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Review on "Biogenic Synthesis of TiO2 Nanoparticles and its Impact on Antimicrobial Properties"

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Abstract:- Nanotechnology offers unique possibilities for the development of advanced materials with unique properties. By combining nanotechnology with medical technology, researchers are creating new antimicrobial agents to fight bacteria and fungi. Examples of these antimicrobial substances include titanium dioxide (TiO_2) and zinc oxide (ZnO). This review focuses on the recent advancements and challenges in the antimicrobial and photocatalytic properties of TiO_2.

Keywords:- *Nanotechnology, Advanced Materials, Unique Properties, Medical Technology, New Antimicrobial Agents, Titanium Dioxide (TiO2), Recent Advancements, Challenges, Antimicrobial and Photocatalytic Properties.*

I. INTRODUCTION

The use of medical devices and implants can sometimes result in bacterial contamination, causing medical problems and increased costs. To tackle this issue, researchers are exploring the creation of artificial surfaces that are both anti-adhesive and have antimicrobial properties. This is achieved through the use of nanotechnology and biology, resulting in surfaces that can reduce infections. Research is currently focusing on surfaces that have been coated with cationic polymers, metal coatings, and anti-fouling micro/nanostructures to improve their antimicrobial properties. Due to the growing threat of antibiotic resistance, there is a need for new and effective antimicrobial materials. Inorganic antimicrobials, such as metal compounds and metal oxides, are gaining attention for their broad-spectrum antibacterial abilities, particularly in the form of antimicrobial nanoparticles. TiO_2 nanoparticles (NPs) are a type of nanomaterial that have received special attention for their antimicrobial and photocatalytic capacities. This paper provides an overview of recent advancements and challenges in synthesizing TiO_2 NPs, as well as their abilities for antimicrobial activity and photocatalysis.

II. NANOPARTICLE CREATION: A GUIDE TO METAL/METAL OXIDE SYNTHESIS

Metal and metal oxide nanoparticles (NPs) are materials with potential applications in various fields such as catalysis, electronics, energy storage, and medicine. Synthesis methods for NPs include physical methods like laser ablation and thermal evaporation and chemical methods like chemical reduction and sol-gel.

Chemical reduction uses reducing agents like sodium borohydride or biological agents to convert metal ions into zero-valent metal atoms that then form NPs. Sol-gel involves precipitation of metal ions from a solution and then hydrolysing and condensing the metal precursors to form NPs, which can be controlled by adjusting pH, temperature, and precursor concentration.

Hydrothermal synthesis uses metal precursors in an aqueous solution under high pressure and temperature to produce metal oxide NPs. Biogenic synthesis uses eco-friendly methods like microorganisms, plants, or natural compounds to produce metal NPs or serve as templates for metal oxide NPs. The properties of NPs produced using biogenic synthesis can be manipulated by the type of biological reducing agent and synthesis conditions.

Metal NPs can also be synthesized by physical top-down methods like breaking down bulk metals or chemical bottom-up methods using organic solvents or biological sources. Synthesis conditions can regulate the size and shape of the NPs, which play a crucial role in their activity.

The synthesis of TiO_2 NPs is influenced by parameters like initial hydrothermal temperature and acid concentration. The crystal structure and shape of the NPs impact their physical and chemical properties, including antimicrobial properties. The anatase form of TiO_2 NPs has the highest photocatalytic and antimicrobial activity due to its ability to generate negative hydroxyl free radicals in a photocatalytic reaction

III. BIOSYNTHESIS OF TiO_2 NANOPARTICLES

The biogenic synthesis of nanoparticles is considered a clean and eco-friendly method for producing a wide range of particle sizes, morphologies, compositions, and physicochemical properties. Marine algae and seagrasses are used as natural resources to synthesize nanoparticles by mixing metal salt solutions with aqueous solutions containing seaweed or seagrass extract. Biomolecules present in the cell walls of seaweeds and seagrasses act as biocatalysts, reducing metal salts to nucleate metal and metal oxide nanoparticles, and as natural surfactants that direct and control nanoparticle growth. The process of biogenic synthesis begins with the reduction of metal ions, followed by nucleation and growth. Biomolecules in seaweeds and seagrasses can also influence the properties of synthesized nanoparticles, but more research is needed to understand the mechanisms involved. Experiments are currently being conducted to investigate the effect of parameters such as concentration of seaweed or seagrass extract, metal salt concentration, solution mixture pH, reaction time, and temperature on the quality of the synthesized nanoparticles. Similar to the biogenic synthesis of nanoparticles from seaweeds and seagrasses, the biogenic synthesis of TiO2 nanoparticles can also be achieved through living organisms such as plants and microorganisms. The size, shape, and stability of NPs are crucial parameters that influence their applications, and biogenic synthesis can result in more stable NPs compared to chemically synthesized particles.

A. "Bactericidal Potential of PVA/TiO2/Chi/Chl Nanocomposite Films: A Comparative Study"

The antibacterial properties of a PVA/TiO2/Chi/Chl nanocomposite film were evaluated using two methods: disk diffusion tests and colony counter method. The suspensions of Escherichia coli and Staphylococcus aureus, which are a Gram-negative and a Gram-positive bacterium respectively, were prepared with 0.5 McFarland turbidity and mixed with the nanocomposite film and a PVA film. The Petri dishes were then incubated at 37°C for 24 hours to observe the antibacterial effects. In the colony counter method, the nanocomposite film was added to two flasks containing a bacterial solution and exposed to light. The samples were added to Mueller Hinton agar and incubated at 37°C for 24 hours to observe bacterial growth and formation of colonies. Both tests were performed for both types of bacteria, and all instruments used were sterilized before use.

Titanium dioxide (TiO2) nanoparticles have gained attention for their potential use as antimicrobial agents. They exhibit high activity against bacteria and are thermally stable, biocompatible, and have high photocatalytic activity. The antimicrobial activity of TiO2 NPs is influenced by various factors such as their morphology, crystal structure, and size. Hollow TiO2 nanotubes, for instance, exhibit increased antimicrobial reduction due to their increased specific surface area.

The mechanism of TiO2 NPs' antimicrobial action involves the generation of reactive oxygen species (ROS) on their surface during photocatalysis when exposed to light at an appropriate wavelength. This leads to the death of bacteria through various mechanisms. The photocatalytic property of TiO2 is its wide band gap of 3.2 eV, which generates high-energy electron-hole pairs under UV-A light with a wavelength of 385 nm or lower. The nanoscale size of TiO2 NPs increases the surface area-to-volume ratio, maximizing contact with water and oxygen, and allowing for easy penetration of the cell wall and membrane, leading to increased intracellular oxidative damage.

ROS produced by TiO2 NPs can cause oxidative damage to cell walls and cell membranes of microorganisms, leading to changes in gene expression and the death of cells. Gram-negative bacteria are particularly sensitive to peroxidation caused by TiO2 NPs, which causes quantifiable damage to the outer membrane and alters gene expression related to the cell wall. The cell membranes of fungi are also affected by TiO2 NPs, causing oxidation of cell membranes and unbalancing cell permeability, leading to decomposition of cell walls.

In addition to their antibacterial properties, TiO2 NPs have also shown antiviral activity with half-maximal inhibitory concentrations against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other viruses.

Hence TiO2 NPs show promising results as an antimicrobial agent and further research is needed to fully understand the specific mechanisms involved in their biocidal activity. The results of the disk diffusion tests and colony counter method indicate that the PVA/TiO2/Chi/Chl nanocomposite film has antibacterial properties and further investigation could lead to potential practical applications.

B. Antimicrobial Properties of Titanium Dioxide Nanoparticles

Titanium dioxide (TiO2) nanoparticles have gained significant attention for their potential use as effective antimicrobial agents. They exhibit high activity against bacteria and are thermally stable, biocompatible, and have high photocatalytic activity. The antimicrobial activity of TiO2 NPs is influenced by factors such as their morphology, crystal structure, and size, with hollow TiO2 nanotubes having increased antimicrobial reduction due to the increased specific surface area.

The mechanism of TiO2 NPs' antimicrobial action is associated with the generation of reactive oxygen species (ROS) on its surface during photocatalysis when exposed to light at an appropriate wavelength. This leads to the death of bacteria through various mechanisms. The photocatalytic property of TiO2 is its wide band gap of 3.2 eV, which generates high-energy electron-hole pairs under UV-A light with a wavelength of 385 nm or lower. The nanoscale size of TiO2 NPs increases the surface area-to-volume ratio, which maximizes contact with water and oxygen and allows for easy penetration of the cell wall and membrane, leading to increased intracellular oxidative damage.

ROS produced by TiO2 NPs can cause oxidative damage to cell walls and cell membranes of microorganisms, leading to changes in gene expression and the death of cells. The cell walls of Gram-negative bacteria are more sensitive to peroxidation caused by TiO2 NPs, causing quantifiable damage to the outer membrane and altering gene expression related to the cell wall. The cell membranes of fungi are also affected by TiO2 NPs, causing oxidation of cell membranes and unbalancing cell permeability and leading to decomposition of cell walls.

In addition to antibacterial properties, TiO2 NPs have also shown antiviral activity, with half-maximal inhibitory concentrations against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and other viruses.

In conclusion, TiO2 NPs have demonstrated promising results as an antimicrobial agent and more research is needed to fully understand the specific mechanisms involved in its biocidal activity.

C. "Characterization of PVA/TiO2/Chi/Chl Bio nanocomposite for Photocatalytic Activity"

The phenomenon of photocatalytic activity refers to the ability of a material to produce electrons and holes (positively charged particles) when exposed to light. These electrons and holes then participate in chemical reactions with the surrounding molecules. In this research, the photocatalytic activity of TiO2 was evaluated through its impact on the degradation of methylene blue. A nanocomposite film composed of PVA, TiO2, Chi, and Chl was synthesized and tested for its ability to break down methylene blue under the illumination of a LED lamp. The effectiveness of the nanocomposite film as a photocatalyst was calculated by comparing the proportion of methylene blue degradation to its initial concentration.

To verify the presence and composition of the PVA/TiO2/Chi/Chl bionanocomposite, various characterization techniques such as FT-IR spectroscopy, EDX analysis, FE-SEM, XRD analysis, and PL analysis were employed. These techniques confirmed the presence of the different components in the bionanocomposite, as well as its rough surface, crystalline structure, and photocatalytic activity. The results were impressive, with a 96% degradation efficiency of methylene blue by the bionanocomposite under visible light exposure.

In addition to its photocatalytic activity, the PVA/TiO2/Chi/Chl bionanocomposite was also tested for its antibacterial properties. The inhibition zone diameter was measured for both S. aureus and E. coli bacteria and compared to those of PVA/TiO2 and PVA films. The results indicated that the growth of bacteria was suppressed in the presence of the bionanocomposite, while no significant inhibition was seen in the other films. This antibacterial effect was mainly due to the photocatalytic process, which generates free radicals that damage the bacteria's cell wall and membrane. The stability and recyclability of the bionanocomposite were also studied, and the results indicated that it can be easily removed and reused multiple times without any significant decrease in performance.

In conclusion, the synthesis of the PVA/TiO2/Chi/Chl bionanocomposite using readily available materials and chlorophyll as a natural photocatalyst offers a promising direction in the field of photocatalytic activity. The resulting film has a high capability in both breaking down pollutants and inhibiting bacterial growth. The photocatalytic activity of TiO2 under UV light produces reactive oxygen species that kill bacteria. Adding 10% TiO2 NPs to the film showed 95% and 80% inhibition of E. coli and S. aureus, respectively. Ag-doped TiO2 NPs degraded 96% of methylene blue under visible light exposure for 60 minutes. Ag/TiO2 nanocomposites also displayed substantial antibacterial activity. The modification of TiO2 NPs with natural polymers like chitosan leads to bionanocomposites with enhanced antibacterial properties. The use of chlorophyll as a natural photocatalyst and the ability to recycle the bionanocomposite multiple times without loss of performance make this approach a potential solution in the field of photocatalytic activity.

IV. CONCLUSION

In conclusion, the use of medical devices and implants can result in bacterial contamination, leading to medical problems and increased costs. To address this, researchers are exploring the development of artificial surfaces with anti-adhesive and antimicrobial properties. This is being achieved through the combination of nanotechnology and biology, resulting in surfaces with reduced infections. The focus is on surfaces coated with cationic polymers, metal coatings, and anti-fouling micro/nanostructures to enhance their antimicrobial properties. The growing threat of antibiotic resistance highlights the need for new and effective antimicrobial materials, with inorganic antimicrobials, such as metal compounds and metal oxides, gaining attention for their broad-spectrum antibacterial abilities, particularly in the form of nanoparticles. TiO_2 nanoparticles are a type of nanomaterial that has received special attention due to its antimicrobial and photocatalytic properties. This review provides an overview of recent advancements and challenges in synthesizing TiO_2 nanoparticles, as well as their abilities for antimicrobial activity and photocatalysis. The synthesis of TiO_2 NPs is influenced by factors such as temperature and acid concentration, with biogenic synthesis being a clean and eco-friendly method for producing stable nanoparticles. The antibacterial properties of a PVA/TiO2/Chi/Chl nanocomposite film were evaluated through disk diffusion tests and colony counter method, and showed promising results as an antibacterial material.

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