#### **BIBLIOGRAPHIC INFORMATION SYSTEM**

Journal Full Title: Journal of Biomedical Research & Environmental Sciences Journal NLM Abbreviation: J Biomed Res Environ Sci Journal Website Link: https://www.jelsciences.com Journal ISSN: 2766-2276 Category: Multidisciplinary Subject Areas: Medicine Group, Biology Group, General, Environmental Sciences **Topics Summation: 128 Issue Regularity: Monthly** Review Process: Double Blind Time to Publication: 21 Days Indexing catalog: Visit here Publication fee catalog: Visit here

#### • **DOI:** 10.37871 (CrossRef)

Plagiarism detection software: iThenticate

Managing entity: USA

Language: English

Research work collecting capability: Worldwide

Organized by: SciRes Literature LLC

**License:** Open Access by Journal of Biomedical Research & Environmental Sciences is licensed under a Creative Commons Attribution 4.0 International License. Based on a work at SciRes Literature LLC.

**IndexCopernicus** 

ICV 2020:

53.77

Manuscript should be submitted in Word Document (.doc or .docx) through

## **Online Submission**

form or can be mailed to support@jelsciences.com

Tision: Journal of Biomedical Research & Environmental Sciences main aim is to enhance the importance of science and technology to the scientific community and also to provide an equal opportunity to seek and share ideas to all our researchers and scientists without any barriers to develop their career and helping in their development of discovering the world.

# Synthesis of Zinc Oxide, Titanium Dioxide and Magnesium Dioxide Nanoparticles and Their Prospective in Pharmaceutical and Biotechnological Applications

# Abhinav Shrivastava<sup>1</sup>, Ravi Kant Singh<sup>1</sup>, Pankaj Kumar Tyagi<sup>2</sup>\* and Dilip Gore<sup>3</sup>

<sup>1</sup>Amity Institute of Biotechnology, Amity University Chhattisgarh, Raipur, C.G.-493225 <sup>2</sup>Department of Biotechnology, Noiwda Institute of Engineering & Technology, Gr. Noida, U.P.-201306 <sup>3</sup>Saibiosystems Pvt. Ltd., Nagpur, Maharashtra, India 440002

## ABSTRACT

The use of nanoparticles for the therapeutic purpose is gaining pronounced importance. In the last two decades, a number of nanomedicines received regulatory approval and several showed promises through clinical trials. In this content, it is important to synthesize nanoparticles from various sources and to check its efficiency, especially its antibacterial activity. In today's scenario number nanomedicines are proving useful to control multidrug resistance and since the mechanism of action of nanoparticles is totally different from the small molecules like antibiotics it obviates the chances of drug resistance. In this review, we discussed three metal-based nanoparticles prepared from various reducing sources namely Zinc Oxide Nanoparticle (ZnO NPs), Titanium Dioxide Nanoparticle (TiO<sub>2</sub> NPs) and Magnesium Dioxide Nanoparticles. In addition, the exact interaction of the nanoparticles with the bacterial cell surface and the resultant changes also been highlighted. The review put forward the sources, method, and antibacterial success of these nanoparticles so that future nanomedicines could be put forward.

## SYNTHESIS OF NANOPARTICLES

#### **ZnO nanoparticles**

Green Synthesis and Characterization: An aqueous extract of orange peel was used as the biological reduction agent for the synthesis of ZnO NPs from zinc acetate dehydrate [1,2]. Shabaani, et al. [3] optimize the loquat (*Eriobutria japonica*) seed aqueous extract mediated green synthesis of Zinc Oxide Nanoparticles (ZnO NPs) through Response Surface Methodology (RSM). Nabi, et al. [4] the TiO<sub>2</sub> Nanoparticles (NPs) have been synthesised by the green synthesis method from lemon peel extract for the first time. Ullah, et al. [5] Bio-molecule capped  $\alpha$ -MnO<sub>2</sub> nanoparticles have been successfully synthesized from the reduction of KMnO4 *via* a facile green synthesis route using an aqueous leaf extract of *Bryophyllum pinnatum* as a reducing and capping agent. ZnO nanoparticles able to control *Klebsiella pneumonia*, *Staphylococcus aureus*, *Penicillium notatum* and *Candida albicans* when tested in the well diffusion assay [6,7] when biosynthesized from

#### \*Corresponding author

Pankaj Kumar Tyagi, Department of Biotechnology, Noida Institute of Engineering & Technology, Gr. Noida, U.P.201306, India

E-mail: pktgenetics@gmail.com

DOI: 10.37871/jbres1180

Submitted: 08 December 2021

Accepted: 08 January 2021

Published: 11 January 2021

Copyright: © 2021 Srivastava A, et al. Distributed under Creative Commons CC-BY 4.0

#### OPEN ACCESS

Subject: Biology

Topic & Subtopic(s): Toxicology, Biotechnology

#### Keywords

- Synthesis
- · Antibacterial activity
- · Metal-based nanoparticles
- ZnO
- TiO
- Mn0,

VOLUME: 2 ISSUE: 1

How to cite this article: Shrivastava A, Singh RK, Tyagi PK, Gore D. Synthesis of Zinc Oxide, Titanium Dioxide and Magnesium Dioxide Nanoparticles and Their Prospective in Pharmaceutical and Biotechnological Applications. J Biomed Res Environ Sci. 2021 Jan 11; 2(1): 011-020. doi: 10.37871/jbres1180, Article ID: JBRES1180



Zingiber officinale rhizome. Efficiency reported with nano size of 23-26 nm when tested by Scanning Electron Microscopy (SEM), Energy Dispersive X-ray spectroscopy (EDX). Synthesized ZnO NPs particles using Artocarpusgomezianus extract and confirmed by using UV-Visible, XRD, SEM and Transmission Electron Microscopy (TEM) methods. As per X-Ray Powder Diffraction (XRD) ZnO NPs does showcase wurtzite structure and having maximum absorption at 370 nm. The NPs with photocatalytic activity able to degrade methylene blue dye. These NPs have also able to represent antioxidant activity against DPPH free radicals [8]. ZnO NPs from Solanum nigrum leaf extract confirmed as wurtzite hexagonal structure with average size of 20-30 nm as per FE-SEM study. As per TEM analysis, ZnO NPs appeared as quasi-spherical in shape and in diameter it was 29.79 nm. NP found to be better in antibacterial activities and useful in medicinal field [9]. Green synthesis of ZnO NPs are capable of reducing in methylene blue as studied in UV-Vis spectroscopy and found to be industrially useful [10]. The ZnO NPs synthesized by microwave assisted method by using Vaccinium arctostaphylos L. fruit extract and reported to be useful in antidiabetic activity [11]. Singh, et al. [12] reported novel method of ZnO NPs synthesis using Curcumin with ChGC@ZnO NPs showcase antioxidant and antibacterial activity. Tang, et al. [13] able to produce Morusnigra-loaded ZnO NPs bringing about apoptosis in gastric cancer cells. The nanoparticles further decreased antioxidants, and induced cell cycle arrest by altering gene expression of marker genes. Soliman, et al. [14] reported ZnO NPs synthesis using bravode-esmolfe apple extract able to form round lamina-like structures and useful in enhancing catalyst activity in apple waste.

Physical and chemical synthesis: ZnO-Ag heterostructure nanoparticles prepared by a precipitation method by involving cellulose nanocrystals as a stabilizer. ZnO-AgNPs showcased spherical shape with size diameter 9-35 nm range. Nanoparticles able to control Salmonella choleraesuis and Staphylococcus aureus [15]. Zinc Oxide Nanoparticles (ZnO NPs) is a bacteriostatic reagent but its small nanoparticles having better Nano dispersibility along with stability in aqueous solution possess a question with its use. Still, ZnO NPs successfully controlled S. aureus and E. coli and under in vivo studies, further its low toxicity and low cytotoxicity promising once tested in mice. As a product of 4 nm, ZnO NPs embeded with Poly (vinyl alcohol) gel was able to showcased antibacterial activity in rodent elyritis model put forward its use in disinfection [16]. Metal also expulsion from liquid alloys can be extended to a wide variety of molten metals for producing metallic and metallic compound nanostructures for advanced applications [17] The thermal decomposition for ZnO NPs found to be positive for antioxidant activity as determined by DPPH method and positive for cytotoxic activity when checked by haemolytic potentiality test along with antibacterial activity [18].

ISSN: 2766-2276

In recent time synthesis of ZnO NPs from microwave heating by using chitosan reported to be of 360 nm in size. As per EDXtesting, ZnO NPs recorded with 23.61% of zinc and 46.57% of oxygen. As per X-ray diffraction particle sizes recorded between 50 to 130 nm and ableto control S. aureus and E. coli in an application part [19]. The Silybummarinum based Zn -AgNPs along with Ag-ZnO heterostructures able to showcase better antioxidant and anti-leishmanial activity that finds its utility in pharmacological relevance [20]. The loading of spindle-shaped Graphene oxide with ZnO nanoparticles having length of ~ 1.0 µm and mean diameter of 100 nm registered MIC as 31.25  $\pm$  0.25  $\mu$ g/ml with Gram positive bacteria while it was 15.625  $\pm$  0.5  $\mu$ g/ml for gram negative bacteria [21]. Ali, et al. [22] synthesized ZnO NPs using co-precipitation method having size range of 15-25 nm able to control P. aeruginosa and A. nigergrowth with ability to showcase anti-inflammatory activity induced by bacterial and fungal strains.

Hussain, et al. [23] noted the ZnO NPs success once synthesized by precipitation method as an immunomodulatory and antimicrobial agent before using it in skin lotions and food products by involving in vivo evaluation of albino mice for potent toxicity. In a green synthesis Turbinariaconoides based ZnO NPs reported for anticancer activity and found to be useful in decreasing tumor volume. The treatment altered the haematological profile, antioxidant status and liver marker enzyme activities [24].

Shankar, et al. [25] prepared hybrid nanomaterial by onepot synthesis of ZnO nanoparticles by involving regeneration of cellulose from cotton linker and microcrystalline cellulose. Results showcased better absorption of NPs on cellulose which increases thermal stability and antibacterial activity. Gupta and Srivastava [26] reported ZnO NPs synthesized from MSP assisted sonochemical flow loop reactor. Once coated on cotton fabric reported with high antibacterial activity especially against Staphylococcus aureus.

### TiO, nanoparticles

Synthesis, functioning and safety of TiO, nanoparticles: Highly crystalized anatase TiO, NPs prepared at minimum temperature of 120°C by involving a glycothermal reaction using amorphous titanium hydrous gel as a precursor in a solvent used as 1, 4-butanediol and water. It is featured with excellent photocatalytic behaviour and its reaction conditions certainly controls the shape and dispersibility and that may change its function [27]. Pezzella, et al. [28] 2013 put forward the use of melanin- a wide class of natural pigments with 5, 6 Dihydroxyindole-2-Carboxylic Acid (DHICA) polymer and TiO, synthesis. TiO, hybrid nanoparticles which were involved in medicinal uses with number of techniques like Electron Paramagnetic Resonance, Fourier-Transform Infrared Spectroscopy (EPR, FTIR), Fluorescence spectroscopy, XRD, NPS reported with narrow size distribution with average particle of about

ISSN: 2766-2276

10 nm. Rapid and sensitive method of synthesis for  $\text{TiO}_2$  NPs in aqueous solution by involving electro oxidation of titanium foil in tetrabutylammonium bromide aqueous solution, which functions as an electrolyte and a surfactant mentioned. After synthesis NPs recorded to be in size of 12nm. Further by diffuse reflectance measurement, the values of NPs were recorded as 2.95 and 3.10 eV and this suggested the successful production of  $\text{TiO}_2$  nanoparticles in aqueous solution [29].

TiO, NPs are mostly used as metal oxide nanoparticles and having oxidative toxicity. TiO, NPs does able to bind to the catalase via electrostatic and hydrogen bonding forces. Upon interaction TiO, brings about destabilization in catalase with decrease in a-helical content and in addition solvent polarity of environment around the fluorescence chromophores on catalase also getting affected. It is observed that TiO, NPs activates catalase at a low concentration and act as an inhibitor at a higher molar concentration. This study related human toxicity of TiO, NPs in a better way [30] Besides number of positive aspects of TiO, NPs, worker reported the negative aspect of NPs when supplemented in food additives and coloring agent. The administration at low dose leads to persistent accumulation of nano-TiO, rise up inflammatory response, apoptosis and oxidative stress and sometimes lead to chronic gastritis which suggest its careful use in coming time [31]. As the TiO, NPs use are increasing in the society its effect on the environment has been better understood NPs applied for viability of mussel hemocytes and gill cells using neutral red and thiazolyl tetrazolium bromide assays. Results showed relatively low and close dependent toxicity for both cell models tested. As per size dependent toxicity, NPs produced by wet chemistry have higher toxicity at 10 nm, >40 nm and 60 nm. In bulk form TiO, NPs were more toxic except for plasma produced one [32].

With increased use of Titanium Oxide  $(TiO_2)$  nanoparticles since they possess features like small size, easy body penetration and less toxicological adverse effects. They recorded the actual effect of  $TiO_2$  NPs on oral, dermal and respiratory system by involving TEM, ICP-OFS, histological studies and proposed that  $TiO_2$  NPs having 10 days of half-life in body if given as an intravenous injection at concentration of 7.7 to 9.4 mg/Kg and it do not showcase any toxicological effects [33].

The possibility of synthesizing Zn Porphyrin (ZnPP) interacted with  $\text{TiO}_2$  NPs as ZnPP-  $\text{TiO}_2$  NPsreproted. The ZnPP-  $\text{TiO}_2$  NPs able to preserve ZnPP's electrostatic properties within  $\text{TiO}_2$  NPs and which makes NPs complex an excellent candidate for nanomedicine and related applications which could be applicable in localization of NPs in cells and tissues or in photodynamic therapy [34]. Effect of TiO<sub>2</sub> NPs on *E. coli* with the crystal size of 10-50 nm has reported and noted particles size dependent. Not only is that,  $\text{TiO}_2$  NPs also involved in cell surface interaction, leading to membrane damage and internalization especially at smaller

particle sizes which puts up a serious question over its use in ecosystem [35]. In one of the unique applications, NPs were involved to retrieve bioactive compound from living cells. They reported that Anatase TiO<sub>2</sub> NPs with 20 nm size able to form strong bond with enediol and especially with catechol group. They reported that NPs can enter plant cells and got attached to enediol and catechol group and comes out as flavonoid nanoparticle conjugate. This method could replace solvent based system of bioactive compound separation and opens the new avenues of separation [36]. The synthesis of Zn doped TiO2 nanoparticles reported by sologel method by using 5% Zn doping at 450 °C and reported with photocatalytic activity [37]. Irshad, et al. [38] involved plant extracts of Trianthemaportulacastrum and Chenopodium quinoa to synthesize TiO, NPs having average size of 15 nm. The NPs found to be promising antifungal agent especially against white rust.

Chemical synthesis of TiO, NPs: Hariharan, et al. [39] succeeded in doping titanium dioxide nanoparticles with silver NPs using hydrothermal method and capped by Aloevera. The NPs further able to produce excess ROS, resulting in complete cancer growth suppression and hence noted as promising anticancer agent. Sellschopp, et al. [40] put forward the concept of TiO, NPs synthesis in controlled shape and reproducible way by using hydrohalic and carboxylic acids since they influence shape under chemical synthesis mode. The method involved computational model system and thermodynamics to learn the concept in detail. Gahlot, et al. [41] reported the role of temperature to synthesize metal selenide nanoparticles (CuAgSe-TiO<sub>2</sub>) which registered improved photocatalytic activity for the photodegradation of formic acid. Wei, et al. [42] reported the success of core-shell structured CDsSiO<sub>2</sub>@ TiO<sub>2</sub> nanoplatforms representing its potential photothermal effect and fluorescence resonance energy transfer. They also reported to be capable of inhibiting cancer cells in vitro and represented new avenue for clinic cancer therapy. Ma, et al. [43] noted the success of chemically synthesized TiO<sub>2</sub> NPs to increase the methane production by electrogenic bacteria and hence proposed TiO<sub>2</sub> NPs as bio-stimulation molecule. The need of sustainable manufacturing of nanoparticles especially of TiO, NPs has been put forward. Here synthesis of NPs via physical, chemical and biological route stands vital. The study noted the chemical route is the best way for TiO, NPs formation as compared to physical and biological route considering environmental impact [44]. The new approach to assemble NPs reported by using gas phase condensation of metal vapours in a He/O<sub>2</sub> atmosphere. The success noted with Fe-co/TiOx nanocomposite reported with features of catalyst and magnetic properties [45].

Lu, et al. [46] reported the success of  $NaHoF_4@TiO_2$ NPs synthesis by involving low temperatures and by using sacrificial  $Al(OH)_3$  template. The resultant formation of 60 nm  $NaHoF_4$  core and a 5 nm anatase  $TiO_2$  shell found to be individually useful. Montaser, et al. [47] noted the success of



salicylaldehyde as a monoaldehyde cross linker once utilised with chitosan forming hydrogel membrane in presence of TiO, NPs via casting method. The membrane reported to be antibacterial. Alberti, et al. [48] noted crystallization of anatase TiO<sub>2</sub> nanoparticles by involving several ferrite nanoparticles under hydrothermal synthesis mode which catalyses hydrothermal reaction in presence of nucleation seeds. Shah, et al. [49] investigated doped and undoped TiO, NPs synthesized and stabilized by polyethylene glycol. The NPs are capable of phototoxicity activity. Resultant PEG-NPs brought about cytotoxicity towards human cervical cancer cells upon solar and ultraviolet radiations. Gaballah, et al. [50] reported chitosan-PVC conjugate improves antibacterial activity comprise of Ag/TiO, NPs once tested with E. coli, S. typhimurium, S. aureus and L. monocytogenes in reduced time period once used in biomedical application. El Mragui, et al. [51] reported the synthesis of pure TiO, and Fe-and Co-doped TiO, nanoparticles as photocatalysts once synthesized by sol-gel and precipitation method. The NPs in doped form reported to enhance photocatalytic degradation of carbamazepine in aqueous solution under UV-A light and visible light irradiations once compared with pure TiO<sub>2</sub>. Locatelli, et al. [52] mentioned the success of titanium oxide octahedral composite (Cu<sub>2</sub>O@TiO<sub>2</sub> -NH<sub>2</sub>) decorated with amino functionalized cuprous oxide capable of quantitative detection of insulin by involving novel nanosheet-loaded gold nanoparticles.

#### MnO, nanoparticles

**Green and chemical methods of synthesis:** Successfully synthesized MnO<sub>2</sub> NPs by involving marine bacterium *Sacchrophagusdegradans* and Yeast *Sacchromyces cerevisiae* which was recorded to be having absorption maxima at 365 nm in UV-Visible spectrophotometry [53]. In a confirmation test, TEM found to contain NPs as uniformly dispersed hexagonal and spherical shaped particles with average size of 34.4 nm. In a comparative synthesis of MnO<sub>2</sub> NPs, yeastbased synthesis proving to be easy, cost effective, reliable and eco-friendly for nanoparticles production.

MnO, NPs was also synthesised by sonochemical reduction of  $MnO_{4}(+)$  at pH 2.2 to 9.3 as per analysis done by XRD, NPs changed the shapes like aggregated sheet-like or needle like structure to spherical nanoparticles and finally it formed the cubic or polyhedron NPs [54]. Synthesized manganese dioxide nanoparticles by reduction of Potassium Permaganate(KMnO,)usingKalopanaxpictusleafextract[55]. As per UV-Vis data MnO, NPs formed an absorption peak at 404 nm. According to electron dispersive X-ray spectroscopy presence of Mn and O in the sample was detected. Further X-ray photoelectron spectroscopy revealed featured binding energies of MnO, nano particles. As per TEM analysis MnO, NPs appeared uniformly dispersed spherical shaped particles with a size of 19.2 nm. As per electron diffraction pattern crystalline nature of MnO, nanoparticles was revealed. In an FTIR analysis MnO, NPs shown O-Mn-O vibration mode at around 518 cm<sup>-1</sup>. In an application part, MnO, NPs able to degrade dyes like Congo red and safranin O which make it eco-friendly and effective NPs prepared by plant extracts. In one of the researches, use of MnO<sub>2</sub> nanoparticles as a mimic to the enzyme has been demonstrated. As Inorganic nanomaterial like MnO, NPs has potential to act like enzyme and can tolerate extreme pH and temperature and remain less sensitive to protease action. In a success story, worker [56] prepared the Bovine Serum Albumin (BSA) stabilized MnO(2) nanoparticles which can showcase peroxidase-, oxidase-, and catalase- like activities. These NPs showcased good dispersion, biocompatibility and solubility and represented typical Michaelis-Menten kinetics with high affinity for H(2)O(2); 3,3',5,5'-Tetramethylbenzidine (TMB) and O- phenylenediamine. This suggested that BSA-MnO<sub>2</sub>NPs can represent better enzyme mimic. Overall study highlighted that BSA-MnO<sub>2</sub>NPs are having potential applications in medical, biochemical and biotechnological sectors. In another aspect of MnO, NPs use, researcher [57] reported the possibility of NPs use in degrading aqueous pharmaceutical chemicals. Here they synthesized MnO, NPs with Carboxymethyl Celluloses (CMC) as a stabilizer, and successfully demonstrated aqueous and soil sorbed estradiol. As per size, MnO, NPs measured to be of 39.5 nm with narrow size distribution. At a typical aquatic pH (6-7), CMC-stabilized MnO<sub>2</sub> NPs showcased increasing degradation kinetics for oxidation of 17  $\beta$ -estradiol as compared to non-stabilized MnO<sub>2</sub>. Hence CMC- stabilized MnO, NPs represents the success for facilitating in situ oxidative degradation of number emerging contaminants entering into soil and water.

#### Antibacterial activity of nanoparticles

Zinc oxide nanoparticles antibacterial activity: Nanoparticles are now routinely tested as an antibacterial agent to overcome the problem of antibiotic resistance. In a success stories, selenium doped ZnO nanoparticles synthesized through mechanochemical method of size 10.2 ± 3.4 nm, with concentration 0.45 mg/ml activity related to Reactive Oxygen Species (ROS) which is responsible for creation of oxygen vacancies making them potential antibacterial agent [58]. The success of silver doped ZnO NPs controlling the E. coli and S. aureus at 5.0 wt% of Ag as compared to only Ag and ZnO NPs reported. The real action of doped AgZnONP slinked with damage to plasmid [21]. The dry ginger rhizome (Zingiber officinale) based ZnO nanoparticles reported with size of 23-26 nm able to control the growth of Klebsiella pneumonia, Staphylococcus aureus, Candida albicans and Penicillium notatum [59]. The increase or decrease in antibacterial activity of ZnO NPs reported to be dependent of type of target pathogens and also with the concentration used. The given capability used in the waste water treatment instead on chlorine disinfection, ultraviolet treatment and other methods [60]. The antibacterial activity of photo activated Zinc oxide nanoparticles against E. coli 0157:H7, Listeria monocytogenes ATCL3C and plant pathogen



Botrytis cinereal [61] reported promising and those remain dependent on increasing concentration and incubation period. ZnO NPs found to functioning by changing morphological structures of bacteria and fungi to register its antibacterial activity which could be useful in medicine and food industries of microbial control. ZnO NPs capping with Polyethylene Glycol (PEG), ascorbic acid, Mercaptoacetic Acid (MAA) and polysorbate 80 with ROS induced antibacterial activity. They found that MAA capped ZnO NPs and T-80 capped NPs exhibited 13% and 43% inhibition of growth of *E. coli*, respectively that leads to increase in ROS generation and resultant antibacterial activity [58].

Titanium dioxide nanoparticles antibacterial activity: In recent study effect of TiO, NPs as an antibacterial agent has been investigated. The antibacterial activity of graphite/ TiO, nanocomposites linked with photocatalytic reaction with subsequent potential interaction of relative oxygen species with bacterial cells recorded. In a test, highest activity reported with MIC at 180 min of irradiation against P. aeruginosa [62]. In a different approach [63] prepared cover shell type Ag@TiO\_nanoparticles and found to be of size as 50 nm tested inhibitory against E.coli and S. aureus. The result directed that AgNPs are getting support from TiO, and SiO, that does not allow bacterial aggregation and hence proved to be better antibacterial agent.TiO2 NPs synthesized with A. hydrophilarich in glycyl-L-proline which has acted as a capping agentable to control E. coli, Pseudomonas aeruginosa, S. aureus, Streptococcus pyogenes and Enterococcus faecalis with more than 33 mm of inhibition [64]. The antibacterial activity of As-annealed TiO, nanotubes doped with Ag nanoparticles when tested against A. actinomycetemcomitans, T. forsythia, and C. rectus [65]. The combined use of ZnO and Ag nanoparticles able to control Staphylococcus epidermidis by weakening cell adherence as tested with TiO, nanotubes. They reported that loading of nanotubes with ZnO nanoparticles diminishes S. epidermidis adhesion simply after 90 minutes. Here composite layer acts as future delivery system which can combat against postoperative infections especially in hard tissue replacement procedures has been reported [66]. TiO, nanoparticles formed in presence of enzyme alpha amylase able to control S.aureus and E. coli, at MIC value 62.50 µg/ml. The activity confers by NPs able to disrupts the bacterial cell wall [67].

The success of combined use of visible light to induce, antibacterial activity when used along with metal-oxide nanoparticles. ZnO and TiO<sub>2</sub> nanoparticles and both been able to increase antibacterial activity upon absorption of visible light without inducing damaging to tissue and cells [68]. Silver coating on an Anodic Oxidized Titanium (TiO<sub>2</sub>) nanotube surface useful in preventing infections in dental implants. This treatment reduces *S. aureus* count as compared to control in an untreated surface. The preparation recorded with low cell cytotoxicity finds the feasibility to develop antibacterial Ag nanoparticle loaded titanium nanotube surfaces with magnetron sputtering [69]. The Anti-Quorum

Sensing (QS) activity recorded with AgCl-TiO, Nanoparticles (ATNPs) and represented its potential in food preservation with Chromobacteriumviolaceum [70]. once tested Antibacterial activity against MDR Acinetobacter baumannii by using a combined therapy of pair of geometrical ferrocenecarborane derivatives (Fc SB1 and FcSB2) with nanoscale TiO, NPs linked with antibacterial activity by the Fc SB1/ or FcSB2 MDR A. baumannii [71]. The use of nanotopographical TiO, films implanted with Ag reported to inhibit effect of implant in an antibacterial mode and showcased E. coli and S. aureus successfully controlled by the Ag@TiO, system. The use of film acquired more potential to control growth on the surface to meet the clinical applications [72]. The combined use of electrospun-titanium dioxide nanofibers (TiO, NFs) along with photocatalytic effect of ultraviolet light reported enhanced antimicrobial activity of hierarchical antanase TiO, NFs against S. aureus; further they recorded that with uniform deposition of Ag nanoparticles on the TiO,NFs surface significantly increases antibacterial activity even without UV light or in dark condition [73].

Magnesium dioxide nanoparticles antibacterial activity: The use of palladium, ruthenium and silver doped MnO, nanoparticles found to be controlling S. aureus, Bacillus subtilis, E. coli, Salmonella abonyand K. pneumoniae as per disc diffusion method. In a comparative study, Ag-doped MnO NPs found to be better controlling all six isolates as compared to Ag-dope Mn<sub>2</sub>O<sub>2</sub> [74]. The synthesis of silver loaded MnO<sub>2</sub> nanoparticles (Ag/MnO<sub>2</sub>) including Ag/a-MnO<sub>2</sub>, Ag/β-MnO<sub>2</sub>, Ag/ $\gamma$ - MnO<sub>2</sub> and Ag/ $\beta$ -MnO<sub>2</sub> nanorods by involving hydrothermal and impregnation method able to control the E. coli, mechanisms involving Ag (+) and reactive oxygen species was recorded and among them Ag/β-MnO<sub>2</sub> reported with higher microbial activity. There was about 6 log decrease in E. coli colony number with Ag/ $\beta$ -MnO, after 120 minutes of treatment. Overall result confirmed that  $\beta$ -MnO<sub>2</sub> promotes ROS formation and disrupts the cell wall and cell membrane of E. coli [75]. The CNT-MnO, nanocomposite synthesized by microwave assisted processing able to bind with carbon nanotubes found to be effective to control Gram-positive and Gram-negative bacteria [76]. The success of eco-friendly production of manganese oxide nanoparticles in Chitosan (CS-MnO<sub>2</sub>). This composite successfully evaluated to absorb Pb2+ ions from aqueous solution and found to be reusable even five times used consistently. In addition, CNT-MnO, reported antibacterial in nature when investigated with Escherichia coli and Staphylococcus aureus [77].

Wang, et al. [78] utilized the template and reductant feature of egg shell membrane to synthesize  $MnO_2$  nanoparticles. The process gives an advantage of handy operation, low cost and easy purification. The ESM-templated  $MnO_2$  recorded ability to decontaminate tetracycline hydrochloride. Nasrollahzadeh, et al. [79] noted the importance of  $MnO_2$  to immobilize various nanoparticles especially copper nanoparticles and once reduced by the plant extract that further stabilizes the immobilization.

## Interaction of nanoparticles with cell surface

In number of studies the ability to control bacterial growth when treated by nanoparticles were measured as changes recorded in membrane potential especially by flow cytometry. Now surface chemical properties of nanoparticles help us to understand their role in interaction with cells. This interaction always plays an important role to decide number of bio applications as given below:

Biofilm formation is common with medical device related infection. It is important to control the biofilm formation and bacterial growth and in requirement Poly Ethyleneimine (PEI) and PEI based nanoparticles (nano PEI) found to be controlling *S. aureus*, *S. epidermidis*, *A. baumannii C.* albicans [80].

ZnO NPs with positive and negative surface potential are tested against different bacteria with varying surface potentials, ranging -14.7 to -23.6 mV. Chemically synthesized ZnO NPs with positive surface potential show very high antimicrobial propensity with minimum inhibitory concentration of 50 and 100 µg/mL for Gram negative and positive bacterium, respectively. ZnO NPs with positive surface potential when interacted with negative surface potential of bacterial membrane it results into reactive oxygen species and exerts mechanical stress on the membrane which resulted in membrane depolarization. Carried out the Study on Rose Bengal- Functionalized Chitosan Nanoparticles (CSRBNPs) for their interaction with mono species bacteria or biofilm to check its antibacterial efficiency on a multi species biofilm model in vitro [81]. Results showcased that CSRBNPs attached to bacteria, make cell surface rough, and later on disrupt the cell after photodynamic therapy. After CSRBNPs treatment, bacterial membrane undergoes significant damage (p < 0.05) and exhibited deeper penetration into the biofilm structure. This treatment is acted on most of the pathogen and eliminated clinically relevant multispecies bacterial biofilm especially in the root canal and act as an antibiofilm agent. Advocated the use of nanoscale material as an antibacterial agent specially to control drug-resistant pathogenic bacteria. They prepared water soluble gold nanoparticles polythiophene (AuNP-PTh) composite and found to be effective against common bacteria by exhibiting a membrane directed mode of action. As per study, it can easily breach the outer membrane defense barrier of Gram-negative pathogens for subsequent killing by using hydrophobic antibiotic which blocks its growth [82]. [83,84] reported the success story of Aluminium Oxide Nanoparticles (Al<sub>2</sub>O<sub>2</sub> NPs) using leaf extract of lemongrass which can control extendedspectrum- $\beta$ -lactamases and metallo- $\beta$ -lactamases positive P. aeruginosa. The action of Al<sub>2</sub>O<sub>2</sub> NPs when investigated by SEM it showcased that, clusters of nanoparticles getting attached to cell surface and that resulted in structural deformities in treated cells. According to high resolution transmission electron microscopy, nanoparticles found to be crossing the cell membrane to reach intracellular region and this insertion of Nanoparticles disrupts the cell membrane integrity and resulted in intracellular oxidative stress. Hence based on the results, Al<sub>2</sub>O<sub>3</sub>NPs remained effective as a bactericidal agent especially against extended spectrum non-extended-spectrum-β-lactamases,  $\beta$ -lactamases, and metallo- $\beta$ -lactamases strains of *P. Aeruginosa* and NPs found to be useful in pharmaceutical and biomedical applications [85]. demonstrated synthesis of stable copper nanoparticles (Cu-NPs) and which can control E. coli via NP- mediated dissipation of call membrane potential which was the main reason for the formation of cell filaments. It is also ascertained that Cu-NPs bring about multiple toxic effects such as generation of relative oxygen species, protein oxidation, lipid peroxidation in E. coli. Overall result highlighted that Cu-NPs acts on membrane to destabilise the structure and hence recognized as antibacterial agent. [86] involved Silver Nanoparticles (AgNPs) in antibacterial and antifungal activity in agriculture study and highlighted phytotoxic effect of AgNPs on Oryza sativa along with that results highlighted AgNPs treatment at 30 µg/ml accelerated root growth and at 60 µg/ml its restricts root growth ability. Further closeness of AgNPs to plants and soil induces reactive oxygen species and that lead to induction of controlling action against plant pathogens like Bacillus thuringiensis and inverse promotes Bacillus amyloliquefaciens further as per electron microscopy with AgNPs treatment bacteria was recorded with release of reducing sugar and protein through bacterial membrane and that hypothesized that AgNPs damages bacterial cell wall and further transform it into protoplasts. [87] investigated on Diamond Nanoparticles (DNPs) and put forward the possibility of antibacterial activity of DNPs and able to control E. coli and S. subtilis. They reported that DNPs activity was certainly influenced by its concentration and the morphology it possesses. According to TEM analysis, DNPs able to interact with bacterial surface and interferes with permeability of the cell functions by disturbing bacterial cell wall and/or cell membrane and that hinder B. subtilis growth for sure. [88,89] also put forward the success of immunological and antibacterial positive Zn nanoparticles (ZnO NPs) which was efficient in disrupting bacterial cell surface hydrophobicity and down regulating the transcription of oxidative stress resistant gene. This NPs used in study demonstrate properties of infection prevention and treatment facility and could act as future drug.

As per all these literatures it is suggested that metal oxide nanoparticles certainly been useful in antimicrobial activity and in relation present study also proposes the same to showcase few more features available with ZnO, TiO<sub>2</sub>, and MnO<sub>2</sub> nanoparticles to control ever increasing multi drug resistant bacterial species.



# CONCLUSION

The field of research is nanotechnology developing several nanoparticles which are proving promising in antibacterial activity. The synthesis of nanoparticles now very well understands which involves UV-visible spectrometry, XRD, and others. The synthesis of ZnO, TiO, and MnO<sub>2</sub> NPs successfully reported with plant extract and another nano-biological reducing agent. The addition of stabilizing agent like carboxymethyl celluloses reported to maintain its activity by obviating aggregation. The testing of these nanoparticles confirmed the antibacterial activity especially towards antibiotic resistance strains by producing reactive oxygen species, by damaging plasmid DNA, by changing cell morphology, and other factors. The application of ZnO. TiO, and MnO, NPs registered for better antibacterial activity in varied means such as in water purification, bandages, medical equipment surface coatings and in food preservation. Moreover, now increasing research also taking the safety and toxicity assessment of these nanoparticles via in vivo and in vitro studies.

## ACKNOWLEDGEMENT

Authors are grateful to the Department of Biotechnology, Noida Institute of Engineering and Technology and Department of Biotechnology, Amity University Raipur, India.

#### References

- Doan Thi TU, Nguyen TT, Thi YD, Ta Thi KH, Phan BT, Pham KN. "Green synthesis of ZnO nanoparticles using orange fruit peel extract for antibacterial activities." RSC Adv. 2020 Jun;vol.10,(40):p.23899–23907. doi: 10.1039/d0ra04926c.
- Tyagi S, Tyagi PK, Gola D, Chauhan N, Bharti RK, "Extracellular synthesis of silver nanoparticles using entomopathogenic fungus: characterization and antibacterial potential," SN Appl. Sci. 2019 Dec;vol.1(12):p.1545. doi: 10.1007/s42452-019-1593-y.
- Shabaani M, Rahaiee S, Zare M. Jafari SM, "Green synthesis of ZnO nanoparticles using loquat seed extract; Biological functions and photocatalytic degradation properties," LWT.2020 Dec;vol.13:p.110133. doi: 10.1016/j.lwt.2020.110133.
- Nabi et al G, "Green synthesis of TiO<sub>2</sub> nanoparticles using lemon peel extract: their optical and photocatalytic properties," Int. J. Environ. Anal. Chem, 2020, doi: 10.1080/03067319.2020.1722816.
- Ullah AKMA et al. "Green synthesis of Bryophyllum pinnatum aqueous leaf extract mediated bio-molecule capped dilute ferromagnetic α-MnO<sub>2</sub> nanoparticles," Mater. Res. Express, 2020 Jan;vol.7(1):p.15088, doi: 10.1088/2053-1591/ab6c20.
- Janaki AC, Sailatha E, Gunasekaran S. Synthesis, characteristics and antimicrobial activity of ZnO nanoparticles. Spectrochim Acta A Mol Biomol Spectrosc. 2015 Jun 5;144:17-22. doi: 10.1016/j. saa.2015.02.041. Epub 2015 Feb 14. PMID: 25748589.
- Tyagi PK, Gola D, Tyagi S, Mishra AK, Kumar A, Chauhan N, Ahuja A, Sirohi S. "Synthesis of zinc oxide nanoparticles and its conjugation with antibiotic: Antibacterial and morphological characterization," Environ. Nanotechnology, Monit. Manag. 2020 Dec;vol.14. doi: 10.1016/j. enmm.2020.100391.
- 8. Suresh D, Shobharani RM, Nethravathi PC, Pavan Kumar MA, Nagabhushana H, Sharma SC. Artocarpus gomezianus aided green

synthesis of ZnO nanoparticles: luminescence, photocatalytic and antioxidant properties. Spectrochim Acta A Mol Biomol Spectrosc. 2015 Apr 15;141:128-34. doi: 10.1016/j.saa.2015.01.048. Epub 2015 Jan 30. PMID: 25668693..

- Ramesh M, Anbuvannan M, Viruthagiri G. Green synthesis of ZnO nanoparticles using Solanum nigrum leaf extract and their antibacterial activity. Spectrochim Acta A Mol Biomol Spectrosc. 2015 Feb 5;136 Pt B:864-70. doi: 10.1016/j.saa.2014.09.105. Epub 2014 Oct 5. PMID: 25459609.
- Anbuvannan M, Ramesh M, Viruthagiri G, Shanmugam N, Kannadasan N. "Anisochilus carnosus leaf extract mediated synthesis of zinc oxide nanoparticles for antibacterial and photocatalytic activities," Mater. Sci. Semicond. Process., 2015 Jun; vol.39; p. 621–628, doi: 10.1016/j. mssp.2015.06.005.
- Bayrami A, Parvinroo S, Habibi-Yangjeh A, Rahim Pouran S. Bio-extract-mediated ZnO nanoparticles: microwave-assisted synthesis, characterization and antidiabetic activity evaluation. Artif Cells Nanomed Biotechnol. 2018 Jun;46(4):730-739. doi: 10.1080/21691401.2017.1337025. Epub 2017 Jun 15. PMID: 28617629.
- Singh R, Kumar A, Kirrolia A, Kumar R, Yadav N, Bishnoi NR, Lohchab RK. Removal of sulphate, COD and Cr(VI) in simulated and real wastewater by sulphate reducing bacteria enrichment in small bioreactor and FTIR study. Bioresour Technol. 2011 Jan;102(2):677-82. doi: 10.1016/j. biortech.2010.08.041. Epub 2010 Aug 24. PMID: 20884204.
- Tang C, Sun P, Yang J, Huang Y, Wu Y. Kinetics simulation of Cu and Cd removal and the microbial community adaptation in a periphytic biofilm reactor. Bioresour Technol. 2019 Mar;276:199-203. doi: 10.1016/j. biortech.2019.01.001. Epub 2019 Jan 2. PMID: 30623876.
- 14. Soliman MMA, Alegria ECBA, Ribeiro APC, Alves MM, Saraiva MS, Fátima Montemor M, Pombeiro AJL. Green synthesis of zinc oxide particles with apple-derived compounds and their application as catalysts in the transesterification of methyl benzoates. Dalton Trans. 2020 May 19;49(19):6488-6494. doi: 10.1039/d0dt01069c. PMID: 32364212.
- Azizi S, Ahmad MB, Hussein MZ, Ibrahim NA. Synthesis, antibacterial and thermal studies of cellulose nanocrystal stabilized ZnO-Ag heterostructure nanoparticles. Molecules. 2013 May 28;18(6):6269-80. doi: 10.3390/molecules18066269. PMID: 23760028; PMCID: PMC6269905.
- 16. Bai X, Li L, Liu H, Tan L, Liu T, Meng X. Solvothermal synthesis of ZnO nanoparticles and anti-infection application in vivo. ACS Appl Mater Interfaces. 2015 Jan 21;7(2):1308-17. doi: 10.1021/am507532p. Epub 2015 Jan 9. PMID: 25537255.
- Mayyas M, Mousavi M, Ghasemian MB, Abbasi R, Li H, Christoe MJ, Han J, Wang Y, Zhang C, Rahim MA, Tang J, Yang J, Esrafilzadeh D, Jalili R, Allioux FM, O'Mullane AP, Kalantar-Zadeh K. Pulsing Liquid Alloys for Nanomaterials Synthesis. ACS Nano. 2020 Oct 27;14(10):14070-14079. doi: 10.1021/acsnano.0c06724. Epub 2020 Sep 21. PMID: 32916049.
- Das J, Paul Das M, Velusamy P. Sesbania grandiflora leaf extract mediated green synthesis of antibacterial silver nanoparticles against selected human pathogens. Spectrochim Acta A Mol Biomol Spectrosc. 2013 Mar;104:265-70. doi: 10.1016/j.saa.2012.11.075. Epub 2012 Dec 5. PMID: 23270884.
- Md Yusoff MF, Siti Rozaimah SA, Hassimi AH, Hawati J, Habibah A. "Performance of continuous pilot subsurface constructed wetland using Scirpus grossus for removal of COD, colour and suspended solid in recycled pulp and paper effluent," Environ. Technol. Innov., 2019 Feb;vol. 13; P.346–352; doi: 10.1016/j.eti.2018.12.008.
- Hameed S, Khalil AT, Ali M, Numan M, Khamlich S, Shinwari ZK, Maaza M. Greener synthesis of ZnO and Ag-ZnO nanoparticles using Silybum marianum for diverse biomedical applications. Nanomedicine (Lond). 2019 Mar;14(6):655-673. doi: 10.2217/nnm-2018-0279. Epub 2019 Feb 4. PMID: 30714480.
- Zhang Y, Gao X, Zhi L, Liu X, Jiang W, Sun Y, Yang J. The synergetic antibacterial activity of Ag islands on ZnO (Ag/ZnO) heterostructure nanoparticles and its mode of action. J Inorg Biochem. 2014 Jan;130:74-83. doi: 10.1016/j.jinorgbio.2013.10.004. Epub 2013 Oct 11. PMID: 24176922.





TOXICOLOGY

- 22. Kermanizadeh A, Jacobsen NR, Roursgaard M, Loft S, Møller P. Hepatic Hazard Assessment of Silver Nanoparticle Exposure in Healthy and Chronically Alcohol Fed Mice. Toxicol Sci. 2017 Jul 1;158(1):176-187. doi: 10.1093/toxsci/kfx080. PMID: 28453772.
- 23. Ali A, Mannan A, Hussain I, Zia M. "Effective removal of metal ions from aquous solution by silver and zinc nanoparticles functionalized cellulose: Isotherm, kinetics and statistical supposition of process," Environ. Nanotechnology, Monit. Manag, 2018 May ;vol. 9;p.1–11: doi: 10.1016/j.enmm.2017.11.003.
- Raajshree RK, Brindha D. In Vivo Anticancer Activity of Biosynthesized Zinc Oxide Nanoparticle using Turbinaria conoides on a Dalton's Lymphoma Ascites Mice Model. J Environ Pathol Toxicol Oncol. 2018;37(2):103-115. doi: 10.1615/JEnvironPatholToxicolOncol.2018025086. PMID: 30055546.
- Shankar S, Oun AA, Rhim JW. Preparation of antimicrobial hybrid nanomaterials using regenerated cellulose and metallic nanoparticles. Int J Biol Macromol. 2018 Feb;107(PtA):17-27. doi: 10.1016/j. ijbiomac.2017.08.129. Epub 2017 Sep 1. PMID: 28855135.
- 26. Gupta A, Srivastava R. Mini submersible pump assisted sonochemical reactors: Large-scale synthesis of zinc oxide nanoparticles and nanoleaves for antibacterial and anti-counterfeiting applications. Ultrason Sonochem. 2019 Apr;52:414-427. doi: 10.1016/j. ultsonch.2018.12.020. Epub 2018 Dec 12. PMID: 30755387.
- 27. Kil HS, Jung YJ, Moon JI, Song JH, Lim DY, Cho SB. Glycothermal Synthesis and Photocatalytic Properties of Highly Crystallized Anatase TiO<sub>2</sub> Nanoparticles. J Nanosci Nanotechnol. 2015 Aug;15(8):6193-200. doi: 10.1166/jnn.2015.10430. PMID: 26369224.
- 28. Pezzella A, Capelli L, Costantini A, Luciani G, Tescione F, Silvestri B, Vitiello G, Branda F. Towards the development of a novel bioinspired functional material: synthesis and characterization of hybrid TiO<sub>2</sub>/ DHICA-melanin nanoparticles. Mater Sci Eng C Mater Biol Appl. 2013 Jan 1;33(1):347-55. doi: 10.1016/j.msec.2012.08.049. Epub 2012 Sep 5. PMID: 25428080.
- Bezares I, del Campo A, Herrasti P, Muñoz-Bonilla A. A simple aqueous electrochemical method to synthesize TiO<sub>2</sub> nanoparticles. Phys Chem Chem Phys. 2015 Nov 21;17(43):29319-26. doi: 10.1039/c5cp05525c. PMID: 26469391.
- Zhang HM, Cao J, Tang BP, Wang YQ. Effect of TiO<sub>2</sub> nanoparticles on the structure and activity of catalase. Chem Biol Interact. 2014 Aug 5;219:168-74. doi: 10.1016/j.cbi.2014.06.005. Epub 2014 Jun 12. PMID: 24931876.
- Mohamed HR. Estimation of TiO<sub>2</sub> nanoparticle-induced genotoxicity persistence and possible chronic gastritis-induction in mice. Food Chem Toxicol. 2015 Sep;83:76-83. doi: 10.1016/j.fct.2015.05.018. Epub 2015 Jun 11. PMID: 26072100.
- 32. A. Katsumiti et al., "Cytotoxicity of TiO<sub>2</sub> nanoparticles to mussel hemocytes and gill cells in vitro: Influence of synthesis method, crystalline structure, size and additive," Nanotoxicology, vol. 9, no. 5, pp. 543–553, Aug. 2015, doi: 10.3109/17435390.2014.952362.
- Elgrabli D, Beaudouin R, Jbilou N, Floriani M, Pery A, Rogerieux F, Lacroix G. Biodistribution and Clearance of TiO<sub>2</sub> Nanoparticles in Rats after Intravenous Injection. PLoS One. 2015 Apr 24;10(4):e0124490. doi: 10.1371/journal.pone.0124490. PMID: 25909957; PMCID: PMC4409301.
- 34. Spadavecchia J, Méthivier C, Landoulsi J, Pradier CM. Interaction of ZnII porphyrin with TiO<sub>2</sub> nanoparticles: from mechanism to synthesis of hybrid nanomaterials. Chemphyschem. 2013 Aug 5;14(11):2462-9. doi: 10.1002/cphc.201300193. Epub 2013 Jul 2. PMID: 23821481.
- 35. Lin X, Li J, Ma S, Liu G, Yang K, Tong M, Lin D. Toxicity of TiO<sub>2</sub> nanoparticles to Escherichia coli: effects of particle size, crystal phase and water chemistry. PLoS One. 2014 Oct 13;9(10):e110247. doi: 10.1371/journal. pone.0110247. PMID: 25310452; PMCID: PMC4195723.
- 36. Kurepa J, Nakabayashi R, Paunesku T, Suzuki M, Saito K, Woloschak GE, Smalle JA. Direct isolation of flavonoids from plants using ultrasmall anatase TiO<sub>2</sub> nanoparticles. Plant J. 2014 Feb;77(3):443-53. doi: 10.1111/tpj.12361. Epub 2013 Nov 29. PMID: 24147867; PMCID: PMC3935720.

- 37. Pang S, Huang JG, Su Y, Geng B, Lei SY, Huang YT, Lyu C, Liu XJ. Synthesis and Modification of Zn-doped TiO<sub>2</sub> Nanoparticles for the Photocatalytic Degradation of Tetracycline. Photochem Photobiol. 2016 Sep;92(5):651-7. doi: 10.1111/php.12626. PMID: 27499076.
- 38. Irshad MA, Nawaz R, Zia Ur Rehman M, Imran M, Ahmad J, Ahmad S, Inam A, Razzaq A, Rizwan M, Ali S. Synthesis and characterization of titanium dioxide nanoparticles by chemical and green methods and their antifungal activities against wheat rust. Chemosphere. 2020 Nov;258:127352. doi: 10.1016/j.chemosphere.2020.127352. Epub 2020 Jun 10. PMID: 32554013.
- 39. Hariharan D, Thangamuniyandi P, Jegatha Christy A, Vasantharaja R, Selvakumar P, Sagadevan S, Pugazhendhi A, Nehru LC. Enhanced photocatalysis and anticancer activity of green hydrothermal synthesized Ag@TiO<sub>2</sub> nanoparticles. J Photochem Photobiol B. 2020 Jan;202:111636. doi: 10.1016/j.jphotobiol.2019.111636. Epub 2019 Nov 12. PMID: 31739259.
- Sellschopp K, Heckel W, G\u00e4ding J, Schr\u00f6ter CJ, Hensel A, Vossmeyer T, Weller H, M\u00fcluer S, Vonbun-Feldbauer GB. Shape-controlling effects of hydrohalic and carboxylic acids in TiO<sub>2</sub> nanoparticle synthesis. J Chem Phys. 2020 Feb 14;152(6):064702. doi: 10.1063/1.5138717. PMID: 32061241.
- 41. Gahlot S, Dappozze F, Singh D, Ahuja R, Cardenas L, Burel L, Amans D, Guillard C, Mishra S. Room-temperature conversion of Cu2-xSe to CuAgSe nanoparticles to enhance the photocatalytic performance of their composites with TiO<sub>2</sub>. Dalton Trans. 2020 Mar 17;49(11):3580-3591. doi: 10.1039/c9dt04726c. PMID: 32129381.
- Pan ZW, Dai ZR, Wang ZL. Nanobelts of semiconducting oxides. Science. 2001 Mar 9;291(5510):1947-9. doi: 10.1126/science.1058120. PMID: 11239151.
- 43. Ma X, Sharifan H, Dou F, Sun W, "Simultaneous reduction of arsenic (As) and cadmium (Cd) accumulation in rice by zinc oxide nanoparticles," Chem. Eng. J. 2020 Mar; vol.384, doi: 10.1016/j.cej.2019.123802.
- 44. Wu Y, Ali MRK, K. Chen, N. Fang, El-Sayed M. A. "Gold nanoparticles in biological optical imaging" Nano Today, 2019 Feb; vol.24; Elsevier B.V, p.120–140, doi: 10.1016/j.nantod.2018.12.006
- 45. Patelli N, Migliori A, Morandi V, Pasquini L. One-Step Synthesis of Metal/ Oxide Nanocomposites by Gas Phase Condensation. Nanomaterials (Basel). 2019 Feb 6;9(2):219. doi: 10.3390/nano9020219. PMID: 30736375; PMCID: PMC6409555.
- 46. Lu H, Peng Y, Ye H, Cui X, Hu J, Gu H, Khlobystov AN, Green MA, Blower PJ, Wyatt PB, Gillin WP, Hernández I. Sensitization, energy transfer and infra-red emission decay modulation in Yb3+-doped NaYF4 nanoparticles with visible light through a perfluoroanthraquinone chromophore. Sci Rep. 2017 Jul 11;7(1):5066. doi: 10.1038/s41598-017-05350-9. PMID: 28698586; PMCID: PMC5505979.
- 47. Montaser AS, Wassel AR, Al-Shaye'a ON. Synthesis, characterization and antimicrobial activity of Schiff bases from chitosan and salicylaldehyde/ TiO<sub>2</sub> nanocomposite membrane. Int J Biol Macromol. 2019 Mar 1;124:802-809. doi: 10.1016/j.ijbiomac.2018.11.229. Epub 2018 Nov 28. PMID: 30502423.
- 48. Alberti S, Villa S, Singh G, Seland F, Martinelli A, Ferretti M, Canepa F, Caratto V. Systematic Study on TiO<sub>2</sub> Crystallization via Hydrothermal Synthesis in the Presence of Different Ferrite Nanoparticles as Nucleation Seeds. J Nanosci Nanotechnol. 2019 Aug 1;19(8):4994-4999. doi: 10.1166/jnn.2019.16787. PMID: 30913812.
- Shah Z, Nazir S, Mazhar K, Abbasi R, Samokhvalov IM. PEGylated dopedand undoped-TiO<sub>2</sub> nanoparticles for photodynamic Therapy of cancers. Photodiagnosis Photodyn Ther. 2019 Sep;27:173-183. doi: 10.1016/j. pdpdt.2019.05.019. Epub 2019 May 25. PMID: 31136827.
- Gaballah ST, El-Nazer HA, Abdel-Monem RA, El-Liethy MA, Hemdan BA, Rabie ST. Synthesis of novel chitosan-PVC conjugates encompassing Ag nanoparticles as antibacterial polymers for biomedical applications. Int J Biol Macromol. 2019 Jan;121:707-717. doi: 10.1016/j. ijbiomac.2018.10.085. Epub 2018 Oct 16. PMID: 30340001.
- 51. Mragui A.El, Daou I, Zegaoui O. "Influence of the preparation method



and  $ZnO/(ZnO + TiO_2)$  weight ratio on the physicochemical and photocatalytic properties of  $ZnO-TiO_2$  nanomaterials," Catal. Today, 2019 Feb; vol.321–322; p.41–51: doi: 10.1016/j.cattod.2018.01.016.

- 52. Locatelli E, Li Y, Monaco I, Guo W, Maturi M, Menichetti L, Armanetti P, Martin RC, Comes Franchini M. A novel theranostic gold nanorodsand Adriamycin-loaded micelle for EpCAM targeting, laser ablation, and photoacoustic imaging of cancer stem cells in hepatocellular carcinoma. Int J Nanomedicine. 2019 Mar 13;14:1877-1892. doi: 10.2147/IJN. S197265. PMID: 30936691; PMCID: PMC6422422.
- Salunke BK, Sawant SS, Lee SI, Kim BS. Comparative study of MnO<sub>2</sub> nanoparticle synthesis by marine bacterium Saccharophagus degradans and yeast Saccharomyces cerevisiae. Appl Microbiol Biotechnol. 2015 Jul;99(13):5419-27. doi: 10.1007/s00253-015-6559-4. Epub 2015 Apr 7. PMID: 25846336.
- 54. Abulizi A, Yang GH, Okitsu K, Zhu JJ. Synthesis of  $MnO_2$  nanoparticles from sonochemical reduction of MnO4(-) in water under different pH conditions. Ultrason Sonochem. 2014 Sep;21(5):1629-34. doi: 10.1016/j. ultsonch.2014.03.030. Epub 2014 Apr 13. PMID: 24793308.
- 55. Moon SA, Salunke BK, Alkotaini B, Sathiyamoorthi E, Kim BS. Biological synthesis of manganese dioxide nanoparticles by Kalopanax pictus plant extract. IET Nanobiotechnol. 2015 Aug;9(4):220-5. doi: 10.1049/ iet-nbt.2014.0051. PMID: 26224352.
- 56. Liu X, Wang Q, Zhao H, Zhang L, Su Y, Lv Y. BSA-templated MnO<sub>2</sub> nanoparticles as both peroxidase and oxidase mimics. Analyst. 2012 Oct 7;137(19):4552-8. doi: 10.1039/c2an35700c. PMID: 22900262.
- 57. Han B, Liu W, Zhao D."In-Situ Oxidative Degradation of Emerging Contaminants in Soil and Groundwater Using a New Class of Stabilized MnO<sub>2</sub> Nanoparticles Hydrodechlorination removal of chlorinated contaminantes View project Pyrolysis of different biomass preimpregnated with steel pickling waste liquor to prepare magnetic biochars and their use for the degradation of metronidazole View project," Elsevier, 2014; doi: 10.4018/978-1-5225-0585-3.ch006.
- 58. Dutta RK, Nenavathu BP, Talukdar S. Anomalous antibacterial activity and dye degradation by selenium doped ZnO nanoparticles. Colloids Surf B Biointerfaces. 2014 Feb 1;114:218-24. doi: 10.1016/j. colsurfb.2013.10.007. Epub 2013 Oct 16. PMID: 24200949.
- 59. Janaki AC, Sailatha E, Gunasekaran S. Synthesis, characteristics and antimicrobial activity of ZnO nanoparticles. Spectrochim Acta A Mol Biomol Spectrosc. 2015 Jun 5;144:17-22. doi: 10.1016/j. saa.2015.02.041. Epub 2015 Feb 14. PMID: 25748589.
- 60. Saravanan M, Gopinath V, Chaurasia MK, Syed A, Ameen F, Purushothaman N. Green synthesis of anisotropic zinc oxide nanoparticles with antibacterial and cytofriendly properties. Microb Pathog. 2018 Feb;115:57-63. doi: 10.1016/j.micpath.2017.12.039. Epub 2017 Dec 14. PMID: 29248514.
- Kairyte K, Kadys A, Luksiene Z. Antibacterial and antifungal activity of photoactivated ZnO nanoparticles in suspension. J Photochem Photobiol B. 2013 Nov 5;128:78-84. doi: 10.1016/j.jphotobiol.2013.07.017. Epub 2013 Jul 29. PMID: 24035847.
- 62. Dědková K, Lang J, Matějová K, Peikertová P, Holešinský J, Vodárek V, Kukutschová J. Nanostructured composite material graphite/ TiO<sub>2</sub> and its antibacterial activity under visible light irradiation. J Photochem Photobiol B. 2015 Aug;149:265-71. doi: 10.1016/j. jphotobiol.2015.06.018. Epub 2015 Jun 19. PMID: 26114221.
- 63. Dhanalekshmi KI, Meena KS. Comparison of antibacterial activities of Ag@TiO<sub>2</sub> and Ag@SiO2 core-shell nanoparticles. Spectrochim Acta A Mol Biomol Spectrosc. 2014 Jul 15;128:887-90. doi: 10.1016/j. saa.2014.02.063. Epub 2014 Mar 7. PMID: 24709355.
- 64. Jayaseelan C, Rahuman AA, Roopan SM, Kirthi AV, Venkatesan J, Kim SK, Iyappan M, Siva C. Biological approach to synthesize TiO<sub>2</sub> nanoparticles using Aeromonas hydrophila and its antibacterial activity. Spectrochim Acta A Mol Biomol Spectrosc. 2013 Apr 15;107:82-9. doi: 10.1016/j. saa.2012.12.083. Epub 2013 Jan 5. PMID: 23416912.
- 65. Yeniyol S, He Z, Yüksel B, Boylan RJ, Urgen M, Ozdemir T, Ricci JL. Antibacterial Activity of As-Annealed TiO<sub>2</sub> Nanotubes Doped with Ag

Nanoparticles against Periodontal Pathogens. Bioinorg Chem Appl. 2014;2014:829496. doi: 10.1155/2014/829496. Epub 2014 Aug 18. PMID: 25202230; PMCID: PMC4151538.

- 66. Roguska A, Belcarz A, Pisarek M, Ginalska G, Lewandowska M. TiO<sub>2</sub> nanotube composite layers as delivery system for ZnO and Ag nanoparticles - an unexpected overdose effect decreasing their antibacterial efficacy. Mater Sci Eng C Mater Biol Appl. 2015 Jun;51:158-66. doi: 10.1016/j.msec.2015.02.046. Epub 2015 Feb 26. PMID: 25842121.
- 67. Ahmad R, Mohsin M, Ahmad T, Sardar M. Alpha amylase assisted synthesis of TiO<sub>2</sub> nanoparticles: structural characterization and application as antibacterial agents. J Hazard Mater. 2015;283:171-7. doi: 10.1016/j.jhazmat.2014.08.073. Epub 2014 Sep 18. PMID: 25270329.
- Lipovsky A, Gedanken A, Lubart R. Visible light-induced antibacterial activity of metaloxide nanoparticles. Photomed Laser Surg. 2013 Nov;31(11):526-30. doi: 10.1089/pho.2012.3339. Epub 2013 Feb 28. PMID: 23448383.
- 69. Uhm SH, Lee SB, Song DH, Kwon JS, Han JG, Kim KN. Fabrication of bioactive, antibacterial TiO<sub>2</sub> nanotube surfaces, coated with magnetron sputtered Ag nanostructures for dental applications. J Nanosci Nanotechnol. 2014 Oct;14(10):7847-54. doi: 10.1166/jnn.2014.9412. PMID: 25942879.
- Nail K, Koshy M. Anti-quorum sensing activity of AgCl-TiO<sub>2</sub> nanoparticles with potential use as active food packaging material. J Apple Microbiol. 2014 Oct;117(4):972-83. doi: 10.1111/jam.12589. Epub 2014 Jul 14. PMID: 24965598.
- 71. Li S, Zhao X, Jiang H. "Synergistic Antibacterial Activity of New Isomeric Carborane Derivatives Through Combination with Nanoscaled Titania TiO<sub>2</sub> nanowhiskers re-introduced the biomedical applications of poephyrin derivatives (tetra sulphonatophenyl porphyrin) by mitigating it's toxic effects. View project," Artic. J. Biomed. Nanotechnol., 2013, doi: 10.1166/jbn.2013.1550.
- 72. Li J, Qiao Y, Zhu H, Meng F, Liu X. Existence, release, and antibacterial actions of silver nanoparticles on Ag-PIII TiO<sub>2</sub> films with different nanotopographies. Int J Nanomedicine. 2014 Jul 16;9:3389-402. doi: 10.2147/IJN.S63807. PMID: 25075186; PMCID: PMC4106954.
- 73. Lee WS, Park YS, Cho YK. Significantly enhanced antibacterial activity of TiO<sub>2</sub> nanofibers with hierarchical nanostructures and controlled crystallinity. Analyst. 2015 Jan 21;140(2):616-22. doi: 10.1039/ c4an01682c. PMID: 25426595.
- 74. Kunkalekar RK, Prabhu MS, Naik MM, Salker AV. Silver-doped manganese dioxide and trioxide nanoparticles inhibit both gram positive and gram negative pathogenic bacteria. Colloids Surf B Biointerfaces. 2014 Jan 1;113:429-34. doi: 10.1016/j.colsurfb.2013.09.036. Epub 2013 Sep 27. PMID: 24140741.
- 75. Wang L, He H, Zhang C, Sun L, Liu S, Wang S. Antimicrobial activity of silver loaded MnO<sub>2</sub> nanomaterials with different crystal phases against Escherichia coli. J Environ Sci (China). 2016 Mar;41:112-120. doi: 10.1016/j.jes.2015.04.026. Epub 2015 Aug 10. PMID: 26969056.
- 76. Sivaraj D, Vijayalakshmi K. Preferential killing of bacterial cells by hybrid carbon nanotube-MnO<sub>2</sub> nanocomposite synthesized by novel microwave assisted processing. Mater Sci Eng C Mater Biol Appl. 2017 Dec 1;81:469-477. doi: 10.1016/j.msec.2017.08.027. Epub 2017 Aug 11. PMID: 28887999.
- Anwar Y. Antibacterial and lead ions adsorption characteristics of chitosan-manganese dioxide bionanocomposite. Int J Biol Macromol. 2018 May;111:1140-1145. doi: 10.1016/j.ijbiomac.2018.01.096. Epub 2018 Feb 19. PMID: 29415409.
- Wang L, Ma L, Yang Z. "Spatial variation and risk assessment of heavy metals in paddy rice from Hunan Province, Southern China." Int. J. Environ. Sci. Technol. 2018 Jul;vol.15(7):p. 1561–1572. doi: 10.1007/ s13762-017-1504-y.
- Nasrollahzadeh M, Sajadi SM, Sajjadi M, Issaabadi Z. "An Introduction to Nanotechnology," in Interface Science and Technology, 2019 vol. 28, Elsevier B.V, p. 1–27.
- 80. Azevedo MM, Ramalho P, Silva AP, Teixeira-Santos R, Pina-Vaz C,





Subject Area(s): TOXICOLOGY | BIOTECHNOLOGY

Rodrigues AG. Polyethyleneimine and polyethyleneimine-based nanoparticles: novel bacterial and yeast biofilm inhibitors. J Med Microbiol. 2014 Sep; vol.63;P. 1167-1173. doi: 10.1099/jmm.0.069609-0. Epub 2014 Jun 9. PMID: 24913563.

- Shrestha A, Kishen A. Antibiofilm efficacy of photosensitizerfunctionalized bioactive nanoparticles on multispecies biofilm. J Endod. 2014 Oct;40(10):1604-10. doi: 10.1016/j.joen.2014.03.009. Epub 2014 Apr 29. PMID: 25260731.
- 82. Adhikari MD, Goswami S, Panda BR, Chattopadhyay A, Ramesh A. Membrane-directed high bactericidal activity of (gold nanoparticle)polythiophene composite for niche applications against pathogenic bacteria. Adv Healthc Mater. 2013 Apr;2(4):599-606. doi: 10.1002/ adhm.201200278. Epub 2012 Nov 22. PMID: 23184755.
- 83. Ansari MA, Khan HM, Alzohairy MA, Jalal M, Ali SG, Pal R, Musarrat J. Green synthesis of Al2O3 nanoparticles and their bactericidal potential against clinical isolates of multi-drug resistant Pseudomonas aeruginosa. World J Microbiol Biotechnol. 2015 Jan;31(1):153-64. doi: 10.1007/s11274-014-1757-2. Epub 2014 Oct 11. PMID: 25304025.
- 84. Tyagi PK. "Use of biofabricated silver nanoparticles-conjugated with antibiotic against multidrug resistant pathogenic bacteria." Biol. Insights. 2016 Dec;Vol.1:p.1-6.
- 85. Chatterjee A, Perevedentseva E, Jani M, Cheng CY, Ye YS, Chung PH, Cheng

CL. Antibacterial effect of ultrafine nanodiamond against gram-negative bacteria Escherichia coli. J Biomed Opt. 2015 May;20(5):051014. doi: 10.1117/1.JBO.20.5.051014. PMID: 25500913.

- Mirzajani F, Askari H, Hamzelou S, Farzaneh M, Ghassempour A. Effect of silver nanoparticles on Oryza sativa L. and its rhizosphere bacteria. Ecotoxicol Environ Saf. 2013 Feb;88:48-54. doi: 10.1016/j. ecoenv.2012.10.018. Epub 2012 Nov 20. PMID: 23174269.
- 87. Beranová J, Seydlová G, Kozak H, Benada O, Fišer R, Artemenko A, Konopásek I, Kromka A. Sensitivity of bacteria to diamond nanoparticles of various size differs in gram-positive and gram-negative cells. FEMS Microbiol Lett. 2014 Feb;351(2):179-86. doi: 10.1111/1574-6968.12373. Epub 2014 Jan 31. PMID: 24386940.
- 88. Pati R, Mehta RK, Mohanty S, Padhi A, Sengupta M, Vaseeharan B, Goswami C, Sonawane A. Topical application of zinc oxide nanoparticles reduces bacterial skin infection in mice and exhibits antibacterial activity by inducing oxidative stress response and cell membrane disintegration in macrophages. Nanomedicine. 2014 Aug;10(6):1195-208. doi: 10.1016/j.nano.2014.02.012. Epub 2014 Mar 6. PMID: 24607937.
- 89. Salati S, Doudi M, Madani M. "The biological synthesis of silver nanoparticles by mango plant extract and its anti-candida effects." J Appl Biotechnol Reports. 2018 Sep:vol.5(4);p.157–161. doi: 10.29252/ JABR.05.04.04.

How to cite this article: Shrivastava A, Singh RK, Tyagi PK, Gore D. Synthesis of Zinc Oxide, Titanium Dioxide and Magnesium Dioxide Nanoparticles and Their Prospective in Pharmaceutical and Biotechnological Applications. J Biomed Res Environ Sci. 2021 Jan 11; 2(1): 011-020. doi: 10.37871/jbres1180, Article ID: JBRES1180