Review Article: 23 to 32 (2023)
ISSN: 2583-7419
biologyforum.actabotanica.org

Fabrication of biopolymers and their use with metal zinc oxide nanop articles: A Review

Jagram Meena[1]*, Jagjeevan ram[2]

[1]*Department of Chemistry, Gurukul Kangri Deemed to be University, Haridwar 249404 India*
[2]*Department of Physics, Ramjas College, Delhi University, Delhi 110007, India*

Citation: Jagram Meena and Jagjeevan ram (2023). Fabrication of biopolymers and their use with metal zinc oxide nanoparticles: A Review. *Acta Biology Forum.* V02i01, **23-32. DOI:** http://dx.doi.org/10.5281/zenodo.8056710

Corresponding Author: **Jagram Meena** | E-Mail: **(jagram.meena@gkv.ac.in)**

Received 11 October 2022 | Revised 28 December 2022 | Accepted 27 February 2023 | Available Online May 16 2023

ABSTRACT

Zinc oxide nanoparticles have engaged most meditation due to their rare character, such as easy separation, surface-to-volume ratio, paramagnetic and high surface area. Natural biopolymers, namely, (Alginate, Chitosan, Dextran, Cellulose, Guar-Gum, Tamarind, and Pectin have posed as an incredible host for the synthesis of zinc oxide nanoparticles. Zinc oxide nanocomposites made of biopolymers have been created for a long-time employing technique including in-situ, ex-situ, co-precipitations, and green synthesis. Researchers are interested in fabricating biopolymer zinc oxide nanocomposites at the nanoscale for a variety of applications, including targeted drug delivery, sensor activity, catalysis activity, anticancer activity, antimicrobial activity, antifungal activity, antioxidant activity, and adsorption of inorganic/organic impurities. This review is designed to the report very firstly reported biopolymer zinc oxide nanocomposites (BZNCs) in last some areas and attractive approach in numerous applications.

Keywords: *Biopolymer, zinc oxide nanoparticles, antimicrobial, antioxidant, anti-catalyst activity etc.*

INTRODUCTION

Nanotechnology deals with materials having nanoscale in one dimension ranging between 1 to 100 nm. Nanotechnology, when integrated with other fields of study such as life sciences, physics, chemistry, medicine, engineering, cognitive sciences, and information technology, has grown in relevance due to its wide range of applications [1]. It entails changing or creating materials of that size to make them more robust, lightweight, quick, and lasting. Numerous fields, including engineering, biology, chemistry, medicine, modelling, and the bioprocessing sector, have benefited from the use of nanotechnology. These uses depend on a few elements, such as increased surface area, physical characteristics, and nanoscale size, which provide chances for control and result in a wide range of functions. Recent discoveries in biological agents have been made possible by new developments in nanotechnology, particularly the capacity to make designed nanoparticles of any shape and size [2]. Zinc oxide nanoparticles are one of the important metal oxides materials that have been extensively employed in materials research due to their distinctive physical, chemical, and biological properties, such as their biocompatibility, environmental friendliness, low cost, and non-toxic nature [3]. Many different synthesis techniques, such as the sol-gel process, the hydrothermal process, the wet chemical procedure, etc., have been reported worldwide. ZnO NPs can have a variety of orientations, morphologies, sizes, and forms by altering a number of factors, including the type of solvent used, reaction temperature, etc. Here is a quick description of some significant kinds of ZnO NP production techniques. Biopolymers are abundant, low-cost, and naturally ecologically benign polymers. Because they are particularly sustainable, renewable, and non-toxic, opportunities are widely employed in agriculture, industries, medicine, and the environment [12]. This has also been shown in the biopolymers studied in the field of metal-polymer nanocomposites, such as chitosan, starch, alginate, tamarind gum, and pectin. Dextran, Mannan, PAA, PVA-A, Guar gum, cellulose, gelatin, etc.) [4,13-25].

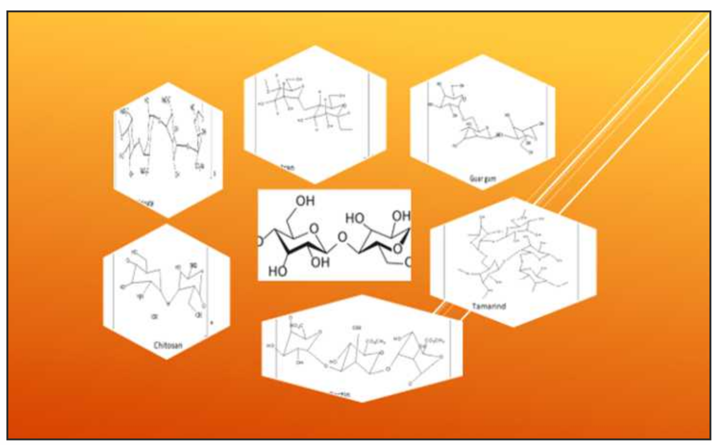

Fig.1 Biopolymers structure

Natural biopolymers are added to zinc oxide nanocomposites, expanding their scope of use for things like biomedical adsorption. Diffusion of drugs in the environment, and microbial activity antioxidant performance anti-cancer and catalytic properties [46-50]. The creation of biopolymer-based magnetic metal nanoparticles and nanocomposites, as well as their uses, are the main topics of the current article. The review will also provide readers with information on current techniques used for the synthesis of BMNPs and their biomedical applications.

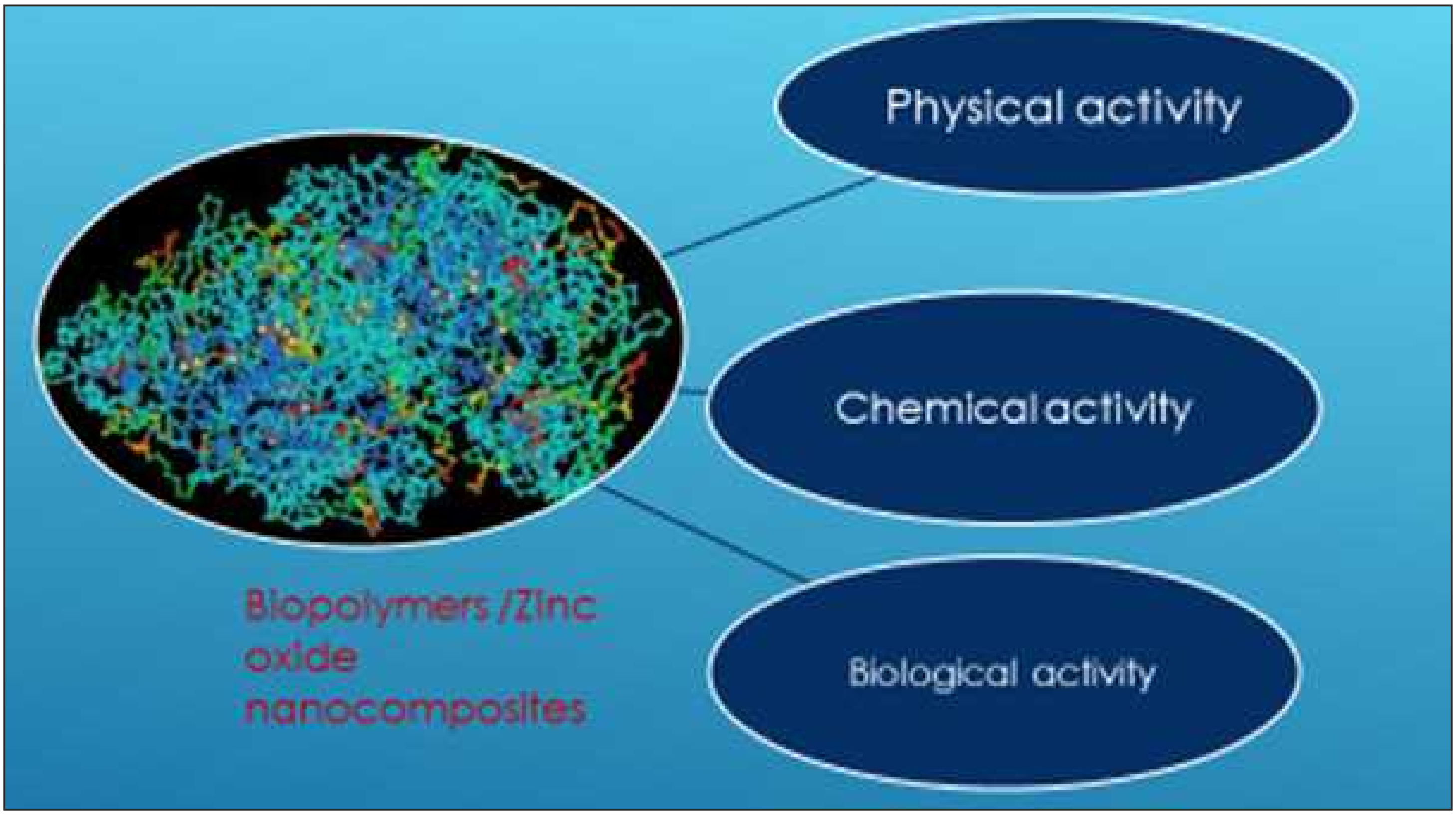

Fig.2 biopolymers zinc oxide physical, chemical and biological activity

2.1 Green synthesis of biopolymer and Zinc oxide nanocomposite (BZNCs)

The green synthesis method is an environmentally friendly, energy-efficient, and cost-effective approach to nanoparticle synthesis. ZnO NPs are synthesized from this method using plants, bacteria, fungi, algae, and viruses. Different ZnO NP orientations, morphologies, sizes, and shapes can be obtained by varying a set of parameters such as solvent type. As novel materials with distinct properties, ZnO-based nanocomposites have piqued the interest of researchers.

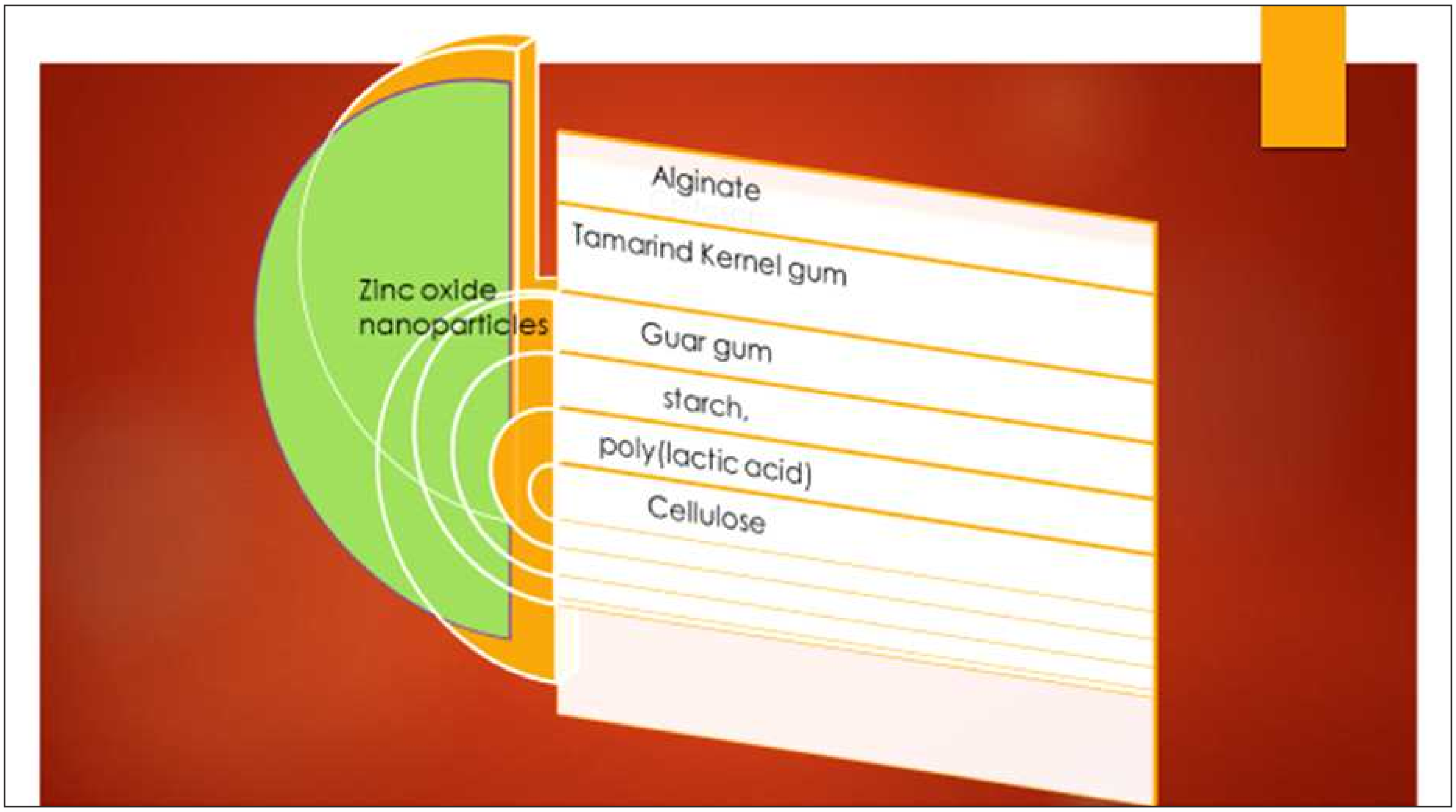

Fig.3 Zinc oxide nanoparticles various biopolymers reduced

The biosynthesis of nanocomposites using environmentally friendly techniques has been the focus of intensive research over the last decade. Green sources function as both reducing agents and stabilizers in the formation of nanoparticles with controlled size and shape. This biopolymer/ZnO composite safeguards the most recent research on essential synthetic techniques and application-driven discussions about biopolymer/ZnO hybrids over the previous decades. The synthetic approach can be divided into two parts: ZnO surface fictionalization and the preparation of biopolymer/ZnO nanocomposites. Polyethylene, chitosan, starch, alginate, tamarind gum, and pectin are examples of biopolymers. Cellulose, gelatine, guar gum, dextran, mannan, PAA, PVA-A, pectin, polyethylene (LLDPE), poly (lactic acid) (PLA), chitosan, tamarind, cellulose, alginate poly (3-hydroxybutyrate-co-3-hydroxy valerate) (PHBV), poly(3-hydroxybutyrate) (PHB), poly(3-hydroxybutyrate) (PHB), semolina flour and bovine skin gelatin type-B (BSG) Different processing methods have been used to combine biopolymer with ZnO NPs of various particle shapes and sizes. A number of synthesis methods for ZnO NPs have been published worldwide, including the sol-gel process [20], the hydrothermal process [21], the wet chemical method, and the chemical vapour deposition (CVD) method [22]. Methods of co-precipitation [23], micro emulsion [24], microwave-assisted synthesis [25], green synthesis [26], etc.

The incorporation of natural biopolymers into zinc oxide nanocomposites expands their applications on a large scale, such as biomedical, adsorption. Environmental drug distribution, antimicrobial activity antioxidant activity anti-cancer activity and catalytic activity [46-50].

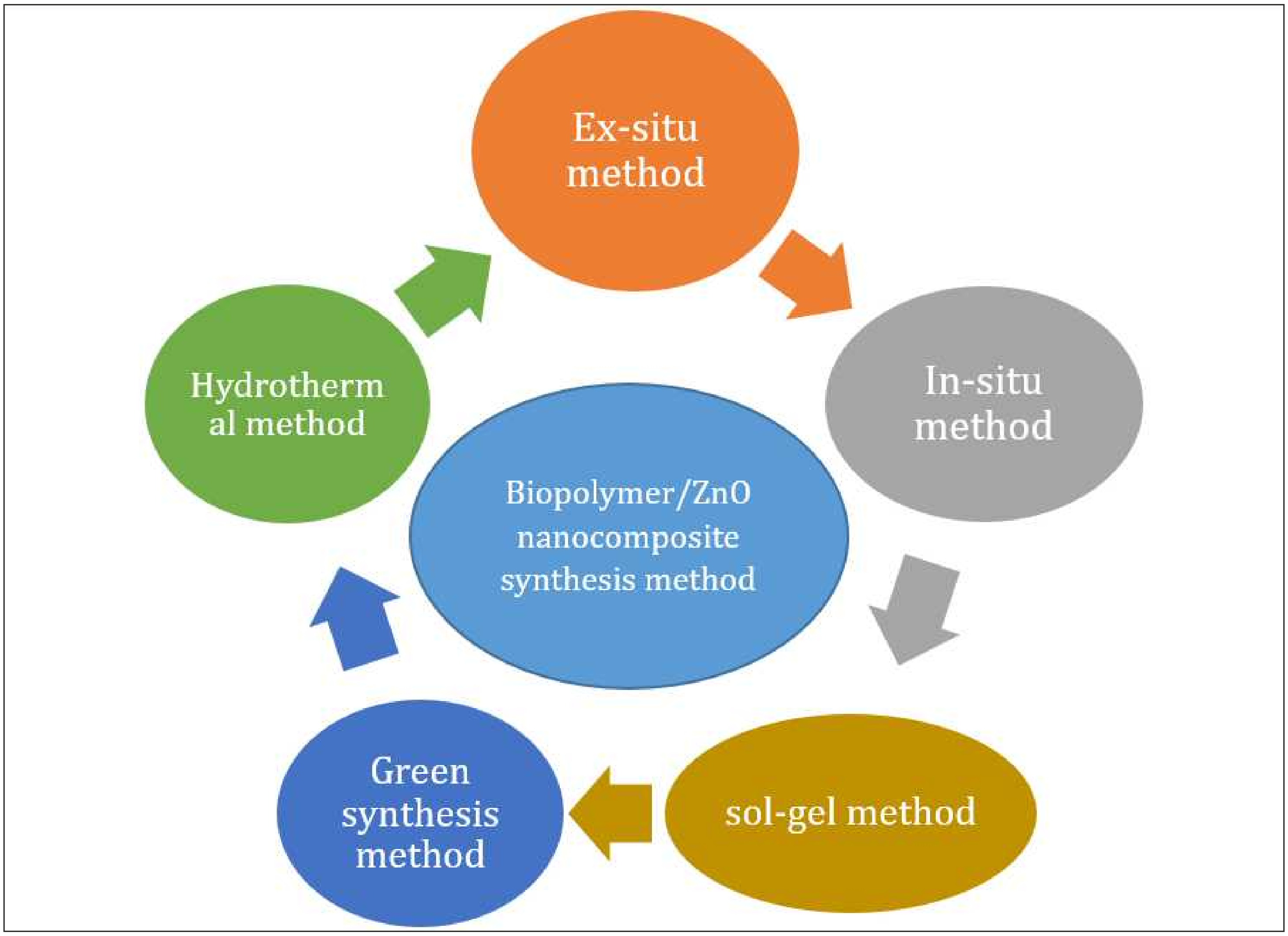

Fig.4 Biopolymer/Zinc oxide nanocomposites various method

2.2 Data from the literature on the synthesis of different biopolymer/ZnO nanocomposite (BZNCs)

Different metal/metallic oxide nanoparticles (Fe, Cu, Au, Ag, Zn, V, Ti, Cr, Ni, Co, etc.) have been created using various biopolymers-based metallic nanocomposites (Table 1). Co-precipitations, green synthesis, in-situ precipitations, ex-situ precipitations, hydrothermal technique, and others are some of the main approaches for biopolymer-based metallic nanoparticle creation. Biopolymers are significant in the preparation of metal/metallic oxide nanoparticles because they act as a capping and reducing agent. Biopolymer is a cation that can form nanocomposites and nanoparticles by forming complexes with anions. ZnO nanoparticles were combined into nanostructured coatings made from chitosan and alginate [5] another survey to reduce mango quality loss, a coating approach is used in this study. As a filler, mango was coated with traditional carrageenan and ZnO nanoparticles of carrageenan [6]. Therefore, in study, a new nanocomposite coating was developed as a potential strategy for preserving the qualitative characteristics of the samples. Chitosan and zinc oxide nanoparticles (Zno) were used to prevent microbial growth on fresh-cut papaya. [7] A combination of two obstacles was considered for the storage life of fresh strawberries: sodium alginate (SA) as an edible covering and nano-ZnO.[8] In other studies, nano-ZnO was combined with carboxymethyl cellulose (CMC) covering and synthesized on pomegranate arils. In this contribution, PLA-based nanocomposite films with multifunctional end-use capabilities were synthesized using the In-corporation method with ZnO nanoparticles (NPs) [untreated: ZnO (UT) and 3-methacryloxypropyltrimethoxysilane treated: ZnO (ST). in a polymer matrix by solvent casting Other studies found that melting PLA with 0.5–3 percent ZnO rod-like nanoparticles produced novel PLA-ZnO nanocomposite films [12].

Table 1 Data from the literature on the synthesis of several biopolymer/ZnO nanocomposite (BZNCs)

Biopolymer	metal	Technique	References
Alginate and chitosan	ZnO	In-situ	[5]
Carrageenan	ZnO	Green synthesis	[6]
Chitosan	ZnO	Co- precipitation	[7]
Sodium alginate	ZnO	In-situ	[8]
Carboxymethyl cellulose	ZnO	In –situ	[9]
3-methacryloxypropyl trimethoxysilane treated	Zinc Oxide	Green synthesis	[11]
PLAY	ZnO	Green synthesis	[12]
Poly (3-hydroxybutyrate	Zinc Oxide	Green synthesis	[13]
poly (3-hydroxybutyrate-co-3-hydroxy valerate	ZnO	Green synthesis	[14]
PBAT	ZnO	Green synthesis	[15]
clove essential oil	ZnO	Hydrothermal method	[16]
Polylactic acid	ZnO	Ex-situ	[17]
linear low-density polyethylene	Zinc Oxide	Precipitation	[18]
PLA film incorporated	Zinc Oxide	Co-precipitation	[19]
modified cellulosic	Zinc Oxide	In-situ	[20]
Polyaniline	Zinc Oxide	In-situ	[21]
poly (lactic acid) or polylactide (PLA)	ZnO	Green synthesis	[22]

hydroxybutyrate) (PHB)-based bio nanocomposites with various concentration of ZnO nanoparticles were synthesized by casting. Biodegradable nanocomposites were generated by solution casting ZnO nanoparticles into the bacterial polyester poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) [14]. The structure of poly (butylene adipate terephthalate) (PBAT) was studied in relation to zinc oxide (ZnO) loadings. [16] We made bovine skin gelatin (BSG) composite films with 2% zinc oxide nanorods (ZnO NRs) and 25 and 50 percent clove essential oil (CEO) (w/w of protein) [16]. Despite no prior treatment of ZnO particles, such as silanization, to reduce their incompatibility with the polymer, the biocomposite films had a high dispersion of ZnO particles in the PLA matrix [18]. A novel nano packaging film was created by incorporating ZnO nanoparticles into a polymer. Matrix of PLA (lactic acid) PLA films with zinc and zinc oxide nanoparticles (ZnO NPs) are recognized as multifunctional materials because of their unique properties [20]. Nanocomposites comprising polyaniline and zinc oxide nanoparticles with polycarbonate as the supporting matrix was created by direct mixing [21-22].

3. Application of Biopolymer Zinc oxide nanocomposites

According to a literature review, the majority of the (BZNCs) containing zinc oxide NPs were initially developed for a variety of applications involving the selective adsorption of target pollutants in the presence of other ions. Because they can combine the properties of nanoparticles and biopolymers, biopolymer zinc oxide nanocomposites (BZNCs) offer a wide range of applications. Supported anticatalysts, antibacterial, antifungal, antioxidant, antifouling activity sensors and biosensors, biomedical devices, electro-conductive pastes and glues, special coatings, paints and varnishes, magnetic fluids, and antifriction biopolymeric coatings are examples of such a wide range of applications in various fields. The following is a list of several applications of (BZNCs) that have been created as of now. From the perspective of applications, encapsulating zinc oxide nanoparticles in a biopolymer host material is obliged; however, it is also necessary to determine whether the host material's functionality influences the overall sorption behaviour of the zinc oxide nanoparticles (BZNCs). In theory, microbial infections cause the majority of clinical disorders in the world, posing serious health risks to humans.

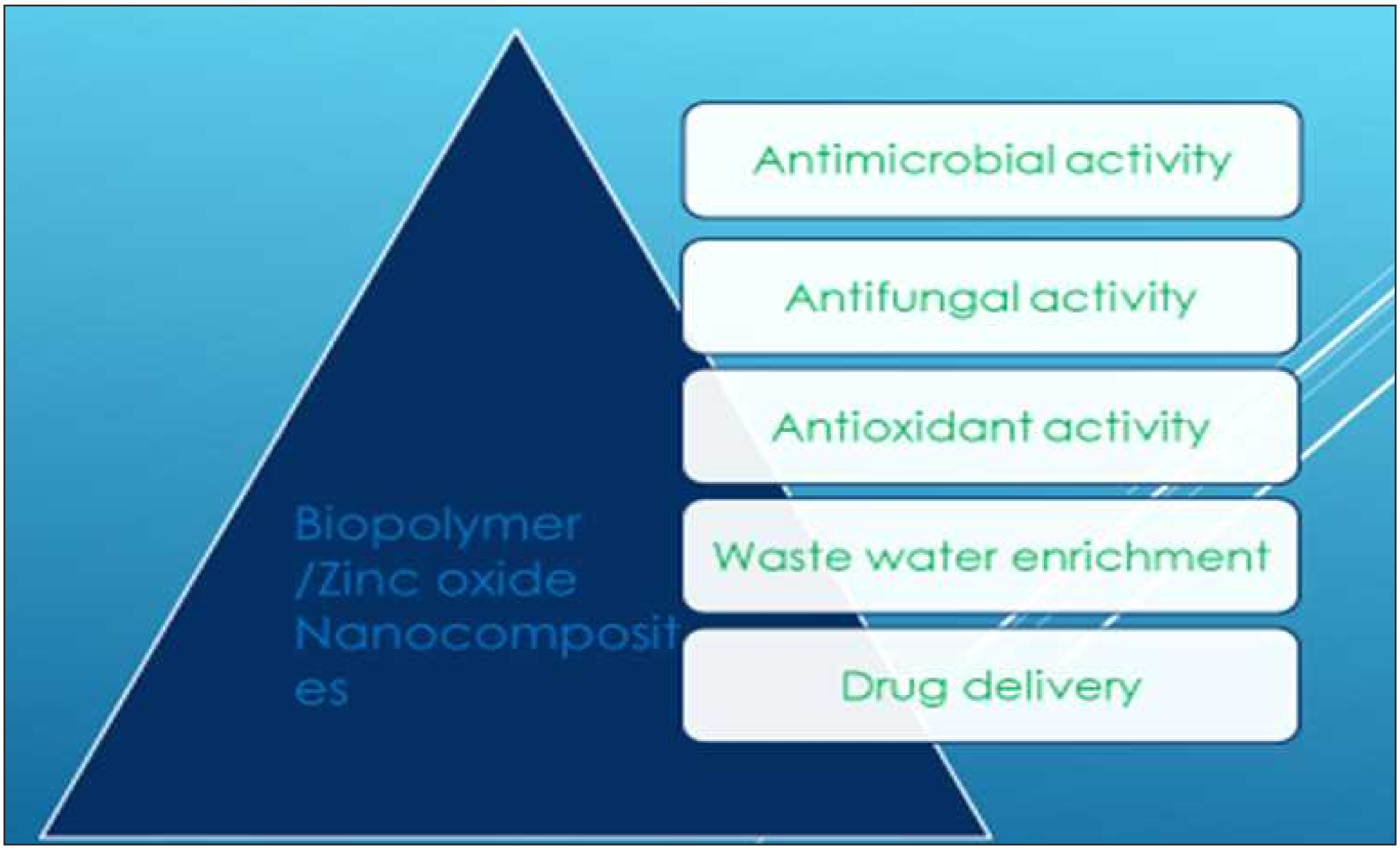

Fig.5 application of Biopolymer/Zinc oxide nanocomposites

3.1 Food packaging applications for biopolymer zinc oxide nanocomposite materials

In recent years, wide kinds of (BZNCs) have been synthesized and proven to exhibit powerful antibacterial properties (Table 5). A variety of methods have been used to assess the antibacterial activity of (BZNCs). The most popular technique for evaluating the antibacterial activity of PMNPs against a variety of bacteria and fungi is the agar well diffusion method since it is easy, rapid, and logical. Antibacterial properties of AgNPs stabilized by different polysaccharides on Gram-positive and Gram-negative bacteria are outstanding. P. aeruginosa, L. fermentum, coil According to the findings, [23]. When compared to Gram-negative (V. parahaemolyticus. and P. Vulgaris) bacteria, the CS/Ag/ZnO nanocomposite showed antibacterial efficacy against Gram-positive (B. licheniformis and B. cereus) bacteria at 8 g mL1. [23] . The complexes were more effective against bacteria than against fungi, with MIC values of 0.000313 percent (CS@Zn) for both E. Coli and Corynebacter. [24] Antibacterial activity of PHBV/ZnO films was shown against human pathogen bacteria, with Escherichia coli showing a larger effect than Staphylococcus aureus. In both nonpolar and polar simulants, the overall migration values of the nanocomposites declined with increasing nanoparticle concentration and fell below the current benchmark for food packaging materials [14]. Finally, the inhibition zone analysis reveals that chitosan-capped ZnO nanorods have a better antibacterial effect against E. coli than uncapped ZnO nanomaterial and chitosan [25]. The in vitro test revealed that gelatin can considerably increase ZnO biocompatibility while maintaining its antibacterial capabilities against E. coli and S. aureus [26].

One of the most important semiconductors at the nanoscale is ZnO, which also possesses a wide range of morphological structures, a high redox potential, outstanding physicochemical stability, high electron mobility, nontoxicity, and n-type carrier defects [18-20]. It can be used to create electronic components like transistors, LEDs, UV photodetectors, and light-emitting diodes (LEDs). [28] It is a desirable choice for mechanical actuators and piezoelectric transducers due to its piezoelectric properties [29–30]. [169] Biopolymer thermal behavior has also been enhanced by ZnO nanoparticles. [34-35]. Besides, it is also frequently employed in catalysis, energy storage, and biological domains. The antibacterial activity of this Chitosan/Ag/ZnO nanocomposite against B. 409 licheniformis, B. cereus, V. parahaemolyticus, and P. Vulgaris was outstanding. The biofilm growth of bacteria and Candida albicans was efficiently suppressed by the C/Ag/ZnO nanocomposite 410. The 411 CS/Ag/ZnO nanocomposite has no harmful effects on murine macrophages, indicating that it might be employed safely for medicinal reasons [52].

The antitumor activity of chitosan-assembled zinc oxide nanoparticles (CZNP) against cervical cancer cells was successfully tested [57].

3.2 Antimicrobial/antifungal anti-catalyst/Drug delivery/anticancer action, of biopolymer and zinc oxide are some of the applications of (BZNCs).

Table 2 Antimicrobial/antifungal anti-catalyst/Drug delivery/anticancer action, metal removal/organic compound removal of biopolymer and zinc oxide are some of the applications of (BZNCs).

Biopolymer/Zinc oxide	Antimicrobial strains	[Ref.]
Chitosan Ag/ZnO	E. coil, P. aeruginosa, L. fermentum	[23]
chitosan–Zn complex	Antibacterial activity	[24]
Alginate and chitosan add ZnO	Antimicrobial activity	[5]
. Poly (3-hydroxybutyrate)/ZnO bio nanocomposites	Antibacterial activity	[13]
ZnO-reinforced poly (3-hydroxybutyrate-co-3-hydroxyvalerate) bio nanocomposites	Antimicrobial activity	[14]
chitosan capped ZnO nanorods	Antimicrobial activity	[25]
Zinc oxide /gelatin	Antibacterial activity	[26]
Crosslinked carboxymethyl starch/cellulose ZnO/Zn	Photo degradation of dyes	]27]
Chitosan/ corn starch/ sodium alginate ZnO	Photocatalytic reaction	[28]
carrageenan and ZnO n	Food packing's	[6]
carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite	Food packings	[27]
Gelatin-Zinc Oxide Nanocomposite	Application in Spinach Packaging.	[28]
ZnO/graphene-oxide nanocomposite w	n photocatalytic p	[29]
Poly(styrene-*co*-acrylonitrile)/ZnO Hybrid Nanoparticles	an Efficient Ligand Exchange Strategy	[30]
Facile synthesis of chitosan/ZnO bio-nano composite	Drug delivery	[41]
ZnO-polystyrene nanocomposite for	UV-shielding applications	[42]
Chitosan-based zinc oxide nanoparticle	Anticancer activity	[43]

3.3 Some of the applications of biopolymer include metal removal, organic compound removal, by Biopolymer and zinc oxide (BZNCs).

Chemical precipitation, adsorption, oxidation-reduction, evaporation, ionic exchange, electrochemical treatment, and membrane separation techniques are the most modern methods for effectively removing heavy metals from wastewaters. The effectiveness and mechanism of cationic heavy metal absorption by ZnO and CuO have not been thoroughly studied. [51]. The adsorptions batch method is being used to remove organic and inorganic pollutants from wastewater treatment utilizing biopolymer and zinc oxide nanocomposites. Then, using the solution casting procedure, such nanoparticle solutions are employed to create films. Different types of metal oxides were disseminated within biopolymer, porous host materials to create (BZNCs) with better durability, mechanical strength, and adsorption properties. Table 2 lists several examples of (BZNCs) that have been developed and used to adsorb various target species from contaminated water and wastewater. In this paper, we investigate the functionalization of graphene oxide with zinc oxide nanoparticles (ZnO) to improve aluminium (Al) and copper (Cu) removal capability in acidic environments. [31,51,52]. The material was used as an adsorbent for the removal of Congo red from aqueous solutions. [32] The adsorbent guar gum–nano and zinc oxide (GG/ZnO) nanocomposite was employed to improve the removal of Cr (VI) from aqueous solution.[33] Another literature review found that nanomaterials like graphene oxide (GO) might be used to remove complicated pollutants. In this publication (ZnO), preliminary findings from the use of GO functionalized with zinc oxide nanoparticles to remove Mn (II) ions from acidic waters are presented. [34] Nano-engineered ZnO NR-rGO nanocomposites demonstrate effective water remediation in terms of organic dye degradation and heavy metal ion removal.. The synthesis of ZnO NR-rGO nanocomposite via a simple template-free hydrothermal approach is described here to boost visible photocatalytic efficiency [35] . According to the findings of this study, adding ZnCl2 to a chitosan–polyaniline hybrid increases reactive dye adsorption and photocatalytic degradation [36]. The goal of this study was to make a ZnO@Chitosan core/organically shell nanocomposite (ZO-CS) that may be used to remove Pb(II), Cd(II), and Cu(II) ions from polluted water [37]. This study presents the development of a Zeolite/Zinc Oxide Nanocomposite. Using a co-precipitation technique, (Zeolite/ZnO NCs) were produced. The adsorption of Lead Pb (II) and Arsenic As (V) from aqueous solution was then investigated on the produced Nanocomposite. Nano-ZnO/Chitosan composite beads (nano-ZnO/CT-CB) were used to remove Reactive Black 5 (RB-5) from an aqueous solution in this investigation. Using a microwave-assisted combustion process, ZnO nanoparticles were created. [39] Another work, "Polyaniline/ZnO nanocomposite: a novel adsorbent for the removal of Cr (VI) from aqueous solution," used sodium tripolyphosphate as the cross-linker to create physically cross-linked chitosan hydrogel beads, and during this process, ZnO nanoparticles were produced in situ. [43] ." The goal of the study was to see if these nanocomposite beads could be used to deliver drugs. [41] Using a solution casting technique, flexible and self-supporting ZnO-polystyrene (PS) nanocomposite thin films (about 360 m) were made. These films were incredibly transparent in the visible range and had good UV-absorbing properties. [42] . The Synthesis of nickel nanorods and their conversion in to nanoparticles and it's have various application may be use like as the cancer therapy, medical, environment, pharmaceutical activity [53].

Table 3 Metal removal/organic compound removal of biopolymer and zinc oxide are some of the applications of (BZNCs).

guar gum–nano zinc oxide	Chromium	[33]
Graphene Oxide–ZnO Nanocomposites	Aluminum and Copper Ions from Acid Mine Drainage Wastewater	[31]
Graphene Oxide–ZnO Nanocomposites	Removal of Mn(II) from Acidic Wastewaters	[34]
Multifunctional ZnO nanorod-reduced graphene oxide hybrids nanocomposites	Metal removal	[35]
s chitosan–polyaniline/ZnO hybrid composite	orange 16 dye	[36]
ZnO@Chitosan	Cu (II), Pb (II) and Cd (II	[37]
Zeolite/Zinc Oxide Nanocomposite	Lead Pb (II) and Arsenic As (V)	[38]
ZnO/Chitosan	Congo Red	[32]
ZnO/Chitosan composite beads	Removal of RB5	[39]
Polyaniline/ZnO nanocomposites is a novel	Adsorbent for the Removal of Cr(VI) from Aqueous Solution	[40]
Synthesis of nickel nanorods	conversion in to nanoparticles	[53]

CONCLUSION

The ability of bioactive molecules found in a variety of different biopolymers to reduce and stabilise was what made it possible to create ZnO NPs utilizing a green synthesis technique. The possibilities of enhancing the quality of ZnO NPs and modifying the reaction conditions to improve the production of ZnO NPs on a wide scale are attainable with the gained comprehensive information on the formation mechanism of ZnO NPs. The efficiency of ZnO NPs synthesized from different biopolymers in agriculture, including fertility efficiency, an increase in the rate of germination, adventitious roots, fruits size, and sugar and protein content of crops, is significantly influenced by the biomolecule content of the extract used in the process.Adsorptions, antioxidants, antifungal activity, anti-cancer activity, antimicrobial activity, biosensor activity, biomedical, drug delivery, gene therapy, catalytic activity, food packaging preservation, electrochemical activity, bioimaging, and property are among the many applications for which biopolymers stabilised metal/metallic oxide nanoparticles have emerged as a competent bio biopolymeric biocomposite. Biopolymers are in charge of the form and size of metal/metallic oxide nanoparticles in addition to capping, decreasing, and stabilizing them. The impact of biopolymers on the shape and size of nanoparticles has received less attention thus far. The size and shape of metal/metallic oxide nanoparticles are determined by biopolymers, according to research. The size of Zinc oxide nanoparticles can be affected by differences in molecular weight. It's critical to remember that biopolymers are in charge of reaction shape and size, as well as reaction temperature, technique variety, reaction time and sonication time. This review will be useful to scientists who are working on improving the stability of Fe/Zn oxide nanoparticles stabilised by biopolymers and their application.

Acknowledgment : The research facilities were provided by Sri Venkateswara College, Delhi University, Delhi, India, and Gurukul Kangri Deemed to be University, Hardwar, India.

Conflict of interest: The authors don't have any conflicts of interest

REFERENCE

1. Abbas, Mohsin, et al. "(Bio) polymer/ZnO nanocomposites for packaging applications: a review of gas barrier and mechanical properties." Nanomaterials 9.10 (2019): 1494.

2. Hamrayev, H., and K. Shameli. "Biopolymer-Based Green Synthesis of Zinc Oxide (Zno) Nanoparticles." IOP Conference Series: Materials Science and Engineering. Vol. 1051. No. 1. IOP Publishing, 2021.

3. Shaba, Elijah Yanda, et al. "A critical review of synthesis parameters affecting the properties of zinc oxide nanoparticle and its application in wastewater treatment." Applied Water Science 11.2 (2021): 1-41.

4. Warkara, Sudhir G., and Jagram Meena. "Synthesis and applications of biopolymer/FeO nanocomposites: A review." Journal of New Materials for Electrochemical Systems 25.1 (2022).

5. Arroyo, B.J.; Bezerra, A.C.; Oliveira, L.L.; Arroyo, S.J.; de Melo, E.A.; Santos, A.M.P. Antimicrobial active edible coating of alginate and chitosan add ZnO nanoparticles applied in guavas (Psidium guajava L.). Food Chem. 2020, 309, 125566. [CrossRef]

6. Meindrawan, B.; Suyatma, N.E.; Wardana, A.A.; Pamela, V.Y. Nanocomposite coating based on carrageenan and ZnO nanoparticles to maintain the storage quality of mango. Food Packag. Shelf Life 2018, 18, 140–146. [CrossRef]

7. Lavinia, M.; Hibarturrahman, S.N.; Harinata, H.; Wardana, A.A. Antimicrobial activity and application of nanocomposite coating from chitosan and ZnO nanoparticle to inhibit microbial growth on fresh-cut papaya. Food Res. 2019, 4, 307–311. [CrossRef]

8. Emamifar, A.; Bavaisi, S. Nanocomposite coating based on sodium alginate and nano-ZnO for extending the storage life of fresh strawberries (Fragaria × ananassa Duch.). J. Food Meas. Charact. 2020, 14, 1012–1024. [CrossRef]

9. Koushesh Saba, M.; Amini, R. Nano-ZnO/carboxymethyl cellulose-based active coating impact on ready-to-use pomegranate during cold storage. Food Chem. 2017, 232, 721–726. [CrossRef]

10. Romadhan, M.F.; Pujilestari, S. Sintesis nanopartikel ZnO dan aplikasinya sebagai edible coating berbasis pektin untuk memperpanjang umur simpan buah belimbing. Jurnal Agroindustri Halal 2019, 5, 030–038. [CrossRef]

11. Arfat, Y.A.; Ahmed, J.; Al Hazza, A.; Jacob, H.; Joseph, A. Comparative effects of untreated and 3-methacryloxypropyltrimethoxysilane treated ZnO nanoparticle reinforcement on properties of polylactide-based nanocomposite films. Int. J. Biol. Macromol. 2017, 101, 1041–1050. [CrossRef] Nanomaterials 2019, 9, 1494 11 of 14

12. Pantani, R.; Gorrasi, G.; Vigliotta, G.; Murariu, M.; Dubois, P. PLA-ZnO nanocomposite films: Water vapor barrier properties and specific end-use characteristics. Eur. Polym. J. 2013, 49, 3471–3482. [CrossRef]

13. Díez-Pascual, A.; Díez-Vicente, A. Poly (3-hydroxybutyrate)/ZnO bionanocomposites with improved mechanical, barrier and antibacterial properties. Int. J. Mol. Sci. 2014, 15, 10950–10973. [CrossRef] [PubMed]

14. Díez-Pascual, A.M.; Diez-Vicente, A.L. ZnO-reinforced poly (3-hydroxybutyrate-co-3-hydroxyvalerate) bionanocomposites with antimicrobial function for food packaging. ACS Appl. Mater. Interfaces 2014, 6, 9822–9834. [CrossRef] [PubMed]

15. Venkatesan, R.; Rajeswari, N. ZnO/PBAT nanocomposite films: Investigation on the mechanical and biological activity for food packaging. Polym. Adv. Technol. 2017, 28, 20–27. [CrossRef]

16. Ejaz, M.; Arfat, Y.A.; Mulla, M.; Ahmed, J. Zinc oxide nanorods/clove essential oil incorporated Type B gelatin composite films and its applicability for shrimp packaging. Food Packag. Shelf Life 2018, 15, 113–121. [CrossRef]

17. Marra, A.; Silvestre, C.; Duraccio, D.; Cimmino, S. Polylactic acid/zinc oxide biocomposite films for food packaging application. Int. J. Biol. Macromol. 2016, 88, 254–262. [CrossRef]

18. Ahmed, J.; Arfat, Y.A.; Al-Attar, H.; Auras, R.; Ejaz, M. Rheological, structural, ultraviolet protection and oxygen barrier properties of linear low-density polyethylene films reinforced with zinc oxide (ZnO) nanoparticles. Food Package. Shelf Life 2017, 13, 20–26. [CrossRef]

19. Li, W.; Li, L.; Cao, Y.; Lan, T.; Chen, H.; Qin, Y. Effects of PLA film incorporated with ZnO nanoparticle on the quality attributes of fresh-cut apple. Nanomaterials 2017, 7, 207. [CrossRef]

20. Wasim, Muhammad, et al. "An overview of Zn/ZnO modified cellulosic nanocomposites and their potential applications." Journal of Polymer Research 28.9 (2021): 1-19.

21. Ansari, Shahid Pervez, and Faiz Mohammad. "Studies on nanocomposites of polyaniline and zinc oxide nanoparticles with supporting matrix of polycarbonate." International Scholarly Research Notices 2012 (2012).

22. Murariu, M., J. M. Raquez, and P. Dubois. "Current Trends in the Field of Bioplastics and Nanotechnology: Polylactide-ZnO Nanocomposites Designed with Multifunctional Properties." Nanotechnol. Adv. Mater. Sci. 2 (2019): 1

23. Thaya, R.; Malaikozhundan, B.; Vijayakumar, S.; Sivakamavalli, J.; Jeyasekar, R.; Shanthi, S.; Vaseeharan, B.; Ramasamy, P.; Sonawane, A. Chitosan coated Ag/ZnO nanocomposite and their antibiofilm, antifungal and cytotoxic effects on murine macrophages. Microb. Pathog. 2016, 100, 124–132

24. Wang, Xiaohui, Yumin Du, and Hui Liu. "Preparation, characterization and antimicrobial activity of chitosan–Zn complex." Carbohydrate polymers 56.1 (2004): 21-26.

25. Bhadra P., Mitra M., Das G., Dey R., Mukherjee S. Interaction of chitosan capped ZnO nanorods with Escherichia coli. Mater. Sci. Eng. C. 2011;31:929–937. doi: 10.1016/j.msec.2011.02.015. [CrossRef] [Google Scholar]

26. Lin, J.; Ding, J.; Dai, Y.; Wang, X.; Wei, J.; Chen, Y. Antibacterial zinc oxide hybrid with gelatin coating. Mater. Sci. Eng., C 2017, 81, 321–326.

27. Noshirvani N., Ghanbarzadeh B., Mokarram R.R., Hashemi M. Novel active packaging based on carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite for increasing the shelf life of bread. Food Packag. Shelf Life. 2017;11:106–114. doi: 10.1016/j.fpsl.2017.01.010

28. Beak S., Kim H., Song K.B. Characterization of an Olive Flounder Bone Gelatin-Zinc Oxide Nanocomposite Film and Evaluation of Its Potential Application in Spinach Packaging. J. Food Sci. 2017;82:2643–2649. doi: 10.1111/1750-3841.13949. [PubMed] [CrossRef] [Google Scholar]

29. B. Li, T. Liu, Y. Wang, Z. Wang, ZnO/graphene-oxide nanocomposite with remarkably enhanced visible-light-driven photocatalytic performance, Journal of colloid and interface science, 377 (2012) 114-121.

30. Wang, Z.; Mahoney, C.; Yan, J.; Lu, Z.; Ferebee, R.; Luo, D.; Bockstaller, M. R.; Matyjaszewski, K. Preparation of Well-Defined Poly(styrene-co-acrylonitrile)/ZnO Hybrid Nanoparticles by an Efficient Ligand Exchange Strategy. Langmuir 2016, 32, 13207– 13213

31. Rodríguez, Carolina, et al. "Graphene oxide–ZnO nanocomposites for removal of aluminum and copper ions from acid mine drainage wastewater." International Journal of Environmental Research and Public Health 17.18 (2020): 6911.

32. Nguyen, Nhu Thanh, Ngoc Thinh Nguyen, and Van Anh Nguyen. "In situ synthesis and characterization of ZnO/chitosan nanocomposite as an adsorbent for removal of Congo Red from aqueous solution." Advances in Polymer Technology 2020 (2020).

33. Khan, Tabrez A., et al. "Removal of chromium (VI) from aqueous solution using guar gum–nano zinc oxide biocomposite adsorbent." Arabian Journal of Chemistry 10 (2017): S2388-S2398.

34. Leiva, Eduardo, Camila Tapia, and Carolina Rodríguez. "Removal of Mn (II) from Acidic Wastewaters Using Graphene Oxide–ZnO Nanocomposites." Molecules 26.9 (2021): 2713.

35. [171]Ranjith, K.S.; Manivel, P.; Rajendrakumar, R.T.; Uyar, T. Multifunctional ZnO nanorod-reduced graphene oxide hybrids nanocomposites for effective water remediation: Effective sunlight driven degradation of organic dyes and rapid heavy metal adsorption. Chem. Eng. J. 2017, 325, 588–600. [CrossRef]

36. Kannusamy, P.; Sivalingam, T. Synthesis of porous chitosan–polyaniline/ZnO hybrid composite and application for removal of reactive orange 16 dye. Colloids Surf. B Biointerfaces 2013, 108, 229–238. [CrossRef] [PubMed]

37. Saad, Abdel Halim A., et al. "Removal of toxic metal ions from wastewater using ZnO@ Chitosan core-shell nanocomposite." Environmental Nanotechnology, Monitoring & Management 9 (2018): 67-75.

38. Alswata, Abdullah A., et al. "Preparation of Zeolite/Zinc Oxide Nanocomposites for toxic metals removal from water." Results in Physics 7 (2017): 723-731.

39. S. Çınar, Ü. H. Kaynar, T. Aydemir, S. Çam Kaynar, and M. Ayvacıklı, "An efficient removal of RB5 from aqueous solution by adsorption onto nano-ZnO/Chitosan composite beads," International Journal of Biological Macromolecules, vol. 96, pp. 459–465, 2017.

40. Ahmad, Rais. "Polyaniline/ZnO nanocomposite: a novel adsorbent for the removal of Cr (VI) from aqueous solution." Advances in Composite Materials Development. London, UK: IntechOpen, 2019. 1-22.

41. Yadollahi, M., et al., Facile synthesis of chitosan/ZnO bio-nanocomposite hydrogel beads as drug delivery systems. Int J Biol Macromol, 2016. 82: p. 273-8

42. Tu, Y.; Zhou, L.; Jin, Y. Z.; Gao, C.; Ye, Z. Z.; Yang, Y. F.; Wang, Q. L. Transparent and flexible thin films of ZnO-polystyrene nanocomposite for UV-shielding applications. J. Mater. Chem. 2010, 20, 1594–1599

43. Wu, H. and J. Zhang, Chitosan-based zinc oxide nanoparticle for enhanced anticancer effect in cervical cancer: A physicochemical and biological perspective. Saudi Pharm J, 2018. 26(2): p. 205-210.

44. Y.F. Lin, H.W. Chen, Y.C. Chen, C.S. Chiou, Application of magnetite modified with polyacrylamide to adsorb phosphate in aqueous solution, J. Taiwan Inst. Chem. Eng. 44 (2013) 45–51

45. S.B. Hammouda, N. Adhoum, L. Monser, Synthesis of magnetic alginatebeads based on Fe3O4nanoparticles for the removal of 3-methylindole fromaqueous solution using Fenton process, J. Hazard. Mater. 294 (2015)128–136

46. Meena, Jagram, and Pyar Singh Jassal. "Cresol and it derivative Organic pollutant removal from waste water by adsorption the magneto chitosan nanoparticle." International Journal of Chemical Studies 5 (2017): 850-854..

47. Meena, J., et al. "POLYANILINE/CARBOXYMETHYL GUAR GUM NANOCOMPOSITES: AS BIODEGRADABLE, CONDUCTIVE FILM."

48. Meena, Jagram, and Pyar Singh Jassal."Phenol Organic Impurity Remove from pollutants Water by Batch Adsorption Studies with using Magneto Chitosan Nanoparticle" AIJREAS 2.6 (2017) 2455-6300

49. Meena, J., Chandra, H., Warkar, S.G. (2022). Carboxymethyl tamarind kernel gum /ZnO- biocomposite: As an antifungal and hazardous metal removal agent. Journal of New Materials for Electrochemical Systems, Vol. 25, No. 3, pp. 206-213. https://doi.org/10.14447/jnmes.v25i3.a08

50. Verma, Devendra Kumar, et al. "Synthesis, characterization and applications of chitosan based metallic nanoparticles: A review." Journal of Applied and Natural Science 13.2 (2021): 544-551.

51. Guzmán, Maribel G., Jean Dille, and Stephan Godet. "Synthesis of silver nanoparticles by chemical reduction method and their antibacterial activity." Int J Chem Biomol Eng 2.3 (2009): 104-111

52. Mahdavi, Shahriar, Mohsen Jalali, and Abbas Afkhami. "Removal of heavy metals from aqueous solutions using Fe 3 O 4, ZnO, and CuO nanoparticles." Nanotechnology for sustainable development. Springer, Cham, 2012. 171-188.

53. D. K. Vermaa J. Meena*, S. K. Verma2Synthesis of nickel nanorods and their conversion in to nanoparticles" published in for publication in the Research Journal of Chemistry and Environment.vol.26 no.12) Dec.2022