第 51 卷第 06 期
2024 年 6 月
湖南大学学报（自然科学版）
Journal of Hunan University（Natural Sciences）
Vol. 51. No. 06.
June 2024

Open Access Article

METAL AND METAL OXIDE NANOPARTICLES: UNVEILING THE MECHANISMS OF ANTIMICROBIAL ACTIVITY

Sharma S.D., Gupta V., Sain D., Rahi R.K., Yadav M. and Neelam D.K.*
Department of Microbiology, JECRC University, Jaipur, Rajasthan, India- 303905
*Corresponding author E-mail: deepesh40neelam@gmail.com; deepesh.neelam@jecrcu.edu.in

Abstract
The creation, characterization, and use of nanomaterials are all aspects of the field of nanotechnology. Newer antimicrobial drugs have been developed with the use of the pharmacology and nanotechnology combination in an effort to combat the multidrug-resistant microorganisms that are becoming more and more prevalent. Considering to their diminutive size, which allows for enhanced proximity to surfaces with bacteria and has adverse effects on microorganisms, metal and metal oxide Nano components have attracted a great deal of interest. Nobel metal nanoparticles [Au, Pt, Ag] are utilized in a variety of biological applications, such as the prevention and treatment of carcinoma, advancement in radiation, medication transportation infrared radiation, antimicrobial, diagnostic tests, and anti-fungal. It is widely recognized that nanoparticles made from metals have general bacterial virulence mechanisms that prevent the emergence of bacterial resistance while also broadening the range of antimicrobial effectiveness. By directly interacting with cell lipids, proteins, and DNA or by causing oxidative stress, nanoparticles can harm these substances. To deal with nanoparticles of metallic elements, Bacteria can upregulate the antioxidant response and DNA restoration systems, downregulate porin, overexpose their metal efflux mechanism, and minimize metal intake. This review mainly focuses on various metals and their oxides, their antibacterial activity against pathogenic bacteria, their mechanisms of action, synthesis and consequences.
Keywords: Nanoparticles, Antimicrobial activity, Metal/metal oxides

Introduction
Due to the potential applications of nanoparticles in medical and technology-related fields, catalysis, energy storage, and the development of customized synthetic nanostructures, materials chemistry studies of nanoparticles have received a lot of attention. Nanomaterials can be synthesized from a variety of metal oxides, including Ag, Al, Ca, Ce, Cu, Mg, Ti, Yt, and Zn.1 Antibiotic resistance in several harmful microorganisms will cause a multitude of health difficulties in the years to come. In this approach, suitable substitutes for anti-infection chemicals and sanitizers have been established by integrating the inherent antibacterial properties of metals and their oxide nanoparticles with the application of nanotechnology and material biology.2 Reactive oxygen species (ROS), which are capable of attacking physicochemical properties including shape, dimension, chemical makeup, crystallinity, orientation, surface area, and mobility that aid in the synthesis of DNA, metabolic pathways, and cell death in prokaryotic cells, are attracted by the bactericidal properties of metal and oxide nanoparticles.3 Four species of bacteria that frequently result in nosocomial infections were used

Received: May 04, 2024 / Revised: May 27, 2024 / Accepted: June 06, 2024 / Published: June 25, 2024
About the authors：Sharma S.D
Corresponding author- Email:

to test the Nano oxides' antibacterial potency.4 Metal oxides can be made from a variety of nanomaterials, including Ce, Zn, Ag, Cu, Ti, Yt, Ca etc. Several dangerous metals, including silver, titanium, and their metal oxides, participate in the ROS-mediated pathway that causes oxidative stress-related cell death, tumors, and cardiovascular diseases. The strong antibacterial capabilities of metal oxide nanoparticles offer a wide range of possibilities for medical and biological applications such as tumor eradication, therapeutic medication delivery, medical imaging, and cell labelling in biological processes.5 The creation of either metal or metal oxide nanoparticles are currently being accomplished using Nano cellulose-based materials as green layouts. Due to this, multipurpose nanomaterials with good antibacterial, UV barrier, and mechanical characteristics were made from nitrocellulose and metal or metal oxide.6 In addition to viruses, nanoparticles can kill or inhibit fungus, bacteria, and yeast. Nanoparticles are a potential antibiotic alternative due to their longevity, minimal toxicity, and powerful antibacterial activity. Magnesium, silver, and gold nanoparticles, for example, have strong antibacterial properties. Non-metallic nanoparticles, on the other hand, such as chitosan, silica, carbon compounds, and others, have good antibacterial characteristics.7 The metal colloid can be modified to have nanoparticles with various chemical compositions, surface functionalities, or primary particle sizes. If the antibacterial activity of each of these qualities, which are combined into a nanoparticle profile, can be quantified, a safe and effective antibacterial nanoparticle design is possible.8 Reactive oxygen species (ROS), which lead to lipid peroxidation in bacteria, are produced by nanoparticles. However, nanoparticles also exhibited non-ROS driven bacterial toxicity, indicating that oxidative stress may not be the main cause of cell death.9 ROS are ions or tiny molecules that contain oxygen ions, free radicals, or peroxide. These ROS are extremely reactive species that are created during oxygen's regular metabolism. ROS are crucial for cell signaling under normal physiological circumstances. Enzymes (like catalase and superoxide dismutase) and tiny molecules (like ascorbic acid) can be used by cells to detoxify ROS. However, this antioxidant activity has a limit, and if the cell is continuously subjected to oxidative stress, the generation and accumulation of ROS will significantly increase.10 It doesn't seem entirely obvious how precisely the antibacterial action of metal oxides or ultra- fine metal particles works. But three speculative hypotheses that could explain how NPs have antibacterial effects are notable today: (1) Electrostatic contact results in biomechanical cell membrane damage.; (2) The production of reactive oxygen species (ROS) causes oxidative stress.; and (3) alteration of protein functionalities and cell structures brought on by metal cation releases.11 Because of bacteria, a cell absorbs ions drawn out by metal nanoparticles, which interfere with ATP and DNA replication.12 Metal or metal oxide nanoparticles (NPs) have been found to have a variety of antimicrobial and anticancer properties, including denaturing biological macromolecules like protein and nucleic acids, inhibiting biofilm, generating radicals that are free and nonradicals of reactive oxygen species, or ROS, and reactive nitrogen species (RNS), inducing immune responses in the host, and damaging cell membranes through direct contact with NPs.13 When the generation of reactive nitrogen species (RNS), ROS, and antioxidant defenses are out of balance, oxidative stress results. Intracellular pathogens can be killed by a significant number of free radicals produced by the oxidative stress that infected cells cause. As part of regular aerobic respiration, intracellular pathogens are exposed to endogenous ROS. In addition, the host immune system produces exogenous ROS and

RNS in response to infection.14 Reactive nitrogen species (RNS), sometimes referred to as nitric oxide (NO), have been linked to numerous biological processes that are relevant to cells. The development of fluorescent probes that can detect NO in living cells with extreme sensitivity and selectivity is greatly desired.15 Essential oxidative metabolites of living things, reactive oxygen species (ROS) and reactive nitrogen species (RNS) have a profound connection with physiological, pathological, and therapeutic processes. For the purpose of comprehending biological processes, tracking drugs effects, and forecasting the progression of disease, precise reactive oxygen species and reactive detection is essential.16 Inflammatory cells produce reactive oxygen species (ROS) and reactive nitrogen species (RNS), damaging intestinal dysmotility, barrier dysfunction, and nutrition absorption. These substances also promote facultative anaerobes and dysbiosis of gut microbiota. Redox-active nanoparticles can selectively target inflammatory sites, scavenging ROS/RNS and regulating IBD.17

Table 1
Nanoparticles Effect on Bacterial Cell

Sn.	Mechanism	Function	References
1.	Disruption of bacterial cellmembrane	Electrostatic contact and circumvent the bacterial defense against drug resistance.	3,8
2.	Generation of ROS	Modulation of cellular signaling	9,10
3.	Penetration of the protein function and cell structure as metal cation release.	Anti-oxidant defense. Oxidative stress cause GENOTOXICITY	7,8,11
4.	Induction of intracellular antibacterial effect include interaction with DNA andProtein	Cause inflammation, involve cell death, proliferation and differentiation	10,12

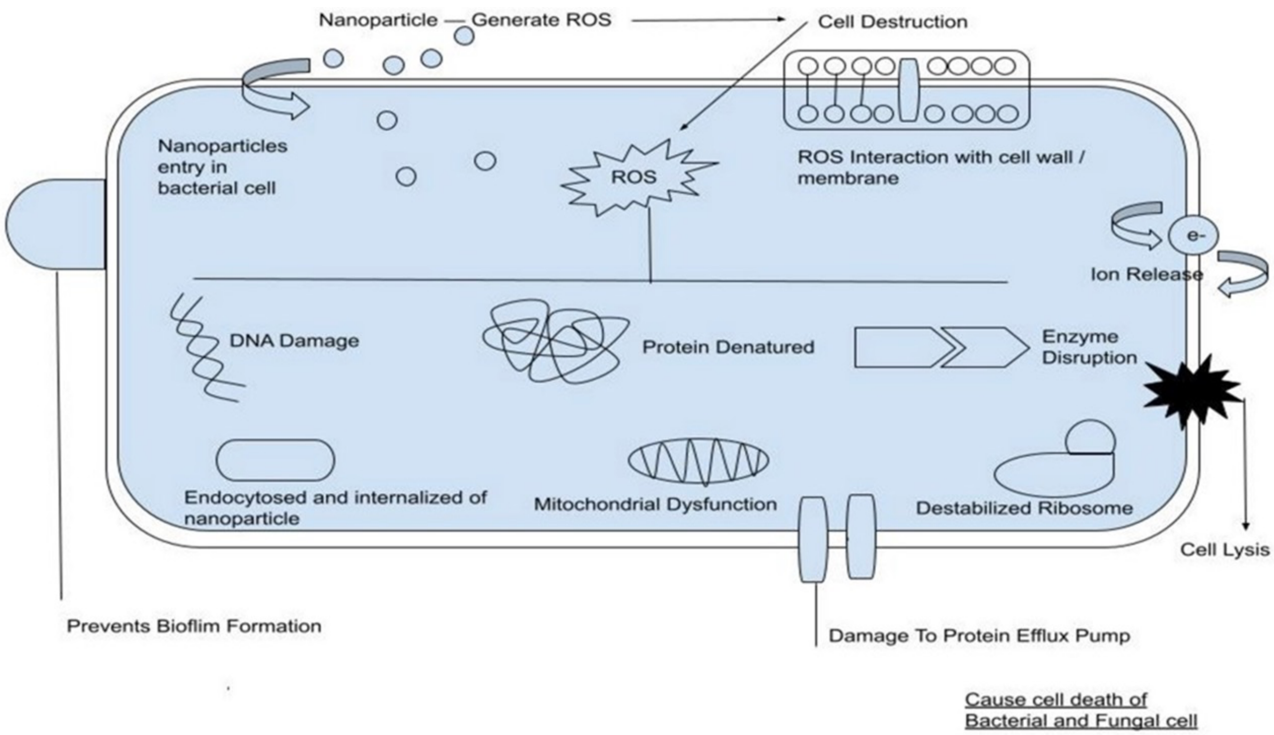

Figure 1: Mechanism of nanoparticle action on bacterial and fungal organism

significant antibacterial activity of several steel oxides with nanotechnology. Typically used metallic oxides with high antibacterial activity against specific types of diseases include ZnO, FeO, and TiO2 nanoparticles.13 Nanotechnology has been discussed as a therapeutic weapon in the fight against drug-resistant bacteria by Pelgrift and Friedman (2013). Numerous nanoparticles are widely used in the medical industry, agriculture, water resources, and environmental settings as antibacterial agents. The disadvantages of conventional antibiotic medications, such as difficulty in penetration and excretion from the body after treatment, have been solved through the use of metal nanoparticles, metal oxide nanoparticles, green nanoparticles, and mixtures of these particles.14

Different approaches during synthesis of Nanoparticles: -

The production of nanoparticles has been carried out using a variety of methods:

Physical methods: These methods typically use high temperatures, but they have drawbacks such as time requirements, space requirements, and negative environmental consequences.15 Further procedures include magnetron sputtering, microwave-thermal method, evaporation or condensation method, pulsed laser ablation, mechanochemical processing (MCP), and light reduction procedure. The direct synthesis of nanoparticles from a metal source is made feasible by the evaporation/condensation technique.16 Create metal nanoparticles using a tiny ceramic heater with a focused heating zone. The source materials were evaporated using a tiny ceramic heater. Inside the generator, dry, filtered air circulates as nucleation and growth processes create nanoparticles. Because there is a much steeper temperature gradient near the heater surface than there would be in a tube boiler, the dissipated water vapor has a reasonable rate of cooling. This makes it possible to produce small nanoparticles at large quantities, which is necessary for the suggested Generation.17

Mechanochemical synthesis

A variety of Nano particulate materials have been synthesized via mechanochemical processes. Numerous transition metals and ceramics, including Fe, Cu, Co, Ni, Al 2O3, ZrO2, Fe2O3, Gd2O3, CeO2, Ce2S3, and ZnS, have been synthesized as nanoparticles using a unique technique that involves the mechanical activation of solid-state displacement processes.16-25 A nanoscale composite structure of the original constituents is produced when precursor powders are processed. A combination of segregated nanocrystals of the required phase inside a soluble salt matrix is produced by the interaction of this composite structure during milling or a subsequent heat treatment.18

Microwave heating

Syntheses of nanomaterials and chemical reactions have both made extensive use of the microwave-assisted technique. The result of the reaction mixture being directly heated, research has demonstrated that the method is a desirable one to encourage reactions and is energy efficient compared to traditional heat conduction methods. Microwave warming is an vitality change prepare instead of a warm exchange since it changes over electromagnetic vitality to warm vitality.19

Photo reduction

process of photo reduction connected to the creation of metallic nanoparticles by plants High spatial resolution, remarkable adaptability, and local control of reducing agents are this method's key benefits.20 The photo reduction process uses water as a solvent, requires no stabilizer or reducing agent, and may be done at room temperature.21 Using semiconductors as photo catalysts, photo reduction is a promising method for producing gasoline. But adding flaws to the photo catalysts' crystal structure significantly reduces their photocatalytic activity.22

Pulsed laser ablations

The pulsed laser treatment in the fluid medium methodology was successfully used to synthesize nanoparticles at the nanoscale with adjustable size fluctuations by modulating the laser fluence with each pulse in order to enhance the antibacterial activity against many pathogens. This method was carried out with a nanosecond infrared Nd: YAG laser.23 Pulsed laser ablation is superior to conventional methods in a number of ways, including reduced porosity, the capacity to create materials with intricate stoichiometry, a more tightly controlled level of impurities and flaws, and a narrower particle size distribution.24

Chemical Method:

The three basic components of the chemical reduction process, which is the most popular method for synthesis, are the metal precursor, the reducing agent, and the capping or stabilizing agent. Among the chemical processes are the irradiation methods, photo-induced reduction, atomic layer deposition method, photo-initiated reduction, electrochemical synthetic methods, and macroemulsion method.

Photo reduction triggered by UV Silver NPs can be created via a quick and efficient process called UV- initiated photo reduction when citrate, polyvinylpyrrolidone, poly acrylic acid, and collagen are present .25

Atomic layer deposition

Chemical vapor deposition techniques like ALD use alternating exposures of gaseous precursors to a substrate to create thin layers. ALD is more adept at creating conformal films that are ultra-thin (10 nm thickness) and pinhole-free on intricate, three-dimensional (3-D) structures with a large aspect ratio. Due to its capacity to increase the surface-to-volume ratio while using the least amount of volume, the ALD process is crucial in surface treatment .26

Electrochemical

The electrochemical measurements were conducted using a three-electrode configuration, 1 M KOH aqueous electrolyte, a Pt wire as the counter electrode, and an Ag/AgCl electrode as the reference electrode.27 Different silver particle sizes can be obtained by varying the current density. With the use of several counter electrode types, the impact of various electrochemical parameters on the final size was investigated .28

Making an appropriate selection from the reaction parameters provided below will ensure a successful electro synthetic reaction:

(1) The ability to select inert or reactive electrodes (2) Appropriate selection of the electrolyte and its composition (3) Appropriate pH, temperature, and electrolyte concentration (4) The ability to divide or leave undivided cells (5) potentiation electrolysis .29

UV-irradiation method

UV-irradiation is a technique used to create Cr_2O_3 nanoparticles. Transmission electron microscopy (TEM) and X-ray diffraction (XRD) characterizations show that producing tiny particles of chromium oxide with a size between 2 and 30 nm is straightforward and easy .30

Ionizing radiation

Ionizing radiation can be a very useful tool in the synthesis of a wide range of metallic NPs with various compositions, leading to core-shell and alloyed NPs, using a combination of different metal ions, polymers, monomers, and even proteins.31

Biological Methods

Metal nanoparticles can be produced using a variety of synthesis techniques, including chemical, physical, and biological ones. It has been claimed that the production of nanoparticles uses coriander, Bischofia javanica (L.), Daucus carota, Solanum lycopersicum, Hibiscus cannabinum leaf, Moringa oliefera flower, lemongrass, Bacopa monnieri, Citrus unshiu peel, and Ananas comosus .32 The reducing capacity of microbial cells, enzymes, and biological molecules is harnessed in biological techniques of NP production. Applications of biosynthesized metallic NPs include environmental sensors, catalytic water treatment, and a variety of medicinal activities, such as antimicrobial coatings, medical imaging, and drug delivery .33 Their fields of use for the biosynthesized nanoparticles are also briefly stated .34

Although biological approaches are thought to be secure, affordable, sustainable, and environmentally friendly, they do have certain downsides, such as the time-consuming and challenging process of microbe cultivation, which makes it difficult to better control size distribution, form, and crystallinity. Additionally, being non-monodisperse and with a sluggish manufacturing rate, biological nanoparticles .35

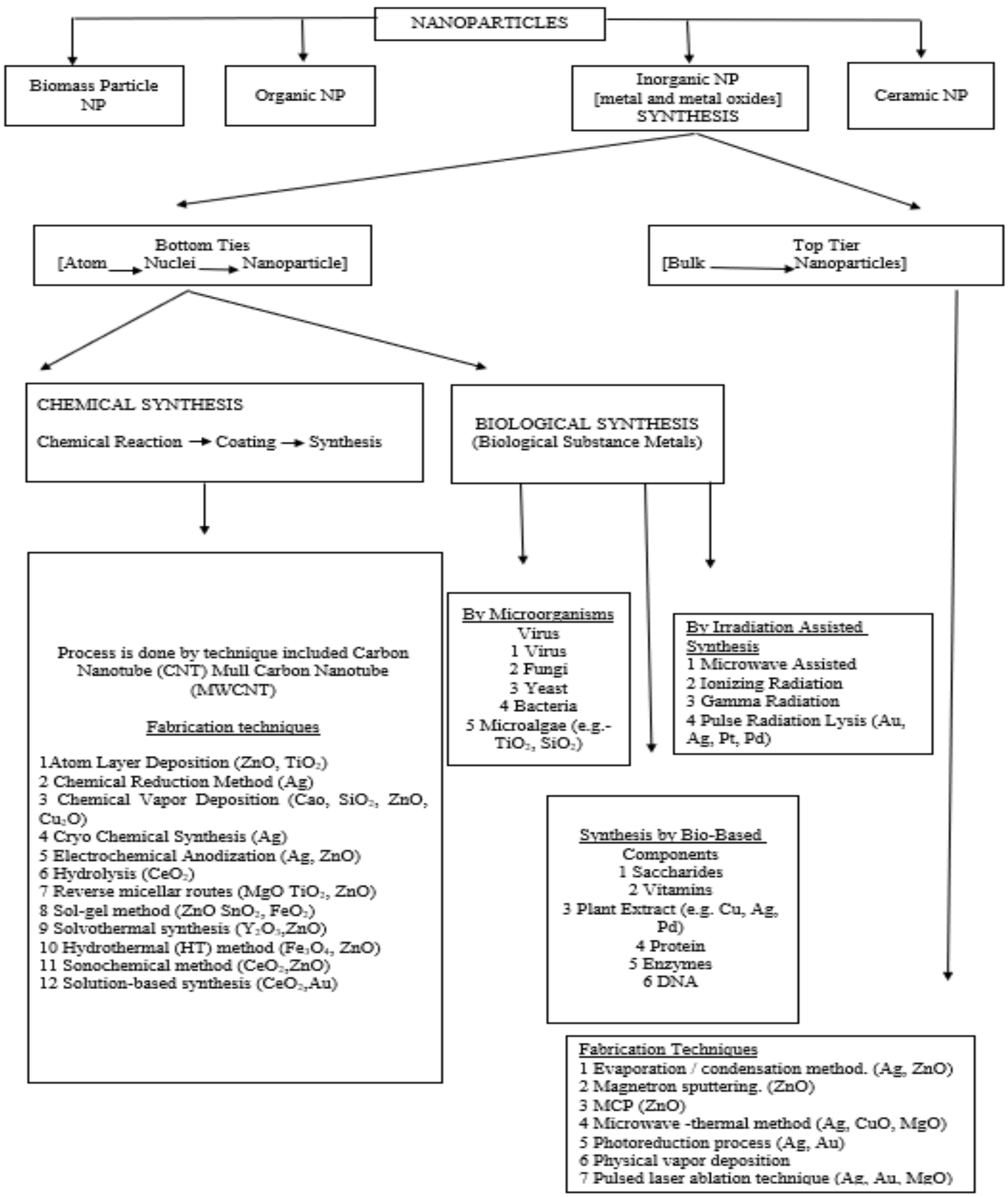

Figure 2: Different types of synthesis carried by nanoparticles carrying antibacterial /fungal activity

Different examples regarding nanoparticle actions and applications: -

ZNO Nanoparticles: -

ZnO nanoparticles seem to be one of the most promising antimicrobial fillers because of their strong performance attributes, which include broad-spectrum antibacterial activity, long-term environmental stability, biocompatibility, and non-toxicity. Because of their high affinity for Staphylococcus aureus cells, ZnO nanoparticles have been identified as one of the most efficient inhibitors of this bacteria. Although it is well known that metals and metal oxides, including ZnO, are hazardous to host human cells at very high doses .36 The size, content, crystallinity, and shape of metal NPs like zinc oxide (ZnO), titanium dioxide (TiO2), and silver are primarily what define their intrinsic features. Their chemical, mechanical, electrical, structural, morphological, and optical properties can be changed by scaling down to the nanoscale .37 An effective, straightforward, and green method has been established to produce ZnO Nano crystallites with a typical measurement of between 23 and 26 nm. The characterization of zinc oxide nanoparticles was done using X- ray diffraction, scanning electron micro (SEM), and energy diffusion X-ray spectroscopy (EDX). The oxygen species that are released on the surface of ZnO and kill bacteria can be used to explain this. They react with hydrogen ions to form molecules of H2O2. The H2O2 created by breaking through the cell membrane can kill the bacterium. The synthesis of H2O2, which increases the total amount of oxygen species on the surface and amplifies the antibacterial activity of the smaller nanoparticles is greatly impacted by the surface area of ZnO .38 Numerous studies have tried to link the size of the component particles to the biological action of inorganic antibacterial agents. The ability to manufacture inorganic Nano crystalline metal oxides with extraordinarily high surface areas and their greater suitability for biological applications make them particularly intriguing. Better selectivity, improved heat resistance, and superior durability are advantages of inorganic antibacterial materials over biological antibacterial materials. TiO2 and ZnO semiconductors' photocatalytic activity under UV light has stimulated extensive research into the antibacterial properties of these substances. In order to understand the antimicrobial mechanism of chemical agents, it is generally possible to know the precise binding of a chemical agent's surface to a microorganism and the agent's subsequent metabolism inside the bacterium .39

Within yeast mitochondria, zinc and iron are both present in equal amounts. A number of zinc metalloproteinases are found throughout the mitochondria and make up the zinc metalloprotease .40

One of the most promising antimicrobial fillers seems to be ZnO nanoparticles because of its strong performance attributes, which include broad-spectrum antibacterial activity, long-term environmental stability, biocompatibility, and non-toxicity. In order to increase the antibacterial effectiveness of dental resin composites while preserving their mechanical qualities, ZnO nanoparticles were created using the spray-drying technique .41 Utilizing NaOH and ZnCl2 as precursors in methanol, ZnO NPs were produced using a wet- chemical process while maintaining a pH of 7. 2. Escherichia coli (K-12 strain of E. coli) .42

TIO Nanoparticles: -

TiO2 nanoparticles have long been employed in antibacterial applications because they effectively remove microorganisms because of their photocatalytic characteristics. In addition to the special qualities associated with their nanosized, their mechanisms of action are typically dependent on their ability to create reactive oxygen species when exposed to UV radiation .43 White painting and the pigment industries favor TiO2 nanostructure materials because of their superior optical, electrical, and photocatalytic capabilities.

These metal oxide nanoparticles were also embraced by the coating and new radiation-resistant pigment industries because of their chemical stability, high refractive index, and large specific area. 44

Because of its high oxidation activity and super hydrophilicity, it is used as an antibacterial agent .45 Over the past ten years, inorganic bacteriostatic substances like titanium dioxide (TiO2) nanoparticles have drawn a lot of interest. In many applications, titanium dioxide (TiO2) is employed as a self-packaging film against E. coli in vitro and in actual conditions under two types of artificial light .46 TiO2 has been identified as a promising metal oxide because of its photocatalytic activity, chemical stability, affordability, biocompatibility, and antibacterial properties. TiO2 NPs combined with chitosan-based coating films could develop into a promising packaging technique for extending the shelf life of produce .47

Copper oxide Nanoparticles: -

Additionally, harmful bacteria are susceptible to CuO impressively broad-spectrum antibacterial action. Antimicrobial action is displayed by these nanoparticles against pathogens like K. pneumoniae, S. dysenteries, and V. cholerae. It has also been reported that NPs produce Cu2+ ions, which in turn cause reactive oxygen species and DNA damage .48 Cu NPs are created using biomineralization methods. Proteins are essential for the transformation and physiologically induced biomineralization of metals by fungi during the synthesis process .49

Various applications in industry employ copper nanoparticles (Cu NP), including heat transfer fluids, electronics, catalysts, gas sensors, and antimicrobial substances. Due to their oxidative nature, copper oxide nanoparticles (CuO NP) are considered to be more hazardous than copper nanoparticles (Cu NP). Elodea densa , a waterweed, was shown to benefit from CuO NP, which was also reported to boost photosynthesis at low concentrations .50 In a number of technologies, such as catalysis, batteries, gas sensors, heat transfer fluids, and solar energy, CuO NPs are being used increasingly often. CuO crystal forms offer favorable photocatalytic and photovoltaic properties due to their low band gap. Alternative antimicrobial agents, such as small antibiotics, cationic polymers, metal nanoparticles, and antimicrobial peptides, are becoming more popular due to the rise of diseases that are resistant to antibiotics .51

Thanks to its distinctive crystal morphologies and large surface areas, CuO is a stable, easily assimilated, and reasonably priced metal oxide that could prove to be an effective antibacterial agent .52

Gold Au Nanoparticle

A lot of people are also interested in gold (Au) nanoparticles because of their special visual qualities and chemical stability. Therefore, putting Au decorations on CeO2 nanoparticles could be used in the biomedical industry. Antibacterial activity is one of many possible biological uses for metal NPs, such as gold (Au) NPs. Compared to antibiotics alone, Au NPs have been shown to have increased antibacterial activity. The unique biocompatibility of Au NPs, which is influenced by their size, shape, concentration, and kind of surface functionality, makes them an effective antibacterial agent. Due to its inherent capacity to create a variety of antimicrobial chemicals, including organic acids, hydrogen peroxide, bacteriocins, or similar substances, various authors have shown that Lactobacillus plant arum has strong antibacterial activity. Bacteriocins are one of these metabolites that is of particular interest because numerous papers have shown their effectiveness against a variety of bacteria .53 Instead of using the outdated citrate approach, sodium borohydride ($NaBH_4$) was used to create gold nanoparticles. Using an enzyme-linked immunosorbent assay (ELISA) reader spectrophotometer, the impact of gold nanoparticles on the kinetics of bacterial growth was investigated .54 T Gold nanoparticles (GNP) are attractive in many fields of medicine for experiments on gum disease, dental caries, tissue engineering, dental implantology, and cancer diagnosis due to their unique properties, including their adjustable size, shape, surface properties, optical properties, biocompatibility, low cytotoxicity, high stability, and multi-functional potential. GNP has antifungal and antibacterial action; therefore, it can be added to some biological materials to give them antibacterial qualities, increasing the materials' suitability for various applications. In addition to having strong antibacterial action against common types of bacteria, modified gold nanoparticles also exhibit distinctive antibacterial activity against multidrug-resistant bacteria. It is difficult to introduce bacteria that are resistant to gold nanoparticles, even after several generations of cultivation .55 Silver and gold nanoparticles' antibacterial and anticancer properties and the environmentally benign method used to create them .56

Silicon dioxide Nanoparticle: -

According to a recent paper, microbial cultures can be harmed by nanoparticles like silver and zinc (or their oxides), SiO_2, TiO_2, and CuO. In contrast to other nanoparticles, SiO_2 is not the most efficient antibacterial agent. The ultra-fine, sharpened points of Nano walls tear bacterial cell membranes when they come into contact with them .57 Nanoparticles with sizes of e100 nm are often more effective biocides, while metallic and metal oxide nanoparticles with diameters of 1 to 500 nm have been shown to demonstrate toxicity towards both gram-positive and gram-negative microbes .58 Due to their huge surface area and large pore diameter, SiO_2 nanoparticles with highly organized Nano pores are frequently used as supporting mediators. Additionally, it offers the following benefits: i) Simple surface modification, ii) potential for recovery from the reaction mixture, and iii) catalyst reuse are significant characteristics from an economic and environmental perspective .59 The effectiveness of silica-collagen type I nanocomposite hydrogels as medicinal dressings to stop infection in chronic wounds is being investigated. Gentamicin and rifampicin are two antibiotics that are combined into a single silica nanoparticle in a single step. It will be determined how effective they are at combating Staphylococcus aureus and Pseudomonas aeruginosa. The effectiveness of silica nanoparticles and collagen nanocomposites as innovative drug delivery methods to stop infection in chronic wounds has been studied. Rifampicin and gentamicin, two antibiotics, were combined into simple silica nanoparticles (SiNPs) of varied sizes for this purpose using a one-step process. These particles' cytotoxicity for L929 fibroblast cells and antibacterial activity against Staphylococcus aureus or Pseudomonas aeruginosa were both assessed [60].

Silver oxide Nanoparticle: -

For a very long time, it has been known that silver ions have potent inhibitory and bactericidal effects as well as a wide range of antimicrobial activities linked to numerous crucial enzymes and DNA .61 When it comes into contact with bacteria, AgNPs begin to build on its cell wall .62 The antibacterial properties of silver-based substances against a variety of microorganisms are well established .63 AgNPs have been tested for their antibacterial effectiveness against bacteria that are resistant to a variety of drugs, including Salmonella species, Enterococcus species, Streptococcus polygenes, S. aureus, and E. coli. AgNPs have also been demonstrated to increase the antibacterial activity of antibiotics, particularly erythromycin, against S. aureus and E. coli, including penicillin G, amoxicillin, vancomycin, and clindamycin .64 Ag+ ions must first be released from NP surfaces before they can interact with cellular targets to produce Ag-NPs. According to other studies, the Ag-NP-induced toxicity, which may result from direct physical processes caused by Nano-objects, such as disruption of the cell membrane, penetration into the cytoplasm of bacteria, and ribosomal damage, is not dependent on the release of Ag+ ions .65 It has antibacterial and anti-filarial properties and combats non-pathogenic germs. Provide extract limits ions to the dispersion of ions with antifungal, antiviral, and anti-filarial activity that also combats the resistance of numerous pathogenic and nonpathogenic microorganisms. The interaction of silver ions with the peptidoglycan cell wall and cell membrane, bacterial DNA, and bacterial proteins, particularly enzymes, is what gives Ag nanoparticles their antibacterial properties. Ag nanoparticles have toxicological effects and biomedical applications in the transport of drugs, molecular imaging, biomedical sensing, and even cancer photodynamic treatment .66 Using plant extracts from Eleusine indica instead of high pressure, energy, or temperature results in the green synthesis of SNPs. Plant extracts contain phytochemicals that function as reducing, capping, or stabilizing agents, which increase catalytic activity. Terpenoids, alkaloids, phenolic compounds, and enzymes are examples of phytochemicals that convert positive silver ions to the zero-oxidation state. Phytochemicals have an impact on the SNP size distribution .67 Due to their distinctive architectures, the Ag core-shell nanoparticles would offer a new opportunity to be promising candidates for antibacterial materials, and at the same time, the shell would shield the Ag nanoparticles and stabilize them against chemical corrosion. It is conceivable that the excellent antibacterial effects would be produced and maintained by the Ag cores slowly releasing Ag ions via the outside porous coating layer .68

Table 2
Different Nanoparticle and their Characteristic, Example and Functions

s.no.	Nanoparticle	Size of Nano article	Shape	Mode of Action	Characteristic	effect	Application	Reference

1	Ag Nanoparticle. ***Geranium leaves***	40 nm	Quasilinear	Ion release, bacterial membrane pits, and enzyme interactions disrupt metabolic processes, leading to DNA damage in the G2/M phase of the cell cycle, resulting in lost replication potential.	This substance exhibits high stability, non-toxicity, antifungal activity against spore-producing fungal plant diseases, and antibacterial activity against both bacteria and drug-resistant bacteria.	Antimicrobial	including cancer, PhotoDNA Mic treatment, drug delivery, molecular imaging, and biomedical sensing.	61,63, 68,23
2	Au Nanoparticle ***Proteus mirabilis PTCC1710***	10-20nm	Spherical	Gold nanoparticles exhibit antibacterial action through two stages: altering membrane potential and decreasing ATP synthase activity, and dismantling the biological framework of the ribosome for tRNA binding. These nanoparticles are less harmful to mammal cells and have electrical properties that enhance their surface reactivity. Small gold nanoparticles with larger surface areas also	Size, form, surface properties, optical properties, biological compatibility, low cytotoxicity, high reliability, and potential for avariety of purposes may all be customized for the capacity.	No reported anti-bacterial activity	dental caries, periodontal disease, tissue engineering , implantology, and cancer diagnostics	26,54, 55,57

6	Si nanoparticle. ***Aspergillus flavus***	1 to 500 nm	Oval	ROS and lipid peroxidation, which increase membrane permeability. a nd jeopardize cell integrity, are the main causes of oxidative stress.	Large surf ace area and highly organized nanopores. Fluconazole-compatible photocatalytic properties a nd antifungal characteristics.	antibacterial	easy surface modification, possibility of recovery from the reaction mixture, reusing of the catalyst.	60,66, 41
				improve their effectiveness.				
3	Ti nanoparticle	40-60 nm	spherical	Lipid per oxidation, which increases membrane permeability and compromises cell integrity, causes oxidative stress by producing reactive oxygen Species (ROS)	substance that is self-cleaning and self-sanitizing strong super hydrophilicity and oxidation activity.	Suppress aquatic biofilm growth	Possibility of a packing solution that would increase the freshness of fruits and vegetables.	46,47
4	Cu nanoparticle. ***K. pneumonia,***	20 nm	spherical	The critical parts of the bacterium are damaged as a result of nanoparticles from the bacteria's cell membrane crossing across. The release of Cu2+ ions from NPs causes	A growing number of applications, including in CuO NPs that are used in solar energy, batteries,gas	Anti-microbial against *B. subtilis*	Antifouling paints include copper nanoparticle s to stop the growth of	51,52, 8

	S. dysenteries, and V. cholera			reactive oxygen species and DNA damage.	sensors, heat transfer fluids, and catalysis. CuO crystal forms have narrowband gaps, which have good photocatalytic and photovoltaic properties.		biofilm on ship hulls.	
5	Zn nanoparticle. ***Staphylococcus aureus***	50-70 nm	spherical	Nanoparticle internalization into the cell, zinc ion release, ROS production on the particle surface, and membrane malfunction.	improved heat resistance, higher selectivity, reduced toxic exposure, and longevity. biocompatibility, non-toxicity, long-term environmental stability, and wide-spectrum antibacterial effectiveness.	antibacterial	the antibacterial effectiveness of dental resin composites while preserving their mechanical qualities, ZnO nanoparticles were created using the spray-drying technique	20,22, 33

Significance of nanoparticle activity on metal and metal oxides

Significant antimicrobial potential exists in nanoparticles. The physical and morphological features of nanoparticles are affected by the use of different synthesis techniques, chemical modification, and collaborative use with other nanomaterials, which, in turn, results in a change in their antibacterial capabilities .69 Significant antimicrobial potential exists in nanoparticles. The physical and morphological features of nanoparticles are affected by the use of different synthesis techniques, chemical modification, and collaborative use with other nanomaterials, which, in turn, results in a change in their antibacterial capabilities .70 Numerous transient metal and metal oxide nanoparticles (NPs) have demonstrated strong biological activity, including activity against a variety of Gram-positive and Gram-negative bacteria, including pathogens and drug-resistant ones. Thus, NPs can be used in biomedicine to treat a variety of ailments as well as nanotechnology to regulate bacterial development .71 NPs either slow down or stop bacterial development by destroying the cell wall or removing the source of nourishment for the bacterium. The antibiotics now being used in clinical settings are known to exert their bactericidal or bacteriostatic activity by destroying the bacterial cell wall or obstructing the source of nourishment for the bacterium. By functioning as enzyme inhibitors, antibiotics make use of the principle of enzyme inhibition to disrupt a crucial metabolic pathway in bacteria, which ultimately results in bacterial death .72 Because of their small size, metal nanoparticles' capacity to destroy bacteria has been altered. It is feasible to immobilize and cover surfaces with antibacterial metal nanoparticles. Many different businesses, including those that produce medical equipment and gadgets, treat water, and prepare food, may employ these materials .73

Conclusion

Even if a number of approaches have been developed to combat microbial resistance, the increasing prevalence of microbes that are multidrug-resistant emphasizes the need for additional therapy alternatives. Metallic NPs are potential antibacterial agents and potential antibiotic alternatives due to their remarkable biocidal action. Due to their unique characteristics and demonstrated applicability in a number of sectors including medicine, catalysis, textiles engineering, biological sciences, nanobiotechnology, biological engineering sciences, electronics, optics, and water treatment, these nanoparticles have grabbed the attention of researchers. Despite the fact that NPs have been linked to cytotoxicity, genotoxicity, and inflammatory reactions in cells, there are still worries about NPs being inadvertently exposed to people. AgNPs' cytotoxic, genotoxic, apoptotic, and antiproliferative effects can be employed to treat sick cells, such as cancer, by inhibiting their proliferation. However, more effective experimental techniques are required to create well-characterized nanoparticles. All things considered, metal and metal oxide-based nanoparticles have a lot of potential as antibacterial agents of the future. Their particular characteristics give them a number of perks over conventional antibiotics, which make them a vital tool in the battle against infectious diseases. Before they are extensively used, though, further research is required to address worries regarding their toxicity and potential effects on the ecosystem.

Acknowledgements
All listed author(s) are thankful to Department of Microbiology, JECRC University for providing the related support to compile this work.

References: -

1. Jagadeeshan, S., & Parsanathan, R. Nano-metal oxides for antibacterial activity. Advanced

Nanostructured Materials for Environmental Remediation, 10,

59-90(2019)

2. Slavin, Y. N., Asnis, J., Hńfeli, U. O., & Bach, H. Metal nanoparticles: understanding the mechanisms behind antibacterial activity. Journal of nanobiotechnology, 15, 1-20 (2017)
3. Gold, K., Slay, B., Knackstedt, M., & Gaharwar, A. K. . Antimicrobial activity of metal and metaloxide based nanoparticles. Advanced Therapeutics, 1(3) ,1-15, (2018)
4. Perelshtein, I., Lipovsky, A., Perkas, N., Gedanken, A., Moschini, E., & Mantecca, P. The influence of the crystalline nature of nano-metal oxides on their antibacterial and toxicity properties. Nano Research, 8, 695-707 (2015)
5. Parham, S., Wicaksono, D. H., Bagherbaigi, S., Lee, S. L., & Nur, H. Antimicrobial treatment of different metal oxide nanoparticles: a critical review. Journal of the Chinese chemical society, 63(4), 385- 393 (2016)
6. Oun, A. A., Shankar, S., & Rhim, J. W. Multifunctional nanocellulose/metal and metal oxide nanoparticle hybrid nanomaterials. Critical reviews in food science and nutrition, 60(3), 435-460 (2020)
7. Gharpure, S., Akash, A., & Ankamwar, B. A review on antimicrobial properties of metal nanoparticles. Journal of nanoscience and nanotechnology, 20(6), 3303-333 (2020)
8. Sayes, C. M., Ameh, T., Zarzosa, K., Dickinson, J., & Evan Braswell, E. W. Nanoparticle surface stabilizing agents influence antibacterial action. Frontiers in Microbiology, 14,1-10, (2023)
9. He, Y., Ingudam, S., Reed, S., Gehring, A., Strobaugh, T. P., & Irwin, P. Study on the mechanism of antibacterial action of magnesium oxide nanoparticles against foodborne pathogens. Journal of nanobiotechnology, 14, 1-9 (2016)
10. Applerot, G., Lellouche, J., Lipovsky, A., Nitzan, Y., Lubart, R., Gedanken, A., & Banin, E. Understanding the antibacterial mechanism of CuO nanoparticles: revealing the route of induced oxidative stress. Small, 8(21), 3326-3337 (2012)
11. Shkodenko, L., Kassirov, I., & Koshel, E. Metal oxide nanoparticles against bacterial biofilms: Perspectives and limitations. Microorganisms, 8(10), 1-21, (2020)
12. Mamonova, I. A., Babushkina, I. V., Norkin, I. A., Gladkova, E. V., Matasov, M. D., & Puchin'yan, D.
M. Biological activity of metal nanoparticles and their oxides and their effect on bacterial cells. Nanotechnologies in Russia, 10(1-2), 128-134 (2015)
13. Alavi, M., & Yarani, R. ROS and RNS modulation: the main antimicrobial, anticancer, antidiabetic, and antineurodegenerative mechanisms of metal or metal oxide nanoparticles. Nano Micro Biosystems, 2(1) , 22-30 (2023)
14. Pandey, R. P., Mukherjee, R., Priyadarshini, A., Gupta, A., Vibhuti, A., Leal, E., ... & Lyu, X. Potential of nanoparticles encapsulated drugs for possible inhibition of the antimicrobial resistance development. Biomedicine & Pharmacotherapy, 141, 1-7, (2021)
15. Liu, L., Zhang, F., Xu, B., & Tian, W. Silica nanoparticles based on an AIE-active molecule for ratiometric detection of RNS in vitro. Journal of Materials Chemistry B, 5(46), 9197-9203 (2017)
16. Suzen, S., Gurer-Orhan, H., & Saso, L. Detection of reactive oxygen and nitrogen species by electron paramagnetic resonance (EPR) technique. Molecules, 22(1), 1-9, (2017)

17. Ren, Q., Sun, S., & Zhang, X. D. Redox-active nanoparticles for inflammatory bowel disease. Nano Research, 14, 2535-2557 (2021)
18. Mizwari, Z. M., Oladipo, A. A., & Yilmaz, E. Chitosan/metal oxide nanocomposites: synthesis, characterization, and antibacterial activity. International Journal of Polymeric Materials and Polymeric Biomaterials, 70(6), 383-391 (2021)
19. Pachaiappan, R., Rajendran, S., Show, P. L., Manavalan, K., & Naushad, M. Metal/metal oxide nanocomposites for bactericidal effect: A review. Chemosphere, 272,1-24, (2021)
20. Fernando, S., Gunasekara, T., & Holton, J. Antimicrobial Nanoparticles: applications and mechanisms of action. Sri Lankan Journal of Infectious Diseases, 8(1), 2-11 (2018)
21. Correa, M. G., Martínez, F. B., Vidal, C. P., Streitt, C., Escrig, J., & de Dicastillo, C. L. Antimicrobial metal-based nanoparticles: A review on their synthesis, types and antimicrobial action. Beilstein journal of nanotechnology, 11(1), 1450-1469 (2020)
22. Jung, J. H., Oh, H. C., Noh, H. S., Ji, J. H., & Kim, S. S. Metal nanoparticle generation using a small ceramic heater with a local heating area. Journal of aerosol science, 37(12), 1662-1670 (2006)
23. Tsuzuki, T., & McCormick, P. G. Synthesis of Cr2O3 nanoparticles by mechanochemical processing. Acta Materialia, 48(11), 2795-2801 (2000)
24. Motshekga, S. C., Pillai, S. K., Ray, S. S., Jalama, K., & Krause, R. W. Recent trends in the microwave-assisted synthesis of metal oxide nanoparticles supported on carbon nanotubes and their applications. Journal of Nanomaterials, 2012, 51-51 (2012)
25. Hegazy, I. M., Geioushy, R. A., El-Sheikh, S. M., Shawky, A., El-Sherbiny, S., & Kandil, A. H. T. Influence of oxygen vacancies on the performance of ZnO nanoparticles towards CO2 photoreduction in different aqueous solutions. Journal of Environmental Chemical Engineering, 8(4), 1-9, (2020)
26. Mostafa, A. M., & Mwafy, E. A. The effect of laser fluence for enhancing the antibacterial activity of NiO nanoparticles by pulsed laser ablation in liquid media. Environmental Nanotechnology, Monitoring & Management, 14, 1-8 (2020)
27. Meidanchi, A., & Jafari, A. Synthesis and characterization of high purity Ta2O5 nanoparticles by laser ablation and its antibacterial properties. Optics & Laser Technology, 111, 89-94 (2019)
28. Franzolin, M. R., Courrol, D. D. S., de Souza Barreto, S., & Courrol, L. C. Eugenia uniflora L. silver and gold nanoparticle synthesis, characterization, and evaluation of the photoreduction process in antimicrobial activities. Microorganisms, 10(5), 1-13, (2022)
29. Van Viet, P., Phan, B. T., Mott, D., Maenosono, S., Sang, T. T., & Thi, C. M. Silver nanoparticle loaded TiO2 nanotubes with high photocatalytic and antibacterial activity synthesized by photoreduction method. Journal of Photochemistry and Photobiology A: Chemistry, 352, 106-112 (2018)
30. Iravani, S., Korbekandi, H., Mirmohammadi, S. V., & Zolfaghari, B. Synthesis of silver nanoparticles: chemical, physical and biological methods. Research in pharmaceutical sciences, 9(6), 1-22, (2014)

31. Park, K. H., Han, G. D., Neoh, K. C., Kim, T. S., Shim, J. H., & Park, H. D. Antibacterial activity of the thin ZnO film formed by atomic layer deposition under UV-A light. Chemical engineering journal, 328, 988- 996 (2017)
32. Hassan, M. S., Amna, T., Yang, O. B., El-Newehy, M. H., Al-Deyab, S. S., & Khil, M. S. Smart copper oxide nanocrystals: synthesis, characterization, electrochemical and potent antibacterial activity. Colloids and Surfaces B: Biointerfaces, 97, 201-206 (2012)
33. Rodriguez-Sanchez, L., Blanco, M. C., & López-Quintela, M. A. Electrochemical synthesis of silver nanoparticles. The Journal of Physical Chemistry B, 104(41), 9683-9688 (2000)
34. Ramimoghadam, D., Bagheri, S., & Abd Hamid, S. B. Progress in electrochemical synthesis of magnetic iron oxide nanoparticles. Journal of Magnetism and Magnetic Materials, 368, 207-229 (2014)
35. Mohammed, M. A., Rheima, A. M., Jaber, S. H., & Hameed, S. A. The removal of zinc ions from their aqueous solutions by Cr2O3 nanoparticles synthesized via the UV-irradiation method. Egyptian Journal of Chemistry, 63(2), 425-431 (2020)
36. Flores-Rojas, G. G., López-Saucedo, F., & Bucio, E. Gamma-irradiation applied in the synthesis of metallic and organic nanoparticles: A short review. Radiation Physics and Chemistry, 169, 1-47, (2020)
37. Bindhu, M. R., & Umadevi, M. J. M. L. Antibacterial activities of green synthesized goldnanoparticles. Materials Letters, 120, 122-125 (2014)
38. Singh, A., Singh, N. Á., Afzal, S., Singh, T., & Hussain, I. Zinc oxide nanoparticles: a review of their biological synthesis, antimicrobial activity, uptake, translocation and biotransformation in plants. Journal of materials science, 53(1), 185-201 (2018)
39. AbdelRahim, K., Mahmoud, S. Y., Ali, A. M., Almaary, K. S., Mustafa, A. E. Z. M., & Husseiny, S. M. Extracellular biosynthesis of silver nanoparticles using Rhizopus stolonifer. Saudi journal of biological sciences, 24(1), 208-216. (2017)
40. Narayanan, K. B., & Sakthivel, N. Biological synthesis of metal nanoparticles by microbes. Advances in colloid and interface science, 156(1-2), 1-13 (2010)
41. Liu, Q., Zhang, M., Fang, Z. X., & Rong, X. H. Effects of ZnO nanoparticles and microwave heating on the sterilization and product quality of vacuum-packaged Caixin. Journal of the Science of Food and Agriculture, 94(12), 2547-2554 (2014)
42. Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N. H. M., Ann, L. C., Bakhori, S. K. M., ... & Mohamad, D. Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism. Nano-micro letters, 7, 219-242 (2015).
43. Janaki, A. C., Sailatha, E., & Gunasekaran, S. Synthesis, characteristics and antimicrobial activity of ZnO nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 144, 17-22 (2015)
44. Padmavathy, N., & Vijayaraghavan, R. Enhanced bioactivity of ZnO nanoparticles—an antimicrobial study. Science and technology of advanced materials. 9,1-7, (2008).
45. Atkinson, A., & Winge, D. R. Metal acquisition and availability in the mitochondria. Chemical reviews, 109(10), 4708-4721 (2009)

46. Yang, D. L., Cui, Y. N., Sun, Q., Liu, M., Niu, H., & Wang, J. X. Antibacterial activity and reinforcing effect of SiO2–ZnO complex cluster fillers for dental resin composites. Biomaterials Science, 9(5), 1795-1804 (2021)
47. Dutta, R. K., Nenavathu, B. P., Gangishetty, M. K., & Reddy, A. V. R. Studies on antibacterial activity of ZnO nanoparticles by ROS induced lipid peroxidation. Colloids and Surfaces B: Biointerfaces, 94, 143-150 (2012)
48. Allahverdiyev, A. M., Abamor, E. S., Bagirova, M., & Rafailovich, M. Antimicrobial effects of TiO2 and Ag2O nanoparticles against drug-resistant bacteria and leishmania parasites. Future microbiology, 6(8), 933-940 (2011)
49. El-Sayed, S. M., Amer, M. A., Meaz, T. M., Deghiedy, N. M., & El-Shershaby, H. A. Microstructure optimization of metal oxide nanoparticles and its antimicrobial activity. Measurement, 151, 1-20, (2020)
50. Zaleska, A. Doped-TiO2: a review. Recent patents on engineering, 2(3), 157-164 (2008)
51. Xing, Y., Li, X., Zhang, L., Xu, Q., Che, Z., Li, W. & Li, K. Effect of TiO2 nanoparticles on the antibacterial and physical properties of polyethylene-based film. Progress in Organic Coatings, 73(2-3), 219-224 (2012)
52. Xing, Y., Li, X., Guo, X., Li, W., Chen, J., Liu, Q., ... & Bi, X. Effects of different TiO2 nanoparticles concentrations on the physical and antibacterial activities of chitosan-based coating film. Nanomaterials, 10(7), 1-19, (2020)
53. Khan, S. T., Musarrat, J., & Al-Khedhairy, A. A. Countering drug resistance, infectious diseases, and sepsis using metal and metal oxides nanoparticles: current status. Colloids and Surfaces B: Biointerfaces, 146, 70-83 (2016)
54. Nthunya, L. N., Mbakop, S., Makgabutlane, B., Matlou, G., Mhlanga, S., & Richards, H. Fungal synthesis of copper nanoparticles and their applications in agri-food, environmental, and biomedical sectors. In Fungal Cell Factories for Sustainable Nanomaterials Productions and Agricultura Applications 4 (pp. 91-114) Elsevier (2023)
55. Rastogi, A., Zivcak, M., Sytar, O., Kalaji, H. M., He, X., Mbarki, S., & Brestic, M. Impact of metal and metal oxide nanoparticles on plant: a critical review. Frontiers in chemistry, 5, 1-16, (2017)
56. Ahamed, M., Alhadlaq, H. A., Khan, M. M., Karuppiah, P., & Al-Dhabi, N. A. Synthesis, characterization, and antimicrobial activity of copper oxide nanoparticles. Journal of Nanomaterials, 2014, 17-17 (2014)
57. Ren, G., Hu, D., Cheng, E. W., Vargas-Reus, M. A., Reip, P., & Allaker, R. P. Characterisation of copper oxide nanoparticles for antimicrobial applications. International journal of antimicrobial agents, 33(6), 587-590 (2009)
58. Sengul, A. B., & Asmatulu, E. Toxicity of metal and metal oxide nanoparticles: a review. Environmental Chemistry Letters, 18, 1659-1683 (2020)
59. Shamaila, S., Zafar, N., Riaz, S., Sharif, R., Nazir, J., & Naseem, S. Gold nanoparticles: an efficient antimicrobial agent against enteric bacterial human pathogen. Nanomaterials, 6(4), 1-10, (2016)
60. Su, C., Huang, K., Li, H. H., Lu, Y. G., & Zheng, D. L. Antibacterial properties of functionalized gold nanoparticles and their application in oral biology. Journal of Nanomaterials, 2020, 1-13 (2020)

61. Patil, M. P., & Kim, G. D. Eco-friendly approach for nanoparticles synthesis and mechanism behind antibacterial activity of silver and anticancer activity of gold nanoparticles. Applied microbiology and biotechnology, 101, 79-92 (2017)
62. Babu, K. S., Anandkumar, M., Tsai, T. Y., Kao, T. H., Inbaraj, B. S., & Chen, B. H. Cytotoxicity and antibacterial activity of gold-supported cerium oxide nanoparticles. International journal of nanomedicine, 9, 1-17, (2014)
63. Carpenter, A. W., Slomberg, D. L., Rao, K. S., & Schoenfisch, M. H. Influence of scaffold size on bactericidal activity of nitric oxide-releasing silica nanoparticles. ACS nano, 5(9), 7235-7244 (2011)
64. Ramya, E., Thirumurugan, A., Rapheal, V. S., & Anand, K. CuO@ SiO2 nanoparticles assisted photocatalytic degradation of 4-nitrophenol and their antimicrobial activity studies. Environmental Nanotechnology, Monitoring & Management, 12, 1-4, (2019)
65. Alvarez, G. S., Hélary, C., Mebert, A. M., Wang, X., Coradin, T., & Desimone, M. F. Antibiotic-loaded silica nanoparticle–collagen composite hydrogels with prolonged antimicrobial activity for wound infection prevention. Journal of Materials Chemistry B, 2(29), 4660-4670 (2014)
66. Kim, S. H., Lee, H. S., Ryu, D. S., Choi, S. J., & Lee, D. S. Antibacterial activity of silver-nanoparticles against Staphylococcus aureus and Escherichia coli. Korean J. Microbiol. Biotechnol, 39(1), 77- 85 (2011)
67. Le Ouay, B., & Stellacci, F. Antibacterial activity of silver nanoparticles: A surface science insight. Nano today, 10(3), 339-354 (2015)
68. Russell, A. D., & Hugo, W. B. 7 antimicrobial activity and action of silver. Progress in medicinal chemistry,31,351-370(1994)
69. Singh, P., Garg, A., Pandit, S., Mokkapati, V. R. S. S., & Mijakovic, I. Antimicrobial effects of biogenic nanoparticles. Nanomaterials, 8(12), 1009 (2018)
70. Dong, Y., Zhu, H., Shen, Y., Zhang, W., & Zhang, L. (2019). Antibacterial activity of silver nanoparticles of different particle size against Vibrio Natriegens. PloS one, 14(9),1-12, (2019)
71. Esmaeili-Faraj, S. H., & Nasr Esfahany, M. Influence of SiO2 and graphene oxide nanoparticles on efficiency of biological removal process. Environmental technology, 38(21), 2763-2774 (2017)
72. Le, T. A. T. Antibacterial Activity of Silver Nanoparticles Synthesized Using Eleusine Indica L. Gaertn Leaf Extract on the Bacteria Isolated from the Vase Solution. Dalat University Journal of Science, 13 ,36-51 (2023)
73. Dhanalekshmi, K. I., & Meena, K. S. Comparison of antibacterial activities of Ag@ TiO2 and Ag@ SiO2 core–shell nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 128, 887-890 (2014)
74. Gudkov, S. V., Burmistrov, D. E., Serov, D. A., Rebezov, M. B., Semenova, A. A., & Lisitsyn, A. B. A mini review of antibacterial properties of ZnO nanoparticles. Frontiers in Physics, 9,1-12, (2021).
75. Yuan, P., Ding, X., Yang, Y. Y., & Xu, Q. H. Metal nanoparticles for diagnosis and therapy of bacterial infection. Advanced Healthcare Materials, 7(13), 1-17, (2018)

76. Gabrielyan, L., & Trchounian, A. (2019). Antibacterial activities of transient metals nanoparticles and membranous mechanisms of action. World Journal of Microbiology and Biotechnology, 35, 1-10, (2019)
77. Ahmed, K. B. A., Raman, T., & Veerappan, A. Future prospects of antibacterial metal nanoparticles as enzyme inhibitor. Materials Science and Engineering: C, 68, 939-947 (2016)
78. Rana, S., & Kalaichelvan, P. T. Antibacterial activities of metal nanoparticles. Antibacterial ActivitiesofMetalNanoparticles,11(02),21-23(2011)