Review Article **CODEN: IJRPJK** **ISSN: 2319 – 9563**

International Journal of Research in Pharmaceutical and Nano Sciences

Journal homepage: www.ijrpns.com

https://doi.org/10.36673/IJRPNS.2020.v09.i04.A20

A REVIEW ON NOVEL APPLICATIONS OF NANOTECHNOLOGY

A. V. S. Rajeswari*[1] and J.V.C. Sharma[2]

[1*]Department of Pharmaceutics, Joginpally B.R Pharmacy College, Faculty of Pharmacy, JNTUH, Bhaskar Nagar, Yenkapally, Moinabad, Telangana, India.

[2]Department of Pharmacognosy, Joginpally B.R Pharmacy College, Faculty of Pharmacy, JNTUH, Bhaskar Nagar, Yenkapally, Moinabad, Telangana, India.

ABSTRACT

The living cells include plant and animal cells including the microbes. Nanomedicine is having wide range of applications from water microbiology, genome research etc. Nanotechnology is utilized after combining with different fields of engineering and biomedical streams. This may be natural or by utilizing the chemical or physical modifications of certain devices. Microbiological synthesis of nanomaterials by bacteria, yeast, molds, and microalgae are vastly studied now a days. The sensoristic and biomedical are combined with nanotechnology. Sensors enable detection of dangerous situations and indexes like total organic carbon, eco permanence, total radical concentration, integral toxicity etc. The sensoristic devices and therapeutic/diagnostic applications have been described. The nanoparticles are also prepared by using leaf extracts and adding them with some enzymes while combining them with some ions of interest. This green chemistry is becoming more and more popular to a large extent and used in various domains. Theranostics based nano therapy has a better improvement in cancer diagnostic studies. The technology uses living cells from molds, bacteria, plants, and yeast to synthesize the easily degradable products (white biotechnology) and tissue engineering. The review focuses on all the applications of novel nanotechnology methods laying more emphasis on the nanoparticles developed using different fields of science like microbiology and biotechnology.

KEYWORDS

Tissue Engineering, Nanotechnological applications, Biomedical applications, DNA vaccines, Diatom nanotechnology, Sensoristic devices, Drug delivery and Theranostics.

Author for Correspondence:

A.V.S. Rajeswari,

Department of Pharmaceutics,

Joginpally B.R Pharmacy College,

Faculty of Pharmacy, JNTUH, Bhaskar Nagar,

Yenkapally, Moinabad, Telangana, India.

Email: rajeswariavs9@gmail.com

INTRODUCTION

Nanoparticles are used to designate particles about submicron in size or particles that are <1µm in size. Nanotechnology is having a lot of applications like,

- Nanomedicine.
- Nanobiotechnology.
- Green nanotechnology.
- Energy applications.

- Industrial applications.
- Carbon nanotubes.
- Atomic force microscopy
- Dendrimers
- Tissue engineering
- DNA Vaccines
- Nanoart.
- Nanoelectronics.
- Warfare.
- Sensoristic devices.
- Biotechnical engineering.
- Development of solar cells, biofuels, and fuel cells.
- Green microbiology.

ANTIMICROBIAL ACTIVITY

Microorganisms have become resistant towards the antibiotics for example, antimicrobial drug resistant bacteria show methicillin-resistant, sulfonamide-resistant, penicillin-resistant, and vancomycin-resistant properties. The metal NPs have shown better anti-microbial activity[1]. The antimicrobial effectiveness of Nps depends on material employed for the synthesis of the nanoparticles and their particle size.

ENVIRONMENTAL REMEDIATION APPLICATIONS

Green synthesis

Green synthesis has been used for the synthesis of the following nanomaterials forms like metal oxides nanomaterials, hybrid materials, and bioinspired materials. Green synthesis overcomes the destructive effects involved in the traditional methods of synthesis of nanoparticles. Green Synthesis involves the synthesis of nano particles using metal oxides of metals like silver (Ag), gold (Au), copper (Cu), and zinc (Zn)] along with essential phytochemicals (e.g., flavonoids, alkaloids, terpenoids, amides, and aldehydes) which are used as reducing agents and solvent systems. It has been studied that the stability of such nanoparticles is more, and toxicity is less.

Pollution control

4-nitrophenol is an environmental pollutant produced as intermediate in synthesis of paracetamol, sulfur dyes, rubber antioxidants, film developers, corrosion inhibitors, and precursors of analgesic drugs[2,3].

The 4-nitrophenol pollution is reduced by introducing NaBH4 as a reductant and a metal catalyst such as Au NPs, Ag NPs, CuO NPs and Pd NPs[4-7].

Because of the high rate of surface adsorption ability and high surface area to volume ratio metal NPs show their effect. They increase the adsorption of reactants on their surface, thereby diminishing activation energy barriers[8-10].

The use of organic dyes in pharmaceutical, food and leather industries are increasing day by day. This led to the release of the dye pollutants in water. This pollution can be reduced by using metal oxide semiconductor nanoparticles. Due to high surface area to mass ratio they enhance the adsorption of organic pollutants as a result, surface energy of Nps increases which leads to increased rate of removal of pollutant dye concentrations. Examples are ZnO and TiO_2 nanoparticles. They also act as photo catalysts[11-16].

MICROBIAL BIOSYNTHESIS OF NANOMATERIALS FOR SENSORISTIC AND BIOMEDICAL APPLICATIONS

The microorganisms like bacteria, fungi, algae, and diatoms are used in nanomaterial synthesis for sensoristic and biomedical applications.

Bacteria[17-31]

Nanomaterials synthesized using bacteria and inorganic nanomaterials have applications in the following

- Development of voltametric sensoristic devices
- Third-generation biosensors for possible diagnostic applications
- Cell imaging and biolabeling
- For applications like annealing and thin film formation.

Bacterial-biosynthesized nanoparticles have shown *in vitro* antimicrobial activity and properties like,

- Antioxidant
- Anti-proliferative
- Anti-migration
- Anticoagulant
- And anticancer

Bacterial nanowires are also very promising nanostructures in the development of new biomaterial for microbial fuel cells and sensoristic devices.

Examples of bacteria used are

- *Bacillus subtilis* used as H2O2 sensoristic device
- *Streptomyces biokiniensis* strain Ess_amA-1 used in study of *in vitro* anticancer activity against human, breast adenocarcinoma cell line and human liver carcinoma cell line

Fungi[32-39]

Myconanotechnology refers to the biosynthesis of nanomaterials by fungi, like yeasts and molds. Yeasts are used for producing semiconductor nanoparticles.

- Cadmium telluride quantum dots, Au-Ag alloy nanoparticles are produced from yeast *Saccharomyces cerevisiae* are used for sensors fabrication, bio-imaging and biolabeling.
- *Aspergillus flavus* used in Optical detection of As (III) in water

Microalgae[40-43]

Microalgae are unicellular with photosynthetic capability. They have attracted significant interest in the field of nanomanufacturing. Mechanisms described for nanoparticles biosynthesis include phenomena of nucleation, control of dimension, and stabilization of nanoparticle structure, mediated by reducing agents.

Example: Microalgae like *Scenedesmus, Tetraselmiskochinensis,* have been used for the biosynthesis of noble metal nanoparticles with good antimicrobial activity, useful for applications in biomedical tool designing.

Diatoms[44-49]

Diatoms are unicellular microalgae. They have characteristic biomineralized silica cell wall called frustules. They possess 3D-porous micro-nanostructure, and functions like mechanical protection, biological protections, and filtration.

- *Tetraselmiskochinensis* used in various applications including catalysis, electronics and coatings.
- *Cyclotella sp* used in label-free photoluminescence-based immunosensor.
- Biomarker Vaspin is a sandwich-type biosensor for the detection of type 2 diabetes.

GENETIC PROFILING FOR CANCER RISK

Nanotechnology is used in cancer detection, diagnosis and risk management, which is caused due to molecular changes in gene, they area lsousedin Pro-active cancer treatment. Nanotechnology is also used to optimize efficacy and minimize toxicity and Gene therapy development. Pharmaco-genomic profiling, genetic predisposition and for drug responses to assist drug selection.

NANOMICROBIOLOGY AND ATOMIC FORCE MICROSCOPY (AFM)

Atomic force microscopy is used in the nanoscale analysis of microbial cells. This method used to observe membrane proteins of live cells at high resolution. Nanoscience and microbiology have been showing tremendous progress in the last 10 years.

DENDRIMERS AND NANOTECHNOLOGY

Dendrimers are nanostructured synthetic molecules which have a regular branching structure projecting from a central core. Dendrimers can be utilized in the field of nanotechnology in medicine. They can be used in gene therapy, in triggering immune response. As they are of small size, they may show potential toxicity as smaller particles can cross the skin, lung, and in some cases the blood/ brain barriers. They may cause further chemical reactions like the creation of free radicals that damage cells. Hence there are some limitations for dendrimers be used as nanoparticles. While designing nanoparticles and dendrimers the limitations must be taken into consideration.

TISSUE ENGINEERING[50-54]

Nanotechnology can be applied in creation of implantable tissues. Tissue engineering is used to create, repair, replace cells, tissues and organs by using cell or combinations with biomaterials and helps to produce materials which very much resembles to body's native tissues. It is a connecting discipline between engineering materials science, medicine and biology. In tissue engineering cells are grown on the biomimicked scaffold providing the adhesive surfaces, and then cells deposit their own protein to make them more biocompatible.

The disadvantages of tissue engineering are,

- The tissues are unable to vascularize properly,
- The cells lack functional activity,
- The cells have low mechanical strength,
- The tissues or cells are not immunologically compatible with host,
- The cells show Nutrient limitation.

Novel biomimetic scaffold and modern technology have been developed for more accuracy. Nanofabrication techniques, materials science, surface, micro and nano-patterning in tissue engineering helps in providing best microenvironment where cells must grow. Micro and nanotechnology are providing them simple substrate for adhesion and proliferation and active agents for their growth.

Tissue engineering from nanotechnology can be used to create nanofibers, nanopatterns and controlled-release nanoparticles for mimicking native tissues since biomaterials to be engineered is of nano-meter size like extracellular fluids, bone marrow, cardiac tissues etc. Stem cells, neural cells, cartilage cells, bone cells, vascular cells, hepatic cells tissue engineering through micro and nanotechnology.

DNA VACCINES FOR PARASITIC, BACTERIAL AND VIRAL DISEASES[55-57]

The major challenges in DNA technology are to overcome weak immune response associated with low gene transfection of DNA vaccines. For DNA vaccines as well as general nucleic acid delivery applications, lipid-based NPs are prominent material used as non-viral vectors. Liposomes have been a widely used for DNA vaccine preparation for nucleic acid delivery due to their high transfection and encapsulation efficiency, and greater immunogenicity.

Polymeric materials if used are highly biocompatible, biodegradable, and non-immunogenic. Hey easily provide controlled release, and targeted delivery. Polymeric gene delivery vectors have disadvantage of poor transfection efficiency and do not have ability to produce significant exogenous protein expression.

In 2018, a lipid nanoparticle system for small interfering ribonucleic acid (siRNA) delivery to treat Transthyretin amyloidosis, a peripheral nerve disease, was approved by the FDA.

The lipid-based delivery systems show higher transfection efficiency, and compatibility but due to the disadvantage is large size, toxicity, structural instability, and they undergo rapid systemic clearance. In order to overcome the disadvantage, we combine the lipid and polymeric technologies for DNA vaccine development. The lipo polyplex which is a combination of the above consists of a polymer-nucleic acid complexed core encapsulated by a liposome shell.

THERANOSTICS AND PERSONALIZED MEDICINE[58-63]

The term “Theranostics” was used by John Funkhouser in the year 1998. Modern nanosystems are used in drug diagnosis and delivery and for monitoring therapeutic responses. Nanostructures have specific and remarkable surface properties as per the requirements that perform action at their target location, while using personalized medicine. Nanoparticles can be engineered into different desired sizes and shapes. Metals such as silver (Ag), gold (Au), zinc (Zn), and titanium have been used as anticancer agents.

GOLD NANO PARTICLES

Gold nanoparticles were designed to kill cancer cells by using tumor necrosis factor alpha (TNFα) along with polyethylene glycol and thiol derivative (PEGTHIOL). These particles were developed by Cyto Immune Company. Cytoimmune is planning a second trial with auramine with other chemotherapy drugs. Citrate acts as a reducing agent because of its ability to produce gold nanospheres of monodisperse nature.

Iron oxide nanoparticles IONPs have diameter in the range of (1-100)nm. They bind to proteins, drugs, antibodies, and nucleotides and targeted toward a cell or tissue or organ or tumor guided by external magnetic field.

MAGNETIC ION BASED NANO CONSTRUCTS[64-67]

Are targeted to receptors such as urokinase plasminogen activator receptor. These nano-constructs are used for killing tumor stromal fibroblasts and have applications in cancer imaging and treatment. Nano sensors, gold nano rods are used for fluorescence imaging in cancer.

CARBON NANOTUBES CNTs

(Allotropes of carbon)[68-70] are cylindrical in structure and have smart optical, chemical, and electrical properties making them widely usable for drug delivery to kill tumor cells. These carbon atoms are graphene sheets rolled in a cylinder that can have open or capped end.

CNTs made of single graphene sheet turns to single walled nanotubes whereas multiple grapheme sheets make up multiwalled CNTs (MWNTs). All these CNTs because of their large surface area can adsorb and conjugate with different therapeutic molecules. The CNTs are subjected to surface engineering to increase their properties like dispersibility in aqueous medium. These CNT s target the therapeutic molecule by and get attached to them.

LIPOSOMES[71-74]

Are now been commercialized to expand the therapeutic use of nanoparticles in cancer extending vast area in using the cancer in possibly better manner. Large liposomes can be cleared easily than smaller ones. Half-life of liposomes is directly proportional to the dose of lipids. In addition, uncharged liposomal systems are not rapidly cleared than charged systems. The liposomal drug delivery is widely used in the treatment of systematic fungal infections with amphotericin B. They are also used in multiple areas of interest such as liposomes for respiratory drug delivery systems, liposomes in nucleic acid therapy, liposomes in eye disorders, in tumor therapy. Liposomes are used for cancer therapy included in capsulation of antineoplastic agents such as doxorubicin and methotrexate, and delivery of N-acetyl muramyl, L-alanine Disoglutamine (the immune modulators). Liposomal drug delivery system showed higher efficacy and reduced toxicity of the drug for the target cell.

NANO PARTICLES AND INDUSTRIAL HAZARD

NIOSH stands for National Institute of Occupational Safety and Health. Workers working in nano industry are at high risk of exposure to different sort of materials. The NIOSH warns that the exposure levels of materials by employees working in nanoparticle industry are increasing in multiple folds. It also publishes safety guidelines for those employed in the nanoindustry. NIOSH concerns on Nanoscience and hopes to raise awareness of the occupational safety and health issues involved with nanotechnology; make recommendations on occupational safety.

CONCLUSION

Nanosciences influences Microbiology. It allows understanding the structure at molecular-assembly levels of a process. It facilitates identification of molecular recognition and self-assembly. The properties of the nanomaterials used for pathogen detection can be tailored by changing the size, shape, composition and surface modification. Electronic, spectroscopic (emissive, absorptive), light scattering and conductive properties can be modified by engineering the nanoparticles structural parameters like size, composition and binding properties.

Numerous kinds of natural extracts (i.e., biocomponents like plant, bacteria, fungi, yeast) have been employed as efficient resources for the synthesis and/or fabrication of materials. Among them, plant extract has been proven to possess high efficiency as stabilizing and reducing agents for the synthesis of controlled materials (i.e., controlled shapes, sizes, structures, and other specific features).

Microbial nanotechnology is a fascinating and booming field for future breakthrough nanomaterial synthesis. The green synthesis and microbial nanotechnology can show impact in several fields, including sensoristics devices and biomedicine.

Theranostic based personalized medicine has more success rate when compared to conventional medicine systems. Nano-formulations are used in curing cancer have been proved to be effectively useful. Multiple therapeutic agents can be delivered by nanocarriers to tumor sites. Liposomes, metallic nanoparticles, CNTs, and quantum dots are examples of nano formulations that can be used for cancer theranostics. For superior theranostic applications and utilization, all the three agents used in imaging, therapeutics, and targeting need some more extensive research and tailored for specific applications as a personalized medicine.

ACKNOWLEDGEMENT

The author wish to express their sincere gratitude to Department of Pharmaceutics, Joginpally B.R Pharmacy College, Faculty of Pharmacy, JNTUH, Bhaskar Nagar, Yenkapally, Moinabad, Telangana, India for providing necessary facilities to carry out this review work.

CONFLICT OF INTEREST

We declare that we have no conflict of interest.

REFERENCES

1. Dizaj S M, Lotfipour F, Barzegar-Jalali M, *et al.* Antimicrobial activity of the metals and metal oxide nanoparticles, *Materials Science and Engineering: C,* 44, 2014, 278-284.
2. Panigrahi S, Basu S, Praharaj S, *et al.* Synthesis and size-selective catalysis by supported gold nanoparticles: study on heterogeneous and homogeneous catalytic process, *J Phys Chem C,* 111(12), 2007, 4596-4605.
3. Woo Y, Lai D Y. Aromatic amino and nitro-amino compounds and their halogenated derivatives, Bingham E, Cohrssen B, Powell C H. Patty's toxicology, *Wiley,* 6^{th} Edition, 2012, 6200.
4. Lim S H, Ahn E Y, Park Y. Green synthesis and catalytic activity of gold nanoparticles synthesized by Artemisia capillaris water extract, *Nanoscale Res Lett,* 11(1), 2016, 474.
5. Rostami-Vartooni A, Nasrollahzadeh M, Alizadeh M. Green synthesis of perlite supported silver nanoparticles using Hamamelisvirginiana leaf extract and investigation of its catalytic activity for the reduction of 4-nitrophenol and Congo red, *Journal of Alloys and Compounds,* 680, 2016, 309-314.
6. Sharma J K, Akhtar M S, Ameen S, *et al.* Green synthesis of CuO nanoparticles with leaf extract of *Calotropisgigantea* and its dye-sensitized solar cells applications, *Journal of Alloys and Compounds,* 632, 2015, 321-325.

7. Gopalakrishnan R, Loganathan B, Dinesh S, Raghu K. Stratergic green-synthesis and characterization and catalytic application to 4-nitrophenol reduction of palladium nano particles, *J Clust Sci,* 28(4), 2017, 2123-2131.
8. Gangula A, Podila R, Rao A M, *et al*. Catalytic reduction of 4-nitrophenol using biogenic gold and silver nanoparticles derived from *Breyniarhamnoides*, *Langmuir,* 27(24), 2011, 15268-15274.
9. Singh J, Kukkar P, Sammi H, *et al*. Enhanced catalytic reduction of 4-nitrophenol and congo red dye by silver nanoparticles prepared from *Azadirachtaindica* leaf extract under direct sun light exposure, *Part Sci Technol,* 37(4), 2017, 434-443.
10. Yuan C G, Huo C, Gui B, *et al*. Green synthesis of silver nanoparticles using *Chenopodiumaristatum* L. stem extract and their catalytic/antibacterial activities, *J Clust Sci,* 28(3), 2017, 1319-1333.
11. Carmen Z, Daniel S. Textile organic dye characteristics, polluting effects and separation or elimination procedures from industrial effluents - a critical overview, Organic pollutants ten years after the stockholm convention environmental and analytical update, *London, In Tech,* 2012, 56-86.
12. Ratna P B S. Pollution due to synthetic dyes toxicity and carcinogenicity studies and remediation, *Int J Environ Sci,* 3(3), 2012, 940-955.
13. Devi H S, Singh T D. Synthesis of copper oxide nanoparticles by a novel method and its application in the degradation of methyl orange, *Adv Electron Electr Eng,* 4(1), 2014, 83-88.
14. Bhuyan T, Mishra K, Khanuja M, *et al*. Biosynthesis of zinc oxide nanoparticles from Azardiractaindica for antibacterial and photocatalytic applications, *Mater Sci Semicond Process,* 32, 2015, 55-61.
15. Stan M, Popa A, Toloman D, *et al*. Enhanced photocatalytic degradation properties of zinc oxide nanoparticles synthesized by using plant extracts, *Mater Sci Semicond Process,* 39, 2015, 23-29.
16. Thandapani K, Kathiravan M, Namasivayam E, *et al*. Enhanced larvicidal, antibacterial, and photocatalytic efficacy of TiO2 nanohybrids green synthesized using the aqueous leaf extract of *Parthenium hysterophorus, Environ Sci Pollut Res,* 25(11), 2017, 1-12.
17. Wang T, Yang L, Zhang B, Liu J. Extracellular biosynthesis and transformation of selenium nanoparticles and application in H2O2 biosensor, *Colloids Surf. B, Bio Interfaces,* 80(1), 2010, 94-102.
18. Du L, Jiang H, Liu X, Wang E. Biosynthesis of gold nanoparticles assisted by *Escherichia coli* DH5_ and its application on direct electrochemistry of hemoglobin, *Electrochemistry Communication,* 9(5), 2007, 1165-1170.
19. Ramya S, Shanmugasundaram T, Balagurunathan R. Biomedical potential of actinobacterially synthesized selenium nanoparticles with special reference to anti-biofilm, antioxidant, wound healing, cytotoxic and anti-viral activities, *J. Trace Elem. Med. Biol,* 32, 2015, 30-39.
20. Bao H, Lu Z, Cui X, Qiao Y, Guo J, Anderson J M, Li C M. Extracellular microbial synthesis of biocompatible CdTe quantum dots, *Acta Biomater,* 6(9), 2010, 3534-3541.
21. Suresh A K, Pelletier D A, Wang W, Broich M L, Moon J W, Gu B, Allison D P, Joy D C, Phelps T J, Doktycz M J. Biofabrication of discrete spherical gold nanoparticles using the metal-reducing bacterium shewanella oneidensis, *Acta Biomater,* 7(5), 2011, 2148-2152.
22. Suresh A K, Pelletier D A, Wang W, Moon J W, Gu B, Mortensen N P, David P, Allison D C, Joy C, Phelps T J, *et al*. Silver nanocrystallites: Biofabrication using *Shewanella oneidensis* and an evaluation of

their comparative toxicity on gram-negative and gram-positive bacteria, *Environ. Sci. Technol,* 44(13), 2010, 5210-5215.

23. Manivasagan P, Alam M S, Kang K H, Kwak M, Kim S K. Extracellular synthesis of gold bio-nanoparticles by Nocardiopsis sp. and evaluation of its antimicrobial, antioxidant and cytotoxic activities, *Biopr Biosyst. Eng,* 38(6), 2015, 1167-1177.
24. Roychoudhury P, Gopal P K, Paul S, Pal R. Cyanobacteria assisted biosynthesis of silver nanoparticles-A potential antileukemic agent, *J. Appl. Phycol,* 28(6), 2016, 3387-3394.
25. Al-Dhabi N, Mohammed Ghilan A K, Arasu M. Characterization of silver nano materials derived from marine Streptomyces sp. al-dhabi-87 and its *in vitro* application against multi- drug resistant and extended-spectrum beta-lactamase clinical pathogens, *Nanomaterials,* 8(5), 2018, 279.
26. Shao W, Liu H, Liu, X, Sun H, Wang S, Zhang R. pH-responsive release behavior and anti-bacterial activity of bacterial cellulose-silver nanocomposites, *Int. J. Biol. Macromol,* 76, 2015, 209-217.
27. Torres S K, Campos V L, Leon C G, Rodriguez-Llamazares S M, Rojas S M, Gonzalez, M, Mondaca M A. Biosynthesis of selenium nanoparticles by Pantoaagglomerans and their antioxidant activity, *J. Nanopart. Res,* 14(11), 2012, 1-9.
28. Kalishwaralal K, Banumathi E, Pandian S R K, Deepak V, Muniyandi J, Eom, S H, Gurunathan S. Silver nanoparticles inhibit VEGF induced cell proliferation and migration in bovine retinal endothelial cells, *Colloids Surf. B Biointerfaces,* 73(1), 2009, 51-57.
29. Kalishwaralal K, Deepak V, Pandian S R K, Kottaisamy M, Barath Mani Kanth S, Kartikeyan B, Gurunathan S. Biosynthesis of silver and gold nanoparticles using *Brevi bacteriumcasei*, *Colloids Surf. B. Biointerfaces,* 77(2), 2010, 257-262.
30. Ahmad M S, Yasser M M, Sholkamy E N, Ali A M, Mehanni M M. Anticancer activity of biostabilized selenium nanorods synthesized by Streptomyces bikiniensis strain Ess_amA-1, *Int. J. Nanomed,* 10, 2015, 3389-3401.
31. Gurunathan S, Han J W, Eppakayala V, Kim J H. Green synthesis of graphene and its cyto-toxic effects in human breast cancer cells, *Int. J. Nanomed,* 8, 2013, 1015-1027.
32. Hulkoti N I, Taranath T C. Biosynthesis of nanoparticles using microbes-A review, *Colloids Surf. B Biointerfaces,* 121, 2014, 474-483.
33. Luo Q Y, Lin Y, Li Y, Xiong L H, Cui R, Xie Z X, Pang D W. Nanomechanical analysis of yeast cells in Cd Se quantum dot biosynthesis, *Small,* 10(4), 2014, 699-704.
34. Wei R. Biosynthesis of silver and gold alloy nanoparticles for sensitive electrochemical determination of paracetamol, *Int. J. Electrochem. Sci,* 12(10), 2017, 9131-9140.
35. Zheng D, Hu C, Gan T, Dang X, Hu S. Preparation and application of a novel vanillin sensor based on biosynthesis of Au-Ag alloy nanoparticles, *Sens. Actuators B Chem,* 148(1), 2010, 247-252.
36. Syed A, Saraswati S, Kundu G C, Ahmad A. Biological synthesis of silver nano- particles using the fungus Humicola sp. and evaluation of their cyto toxicity using normal and cancer cell lines, *Spectrochim. Acta Part A Mol. Biomol. Spectrosc,* 114, 2013, 144-147.
37. Mishra A, Tripathy S K, Wahab R, Jeong S H, Hwang I, Yang Y B, Kim Y S, Shin H S, Yun S I. Microbial synthesis of gold nanoparticles using the fungus *Penicilliumbrevi compactum* and their cytotoxic effects against mouse mayo blast cancer C2 C12 cells, *Cancer Microbiol. Biotechnol,* 92(3), 2011, 617-630.
38. Uddandarao P, Balakrishnan R M, Ashok A, Swarup S, Sinha P. Bioinspired ZnS: Gd Nanoparticles Synthesized from an Endophytic Fungi Aspergillus flavus for

Fluorescence-Based Metal Detection, *Biomimetics,* 4(1), 2019, 11.

39. Priyanka U, Akshay Gowda K M, Elisha M G, Nitish N. Biologically synthesized PbS nanoparticles for the detection of arsenic in water, *Int. Biodeterior. Biodegrad,* 119, 2017, 78-86.
40. Dahoumane S A, Mechouet M, Alvarez F J, Agathos S N, Je-ryes C. Microalgae: An outstanding tool in nanotechnology, *Bionatura,* 1(4), 2016, 196-201.
41. Senapati S, Syed A, Moeez S, Kumar A, Ahmad A. Intracellular synthesis of gold nanoparticles using alga Tetraselmis kochinensis, *Mater. Lett,* 79, 2012, 116-118.
42. Jena J, Pradhan N, Nayak R R, Dash B P, Sukla L B, Panda P K, Mishra B K. Microalga scenedesmus sp: A potentil low-cost green machine for silver nanoparticle synthesis, *J. Microbiol. Biotechnol,* 24(4), 2014, 522-533.
43. Ozturk B Y. Intracellular and extracellular green synthesis of silver nanoparticles using *Desmodesmus sp*: Their Antibacterial and antifungal effects, *Caryol. Int. J. Cytol. Cytosystem Cytogenet,* 72(1), 2019, 29-43.
44. Skeffington A W, Scheffel A. Exploiting algal mineralization for nanotechnology: Bringing coccoliths to the fore, *Curr. Opin. Biotechnol,* 49(C), 2018, 57-63.
45. Pannico M, Rea I, Chandrasekaran S, Musto P, Voelcker N H, De Stefano L. Electroless gold-modified diatoms as surface-enhanced Raman scattering supports, *Nanoscale Res. Lett,* 11, 2016, 315.
46. Kim S H, Nam O, Jin E, Gu M B. A new coccolith modified electrode-based biosensor using a cognate pair of aptamers with sandwich-type binding, *Biosens. Bioelectron,* 123, 2019, 160-166.
47. Gale D K, Gutu T, Jiao J, Chang C H, Rorrer G L. Photoluminescence detection of bio-molecules by antibody-functionalized diatom biosilica, *Adv. Funct. Mater,* 19(6), 2009, 926-933.
48. Zhen L, Ford N, Gale D K, Roesijadi G, Rorrer G L. Photoluminescence detection of 2, 4, 6-trinitrotoluene (TNT) binding on diatom frustule biosilica functionalized with an anti-TNT monoclonal antibody fragment, *Biosens. Bioelectron,* 79, 2016, 742-748.
49. Li A, Cai J, Pan J, Wang Y, Yue Y, Zhang D. Multi-layer hierarchical array fabricated with diatom frustules for highly sensitive bio-detection applications, *J. Micromech. Microeng,* 24(2), 2014, 025014.
50. Khetani S R, Bhatia S N. Engineering tissues for *in vitro* applications, *Curr Opin Biotechnol,* 17(5), 2006, 524-531.
51. Rivron N C, Liu J, Rouwkema J, De Boer J, Van Blitterswijk C A. Engineering vascularised tissues *in vitro*, *Eur Cell Mater,* 15, 2008, 27-40.
52. Ryu W, Fasching R J, Vyakarnam M, *et al*. Microfabrication technology of biodegradable polymers for interconnecting microstructures, *J Microelectromech Syst,* 15(6), 2006, 1457-1465.
53. Nakanishi J, Takarada T, Yamaguchi K, *et al*. Recent advances in cell micro patterning techniques for bioanalytical and biomedical sciences, *Anal Sci,* 24(1), 2008, 67-72.
54. Chung Bong Geun, Kang Lifeng, Khademhosseini Ali. Micro-and nanoscale technologies for tissue engineering and drug discovery applications, *Expert Opin Drug Discovery,* 2(12), 2007, 1653-1668.
55. Hobernik D, Bros M. DNA vaccines-how far from clinical use? *Int. J. Mol. Sci,* 19(11), 2018, 3605.
56. Shah M A A, Ali Z, Ahmad R, Qadri I, Fatima K, He N. DNA mediated vaccines delivery through nanoparticles, *J. Nanosci. Nanotechnol,* 15(1), 2015, 41-53.
57. Garber K. Alnylam launches era of RNAi drugs, *Nat. Publ. Group,* 36(9), 2018, 777-778.
58. Lim E K, Kim T, Paik S, Haam S, Huh Y M, Lee K. Nanomaterials for theranostics: Recent

advances and future challenges, *Chem Rev,* 115(1), 2015, 327-394.

59. Chen J, Wang D, Xi J, Au L, Siekkinen A, Warsen A, *et al*. Immuno gold nanocages with tailored optical properties for targeted photothermal destruction of cancer cells, *Nano Lett,* 7(5), 2007, 1318-1322.
60. Huang X, El Sayed I H, Qian W, El Sayed M A. Cancer cells assemble and align gold nano rods conjugated to antibodies to produce highly enhanced, sharp, and polarized surface Raman spectra: A potential cancer diagnostic marker, *Nano Lett,* 7(6), 2007, 1591-1597.
61. Rose D P, Connolly J M. Antiangiogenicity of docosahexaenoic acid and its role in the suppression of breast cancer cell growth in nude mice, *Int J On,* 15(5), 1999, 1011-1015.
62. Turkevich J, Stevenson P C, Hillier J. A study of the nucleation and growth processes in the synthesis of colloidal gold, *Discuss Faraday Soc,* 11, 1951, 55-75.
63. Han S, Lin J, Zhou F, Vellanoweth R L. Oligonucleotide capped gold nanoparticles for improved atomic force microscopic imaging and enhanced selectivity in polynucleotide detection, *Biochem Biophys Res Commun,* 279(1), 2000, 265-269.
64. Son S J, Bai X, Lee S B. Inorganic hollow nanoparticles and nanotubes in nanomedicine: Part 1, Drug/gene delivery applications, *Drug Discov Today,* 12(15-16), 2007, 650-656.
65. Li Y, Lee H J, Corn R M. Fabrication and characterization of RNA aptamer microarrays for the study of proteinaptamer interactions with SPR imaging, *Nucleic Acids Res,* 34(22), 2006, 6416-6424.
66. Lee J S, Ulmann P A, Han M S, Mirkin C A. A DNA gold nanoparticle based colorimetric competition assay for the detection of cysteine, *Nano Lett,* 8(2), 2008, 529-533.
67. Kim S Y, Lee Y, Cho M S, Son Y, Chang J K. Formation of gold nanoparticles during the vapor phase oxidative polymerization of EDOT using HAuCl4 oxidant, *Mol Cryst Liq Cryst,* 472(1), 2007, 201-591.
68. Aroui S, Brahim S, Waard M D, Kenani A. Cytotoxicity, intracellular distribution and uptake of doxorubicin and doxorubicin coupled to cell penetrating peptides in different cell lines: A comparative study, *Biochem Biophys Res Commun,* 391(1), 2010, 419-425.
69. Wang C H, Huang Y J, Chang C W, Hsu W M, Peng C A. *In vitro* photo thermal destruction of neuro blastoma cells using carbon-nanotubes conjugated with GD 2 monoclonal antibody, *Nanotechnology,* 20(31), 2009, 315101.
70. Liu Z, Robinson J T, Tabakman S M, Yang K, Dai H. Carbon materials for drug delivery and Cancer Therapy, *Mater Today,* 14(7-8), 2011, 316-323. Xie J, Lee S, Chen X. Nanoparticle based theranostic agents, *Adv Drug Deliv Rev,* 62(11), 2010, 1064-1079.
71. Xie J, Lee S, Chen X. Nanoparticle based theranostic agents, *Adv Drug Delivery Rev,* 62(11), 2010, 1064-1079.
72. Tanaka T, Shiramoto S, Miyashita M, Fujishima Y, Kaneo Y. Tumor targeting based on the effect of enhanced permeability and retention (EPR) and the mechanism of receptor mediated endocytosis (RME), *Int J Pharm,* 277(1-2), 2004, 39-61.
73. Gregoriadis G, Florence A T. Liposomes in drug delivery, *Drugs,* 45(1), 1993, 15-28.
74. Sharma A, Sharma U S. Liposomes in drug delivery: Progress and limitations, *Int J Pharma,* 154(2), 1997, 123-140.

Please cite this article in press as: Rajeswari A V S and Sharma J V C. A review on novel applications of nanotechnology, *International Journal of Research in Pharmaceutical and Nano Sciences,* 9(4), 2020, 174-183.