_2 NPs from aloe vera plant where the metal salts present in plant extract leads to the formation of hydroxides. The prepared SnO_2 exhibited antibacterial property with more inhibition in gram positive strain compared to gram negative strain [39]. The green synthesis of the SnO_2 NPs by using the leaf extract of the *Delonix elata* leaf extract. In this study different route of synthesis was used. The synthesized materials were characterized by using various analytical techniques like XRD (X-ray diffraction), FTIR (Fourier transform infra red spectroscopy) SEM (Scanning Electron microscopy) and TEM (Transmission electron microscopy). The fabricated NPs exhibited very good photocatalytic activity in the degradation of Rhodamine B (Rh B) dye [40].

4.2. Fruits

This study focused on synthesizing SnO_2 NPs via greener method. The study wrapped the use of *Cyphomandra betacea* fruit extract in methanol to biosynthesize SnO_2 NPs [41]. In an article [42], researchers introduced a one-step, inexpensive and environmentally friendly method for synthesizing SnO_2 NPs from *Averrhoa bilimbi* fruit essence. During one attempt *jujube* fruit was employed as a non-toxic renewable reducing agent and excellent stabilizer to synthesize SnO_2 NPs in a green manner [43].

4.3. Vegetable

Attempts were made to use vegetables in the biosynthesis of $Sn(OH)_2$ using the water extract of fresh cauliflower (*Brassica oleracea* L. *var botrytis*). The obtained SnO_2 NPs were identified to be rutile tetragonal phase having quasi spherical and spherical morphologies for two samples. The average size range was found to be 3.62–6.34 nm. The photocatalysis of methylene blue (MB) under UV irradiation showed 91.89 and 88.23% degradation efficiency respectively [44].

4.4. Seeds

Considering the possible applications of nanostructured materials doped with transition metals and the advantages of new, economical and environmentally friendly biosynthesis methods, the Nickel SnO_2 nano material doping is synthesized using water (ideally kitchen garbage) obtained from soaked Bengal gram beans (*Cicer arietinum* L.) extract [45].

4.5. Peels

While working on the synthesis of SnO_2 NPs through green chemistry using of *C. aurantifolia* peels extract at different concentrations as reducing agent. Thus, high-purity SnO_2 NPs with good photocatalytic performance were synthesized using this green approach [46].

Different concentrations of *Lycopersicon esculentum* peel extract to fabricate SnO_2 NPs. The obtained NPs are crystalline, purely tetragonal crystal structure having Sn–O bond at 666 cm^{-1} with band gap of around 3.3 eV. The sample with 4% peel extract degraded methylene blue dye with 100% efficiency under UV exposure [47].

4.6. Flower

During an attempt to biosynthesized spherical tetragonal rutile SnO_2 NPs of average particles size 2.1 nm–4.1 nm using *Saraca indica* flower. The synthesized NPs exhibit antibacterial activity against GNB *E. coli* and the antioxidant activity of the furnished NPs was also evaluated [48].

4.7. Root

A team of researchers [49] focused on synthesizing materials that decompose toxic substances such as dyes through environmental synthesis. They synthesized SnO_2 NPs using the water extract of the root cortex of *Catunaregamspinosa*.

5. Synthesis from biomolecules

A team of researchers employed biosynthesis methods and described the green synthesis of SnO_2 NP using vitamin C as a reducing agent [50].

5.1. Synthesis from bacterial sources

Bacterial extracts and fungal extracts have been reported to be an alternate source for biosynthesis of SnO_2 NPs. The metabolites like bacterial proteins and biomolecules present in the bacterial biomass serve as effective stabilizing and reducing agent for the biosynthesis of SnO_2 NPs. Although much bacterial and fungal specie are reported to serve as potential candidates for reducing and capping agents in the SnO_2 NPs synthesis, yet till date only one research study has been reported in which SnO_2 NPs obtained by using the bacterium *Erwinia herbicola* [51].

6. Applications

The rapid pace of urbanization has led to a faster environment deterioration, faster fossil fuel depletion, rapid water contamination and what not. This increasing energy crisis and the depletion of natural resources have begun to plague mankind as a result of this, arose an earnest demand for alternative energy sources and highly efficient energy storage methodsfor a sustainable future. In this regard, modern technology has given the mankind a chance to redemption by righting all the wrongs committed. Nanotechnology perhaps has been of most use and importance. Various engineered metal and metal NP has served this purpose quite rightfully, of which SnO_2 NPs have shown commendable results.

6.1. Biological applications

The green synthesized SnO_2 NPs have been reported to have displayed anti-microbial, antioxidant, anti-cancerous and excellent photocatalytic degradation property (Fig. 2).

6.2. Anti-bacterial

The activity of SnO_2 NPs against various bacterial species has been reported. Both gram negative and gram-positive bacterial strains are effectively defensed by the green synthesized SnO_2 NPs. The

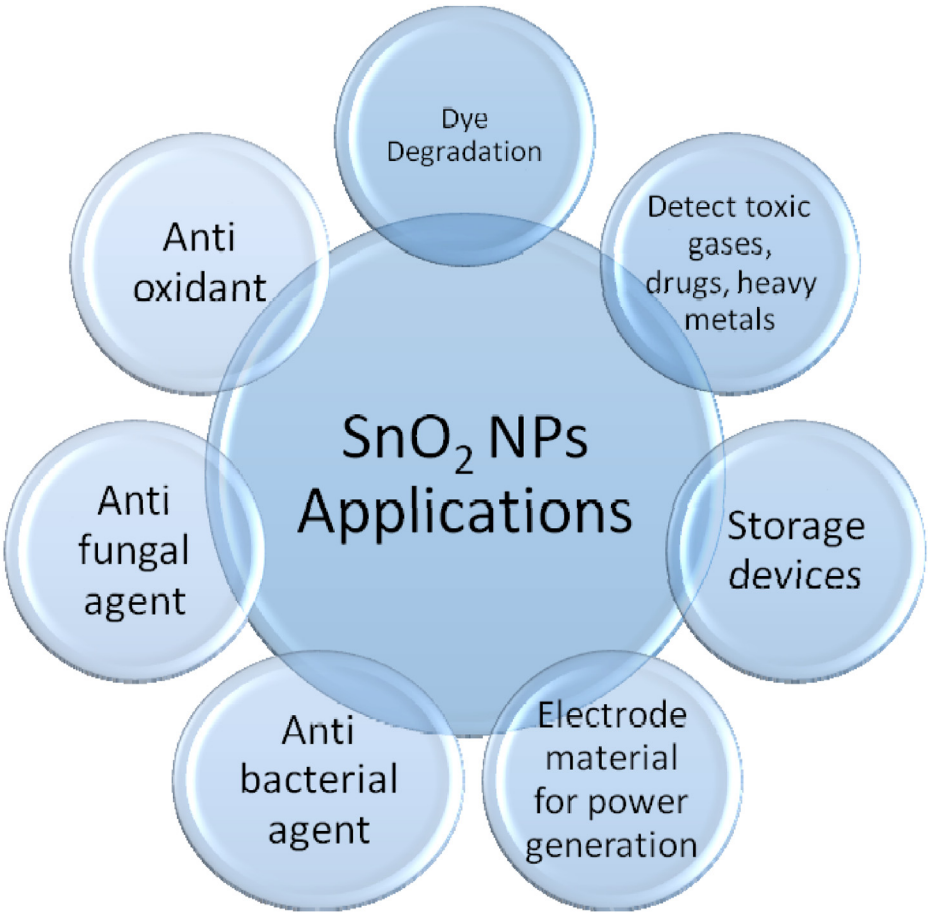

Fig. 2. Various applications of green synthesized SnO_2NPs. (for interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Table 1) precisely set forth various plant mediated SnO_2 NPs having shown anti-bacterial activity against different bacterial strains (Fig. 3).

Anti-bacterial inhibition zones developed through agar method, using differently concentrated NPs samples against the bacterial specimens of *Escherichia coli* and *S. aureus*, of which *E. coli* exhibited better activity [84,85].

Agar well diffusion method was employed, to study the antibacterial activity of the synthesized doped SnO_2 NPs against the bacterial strains *of Bacillus subtilis* and *Escherichia coli*. The activity was confirmed using various characterization techniques as well, namely SEM (Scanning Electron Microscopy), TEM (Transmission electron microscopy) and CLSM (confocal laser scanning microscopic) analysis [86].

Other than these, anti-bacterial studies have been conducted and observations were made on activities follow two different methodologies where firstly, NAM (nutrient agar media) is prepared, poured on sterile petri dishes, and is solidified for an hour or so. Bacterial culture is then swabbed over it. After this, either agar wells are made using cork borer or the loaded disc are placed on the inoculated petri plates. The former is called the agar well diffusion method and the latter are referred to as agar disc diffusion method. In the age well diffusion method the NPs solutions to be tested are poured into the agar wells, while in the disc diffusion method the NPs loaded Whatman paper discs are gently placed on the inoculated plates. The plates are then covered and incubated for 24 h at 37 °C. After incubation, the inhibition zones are measured in mm using transparent ruler. The picture below depicts the procedure of determining the anti-bacterial activity of the synthesized NPs using the agar diffusion method [87,88].

6.3. Anti-fungal

While studying the anti-fungal propensity of doped and undoped NPs against *A. niger*, *A. flavus*, and *C. albicans* fungi specimens [89]. On other hand, in some other attempts the anti-fungal activity of the green synthesized SnO_2 NPs along with the anti-bacterial activity was employed. The antifungal activity of SnO_2 NPs carried out via Potato Dextrose Broth antifungal assay, reveals that the *Asperjillus nigar* had a significant activity as compared to *T. viridea* fungi species [90].

6.4. Antioxidant

For the analysis of free radical equivalent of DPPH (1, 1-diphenyl-2-picrylhydrazyl) per mg of the sample to be 0.8026, ensuring the use in biomedical purposes. The plant extracts contain alkaloids, cyclopeptides, flavonoids, phenols, tannins and minerals like Cu, Fe, Mn, Zn, Se which attribute to the therapeutic and antioxidant property of the NPs thus synthesized [91].

6.5. Anti-cancerous

Fabricated green synthesized NPs unveil robust cytotoxic effect on the breast cancer MCF-7 in comparison to human lung fibroblast (WI38) and human amnion (WISH) cell lines. Furthermore, the green synthesized undoped SnO_2 and Co-doped SnO_2 NPs demonstrated the significant in vitro anticancer activity and in vivo antitumor propensity against mammary gland breast cancer (MCF-7) cell lines and Ehrlich ascites tumor respectively, which exhibited their potential applications in Oncology field [92].

Table-1
Varity of Plant extract used in the synthesis of SnO_2 NPs with their shape, Size & brief application.

Plant specie (Plant part)	Precursor	Bioactive compounds	Crystal lattice and shape	Size of NPs	Shape of NPs morphology	Application	Ref.
Aloe barbadensis (peels)	$Sn(NO_3)_2{\cdot}3H_2O$	–	Spherical	17 nm	Spherical	Antibacterial and antifungal	[52]
Annona squammosa (peels)	$SnCl_2{\cdot}2H_2O$	–	Tetragonal, 20 nm	27.5 nm	Spherical	Cytotoxicity effect against hepG2	[53]
Annona squamosalinn (leaves)	metallic tin	_	Tetragonal	29–37 nm	Irregular spherical	Antioxidant	[54]
Aspalathus linearis (leaves)	$SnCl_4{\cdot}5H_2O$	Aspalathin, orientin, isoorientin, luteolin, nothofagin etc.	Tetragonal rutile	2.1–19.3 nm	Spherical quasi-spherical	Congo red, methylene blue and Eosin Y degradation	[55]
Aquilaria malaccensis (leaves)	$SnCl_4{\cdot}5H_2O$	Terpenoids, saponin, tannin, alkaloids, flavonoids, squalene, polyphenol etc.	Tetragonal	6.3 and 3.4 nm	Spherical	_	[56]
Brassica oleracae L. var. botrytis (leaves)	$SnCl_2{\cdot}2H_2O$	Vitamin C, glucosinolates and flavonoid	Tetragonal rutile	3.62–6.34 nm	Quasi spherical and spherical	Aqueous methylene blue degradation	[57]
Cyphomandra betacae (Fruits)	$SnCl_2$	_	Spherical	15−20 nm	Spherical cluster	Methylene blue degradation	[58]
Calotropis gigantea (leaves)	$SnCl_4{\cdot}5H_2O$	Alkaloids, Tannins, Saponins, Quinons Flavonoids, Phenols, Terpenoids, Proteins	Tetragonal	30–40 nm	Spherical	Methylene orange degradation	[59]
Camellia sinensis (leaves)	$SnCl_2$	Catechins	Tetragonal	<20 nm	Spherical	_	[60]
Catunaregam spinosa	$SnCl_2$	7-hydroxy-6-methoxy-2H-1benzopyran-2(% of 67.47) etc.	_	47 ± 2 nm	Spherical	Congo red degradation	[61]
Cicerarietinum (seeds)	$SnCl_4$	_	Tetragonal s	~11 nm and 6 nm	Spherical	NO_2 gas sensing	[62]
Cleistanthus collinus (leaves)	Aq. tin oxide soln.	Lignan lactone glucosides	Tetragonal primitive	49.26 nm	_	Antibacterial and antioxidant	[63]
Clerodendrum ineume (leaves)	$SnCl_4{\cdot}2H_2O$ NaOH, NH_4OH	Flavonoids and phenolic compounds	_	30 nm	Spherical	Antibacterial, antifungal, and anticancer	[64]
Daphne alpina (leaves)	$SnCl_4{\cdot}5H_2O$	_	Tetragonal and orthorhombic	23 (±2) nm	Elongated	Adsorption of Cd^{2+}	[65]
Delonixelata	tin chloride	Phenolic compounds mainly two flavanones namely Quercetin and Rutin	_	13–18 nm.	Clusters like foam	Rhodamine B degradation	[66]
Ficus carica (leaves)	$SnCl_2{\cdot}2H_2O$	Volatile essential oil and flavonoids	Tetragonal	128 nm	Spherical	Hg^{2+} electrochemical sensor	[67]
Jujube (fruits)	$SnCl_2.2H_2O$	–	Tetragonal	23 nm	Clusters like foam		[68]
Litsea cubeba (fruits)	$SnCl_2$	_	_	30 nm	Irregular	Congo red degradation and antioxidant	[69]
Lycopersicon esculentum (peels)	$SnCl_2{\cdot}2H_2O$	Metal salts, phenolic compounds, carotenoids, ascorbic acid (vitamin C), vitamin E, folic acid, and flavonoid	Tetragonal rutile	5.56 nm	Quasi-spherical	Methylene blue degradation	[70]
Parkia speciosa (pods)	$SnCl_4{\cdot}5H_2O$	Vitamins, polyphenolic compounds, and amino acids	Tetragonal rutile	~1.9 nm	Spherical	Acid yellow 23 degradation	[71]
Persia americana (seeds)	$SnCl_2$	_	Tetragonal rutile	4 nm	Fine flakes	Phenolic red dye degradation	[72]
Phaseolus lunatus L (leaves)	$SnCl_2{\cdot}2H_2O$	_	_	18 nm	Porous	Alizarin red S degradation	[73]
Piper betle (leaves)	$SnCl_2$	Monoterpenes, esters, alcohol, aldehyde and phenol	Tetragonal	8.4 nm	Hollow spherical	RY 186 dye degradation	[74]
Piper nigrum (seeds)	$SnCl_2{\cdot}2H_2O$	_	Tetragonal rutile	10−15 nm	spherical	Cytotoxicity studies	[75]
Plectranthus amboinicus (leaves)	$SnCl_2{\cdot}2H_2O$	_	Tetragonal	63 nm	Cluster	Rhodamine B degradation	[76]
Psidium guajava (leaves)	$SnCl_4$	Phenolic compounds, flavonoids, sesquiterpene alcohols and triterpenoid acids	Tetragonal rutile	8−10 nm	Spherical	RY 186 dye degradation	[77]
Punica granatum (seeds)	$SnCl_4{\cdot}xH_2O$	Phenolics, flavonoids, ellagitannins, and proanthocyanidin compounds	Tetragonal rutile	20 nm	Spherical and cuboidal	Antioxidant and antibacteria	[78]
Stevia rebaudiana (leaves)	Aqueous tin oxide	Austroinullin, β-carotene, dulcoside, nilacin, rebaudi oxides, riboflavin, steviol and stevioside	_	20−30 nm	Spherical	Antibacterial	[79]
Saraca indica(flowers)	$SnCl_4{\cdot}xH_2O$	Flavanones and terpenoids	Tetragonal	2.1–4.1 nm	Spherical	Antibacterial and antioxidant	[80]
Solanum nigrum(leaves)	($SnCl_2$) (aqueous)	_	_	19.56 nm	Trigonal and spherical	Antibacterial	[81]
Tradescantias pathacea	$SnCl_4{\cdot}5H_2O$	Coumarins, alkaloids, saponins, flavonoids and terpenoids.	Tetragonal rutile	46.36–89.10 nm.	Spherical		[82]

(*continued on next page*)

Table-1 (*continued*)

Plant specie (Plant part)	Precursor	Bioactive compounds	Crystal lattice and shape	Size of NPs	Shape of NPs morphology	Application	Ref.
Carica papaya, Murraya koenigii, Moringa oleifera, and Acalypha indica	$SnCl_2.2H_2O$	_	Tetragonal	5 nm, 19 nm, 38 nm,11 nm	Tiny particles along with rods.	Rhodamine B degradation	[83]

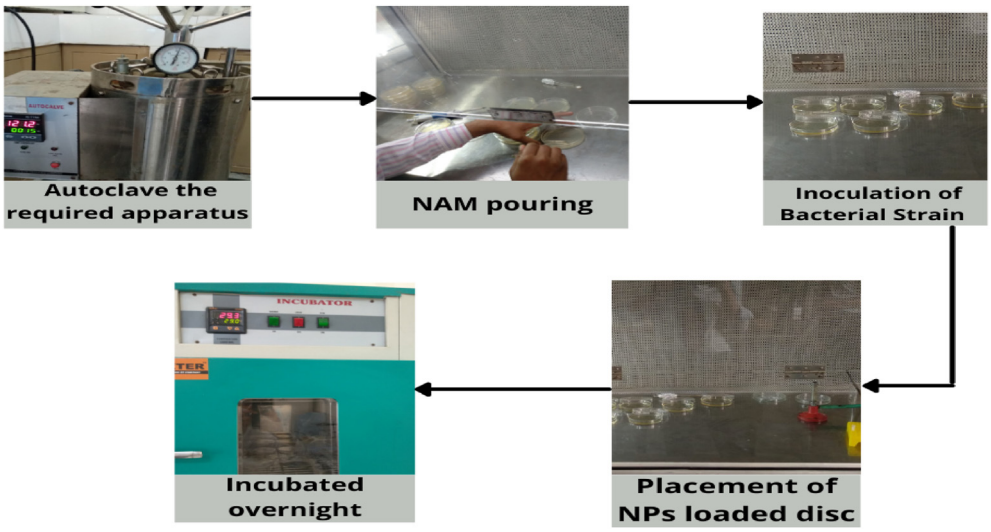

Fig. 3. General procedure for the determination of antimicrobial activity.

6.6. Photocatalytic

Based on a report mentioning that 99.70% degradation of R6G dye catalyzed by the synthesized SnO_2 NPs [93]. While on other hand, in an attempt on the degradation proficiency of methylene blue dye catalyzed by synthesized SnO_2 NPs [94].

The prepared SnO_2 NPs for their photocatalytic degradation proficiency against Congo red, Methylene blue and Eosin Y under UV light irradiation were checked and based on findings it may be concluded that the NPs synthesized by them exhibited excellent photocatalytic degradation for Methylene blue and Eosin Y, while in the case of Congo red, the photodecomposition was quite low [95].

In addition to the above-mentioned studies, many research papers reported the photocatalytic response of the green furnished SnO_2 NPs for the methylene blue dye [96], dealt with the aqueous MB dye [97], and MB photo catalyzed degradation using the respectively synthesized SnO_2 NPs [98]. While 80% degradation reported of methyl orange dye within 120 min of UV exposure [99]. SnO_2 catalyzed degradation of Congo red dye was studied with a 92% degradation rate within 50 min of irradiation whereas Rhodamine b dye was a part of photocatalytic analysis [100, 101]. Acid yellow 23 was employed during the degradation of alizarin red using differently synthesized SnO_2 NPs [102]. Whereas in another attempt phenol red examination showed total degradation of phenol red dye using green synthesized SnO_2 NPs [103]. RY186 reported a cumulative percentage degradation of the RR-120 and RG-19 as 38.2% and 61.7%, respectively under similar conditions whereas the selective potential was however more for RY-186 dye over other dyes towards the photo catalyzed degradation [104]. Examination of photocatalytic property of the biosynthesized SnO_2 NPs using rhodamine B (Rh B) dye which was studied for degradation activity under visible light illumination [105]. During the examination of degradation almost 90% degradation of reactive yellow 186 dye in sunlight on an exposure of 180 min [106]. In another attempt of study based on photocatalytic property of silver doped SnO_2NPS against Methylene Blue, Rose Bengal, Methyl Violet 6B, and 4-nitrophenol [107].

A noticeable degradation (84%) of Eriochrome Black T dye was recorded, by the green synthesized SnO_2 NPs. The image shown below shows the setup for photocatalytic activity analysis of the synthesized SnO_2NPs on methyl red and Coomassie brilliant blue dyes (Figs. 4 and 5) [108].

7. Physiochemical applications

7.1. Gas sensing

During the study of the gas sensing efficacy of Ni-doped SnO_2 sensors towards a number of flammables, poisonous, toxic and corrosive gases like hydrogen sulfide, liquefied petroleum gas, ammonia and nitrogen dioxide at 200 °C which is optimal operating temperature for NO_2 gas. The results suggest that the Ni-doped SnO_2 films can be used to monitor the NO_2 emissions [44].

7.2. Adsorption of Cd^{2+}

Study confirmed that the green fabricated SnO_2 NPs have great compatibility to be used as heavy metal ion like cadmium (Cd^{2+}) [109].

7.3. Hg^{2+} electrochemical sensor

In another successful attempt to obtain biosynthesized SnO_2 NPs as electrode modifier for electrochemically detection of Hg^{2+} in various water samples [110].

8. Conclusions

Present review article was focused on the various available green synthesis methods for the preparation of SnO_2 NPs. Attempt was made to accumulate maximum possible findings in the field of green synthesis method for the preparation SnO_2 NPs, furthermore various potential applications of SnO_2 NPs like antimicrobial, Photo-catalytic and

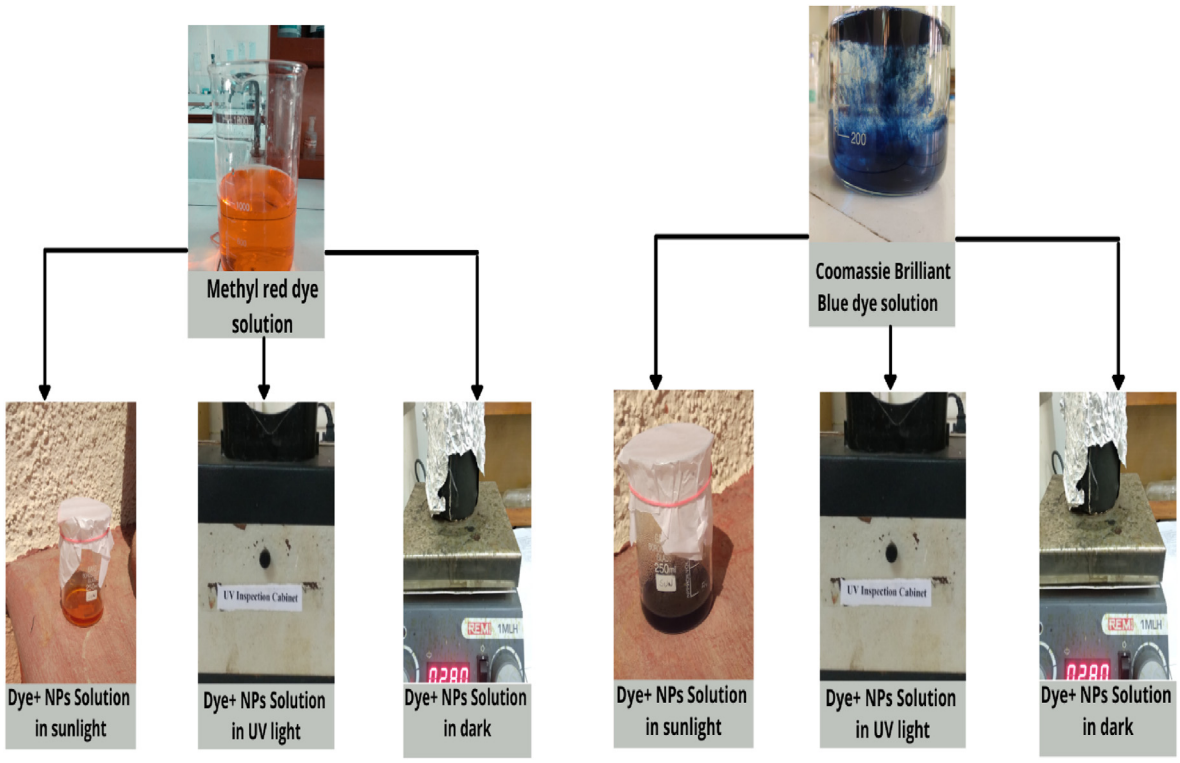

Fig. 4. General procedure for the determination of photo-catalytic activity.

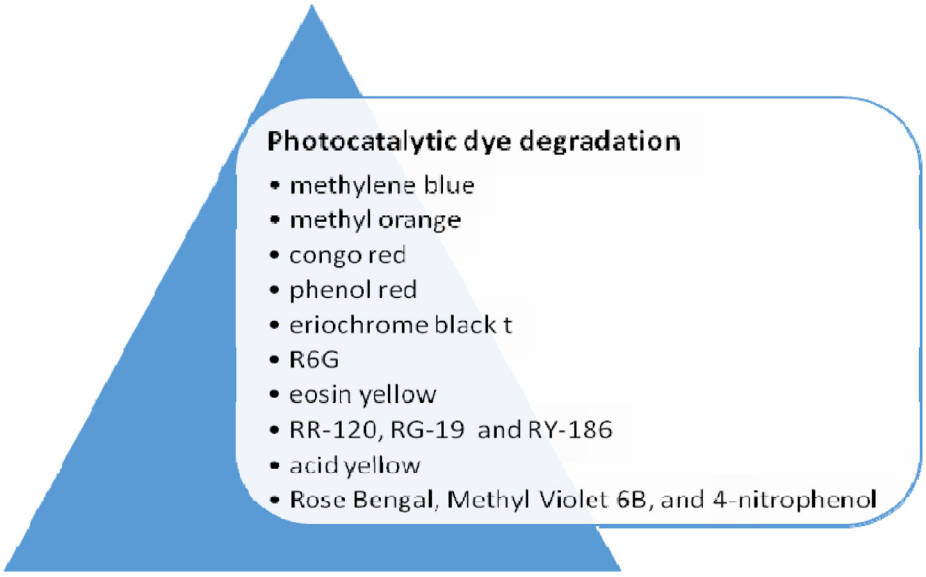

Fig. 5. Photo catalytic activity of SnO_2 NPs.

physiochemical applications were discussed in detail. This work, emphasized on different mediated green synthesis of SnO_2 NPs, simultaneously elaborated their properties and multidisciplinary applications as well as the elucidation of characterization of the SnO_2 NPs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personnel relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] C. Buzea, I.I. Pacheco, K. Robbie, Nanomaterials and nanoparticles: sources and toxicity, Biointerphases 2 (4) (2007) MR17–MR71.
[2] S. Meena, V. Dipti, K. Ravi, K. Das Bijoy, Role of EDTA capped cobalt oxide nanomaterial in photocatalytic degradation of dyes, J. Serb. Chem. Soc. 86 (2021) 327–340.

[3] B.K. Thakur, A. Kumar, Kumar, D. Green synthesis of TiO2 nanoparticles using azadirachataindica leaf extract and evaluation of their antibacterial activity, South Afr. J. Bot. 124 (2019) 223–227.

[4] J. Jeevanandam, A. Barhoum, Y.S. Chan, A. Dufresne, M.K. Danquah, Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations, Beilstein J. Nanotechnol. 9 (1) (2018) 1050–1074.

[5] P.N. Sudha, K. Sangeetha, K. Vijayalakshmi, A. Barhoum, Chapter 12 - nanomaterials history, classification, unique properties, production and market, in: Emerging Applications of Nanoparticles and Architecture Nanostructures, Elsevier Inc, 2018.

[6] V. Dipti, K. Babita, K.S. Praveen, Recent advances in graphitic carbon nitride semiconductor: structure, synthesis and application, Mater. Sci. Semicond. Process. 137 (2022) 106181.

[7] E.C. Wang, A.Z. Wang, Nanoparticles and their applications in cell and molecular biology, Integrative Biology (United Kingdom) 6 (1) (2014) 9–26.

[8] S.A. Ansari, M.M. Khan, M.O. Ansari, J. Lee, M.H. Cho, Visible light-driven photocatalytic and photoelectrochemical studies of Ag-SnO2 nanocomposites synthesized using an electrochemically active biofilm, RSC Adv. 4 (49) (2014) 26013–26021.

[9] A. Raghunath, E. Perumal, Metal oxide nanoparticles as antimicrobial agents: a promise for the future, Int. J. Antimicrob. Agents 49 (2) (2017) 137–152.

[10] D. Zhang, Y. Sun, P. Li, Y. Zhang, Facile fabrication of MoS2- modified SnO2 hybrid nanocomposite for ultrasensitive humidity sensing facile fabrication of MoS2 -modified SnO2 hybrid nanocomposite for ultrasensitive humidity sensing, ACS Appl. Mater. Interfaces 8 (2016) 14142–14149.

[11] Q.A. Pankhurst, J. Connolly, S.K. Jones, J. Dobson, Applications of magnetic nanoparticles in biomedicine, J. Phys.D 36 (2003) 167–181.

[12] H. Greim, Constitution and procedures of the commission for the investigation of health hazards of chemical compounds in the work area, in: Occupational Toxicants and MAK Values, 2004.

[13] C. Nayral, E. Viala, P. Fau, F. Senocq, J.C. Jumas, A. Maisonnat, B. Chaudret, Synthesis of tin and tin oxide nanoparticles of low size dispersity for application in gas sensing, Chem. Eur J. 6 (22) (2000) 4082–4090.

[14] S. de Monredon, A. Cellot, F. Ribot, C. Sanchez, L. Armelao, L. Gueneau, L. Delattre, Synthesis and characterization of crystalline tin oxide nanoparticles, J. Mater. Chem. 12 (8) (2002) 2396–2400.

[15] T. Krishnakumar, N. Pinna, K.P. Kumari, K. Perumal, R. Jayaprakash, Microwave-assisted synthesis and characterization of tin oxide nanoparticles, Mater. Lett. 62 (19) (2008) 3437–3440.

[16] R. Adnan, N.A. Razana, I.A. Rahman, M.A. Farrukh, Synthesis and characterization of high surface area tin oxide nanoparticles via the sol-gel method as a catalyst for the hydrogenation of styrene, J. Chin. Chem. Soc. 57 (2) (2010) 222–229.

[17] Y.S. Feng, S.M. Zhou, Y. Li, C.C. Li, L.D. Zhang, Synthesis and characterization of tin oxide nanoparticles dispersed in monolithic mesoporous silica, Solid State Sci. 5 (5) (2003) 729–733.

[18] P. Sarabadani, M. Sadeghi, M. Ghasemi, Z. Asadollahi, N. Afshari, Synthesis and characterization of tin oxide nanoparticles by solid state chemical reaction method, J. Cluster Sci. 22 (2) (2011) 131–140.

[19] B. Rellinghaus, D. Lindackers, M. Köckerling, P. Roth, E.F. Wassermann, The process of particle formation in the flame synthesis of tin oxide nanoparticles, Phase Transitions 76 (4–5) (2003) 347–354.

[20] G.J.A.A. Soler-Illia, Molecular Chemistry of Sol-Gel Derived Nanomaterials. Herausgegeben von Robert J. P. Corriu und Nguyen Trong Anh, Angew. Chem. 121 (47) (2009).

[21] G. Nabi, W. Raza, M.B. Tahir, Green synthesis of TiO2 nanoparticle using cinnamon powder extract and the study of optical properties, J. Inorg. Organomet. Polym. 30 (2020) 1425–1429.

[22] T. Santhoshkumar, A.A. Rahuman, C. Jayaseelan, G. Rajakumar, S. Marimuthu, A.V. Kirthi, K. Velayutham, J. Thomas, J. Venkatesan, S.-K. Kim, Green synthesis of Titanium dioxide nanoparticles using psidiumguajava extract and its antibacterial and antioxidant properties, Asian Pac. J. Trop Me 7 (2014) 968–976.

[23] T. Krishnakumar, N. Pinna, K.P. Kumari, K. Perumal, R. Jayaprakash, Microwave-assisted synthesis and characterization of tin oxide nanoparticles, Mater. Lett. 62 (19) (2008) 3437–3440.

[24] Y.S. Feng, S.M. Zhou, Y. Li, C.C. Li, L.D. Zhang, Synthesis and characterization of tin oxide nanoparticles dispersed in monolithic mesoporous silica, Solid State Sci. 5 (5) (2003) 729–733.

[25] M. Krishna, S. Komarneni, Conventional- vs microwave-hydrothermal synthesis of tin oxide, SnO2 nanoparticles, Ceram. Int. 35 (8) (2009) 3375–3379.

[26] N. Zikalala, K. Matshetshe, S. Parani, O.S. Oluwafemi, Biosynthesis protocols for colloidal metal oxide nanoparticles, Nano-Structures and Nano-Objects 16 (2018) 288–299.

[27] M. Kumar, A. Mehta, A. Mishra, J. Singh, M. Rawat, S. Basu, Biosynthesis of tin oxide nanoparticles using Psidium Guajava leave extract for photocatalytic dye degradation under sunlight, Mater. Lett. 215 (2018) 121–124.

[28] T. Bhosale, H. Shinde, N. Gavade, S. Babar, V. Gawade, S. Sabale, et al., Biosynthesis of SnO 2 nanoparticles by aqueous leaf extract of Calotropis gigantea for photocatalytic applications, J. Mater. Sci. Mater. Electron. 29 (8) (2018) 6826–6834.

[29] I. Buniyamin, R. Md Akhir, N. Asnida Asli, Z. Khusaimi, M. Rusop Mahmood, Biosynthesis of SnO 2 nanoparticles by aqueous leaves extract of Aquilaria malaccensis (agarwood), IOP Conf. Ser. Mater. Sci. Eng. 1092 (1) (2021), 012070.

[30] S. Haq, W. Rehman, M. Waseem, A. Shah, A.R. Khan, M.U. Rehman, P. Ahmad, B. Khan, G. Ali, Green synthesis and characterization of tin dioxide nanoparticles for photocatalytic and antimicrobial studies, Mater. Res. Express 7 (2) (2020).

[31] K.C. Suresh, S. Surendhiran, P. Manoj Kumar, E. Ranjth Kumar, Y.A.S. Khadar, A. Balamurugan, Green synthesis of SnO2 nanoparticles using Delonix elata leaf extract: evaluation of its structural, optical, morphological and photocatalytic properties, SN Applied Sciences 2 (10) (2020) 1–13.

[32] P.S. Sundara Selvam, D. Ganesan, V. Rajangam, A. Raji, V. Kandan, Green synthesis of SnO2 nanoparticles for catalytic degradation of rhodamine B, Iran. J. Sci. Technol. Trans. A-Science 44 (3) (2020) 661–676.

[33] J. Ma, M. Zhao, C. Zhang, X. Wu, G. Yang, Synthesis of L. Acidissima mediated tin oxide nanoparticles for cervical carcinoma treatment in nursing care, J. Drug Deliv. Sci. Technol. 57 (288) (2020) 101745.

[34] M. Kumar, A. Mehta, A. Mishra, J. Singh, M. Rawat, S. Basu, Biosynthesis of tin oxide nanoparticles using Psidium Guajava leave extract for photocatalytic dye degradation under sunlight, Mater. Lett. 215 (April 2020) (2018) 121–124.

[35] J. Singh, N. Kaur, P. Kaur, S. Kaur, J. Kaur, P. Kukkar, V. Kumar, D. Kukkar, M. Rawat, Piper betle leaves mediated synthesis of biogenic SnO2 nanoparticles for photocatalytic degradation of reactive yellow 186 dye under direct sunlight, Environmental Nanotechnology, Monitoring and Management 10 (2018) 331–338.

[36] M.G.T. Nathan, P. Myvizhi, Green synthesis and characterization of tin oxide nanoparticles using plant extract, Int. J. Pure Appl. Math. 119 (12) (2018) 6439–6448.

[37] J.C. Selvakumari, M. Ahila, M. Malligavathy, D.P. Padiyan, Structural, morphological, and optical properties of tin(IV) oxide nanoparticles synthesized using Camellia sinensis extract: a green approach, International Journal of Minerals, Metallurgy and Materials 24 (9) (2017) 1043–1051.

[38] S. Gowri, R.R. Gandhi, M. Sundrarajan, Green synthesis of tin oxide nanoparticles by aloe vera: structural, optical and antibacterial properties, J. Nanoelectron. Optoelectron. 8 (3) (2013a) 240–249.

[39] J. Hu, Biosynthesis of SnO2 nanoparticles by fig (Ficus Carica) leaf extract for electrochemically determining Hg(II) in water samples, International Journal of Electrochemical Science 10 (12) (2015) 10668–10676.

[40] S. Gowri, R.R. Gandhi, M. Sundrarajan, Green synthesis of tin oxide nanoparticles by aloe vera: structural, optical and antibacterial properties, J. Nanoelectron. Optoelectron. 8 (3) (2013b) 240–249.

[41] K.C. Suresh, S. Surendhiran, P. Manoj Kumar, E. Ranjth Kumar, Y.A. Syed Khadar, A. Balamurugan, Green synthesis of SnO2 nanoparticles using *Delonix elata* leaf extract: evaluation of its structural, optical, morphological and photocatalytic properties SN, Appl. Sci. 2 (2020) 1735.

[42] G. Elango, S.M. Roopan, Efficacy of SnO2 nanoparticles toward photocatalytic degradation of methylene blue dye, J. Photochem. Photobiol. B Biol. 155 (2016) 34–38.

[43] N.E. Sunny, V.K. S, Biogenesis, characterization and bioefficacy of tin oxide nanoparticles from Averrhoa bilimbi fruit extract, Int. J. Recent Technol. Eng. 8 (4) (2019) 10309–10315.

[44] M. Honarmand, M. Golmohammadi, A. Naeimi, Biosynthesis of tin oxide (SnO2) nanoparticles using jujube fruit for photocatalytic degradation of organic dyes, Adv. Powder Technol. 30 (8) (2019) 1551–1557.

[45] J. Osuntokun, D.C. Onwudiwe, E.E. Ebenso, Biosynthesis and photocatalytic properties of SnO2 nanoparticles prepared using aqueous extract of cauliflower, J. Cluster Sci. 28 (4) (2017) 1883–1896.

[46] K.P. Gattu, K. Ghule, A.A. Kashale, V.B. Patil, D.M. Phase, R.S. Mane, S.H. Han, R. Sharma, A.V. Ghule, Bio-green synthesis of Ni-doped tin oxide nanoparticles and its influence on gas sensing properties, RSC Adv. 5 (89) (2015) 72849–72856.

[47] P.A. Luque, O. Nava, C.A. Soto-Robles, H.E. Garrafa-Galvez, M.E. Martínez-Rosas, M.J. Chinchillas-Chinchillas, A.R. Vilchis-Nestor, A. Castro-Beltrán, SnO2 nanoparticles synthesized with Citrus aurantifolia and their performance in photocatalysis, J. Mater. Sci. Mater. Electron. 31 (19) (2020) 16859–16866.

[48] H.E. Garrafa-Galvez, O. Nava, C.A. Soto-Robles, A.R. Vilchis-Nestor, A. Castro-Beltrán, P.A. Luque, Green synthesis of SnO2 nanoparticle using Lycopersicon esculentum peel extract, J. Mol. Struct. 1197 (2019) 354–360.

[49] V.K. Vidhu, D. Philip, Phytosyn thesis and applications of bioactive SnO2 nanoparticles, Mater. Char. 101 (2015b) 97–105.

[50] E. Haritha, S.M. Roopan, G. Madhavi, G. Elango, N.A. Al-Dhabi, M.V. Arasu, Green chemical approach towards the synthesis of SnO2 NPs in argument with photocatalytic degradation of diazo dye and its kinetic studies, J. Photochem. Photobiol. B Biol. 162 (2016) 441–447.

[51] J. Yang, K. qing Yang, L. Qiu, Biosynthesis of vitamin C stabilized tin oxide nanoparticles and their effect on body weight loss in neonatal rats, Environ. Toxicol. Pharmacol. 54 (2017) 48–52, https://doi.org/10.1016/j.etap.2017.06.013.

[52] N. Srivastava, M. Mukhopadhyay, Biosynthesis of SnO_2 nanoparticles using bacterium erwinia herbicola and their photocatalytic activity for degradation of dyes, Ind. Eng. Chem. Res. 53 (36) (2014) 13971–13979.

[53] D.S. Chauhan, C.S.A. Gopal, D. Kumar, N. Mahato, M.A. Quraishi, M.H. Chod, Microwave induced facile synthesis and characterization of ZnO nanoparticles as efficient antibacterial agents, Mater. Discov. 11 (2018) 19–25.

[54] S.M. Roopan, S.H.S. Kumar, G. Madhumitha, K. Suthindhiran, Biogenic-production of SnO2 nanoparticles and its cytotoxic effect against hepatocellular carcinoma cell line (HepG2), Appl. Biochem. Biotechnol. 175 (3) (2015) 1567–1575.

[55] S. Sudhaparimala, Green synthesis of tin based nano medicine: assessment of microstructure and surface property, Am. J. Nanosci. Nanotechnol. 2 (4) (2014) 75.

[56] A. Diallo, E. Manikandan, V. Rajendran, M. Maaza, Physical & enhanced photocatalytic properties of green synthesized SnO2 nanoparticles via Aspalathus linearis, J. Alloys Compd. 681 (October) (2016) 561–570.

[57] I. Buniyamin, R. Md Akhir, N. Asnida Asli, Z. Khusaimi, M. Rusop Mahmood, Biosynthesis of SnO 2 nanoparticles by aqueous leaves extract of Aquilaria malaccensis (agarwood), IOP Conf. Ser. Mater. Sci. Eng. 1092 (1) (2021), 012070.
[58] J. Osuntokun, D.C. Onwudiwe, E.E. Ebenso, Biosynthesis and photocatalytic properties of SnO2 nanoparticles prepared using aqueous extract of cauliflower, J. Cluster Sci. 28 (4) (2017) 1883–1896.
[59] G. Elango, S.M. Kumaran, S.S. Kumar, S. Muthuraja, S.M. Roopan, Green synthesis of SnO2 nanoparticles and its photocatalytic activity of phenolsulfonphthalein dye, Spectrochim. Acta Mol. Biomol. Spectrosc. 145 (2015) 176–180.
[60] T.T. Bhosale, H.M. Shinde, N.L. Gavade, S.B. Babar, V.V. Gawade, S.R. Sabale, R.J. Kamble, B.S. Shirke, K.M. Garadkar, Biosynthesis of SnO2 nanoparticles by aqueous leaf extract of Calotropis gigantea for photocatalytic applications, J. Mater. Sci. Mater. Electron. 29 (8) (2018) 6826–6834.
[61] J.C. Selvakumari, M. Ahila, M. Malligavathy, D.P. Padiyan, Structural, morphological, and optical properties of tin(IV) oxide nanoparticles synthesized using Camellia sinensis extract: a green approach, International Journal of Minerals, Metallurgy and Materials 24 (9) (2017) 1043–1051.
[62] S.R. Goswami, M. Singh, Microwave-mediated synthesis of zinc oxide nanoparticles: a therapeutic approach against Malassezia species, IET Nanobiotechnol. 12 (2018) 903–908.
[63] P. Kamaraj, R. Vennila, M. Arthanareeswari, Biological activities of tin oxide nanoparticles synthesized using plant extract, World J. Pharm. Pharmaceut. Sci. 3 (9) (2014) 382–388.
[64] S.A. Khan, S. Kanwal, K. Rizwan, S. Shahid, Enhanced antimicrobial, antioxidant, in vivo antitumor and in vitro anticancer effects against breast caner cell line by green synthesized un-doped SnO2 and Co-doped SnO2 nanoparticles from Clerodendrum inerme, Microb. Pathog. 125 (2018) 366–384, https://doi.org/10.1016/j.micpath.2018.09.041.
[65] S. Haq, W. Rehman, M. Waseem, M. Shahid, M.U. Rehman, K.H. Shah, M. Nawaz, Adsorption of Cd2+ ions on plant mediated SnO2 nanoparticles, Mater. Res. Express 3 (10) (2016) 1–9, https://doi.org/10.1088/2053-1591/3/10/105019.
[66] K.C. Suresh, S. Surendhiran, P. Manoj Kumar, E. Ranjth Kumar, Y.A.S. Khadar, A. Balamurugan, Green synthesis of SnO2 nanoparticles using Delonix elata leaf extract: evaluation of its structural, optical, morphological and photocatalytic properties, SN Applied Sciences 2 (10) (2020) 1–13, https://doi.org/10.1007/s42452-020-03534-z.
[67] J. Hu, Biosynthesis of SnO2 nanoparticles by fig (Ficus Carica) leaf extract for electrochemically determining Hg(II) in water samples, International Journal of Electrochemical Science 10 (12) (2015) 10668–10676.
[68] M. Honarmand, M. Golmohammadi, A. Naeimi, Biosynthesis of tin oxide (SnO2) nanoparticles using jujube fruit for photocatalytic degradation of organic dyes, Adv. Powder Technol. 30 (8) (2019) 1551–1557, https://doi.org/10.1016/j.apt.2019.04.033.
[69] G.B. Hong, C.J. Jiang, Synthesis of SnO2 nanoparticles using extracts from Litsea cubeba fruits, Mater. Lett. 194 (2017) 164–167, https://doi.org/10.1016/j.matlet.2017.02.058.
[70] H.E. Garrafa-Galvez, O. Nava, C.A. Soto-Robles, A.R. Vilchis-Nestor, A. Castro-Beltrán, P.A. Luque, Green synthesis of SnO2 nanoparticle using Lycopersicon esculentum peel extract, J. Mol. Struct. 1197 (2019) 354–360, https://doi.org/10.1016/j.molstruc.2019.07.052.
[71] S. Begum, M. Ahmaruzzaman, Green synthesis of SnO2 quantum dots using Parkia speciosa Hassk pods extract for the evaluation of anti-oxidant and photocatalytic properties, J. Photochem. Photobiol. B Biol. 184 (2018b) 44–53, https://doi.org/10.1016/j.jphotobiol.2018.04.041.
[72] G. Elango, S.M. Kumaran, S.S. Kumar, S. Muthuraja, S.M. Roopan, Green synthesis of SnO2 nanoparticles and its photocatalytic activity of phenolsulfonphthalein dye, Spectrochim. Acta Mol. Biomol. Spectrosc. 145 (2015) 176–180, https://doi.org/10.1016/j.saa.2015.03.033.
[73] S. Begum, M. Ahmaruzzaman, Green synthesis of SnO2 nanoparticles loaded on activated carbon and its application as photocalayst in the degradation of alizarin red S dye, Mater. Today: Proceedings 5 (1) (2018a) 2314–2320, https://doi.org/10.1016/j.matpr.2017.09.235.
[74] J. Singh, H. Kaur, D. Kukkar, V.K. Mukamia, S. Kumar, M. Rawat, Green synthesis of SnO2 NPs for solar light induced photocatalytic applications, Mater. Res. Express 6 (11) (2019), https://doi.org/10.1088/2053-1591/ab4412.
[75] S.K. Tammina, B.K. Mandal, S. Ranjan, N. Dasgupta, Cytotoxicity study of Piper nigrum seed mediated synthesized SnO2 nanoparticles towards colorectal (HCT116) and lung cancer (A549) cell lines, J. Photochem. Photobiol. B Biol. 166 (2017) 158–168, https://doi.org/10.1016/j.jphotobiol.2016.11.017.
[76] L. Fu, Y. Zheng, Q. Ren, A. Wang, B. Deng, Green biosynthesis of SnO2 nanoparticles by plectranthus amboinicus leaf extract their photocatalytic activity toward rhodamine B degradation, Journal of Ovonic Research 11 (1) (2015) 21–26.
[77] M. Kumar, A. Mehta, A. Mishra, J. Singh, M. Rawat, S. Basu, Biosynthesis of tin oxide nanoparticles using Psidium Guajava leave extract for photocatalytic dye degradation under sunlight, Mater. Lett. 215 (April 2020) (2018) 121–124, https://doi.org/10.1016/j.matlet.2017.12.074.
[78] Y. Hirai, K. Furukawa, H. Sun, Y. Matsushima, K. Shito, A. Masuhara, R. Ono, Y. Shimbori, H. Shiroishi, Microwave-assisted hydrothermal synthesis of ZnO and Zn-terephthalate hybrid nanoparticles employing benzene dicarboxylic acids, Microsyst. Technol. 24 (2018) 699–708.
[79] M.G.T. Nathan, P. Myvizhi, Green synthesis and characterization of tin oxide nanoparticles using plant extract, Int. J. Pure Appl. Math. 119 (12) (2018) 6439–6448.
[80] V.K. Vidhu, D. Philip, Biogenic synthesis of SnO2 nanoparticles: evaluation of antibacterial and antioxidant activities, Spectrochim. Acta Mol. Biomol. Spectrosc. 134 (2015a) 372–379, https://doi.org/10.1016/j.saa.2014.06.131.
[81] V. Raj, P. Kamaraj, M. Sridharan, J. Arockiaselvi, Green synthesis, characterization of yttrium oxide, stannous oxide, yttrium doped tin oxide and tin doped yttrium oxide nanoparticles and their biological activities, Mater. Today: Proceedings 36 (xxxx) (2019) 920–922, https://doi.org/10.1016/j.matpr.2020.07.032.
[82] S.N. Matussin, M.H. Harunsani, A.L. Tan, A. Mohammad, M.H. Cho, M.M. Khan, Photoantioxidant studies of SnO2 nanoparticles fabricated using aqueous leaf extract of Tradescantia spathacea, Solid State Sci. 105 (2020) 106279, https://doi.org/10.1016/j.solidstatesciences.2020.106279.
[83] P.N. Sudha, K. Sangeetha, K. Vijayalakshmi, A. Barhoum, Chapter 12 - nanomaterials history, classification, unique properties, production and market, in: Emerging Applications of Nanoparticles and Architecture Nanostructures, Elsevier Inc, 2018, https://doi.org/10.1016/B978-0-323-51254-1/00012-9.
[84] D. Mohanta, M. Ahmaruzzaman, Tin oxide nanostructured materials: an overview of recent developments in synthesis, modifications and potential applications, RSC Adv. 6 (112) (2016) 110996–111015.
[85] A. Bhattacharjee, M. Ahmaruzzaman, Photocatalytic-degradation and reduction of organic compounds using SnO2 quantum dots (via a green route) under direct sunlight, RSC Adv. 5 (81) (2015) 66122–66133.
[86] C.S. Moon, H.-R. Kim, G. Auchterlonie, J. Drennan, J.-H. Lee, Highly sensitive and fast responding CO sensor using SnO2 nanosheets, Sensor. Actuator. B Chem. 131 (2) (2008) 556–564.
[87] T. Sinha, M. Ahmaruzzaman, P.P. Adhikari, R. Bora, Green and environmentally sustainable fabrication of Ag-SnO 2 nanocomposite and its multifunctional efficacy as photocatalyst and antibacterial and antioxidant agent, ACS Sustain. Chem. Eng. 5 (6) (2017) 4645–4655.
[88] J. Cao, A. Zhang, Enhanced antimicrobial, antioxidant, in vivo antitumor and in vitro anticancer effects against breast caner cell line by green synthesized un-doped SnO2 and Co-doped SnO2 nanoparticles from Clerodendrum inerme, Microb. Pathog. 125 (2019) 366–384.
[89] M. Giridhar, H.S.B. Naik, C.N. Sudhamani, M.C. Prabakara, R. Kenchappa, N. Venugopal, S. Patil, Microwave-assisted synthesis of water-soluble styrylpyridine dye-capped zinc oxide nanoparticles for antibacterial applications, J. Chin. Chem. Soc. 67 (2019) 316–323.
[90] S. Sudhaparimala, Green synthesis of tin based nano medicine: assessment of microstructure and surface property, Am. J. Nanosci. Nanotechnol. 2 (4) (2014) 75, https://doi.org/10.11648/j.nano.20140204.13.
[91] A.U.H.S. Rana, S.B. Chang, H.S. Kim, pH-Dependent growth of ZnO nanostructures via microwave-assisted growth method, J. Nanosci. Nanotechnol. 18 (2018) 2125–2127.
[92] S. Haq, W. Rehman, M. Waseem, A. Shah, A.R. Khan, M.U. Rehman, P. Ahmad, B. Khan, G. Ali, Green synthesis and characterization of tin dioxide nanoparticles for photocatalytic and antimicrobial studies, Mater. Res. Express 7 (2) (2020), https://doi.org/10.1088/2053-1591/ab6fa1.
[93] J. Singh, H. Kaur, D. Kukkar, V.K. Mukamia, S. Kumar, M. Rawat, Green synthesis of SnO2 NPs for solar light induced photocatalytic applications, Mater. Res. Express 6 (11) (2019), https://doi.org/10.1088/2053-1591/ab4412.
[94] A. Diallo, E. Manikandan, V. Rajendran, M. Maaza, Physical & enhanced photocatalytic properties of green synthesized SnO2 nanoparticles via Aspalathus linearis, J. Alloys Compd. 681 (October) (2016) 561–570, https://doi.org/10.1016/j.jallcom.2016.04.200.
[95] W. Jeffry, A. Duglus, Biosynthesis and photocatalytic properties of SnO2 nanoparticles prepared using aqueous extract of cauliflower, J. Cluster Sci. 28 (4) (2019) 1883–1896.
[96] H.U. Chae, A.U.H.S. Rana, Y.J. Park, H.S. Kim, High-speed growth of ZnO nanorods in preheating condition using microwave-assisted growth method, J. Nanosci. Nanotechnol. 18 (2018) 2041–2044.
[97] M. Kumar, A. Mehta, A. Mishra, J. Singh, M. Rawat, S. Basu, Biosynthesis of tin oxide nanoparticles using Psidium Guajava leave extract for photocatalytic dye degradation under sunlight, Mater. Lett. 215 (April 2020) (2018) 121–124, https://doi.org/10.1016/j.matlet.2017.12.074.
[98] T.T. Bhosale, H.M. Shinde, N.L. Gavade, S.B. Babar, V.V. Gawade, S.R. Sabale, R.J. Kamble, B.S. Shirke, K.M. Garadkar, Biosynthesis of SnO2 nanoparticles by aqueous leaf extract of Calotropis gigantea for photocatalytic applications, J. Mater. Sci. Mater. Electron. 29 (8) (2018) 6826–6834, https://doi.org/10.1007/s10854-018-8669-0.
[99] E. Haritha, S.M. Roopan, G. Madhavi, G. Elango, N.A. Al-Dhabi, M.V. Arasu, Green chemical approach towards the synthesis of SnO2 NPs in argument with photocatalytic degradation of diazo dye and its kinetic studies, J. Photochem. Photobiol. B Biol. 162 (2016) 441–447, https://doi.org/10.1016/j.jphotobiol.2016.07.010.
[100] J. Singh, N. Kaur, P. Kaur, S. Kaur, J. Kaur, P. Kukkar, V. Kumar, D. Kukkar, M. Rawat, Piper betle leaves mediated synthesis of biogenic SnO2 nanoparticles for photocatalytic degradation of reactive yellow 186 dye under direct sunlight, Environmental Nanotechnology, Monitoring and Management 10 (2018) 331–338, https://doi.org/10.1016/j.enmm.2018.07.001.
[101] K.C. Suresh, S. Surendhiran, P. Manoj Kumar, E. Ranjth Kumar, Y.A.S. Khadar, A. Balamurugan, Green synthesis of SnO2 nanoparticles using Delonix elata leaf extract: evaluation of its structural, optical, morphological and photocatalytic properties, SN Applied Sciences 2 (10) (2020) 1–13, https://doi.org/10.1007/s42452-020-03534-z.
[102] F. Ahmed, N. Arshi, M.S. Anwar, R. Danish, B.H. Koo, Facile growth of ZnO nanorod arrays by a microwave-assisted solution method for oxygen gas sensing, Thin Solid Films 547 (2013) 168–172.

[103] G. Elango, S.M. Kumaran, S.S. Kumar, S. Muthuraja, S.M. Roopan, Green synthesis of SnO2 nanoparticles and its photocatalytic activity of phenolsulfonphthalein dye, Spectrochim. Acta Mol. Biomol. Spectrosc. 145 (2015) 176–180, https://doi.org/10.1016/j.saa.2015.03.033.

[104] J. Singh, N. Kaur, P. Kaur, S. Kaur, J. Kaur, P. Kukkar, V. Kumar, D. Kukkar, M. Rawat, Piper betle leaves mediated synthesis of biogenic SnO2 nanoparticles for photocatalytic degradation of reactive yellow 186 dye under direct sunlight, Environmental Nanotechnology, Monitoring and Management 10 (2018) 331–338, https://doi.org/10.1016/j.enmm.2018.07.001.

[105] L. Fu, Y. Zheng, Q. Ren, A. Wang, B. Deng, Green biosynthesis of SnO2 nanoparticles by plectranthus amboinicus leaf extract their photocatalytic activity toward rhodamine B degradation, Journal of Ovonic Research 11 (1) (2015) 21–26.

[106] M. Kumar, A. Mehta, A. Mishra, J. Singh, M. Rawat, S. Basu, Biosynthesis of tin oxide nanoparticles using Psidium Guajava leave extract for photocatalytic dye degradation under sunlight, Mater. Lett. 215 (April 2020) (2018) 121–124, https://doi.org/10.1016/j.matlet.2017.12.074.

[107] T. Sinha, M. Ahmaruzzaman, P.P. Adhikari, R. Bora, Green and environmentally sustainable fabrication of Ag-SnO 2 nanocomposite and its multifunctional efficacy as photocatalyst and antibacterial and antioxidant agent, ACS Sustain. Chem. Eng. 5 (6) (2017) 4645–4655, https://doi.org/10.1021/acssuschemeng.6b03114.

[108] P. Sutradhar, M. Debbarma, M. Saha, Microwave synthesis of zinc oxide nanoparticles using coffee powder extract and its application for solar cell, Syn. React. Inorg. Metal.-Org. Nano-Met. Chem. 46 (2016) 1622–1627.

[109] N.F. Hamedani, F. Farzaneh, Synthesis of ZnO nanocrystals with hexagonal (wurtzite) structure in water using microwave irradiation, J. Sci. Islam. Repub. Iran 17 (2006) 231–234.

[110] S.M. Mahpeykar, J. Koohsorkhi, H. Ghafoori-fard, Ultra-fast microwave-assisted hydrothermal synthesis of long vertically aligned ZnO nanowires for dye-sensitized solar cell application, Nanotechnology 23 (2012) 165602.