Biomedical
Communication

BBRC
Bioscience Biotechnology
Research Communications

Biosc.Biotech.Res.Comm. Vol 13 No (4) Oct-Nov-Dec 2020 Pp-1717-1722

Biomedical Properties of Metal Nanoparticles for Cancer Therapeutics and Management

Rangnath Ravi[1], A.M. Khan[2] and Abhijeet Mishra*[3]

[1]*Department of Chemistry, Sri Aurobindo College, University of Delhi, New Delhi-110017, India.*
[2]*Department of Chemistry, Motilal Nehru College, University of Delhi, New Delhi-110021, India*
[3]*School of Life Sciences, Jawaharlal Nehru University, New Delhi-110067, India*

ABSTRACT

The nanoparticles (NPs) drawn more interest as they fill the gap between bulk materials and atomic, molecular, bio-molecular or cellular structures. The fabrication of novel metal NPs is a demanding area of research because they display distinctive properties, different from those of bulk counterparts. Because of stability, oxidation resistance metal NPs find wide applications in different areas. For each unique application, NPs of different size and shape are mandatory, therefore several protocols for the preparations of NPs are required. However, other methods such as chemical and physical methods may fruitfully generate pure and well-defined nanoparticles, these are expensive and potentially hazardous to the environment. The use of biological agents can be an alternative to chemical and physical agents for the production of NPs in an eco-friendly manner. In the past decade, plants, algae, fungi, bacteria, viruses and enzymes have been used for the production of low-cost, energy-efficient and nontoxic metallic nanoparticles. Metallic NPs have wide applications in many areas such as engineering, biosensors, catalysis, biomedical and drug delivery. The smaller size of the NPs allows readily interaction with biological system while the material compositions of NPs gives stability and specificity which are important for drug delivery and biocompatibility. In addition, anticipation for development in personalized treatment and management so it make possible to develop and manage the suitable drug. Presently, the utmost area of nanomedicine is the improvement and use of NPs for drug delivery in cancer. NPs are engineered so that they are appealed to cancer cells, which leads to direct treatment of those cells. This methodology decreases damage to healthy cells in the body and also allows for earlier detection of cancer.

KEY WORDS: METAL NANOPARTICLES, SILVER, GOLD, CANCER, BIOMEDICAL.

Article Information:
Corresponding author email: *abhijeetjmi@gmail.com*
Received 20/10/2020 Accepted after revision 12/12/2020
P-ISSN: 0974-6455 E-ISSN: 2321-4007
Thomson Reuters ISI Clarivate Analytics
Web of Science ESCI Indexed Journal

Identifiers & Pagination:
Vol 13(4) E-Pub 31st Dec 2020 Pp- 1717-1722

Published by Society for Science & Nature India
DOI: *http://dx.doi.org/10.21786/bbrc/13.4/13*

INTRODUCTION

Novel metal nanoparticles show outstanding unique physiochemical and biological characteristics. Noble metal nanoparticles can be used in different areas such as biosensor, catalysis, antibacterial, anticancer, antimalarial and antiviral (Marin et al., 2015). In the present decade, fabrication of novel metal nanoparticles can be achieved via various procedures (Mousavi et al., 2016). Although, chemical based methods are the widely applied methods for the fabrication of nanostructure. Though, chemical processes cannot prevent the use or generation of by-product of hazardous chemicals (Celik et al., 2017). However, metallic nanoparticles are extensively used for medical biotechnology including human contacting areas.

Therefore, there is an increasing demand to develop environmentally sustainable methods of nanoparticle fabrication without uses of toxic ingredients (Saratale et al., 2018, Iravani et al., 2020). Among several metal nanoparticles, silver and gold, have been studied and are useful in different fields such as antimicrobials, biosensors, drug and gene delivery etc. In addition, Ag and Au nanoparticles have a unique surface plasmon resonance (SPR) absorption in the UV-vis region. However, now a days bimetallic and trimetallic nanoparticles have also used due to unique properties for biomedical applications such as cancer treatment. (Ali et al., 2020, Ravi et al., 2020) There are different types of metal nanoparticles are described below:

Based on morphology: NPs can also be classified on the basis of their morphologies such as aspect ratio and sphericity. The high aspect ratio nanomaterials of various design such as nano-sphere and nanocubes having low aspect ratio while nanowires having high aspect ratio (You et al., 2017, Singh et al., 2020).

Based on constituents and structures: NPs are either of single or multiple moieties, they may be of organic-inorganic hybrid nature (more than one constituent). The structures of the NPs depend on the nature of these constituents, which are used as reaction precursors during their preparation. Based on nature of constituents, NPs can also be classified as:

Organic NPs: Organic moieties such as lipid, polymers and natural/synthetic organic materials are covered in the class of organic NPs (ONPs) (Rizwan et al., 2017). They are applied in the form of liposomes, metal organic frameworks, polymeric micelles of polyacrylate, polycarbonate, polyester etc. (Zakharova et al., 2017). There are many FDA approved ONPs, which are used as controlled release agents to deliver the desired moiety to the target site. For instance, leuprorelin acetate (synthetic gonadotropin release hormone, GnRH) depot releases in 6 months, is used for the cure of prostate cancer (Hebenstreit et al.,2020).

Polymeric NPs: The polymeric nanoparticles (PNPs) are categorized as colloidal particles of nano scale, which are derived from various polymers including natural, semisynthetic and synthetic polymers (Mohammadi et al., 2020). Some of these NPs are pH and temperature sensitive and prepared from biocompatible and biodegradable polymers.

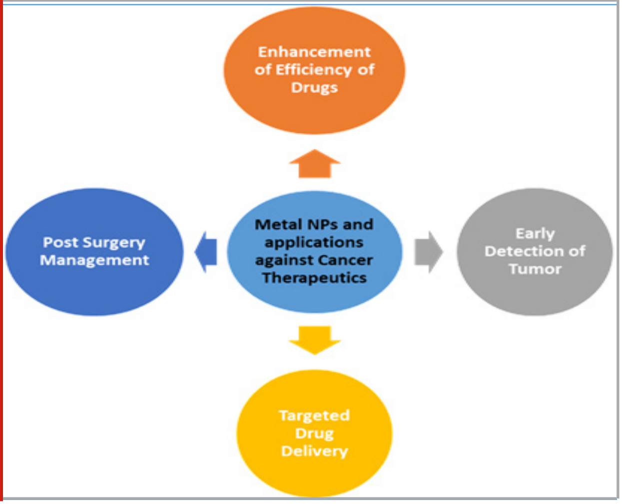
Dendrimers: Dendrimers are three dimensions globular molecules, mono-dispersed with repeating units having large number of functional groups present on their surfaces. The word “dendrimer” was elicited from Greek word “dendron” that symbolizes a tree (Sapra et al., 2019). They are highly dense and less viscous due to their extensive branching (Patel et al., 2020).

Liposomes: Liposomes are colloidal nanomaterial having vesicular structure. Liposomes are usually made up of phospholipids while few are made up of phosphatidylcholine (Daraee et al., 2016). In liposomes, the double phospholipid layers have an internal aqueous cavity. They are amphiphilic nature and exhibits biocompatibility (Ding et al., 2020).

Inorganic NPs: Inorganic NPs are characterized as particles of nano-sized prepared by the applications of inorganic moieties like metalloid and metal (Tabesh et al., 2017). They possess specific and unique properties, which mainly depend on their sizes. Special properties of inorganic NPs such as versatile physical, chemical, optical and magnetic makes them available for various applications in water treatment to biomedical (Zhao et al., 2018). NPs like gold and silver have strong absorbance and high electron density and particles like iron oxide has great magnetic characteristics. From literature, it can be concluded that Metallic NPs are particularly, prepared at optimum temperature, have no effect on changing the pH and are non-toxic to healthy cells (Yilmaz et al., 2018). Moreover, the novel inventions of magnetic metallic NPs introduced them in environmental applications. (Ravi et al.2019) The use of magnetic NPs particularly in adsorption technology may promise to advance the technique through the post adsorption magnetic separation of adsorbents (Arabkhani et al.,2020). All these features of metallic NPs are size dependent and in many cases, they are considered as best materials. These metallic NPs can be classified as:

Zerovalent (ZV) metallic NPs: ZV Metallic NPs have significant importance due to their distinguished properties in nanoscale compared to their bulk state. They are employed in several applications such as sensing, catalysis, adsorption and imaging due to their unique optical property, sensitivity and larger surface area along with significant photo-stability (Hai et al., 2018). Several methods are employed for the synthesis of these NPs, such as chemical, biological, electrochemical, photolytic, etc. Among them, the most significant and widely used synthetic method is the wet chemical method (chemical precipitation or chemical reduction) and biological. ZV Metallic NPs are synthesized in their uncharged state (zero-valent) through the reduction of their metal precursor using a common reducing agent i.e., chemical reduction and/or plant extraction method (Reverberi et al., 2018).

Figure 1: Graphical representation of metal nanoparticles and their different applications against various cancer types.



The ZV metallic NP appears different in different conditions, e.g. ZV gold NPs in bulk state is yellow but its aqueous dispersion in nanoscale ranges from red or violet. Similarly, ZV silver NPs looks yellow in their aqueous nanoscale formulation while ZV iron NPs appear in greenish color under aerobic conditions. These changes in appearance are mainly attributed to the mutual oscillations of the electrons in conduction band caused due to the light exposure of a specific wavelength and power. This is a well-known phenomenon termed as localized surface plasmon resonance (LSPR), which occurs due to the collective oscillations of electrons in an externally applied electric field (Feng et al., 2020).

Metal NPs as cancer treatment agent: Cancer is considered as one of the biggest challenges faced by the medical researchers in recent time. The high cost and strong side effects of available options limits their applications for cancer treatment. Further, the timely diagnosis and prognosis of cancer is still a difficult task (Mishra et al., 2012, Restifo et al., 2016) Moreover, the approaches usually used for cancer treatment such as surgery, radiation and chemotherapy have considerable harmful effects (Gill et al., 2014). Thus, there is a crucial need for application of new feasible and novel methods (non-invasive and minimally invasive) for the early diagnosis and therapy of cancers (Li et al., 2015). In this regard, bimetallic nanoparticles (BNPs) and trimetallic nanoparticles (TNPs) have come up as a potential candidate for the cancer therapeutics, which has given a new field of research in the form of cancer nanomedicine. BNPs and TNPs provide the basis for the continuous and targeted release of the anticancer agent at a pace and at a venue to overcome the issues of standard diagnostic and therapeutic methods (Senapati et al.,2018, Sivamaruthi et al., 2019). Fig 1. shows illustration of applications of different metal nanoparticles against various cancers.

Table 1. Anticancer Applications of Metal Nanoparticles

S.N.	Name of Metal Nanoparticles	Size of Nanoparticles (nm)	Application against Cancer Cells/ Tumors	Ref.
1	Silver (Ag)	4.99-25.83	MCF-7	(Jhang et al., 2016)
2	Silver (Ag)	22–85	MCF-7, PC-3, A549, HCT-116	(Abd-Elnaby et al., 2016)
3 4	Silver (Ag) Silver (Ag)	10-80	HepG2, A549	(Rajeshkumar et al., 2016)
	Gold (Au)	24-150	HCT-116	(Kuppusamy et al., 2016)
5	Gold (Au)	50-100	HT-29	(Bai et al., 2018)
6	Gold (Au)	10-40	HeLa	(Patil et al., 2019)
7	Silver (Ag)	10-20	DU154, A549, MCF-7, A431	(Singh et al., 2020)
8	Silver (Ag)	24-54	MCF-7	(Kiran et al., 2020)
9	Gold (Au)	5-10	MCF-7	(Munawer et al., 2020)
10	Silver (Ag)	15.45	MCF-7	(Nawaz et al., 2020)

On this account, several researchers have made their effort to synthesize BNP and TNPs also investigated their cancer therapeutic activities. For instance, wang et al. have reported rapid and single-pot approach for the synthesis of Cu/Au/Pt TNPs. The TNPs showed high catalytic behaviour and strong plasmonic absorption in the NIR-I bio window (650-950 nm). Because of these properties, the synthesized Cu/Au/Pt TNPs was used for the application in biosensing and cancer theranostics. The trimetallic nanoparticles have also been used for dye removal and cancer treatment. For instance, Basavegowda et al. (2017) have synthesized trimetallic Fe-Ag-Pt nanoparticles via ultra-sonication. These trimetallic alloys nanostructures have exhibited excellent catalytic efficiency and have also been used for other applications. Ahmad et al. (2019) formulated trimetallic.

Au/Pt/Ag nanoparticle based nanofluids by green microwave assisted successive chemical reduction method and used this to check the antibacterial activity and compared to these of monometallic Au and bimetallic Au/Pt nanofluid. Liang et al. (2018) immobilized trimetallic Cu-Ni-Co nanoparticles onto the pores of the metal-organic framework by a simple but unique solvent evaporation approach and compared to their bimetallic and monometallic equivalents.

These investigations revealed that the Cu-Ni-Co trimetallic catalysts display superior catalytic activity. Recently, Gu et al. (2019) have synthesized carbon dots embedded bimetallic ZrHf-based metal-organic framework (CDs@ZrHf-MOF). The synthesized bimetallic NP was used to assess to differentiate human epidermal growth factor receptor-2 (HER2) and living HER2-overexpressed MCF-7 cells. Ma et al. (2015) fabricated extremely sensitive electrochemical immune sensor for the sensing of bladder cancer biomarker i.e. nuclear matrix protein 22 (NMP22). This sensor contain reduced graphene oxide–tetraethylene pentamine (rGO–TEPA) and trimetallic AuPdPt NPs. Sharma et al. (2018) have designed Zr2Ni1Cu7 trimetallic nanoparticle and its composite with Si3N4. Both the composite and TNPs were subjected to photo-degradation of methylene blue under visible light. Pradhan et al. (2007) have reported the synthesis and characterization of manganese ferrite based magnetic liposomes. The synthesized materials was further applied for hyperthermia cancer treatment.

CONCLUSION

Thus, based on above literature survey, it can be concluded that the metal NPs could be used as anticancer agent. However, the scant work has been reported on their applications in cancer treatment. Tireless efforts are being made to use metal NPs in the field of cancer management, and further, it was observed that metal NPs have an enormous capability to improve the efficacy of cancer therapeutics. In addition, animal model and clinical human trials are necessary part for the practical applications for these nanoparticles.

REFERENCES

Abd-Elnaby, H. M., Abo-Elala, G. M., Abdel-Raouf, U. M., & Hamed, M. M. (2016). Antibacterial and anticancer activity of extracellular synthesized silver nanoparticles from marine *Streptomyces rochei* MHM13. The Egyptian Journal of Aquatic Research, 42(3), 301-312.

Ahmed, H. B., Emam, H. E. (2019). Synergistic catalysis of monometallic (Ag, Au, Pd) and bimetallic (AgAu, AuPd) versus Trimetallic (Ag-Au-Pd) nanostructures effloresced via analogical techniques. Journal of Molecular Liquids, 287, 110975.

Ali, S., Sharma, A. S., Ahmad, W., Zareef, M., Hassan, M. M., Viswadevarayalu, A., Chen, Q. (2020). Noble Metals Based Bimetallic and Trimetallic Nanoparticles: Controlled Synthesis, Antimicrobial and Anticancer Applications. Critical Reviews in Analytical Chemistry, 1-28.

Arabkhani, P., Asfaram, A. (2020). Development of a novel three-dimensional magnetic polymer aerogel as an efficient adsorbent for malachite green removal. Journal of hazardous materials, 384, 121394.

Bai Aswathanarayan, J., Rai Vittal, R., & Muddegowda, U. (2018). Anticancer activity of metal nanoparticles and their peptide conjugates against human colon adenorectal carcinoma cells. Artificial Cells, Nanomedicine, and Biotechnology, 46(7), 1444-1451.

Basavegowda, N., Mishra, K., Lee Y.R., (2017) Trimetallic FeAgPt alloy as a nanocatalyst for the reduction of 4-nitroaniline and decolorization of rhodamine B: A comparative study. J. Alloys Compd., 701, 456-464.

Çelik, D., & Yıldız, M. (2017). Investigation of hydrogen production methods in accordance with green chemistry principles. International journal of hydrogen energy, 42(36), 23395-23401.

Daraee, H., Etemadi, A., Kouhi, M., Alimirzalu, S., & Akbarzadeh, A. (2016). Application of liposomes in medicine and drug delivery. Artificial cells, nanomedicine, and biotechnology, 44(1), 381-391.

Ding, X., Yin, C., Zhang, W., Sun, Y., Zhang, Z., Yang, E.,Wang, W. (2020). Designing Aptamer-Gold Nanoparticle-Loaded pH-Sensitive Liposomes Encapsulate Morin for Treating Cancer. Nanoscale research letters, 15, 1-17.

Feng, C., Tang, L., Deng, Y., Wang, J., Liu, Y., Ouyang, X., Wang, J. (2020). Maintaining stable LSPR performance of W18O49 by protecting its oxygen vacancy: A novel strategy for achieving durable sunlight driven photocatalysis. Applied Catalysis B: Environmental, 119167.

Gill, B. S., Lin, J. F., Krivak, T. C., Sukumvanich, P., Laskey, R. A., Ross, M. S., Beriwal, S. (2014). National Cancer Data Base analysis of radiation therapy consolidation modality for cervical cancer: the impact of new technological advancements. International Journal of Radiation Oncology Biology Physics, 90(5), 1083-1090.

Gu, C., Guo, C., Li, Z., Wang, M., Zhou, N., He, L., Du, M. (2019). Bimetallic ZrHf-based metal-organic framework embedded with carbon dots: Ultra-sensitive platform for early diagnosis of HER2 and HER2-overexpressed living cancer cells. Biosensors and Bioelectronics, 134, 8-15.

Hai, X., Feng, J., Chen, X., & Wang, J. (2018). Tuning the optical properties of graphene quantum dots for biosensing and bioimaging. Journal of Materials

Chemistry B, 6(20), 3219-3234.
Hebenstreit, D., Pichler, R., & Heidegger, I. (2020). Drug-drug interactions in prostate cancer treatment. Clinical genitourinary cancer, 18(2), e71-e82.
Iravani, S., & Varma, R. S. (2020). Greener synthesis of lignin nanoparticles and their applications. Green Chemistry, 22(3), 612-636.
Jang, S. J., Yang, I. J., Tettey, C. O., Kim, K. M., & Shin, H. M. (2016). In-vitro anticancer activity of green synthesized silver nanoparticles on MCF-7 human breast cancer cells. Materials Science and Engineering: C, 68, 430-435.
Kiran, M. S., Betageri, V. S., Kumar, C. R., Vinay, S. P., Latha, M. S. (2020). In-Vitro Antibacterial, Antioxidant and Cytotoxic Potential of Silver Nanoparticles Synthesized Using Novel *Eucalyptus tereticornis* Leaves Extract. Journal of Inorganic and Organometallic Polymers and Materials, 1-10.
Ko, S. H., Park, I., Pan, H., Grigoropoulos, C. P., Pisano, A. P., Luscombe, C. K., Fréchet, J. M. (2007). Direct nanoimprinting of metal nanoparticles for nanoscale electronics fabrication. Nano letters, 7(7), 1869-1877.
Kuppusamy, P., Ichwan, S. J., Al-Zikri, P. N. H., Suriyah, W. H., Soundharrajan, I., Govindan, N., Yusoff, M. M. (2016). In vitro anticancer activity of Au, Ag nanoparticles synthesized using *Commelina nudiflora* L. aqueous extract against HCT-116 colon cancer cells. Biological trace element research, 173(2), 297-305.
Li, H. Y., Cui, Z. M., Chen, J., Guo, X. Z., Li, Y. Y. (2015). Pancreatic cancer: diagnosis and treatments. Tumor Biology, 36(3), 1375-1384.
Liang, Z., Xiao, X., Yu, X., Huang, X., Jiang, Y., Fan, X., & Chen, L. (2018). Non-noble trimetallic Cu-Ni-Co nanoparticles supported on metal-organic frameworks as highly efficient catalysts for hydrolysis of ammonia borane. Journal of Alloys and Compounds, 741, 501-508.
Ma, H., Zhang, X., Li, X., Li, R., Du, B., & Wei, Q. (2015). Electrochemical immunosensor for detecting typical bladder cancer biomarker based on reduced graphene oxide–tetraethylene pentamine and trimetallic AuPdPt nanoparticles. Talanta, 143, 77-82.
Marin, S., Mihail Vlasceanu, G., Elena Tiplea, R., Raluca Bucur, I., Lemnaru, M., Minodora Marin, M., & Mihai Grumezescu, A. (2015). Applications and toxicity of silver nanoparticles: a recent review. Current topics in medicinal chemistry, 15(16), 1596-1604.
Mishra, A., Mehdi, S. J., Irshad, M., Ali, A., Sardar, M., Moshahid, M., Rizvi, A. (2012). Effect of biologically synthesized silver nanoparticles on human cancer cells. Science of Advanced Materials, 4(12), 1200-1206.
Mohammadi, M. S., Sahraei, E., Bayati, B. (2020). Synthesis optimization and characterization of high molecular weight polymeric nanoparticles as EOR agent for harsh condition reservoirs. Journal of Polymer Research, 27(2), 41.
Mousavi, M., Habibi-Yangjeh, A., & Abitorabi, M. (2016). Fabrication of novel magnetically separable nanocomposites using graphitic carbon nitride, silver phosphate and silver chloride and their applications in photocatalytic removal of different pollutants using visible-light irradiation. Journal of colloid and interface science, 480, 218-231.
Munawer, U., Raghavendra, V. B., Ningaraju, S., Krishna, K. L., Ghosh, A. R., Melappa, G., & Pugazhendhi, A. (2020). Biofabrication of gold nanoparticles mediated by the endophytic *Cladosporium* species: Photodegradation, in vitro anticancer activity and in vivo antitumor studies. International Journal of Pharmaceutics, 588, 119729.
Nawaz, M. P., Banu, A. A., Mohamed, S. R., Palanivelu, M., & Ayeshamariam, A. (2020). Anticancer Activity of Silver Nanoparticle by Using *Cassia auriculata* Extract. European Journal of Medicinal Plants, 1-9.
Patel, V., Rajani, C., Paul, D., Borisa, P., Rajpoot, K., Youngren-Ortiz, S. R., & Tekade, R. K. (2020). Dendrimers as novel drug-delivery system and its applications. In Drug Delivery Systems (pp. 333-392). Academic Press
Patil, M. P., Bayaraa, E., Subedi, P., Piad, L. L. A., Tarte, N. H., & Kim, G. D. (2019). Biogenic synthesis, characterization of gold nanoparticles using *Lonicera japonica* and their anticancer activity on HeLa cells. Journal of Drug Delivery Science and Technology, 51, 83-90.
Pradhan, P., Giri, J., Banerjee, R., Bellare, J., Bahadur, D. (2007). Preparation and characterization of manganese ferrite-based magnetic liposomes for hyperthermia treatment of cancer. Journal of Magnetism and Magnetic Materials, 311(1), 208-215.
Qu, Z., Wu, J., Wu, J., Ji, A., Qiang, G., Jiang, Y., Ding, Y. (2017). Exosomal miR-665 as a novel minimally invasive biomarker for hepatocellular carcinoma diagnosis and prognosis. Oncotarget, 8(46), 80666.
Rajeshkumar, S., Malarkodi, C., Vanaja, M., & Annadurai, G. (2016). Anticancer and enhanced antimicrobial activity of biosynthesizd silver nanoparticles against clinical pathogens. Journal of molecular structure, 1116, 165-173.
Ravi, R., Mishra, A., (2020) Preparation of Bimetallic and Trimetallic Nanomaterials and their Role in Waste Water Treatment: A Review, Biosc. Biotech. Res. Comm. Vol 13 (3) July-Aug-Sep.
Ravi, R., Iqbal, S., Ghosal, A., & Ahmad, S. (2019). Novel mesoporous trimetallic strontium magnesium ferrite ($Sr0.3Mg0.7Fe2O4$) nanocubes: A selective and recoverable magnetic nanoadsorbent for Congo red.

Journal of Alloys and Compounds, 791, 336-347.

Rizwan, M., Yahya, R., Hassan, A., Yar, M., Azzahari, A. D., Selvanathan, V., Abouloula, C. N. (2017). pH sensitive hydrogels in drug delivery: Brief history, properties, swelling, and release mechanism, material selection and applications. Polymers, 9(4), 137.

Restifo N. P., Smyth M. J., Snyder A. (2016) Acquired resistance to immunotherapy and future challenges. Nat. Rev. Cancer., 16 -121

Reverberi, A. P., Varbanov, P. S., Lauciello, S., Salerno, M., & Fabiano, B. (2018). An eco-friendly process for zerovalent bismuth nanoparticles synthesis. Journal of cleaner production, 198, 37-45.

Sapra, R., Verma, R. P., Maurya, G. P., Dhawan, S., Babu, J., & Haridas, V. (2019). Designer peptide and protein dendrimers: A cross-sectional analysis. Chemical reviews, 119(21), 11391-11441.

Saratale, R. G., Saratale, G. D., Shin, H. S., Jacob, J. M., Pugazhendhi, A., Bhaisare, M., Kumar, G. (2018). New insights on the green synthesis of metallic nanoparticles using plant and waste biomaterials: current knowledge, their agricultural and environmental applications. Environmental Science and Pollution Research, 25(11), 10164-10183.

Senapati, S., Mahanta, A. K., Kumar, S., Maiti, P. (2018). Controlled drug delivery vehicles for cancer treatment and their performance. Signal transduction and targeted therapy, 3(1), 1-19.

Sharma, G., Kumar, A., Sharma, S., Naushad, M., Ahamad, T., Al-Saeedi, S. I., Stadler, F. J. (2018). Facile fabrication of Zr2Ni1Cu7 trimetallic nano-alloy and its composite with Si3N4 for visible light assisted photodegradation of methylene blue. Journal of Molecular Liquids, 272, 170-179.

Singh, S. P., Mishra, A., Shyanti, R. K., Singh, R. P., & Acharya, A. (2020). Silver Nanoparticles Synthesized Using *Carica papaya* Leaf Extract (AgNPs-PLE) Causes Cell Cycle Arrest and Apoptosis in Human Prostate (DU145) Cancer Cells. Biological trace element research, 1-16.

Sivamaruthi, B. S., Ramkumar, V. S., Archunan, G., Chaiyasut, C., Suganthy, N. (2019). Biogenic synthesis of silver palladium bimetallic nanoparticles from fruit extract of *Terminalia chebula*–In vitro evaluation of anticancer and antimicrobial activity. Journal of Drug Delivery Science and Technology, 51, 139-151.

Singh, S., Pandey, P. C. (2020). Synthesis and application of functional Prussian blue nanoparticles for toxic dye degradation. Journal of Environmental Chemical Engineering, 8(3), 103753.

Tabesh, S., Davar, F., Loghman-Estarki, M. R. (2018). Preparation of γ-Al2O3 nanoparticles using modified sol-gel method and its use for the adsorption of lead and cadmium ions. Journal of Alloys and Compounds, 730, 441-449.

Yilmaz, G., Guler, E., Geyik, C., Demir, B., Ozkan, M., Demirkol, D. O., Becer, C. R. (2018). pH responsive glycopolymer nanoparticles for targeted delivery of anti-cancer drugs. Molecular Systems Design & Engineering, 3(1), 150-158.

You, J., Li, M., Ding, B., Wu, X., & Li, C. (2017). Crab Chitin-Based 2D Soft Nanomaterials for Fully Biobased Electric Devices. Advanced Materials, 29(19), 1606895.

Zakharova, L., Pashirova, T., Kashapov, R., Gabdrakhmanov, D., Sinyashin, O. (2017). Drug delivery mediated by confined nanosystems: structure-activity relations and factors responsible for the efficacy of formulations. In Nanostructures for Drug Delivery (pp. 749-806). Elsevier.

Zhao, N., Yan, L., Zhao, X., Chen, X., Li, A., Zheng, D., Xu, F. J. (2018). Versatile types of organic/inorganic nanohybrids: from strategic design to biomedical applications. Chemical reviews, 119(3), 1666-1762.