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Antimicrobial Activity of Nanoparticles: A Review

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Abstract:- Metal nanoparticles have been employed for antimicrobial purposes since the dawn of time. Metal nanoparticles have gotten a lot of interest as the need for nanotechnology has grown due to their wide range of applications. Chemical and biological methods are preferred as they possess great efficiency, low production costs, and environmental friendliness. Precursors, reducing agents, and stabilizers can all be used in the chemical production of nanoparticles. Fungi, bacteria, yeast, plant components, and plant extracts are all used in biological methods. Researchers have turned their attention towards inorganic disinfectants due to the toxicity of organic chemicals. Although silver is thought to have the best antibacterial activity, other inorganic metals such as ZnO, CuO, Gold, and TiO2 have also attracted researcher's attention. Microorganisms are microscopic living organisms that are found all over the world. Bacteria, fungi and yeast are the most common microorganisms. Antibacterial capabilities of nanoparticles have been discovered for both Gram-positive and Gram-negative microorganisms. Metal nanoparticles antimicrobial mechanisms involve the production of metal ions that damage the intracellular membrane, causing ROS, and then intrude the bacterial cell membrane, damaging bacterial DNA, and causing cell death. The efficiency of the antimicrobial action of NPs depends on the shape and size of the particle. This review focus on the literature, advancement in antimicrobial action of nanoparticle, the antibacterial activity of nanoparticles, the action of nanoparticles on microbes and commercial applications of metal nanoparticles are all explored in this paper.

Keywords:- *Metal Nanoparticles, Microbes, Biological Synthesis, Metal Oxide.*

I. INTRODUCTION

Nanoscience has recently been established as a new multidisciplinary science. It is frequently described in all information on the major properties of nanoscale objects. Nanoparticles are small particles that range in size below hundred nanometers [1]. Now a day's nanotechnology is emerging rapidly in every field due to its vast range of application in nano chemistry [2]. Nanotechnology is acknowledged for its exceptional properties such as chemical, physical [3] and biological properties. Inorganic nanoparticles remain preferred owing its high versatility availability, ease of release of drugs in medicinal field.

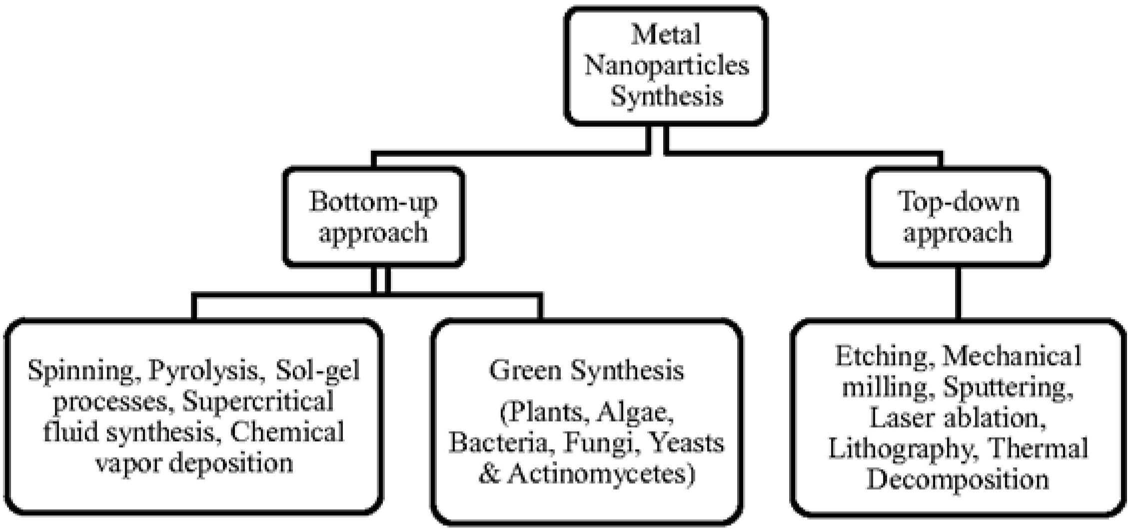
Metal nanoparticles can be made via physical and chemical means, and they've sparked a lot of attention due to their enormous potential in nanotechnology [4]. Metal nanoparticles can be manufactured using both a "top-down" also "bottom-up" technique. Top-down approach refers to bifurcation of bulk metal into successive smaller pieces, it comes under physical approach. Physical approach is not the best choice to synthesis MNPs as it produces imperfect structures [5]. Bottom-up approach relates to the construction of substance from bottom level to the bulkier one. It gives more emphasis on the utilization of various microorganisms in green synthesis [6].

Chemical reduction method is the preferred method as it is well-organized, easy availability of reagents and convenience [7]. Chemical reduction method has many advantages over physical method such as it is highly efficiency, low production cost. Using reducing chemicals, metal can be chemically reduced (Ethylene glycol. sodium borohydride, ascorbic acid, hydrazine and to prevent agglomeration stabilizers are used (PVP, Trisodium citrate, PMMA, cellulose etc.) and can be utilized as better reducing and stabilizing agent depending upon desired characteristic as of particle size, dispersion, physiology and surface structure of the particle.

Biological method can be performed by using fungi, yeast, plant parts, plant extract, bacteria and diatoms [8]. Because of its quick production, low cost, and controlled toxicity, and environmental friendliness, biological synthesis is preferred.

Metal precursors are used to make metal nanoparticles. In nature, there are many metals, but only a few of them are useful can be used for example nanostructured form such as gold, silver, zinc, iron, copper, aluminum [9,10,11]. Metallic nanoparticles have size and shape-dependent features that are useful in a variety of applications, including propulsion and detection, as well as optics and antibacterial action. [12] and frequently used in cosmetics and textile industries [13]. Depending upon shape, size and structure metal nanoparticles can be used in catalytic, electrical and magnetic properties. Reducing agents and stabilisers can influence the shape and size of particles [14].

This review article gives a quick overview of current research on metallic nanoparticle manufacturing, both chemically and biologically. The biosynthesis, mechanism, and commercial applications of metallic nanoparticles are then discussed. The report finishes with a discussion of the existing limitations and future opportunities of microorganism-based nanoparticle production.



Method of Synthesis of Metal Nanoparticles [61]

II. ANTIMICROBIAL ACTION OF METAL NANOPARTICLES

Some microorganisms are beneficial and are used in the production of curd, bread, and alcohol, while others are harmful and are responsible for food spoilage and disease transmission. Microorganisms can interact with metals that come into contact with their cells and form nanoparticles. Metallic ions can be separated by certain microorganisms. This is commonly used to recover precious metals or to purify water.

Antimicrobial properties of silver nanoparticles are widely recognized. Silver is an inorganic noble MNPs and they provide advanced material with functional versatility [15]. Silver is the ideal material since it is inexpensive and has excellent electrical and thermal conductivity. AgNPs can be synthesized by various method but the most preferred is chemical reduction method and have various applications in agriculture, industry, pharmaceutical industry, water purification etc. Silver nanoparticles can also be used in inks, medicinal equipment's [16]. Silver nanoparticles suppress microorganism that are Gram positive and Gram-negative bacteria [17].

Green method is more advantageous than chemical method due to the use of chemical reagents. Therefore, the use of ecofriendly methods has widely been used. The utilization of plant extracts in the production of AgNPs is based on their comparatively high quantities of reducing agents such as steroids, biological chemicals, and flavonoids, as well as bio-capping chemicals that inhibit nanoparticle aggregation and allow for better size control [18].

A. SILVER NANOPARTICLE

Silver nanoparticles from plant extract are relatively simple. Plant part is collected and washed with clean water and dried. Formerly the plant part is boiled in DI water, keep it until cool and then filtered. To the silver nitrate solution, add the required amount of extract and stir until the colour changes.

The below picture is of bread at day1, day3 and day 5 Green tea extract containing silver nanoparticles is used in this experiment, and it is sprayed on a regular basis. The observation was there was no fungus grown on bread till day 5 and it is a proof that silver nanoparticles act as antimicrobial agent.

Day1 Day 3 Day 5

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Durán, *etal*, the antibacterial activity of *oxysporum* extracellular production of silver nanoparticles when included in cotton fabrics against S. aureus was examined. Moreover, *C. violaceum* treatment was used to bioremediate all effluent. According to the findings, cotton fabrics impregnated with silver nanoparticles had substantial antibacterial action against *S. aureus*. The process effluent was treated with *C. violaceum*, as a result, the concentration of silver nanoparticles was significantly reduced. [19].

To reduce the toxicity in environment ecofriendly synthesis of nanoparticles are being used. Gurunathan, Sangiliyandi, et al. found that decreasing silver ions produces the most silver nanoparticles. by cultivating E. coli bacteria under ideal conditions Particles having a diameter of 50nm were discovered. This research also showed that particle size can be used by altering variables such as temp, conc, and pH value [20]. Yeast is utilised to make Ag-Au alloy nanoparticles, which is an environmentally beneficial technique [21].

Fungi release extracellular enzymes that are responsible for extracellular macromolecule breakdown followed by nutrition assimilation outside the cell. Because of this one-of-a-kind property, they are extremely important in the extracellular synthesis of AgNPs. Fungi are typically separated from the extracellular enzyme-containing aqueous medium after incubation and colony growth. The first ones are removed from the medium, and AgNO3 is added. After that, Incubation is performed on the mixture, which is normally done at room temperature. The above-mentioned equations govern AgNPs production. The synthesis reaction can be confirmed by a change in the colour of the liquid [22].

B. ZINC NANOPARTICLE

Zinc oxide NPs have piqued the interest of researchers because of their nifty and promising biomedical science applications, UV and optical applications [23]. They are highly toxic to bacteria and have been shown to be resistant to high temperatures and pressure [24]. *S. aureus, Streptococcus pyrogens* inhibit 95% growth [25]. Antimicrobial agents have very minimum effect on humans [26]. Zinc oxide prevent spoilage of food and widely used in food industry [27]. ZnO NPs' antibacterial capabilities are due to intracellular buildup of ZnO NPs, which damages cell walls and inhibits DNA replication. Inside the cells, nanoparticles (NPs) produce metal ions and reactive oxygen species (ROS), which build up on the bacterial membrane. ZnO NPs have a high ROS generating potential, showing that they play a key role in bacterial death by damaging cell walls, increasing membrane permeability, internalization of NPs due to proton motive force loss, and uptake of poisonous dissolved zinc ions [28]. Zinc ions (Zn^{2+}) exhibit antimicrobial properties against a wide range of bacterial and fungal species. The current study aims to assess the contribution of soluble zinc species to the antimicrobial activity of ZnO on microbial cultures (*Escherichia coli, Staphylococcus, Pseudomonas aeruginosa, Candida albicans, Aspergillus brasiliensis*) in broth medium, as well as to investigate zinc dissolution from ZnO suspensions. ZnO appears to be a better option than soluble zinc salts like zinc gluconate [29]. Mg-doped ZnO NPs was more effective than alkaline metallic ion-doped Zinc nps in suppressing the growth of *C. albicans* strains in antifungal testing [30]. Fungi are responsible for a wide range of infectious disorders. Zinc oxide nanoparticles have antifungal capabilities, as evidenced by the elimination of ringworm infection using disinfecting chemicals [31].

C. TITANIUM DIOXIDE

At low temperatures, an aqueous titania sol was employed to form a well-adherent surface of TiO_2NPs on cellulose fibers by hydrolysis and condensation processes of titanium isopropoxide in water. In dark, they are less effective than UV. This shows major applications in textile, biomaterials [32]. In this method, the toxin decomposition with antimicrobial activity. An investigation by using electrospinning method. Nano silver , (TiO_2) nanofibers were developed having antibacterial activity, self-cleaning ability, and potential for hazardous disintegration were created. [33].

D. COPPER NANOPARTICLES

Over the last several years copper shows remarkable antimicrobial activity. Copper NPs are found to perform 2 roles as antibacterial agents as well as enhance porosity in beads [34]. Copper oxide is a semiconductor which exhibit wide range of properties such as superconductivity, withstand high temperature. Oral infections are also shown to be resistant to antibacterial action when copper oxide nanoparticles are used [35].

The bactericidal conc required to stop E. coli growth was determined using suspended CuO NPs. Thus, MBC value was obtained [36]. Usman *et al*, in this the effect growth of microorganisms were studied using chitosan medium. Microorganisms used are *S. aureus, Aeruginosa, Salmonella choleraesuis*, and *C. albican* depending on chitosan stabilizer the size of nanoparticles was found to be 2-230nm [37].

A polyol method was used to create copper nanoparticles in an ambient atmosphere. Copper nanoparticles found to have antimicrobial activity against five bacterial strains and three fungal strains E. coli was shown to be more suppressive than fungus [38].

E. GOLD NANOPARTICLES

Gold is highly stable, resistant to heavy chemicals and it is good conductor of heat. From past few decades, gold nanoparticles are known for its antimicrobial, catalytic, optical properties. At high concentrations, gold nanoparticles inhibit cell development, but there is little evidence that they have any effect on bacterial multiplication. On the basis of antimicrobial activity gold shows dual activity: inhibit membrane and generating ROS. Gold NPs is a bactericide with a broad spectrum of action, killing both gram negative and positive bacteria. *P. aeruginosa and E. coli* are synthesized by biological method and have particle size of 18.2 and 150nm respectively [40,41].

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III. MICROBES

Microorganisms are also known as microbes. Microbes are the tiny, unicellular organism and ubiquitous in nature. Microbes are diverse and can adapt to any habitat from poles to equator. Microorganisms are important to humans and also contribute to many health benefits. microorganisms are classified into 2 categories i.e., prokaryotes and eukaryotes. Prokaryotes include archaea, bacteria and eukaryotes include protists, fungi and plants.

Table 1 Synthesis of metal nanoparticles, method, microorganisms and particle size

NP	METHOD	MICROORGANIAM	SIZE	REF
Silver	Biological	*S. Aureus*	-	[19]
Silver	Biological	*E. Coli*	50nm	[20]
Silver/Gold	Biological	*Yeast*	9-25nm	[21]
Zinc	Biological	*Escherichia Coli, Candida Albicans, Aspergillus Brasiliensis*	-	[29]
Zinc	Chemical	*C.Albicans*	47-63nm	[30]
Zinc	Biological	*Trichophyton Mentagrophytes, Micros Porum Canis, C. Albicans and A. Fumigatus*	57nm	[31]
Titanium Dioxide	Chemical	*S. Aureus, Enterococcus Hirae, E. Coli, And Bacteroides Fragilis*	20nm	[32]
Titanium Dioxide	Chemical	*Staphylococcus Aureus, E. Coli*	-	[33]
Copper	Biological	*E.Coli*	20-95nm	[36]
Copper	Chemical	*Staphylococcus Aureus, Bacillus Subtilis.*	20-350nm	[37]
Copper	Chemical	*Micrococcus Luteus, Staphylococcus Aureus, Escherichia Coli*	-	[38]
Gold	Biological	*E. coli, S Aureus, Staphylococcus Epidermidis.*	-	[39]
Gold	Biological	*P. Aeruginosa S. Aureus*	18.32 nm	[40]
Gold	Biological	*E. Coli*	150nm	[41]

IV. ACTION OF METAL NANOPARTICLES ON MICROBES

Bacteria is classified into two categories on the basis of its structure that is gram (+) bacteria and gram (-) bacteria. Peptidoglycan, the main component of gram-positive bacteria's cell wall. Due to differences in cell walls of different bacteria, gram (+) bacteria's cell walls are resistant to nanoparticles. The gram-positive bacterium S. aureus possesses a peptidoglycan cell wall. Several researchers believe that a thick layer of peptidoglycan in gram-positive bacteria acts as a protective coating, preventing nanoparticles from interacting with the cell wall. Gram negative bacteria consist of thin peptidoglycan layer and additional lipopolysaccharide membrane. *E. coli*, a Gram (-) bacteria covered with peptidoglycan layer and lipopolysaccharide layer. These molecules carry negative charge and attached with positively charged nano particles which increase up take of ions and cause intracellular damage.

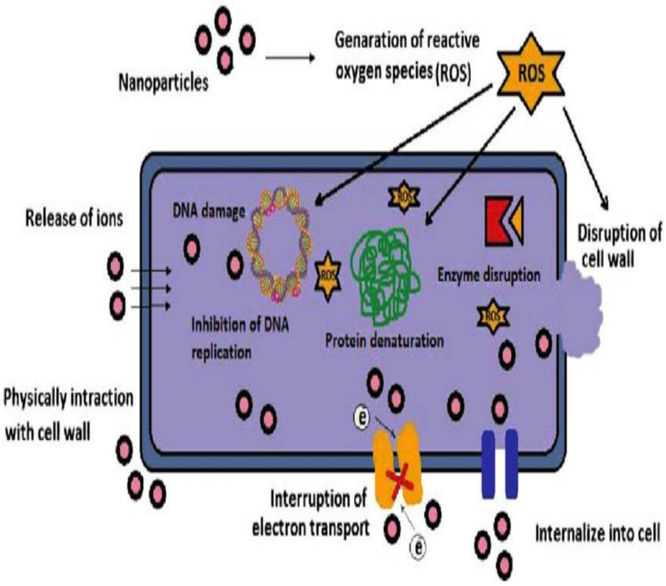
Negatively charged ROS, such as hydroxyl radicles, have a difficult time penetrating the negative cell membrane [42]. When charged capping agents are utilized in NP manufacturing, electrostatic characteristics become increasingly relevant. Heavy metals are used in the production of antimicrobial NPs. Because these metals are predominantly transition metals with partially filled d-orbitals, they are more redox active, making NP production easier.

The most common technique for producing NP is 'bottom-up' chemical reaction that involves a metal salt and strong reducer [43]. The metal cation is reduced to a neutral state, allowing the metal atom to combine and form NP The metal cation is reduced to a neutral state, allowing the metal atom to combine and form NP. [44]. The produced NP is a neutral metal that cannot penetrate the cellular membrane; however, Metal NP is recognized for slowly releasing metal ions and the ability to permeate the membrane, affecting cellular processes from within the cell [45].

Many different features can be attributed to the bactericidal activity of transition metal NP. The ability to create ROS and their proclivity for forming tight bonds with R-SH groups is the most essential feature. The SH group can easily attach to non-essential transition metal ions with a high at. no, such as Ag^+. The construction of (ROS) is highly harmful for bacterial cells After a nanoparticle comes into contact with a bacterium, a chain of events starts with possible oxidation of respiratory enzymes, supporting in generating ROS and radical species, eventually affecting mobile body structure and promoting DNA destruction [46].

Despite the fact that oxygen is the best acceptor of electrons when breathing, certain tiny creatures may be killed by it. The ground state of the oxygen molecule, trio oxygen ($3O_2$), is exceedingly harmful to cells, but singlet oxygen (O_2) is also lethal to germs. Peroxidation of biological components such as proteins and lipids are well known to occur when singlet oxygen is produced [47]. Singlet oxygen promotes both beneficial and harmful oxidations within the cell. The respiratory burst, which consumes oxygen while producing free radicals, produces

H_2O_2 throughout several processes. As a result, free hydroxyl radical production is unquestionably at the center of H_2O_2 activity, and leading to the oxidation of DNA, proteins, and lipids abounds [47]. Bacteria that are exposed to ROS gradually lose the integrity of their membranes, making it impossible for them to stick to surfaces, uphold adequate interaction with other bacteria. The release of (ROS) and suppression of cellular adhesion are two theories on how nanoparticles work. In response to ROS, certain bacteria produce enzymes like superoxide dismutase, which can help them fight back. This method of neutralizing oxidative stress may be effective. Furthermore, bacteria can offer two key mechanisms to cope with high oxidative stress: the superoxide response system and the oxidative response system responding to hydrogen peroxide. These methods have been shown to be effective in repairing damaged cell components and controlling reducing circumstances [48,49]. Finally, ROS, generate oxidative injury in microorganisms exposed to nanoparticles.



Action of metal nanoparticles on microbes [62]

AgNPs have a more potent antibacterial effect against microorganisms. The permeability of a bacterial cell membrane is altered by silver nanoparticles, allowing silver nanoparticles to enter. Cell division is inhibited and cell death occurs when nanoparticles contact with the intracellular membrane. [50].

The metal enters the cell intracellularly in zinc oxide nps, damage cell wall and DNA replication. Processes inside the cytomembrane are: metal ions are released by ZnO NPs, generation of ROS and then it spread inside the membrane leads to the damage of cell wall.[51]

Due to photocatalytic activity of TiO_2NPs it can destroy microorganisms. ROS oxidise the cell membrane resulting in cell death. In the absence of light, it causes membrane disruption [52].

The antimicrobial activity of CuO NPs depends upon aggregation, minimum aggregation result in lesser nanoparticles, extensive surface area, resulting in increased toxicity. Copper in its metallic and ionic forms produces hydroxyl radicals, which harm critical proteins and DNA [53]. Gold nanoparticles of size less than 2nm found to be stronger against microbes [54].

V. COMMERCIAL APPLICATIONS OF METAL NANOPARTICLES

1.Cosmetics

Nanomaterials are found to be very affective in blocking UV radiation in sun screens. Metal nanomaterial such as titanium dioxide helps in the protection of skin by applying sunscreen lotion contain SPF [55]. Nanoscale ingredients show long last effects on skin. In the presence of silver nanoparticles, the deodorant producer claims that the impact lasts up to 24 hours. Gold nanoparticles if added in toothpaste helps in disinfecting strains of bacteria in mouth [56].

2.Catalysts and Elimination of Pollutants

In catalysis, metal nanoparticles play an important function. Metal nanoparticles with surface area and many active spots, in particular, improve reaction speed and increase yield [57] catalysts are classified as heterogenous, homogenous and biocatalysts. These homogeneous catalysts are commonly utilized in a variety of industrial processes in which the reactants and products are in the same (gaseous or liquid) phase and when in different phase it is heterogenous. Green catalyst helps in minimizing waste product [58]. Platinum-supported nanoparticles widely used in many disciplines, electrocatalytic oxidation of fuel cells, due to their excellent dispersibility and catalytic activity.

3.Paint

Nanotechnology has also been used fully in the paint industry. Metal nanoparticles in paint operate as anticorrosive, insect repellent, and self-cleaning agents. Silicon dioxide, ZnO, and TiO_2 nanoparticles have the most protective coatings.

4.Water purifier

Water purifiers are the emerging field in nanotechnology. The use of silver's antibacterial properties is most commercialized application. [59]. Mercury is also removed from drinking water using gold nanoparticles. In another fascinating examination, A method for releasing ultra-fine gold particles into water has been developed, with the goal of exploiting gold's medicinal capabilities [60].

VI. CONCLUSION

This work has been done to explore the antimicrobial activity of nanomaterials via chemical and biological method. Though silver nanoparticles are believed to be the best antimicrobial activity but, in this study, it is shown that copper, zinc, titanium and gold too play an important role in inhibiting the microbial growth. Commercial applications show that the future of nanomaterials is vast and will going to help in long run as they less toxic to human cells.

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