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INVESTIGATION OF MECHANISM AND EFFECTIVENESS OF METAL NANOPARTICLES IN SELF-STERILIZING PACKAGING

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Introduction

Packaging materials play an important role in extending the shelf life of food products. They protect the food from deterioration by providing passive protection against the migration of water vapour and gases such as oxygen and carbon dioxide from the atmosphere into the package.
Active packaging technology is a branch of packaging science that deals with packages that provide added functionalities and are a passive barrier. Antimicrobial/Self-sterilizing Packaging is a type of active packaging technology wherein antimicrobial agents are either blended into or coated on the packaging materials' surface to extend the product's shelf life.
Metal and metal oxide nanoparticles (NPs) have been reported to be effective against bacteria and other microorganisms (Anita Staron et. al., 2021). Nanoparticles of silver, gold, zinc oxide, titanium dioxide, magnesium oxide, copper and iron oxides are some of the commonly used metal NPs.
The main agenda will be on learning the mechanism of the antimicrobial action and the properties they possess in order to be useful and efficient self-sterilizing packaging materials. Also, these NPs will be ranked for thier effciency in using them for making the self-sterilization packages.

Problem Description

Microbial contamination poses to be the major obstacle when food safety is concerned. Chemical preservatives are widely being used for food presrvation. However, there is a growing demand for replacing this sustained use of chemical preservatives in food products. Metal NPs have, in may ways, proven to be a smart solution to this problem.

Mechanism

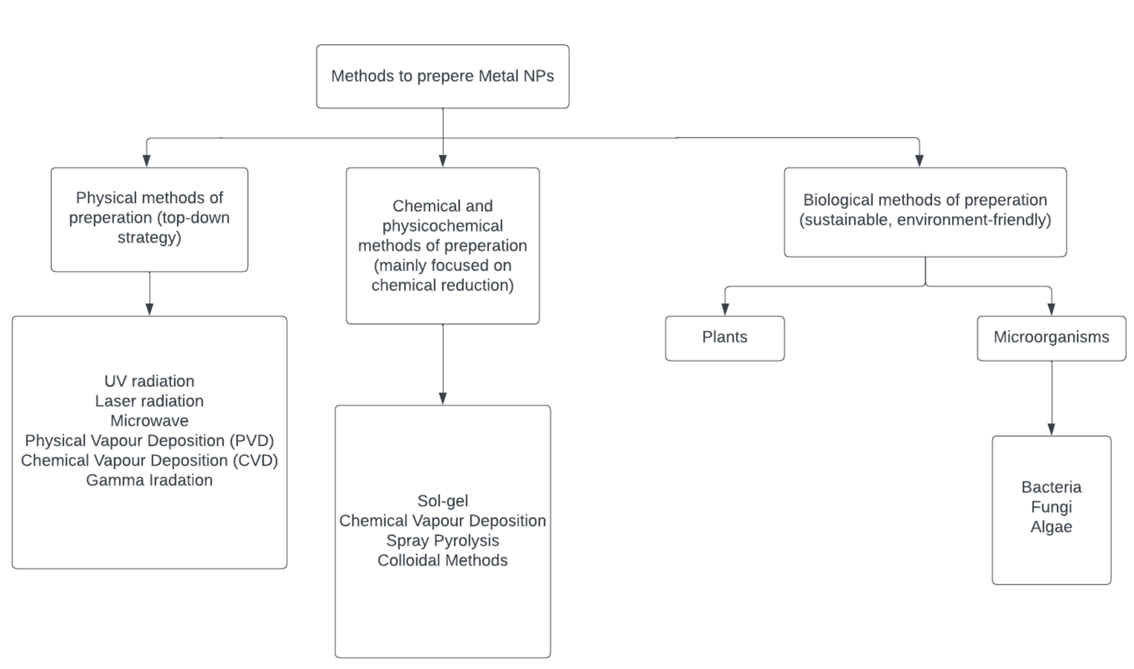

Figure 1

Different proccesses to synthesis metal nanoparticles.

On interaction with the bacterial cell membrane, the metal NPs affect the membrane integrity, induce oxidative stress, disrupt enzymes, and damage proteins and DNA. The NPs can also get converted into ions and disrupt the metabolic activities of the microoganisms. Moreover, NPs can attack the microorganisms without any direct contact by producing a reactive oxygen species (ROS) which in turn migrates to the surface of the packaging materials and reacts with them. This reaction causes oxidation of lipids and proteins and degradation of DNA.

Discussion

Nanotechnology makes it possible for us to incorporate metal nanoparticles into polymer materials to introduce or enhance antimicrobial properties which has also eliminated the use of metal ions.
Silver NPs: Proven to be potentially safer to use and that the properties can be enhanced by additives (Wolska et al., 2017) or by combining two metals NPs together. The nanocomposite films that contained both copper and silver were more effective in the bactericidal action against L. monocytogenes and Salmonella sp. (Arfat et al., 2017). LLDPE/Ag-Cu films showed an appreciative bactericidal activity against pathogens like L. monocytogenes, Salmonella typhimurium and Campylobacter jejuni on raw chicken meat (Ahmed, J. et al., 2018).
Zinc Oxide NPs:The mechanical properties, thermal stability and crystallinity of films made of PVA can be increased by reinforcing ZnONPs. The addition of ZnONPs to the PVA did not affect the oxygen barrier properties and OTR.Thus, from the constant OTR that ZnO did not introduce porosity and did not alter the structure of PVA. However, the OTR decreased minutely when the ZnO concentration increased (Channa et al., 2022).
Magnesium oxide NPs: The mechanical properties on introducing MgO NPs, block the crack on the surface of the film caused due to a deforming force. But it was also observed that when the concentration exceeded 3 wt%, MgO NPs had a negative impact on the mechanical properties. This was attributed to the agglomeratin of these NPs that disrupted the structure of the film (Zhang et al., 2020). The MIC and MBC for E.coli were greater than that B. subtilis.This suggests that E.coli is more resistant to the MgONPs. (Bhattacharya et al., 2021).
Gold NPs: PVA/AuNPs films showed that there was a significant increase in the tensile strength, Youngs modulus and a decrease in the elongation at break were observed in the films having PVA-GA cross-linking than in PVA films (Chowdhury et al., 2020). When tested for antimicrobial activity, the chitosan/ aminopropyl silane/ AuNPs films showed antibacterial activity against Salmonella bacteria, a food-borne pathogen.The composite film interacted with the bacterial cell wall to damage it and eventually lead to the lysis of the bacterial cell (Virgili et al., 2021). The Minimum Inhibitory Concentration (MIC) for the AuNPs increased on a small scale with the increase in their size (Shamaila et al., 2016).
Titanium dixode NPs: It was observed that LDPE/Ag/-TiO2 and LDPE/Ag + Cu/TiO2 nanocomposite films, exhibited the maximum antibacterial protection to Tilapia when the concentration of silver, copper and titanium dixoide were 2.5%, 2.5% and 5% respectively (Efatian et al., 2021).
Tin dioxide, copper-based adn ferrous oxide NPs: Indium Tin Oxide NPs (ITONPs) enhanced the electrical conductivity of the pristine PANI (polyaniline) films as the ITONPs filled the gaps present in it. Also, it increased the crystallinity of the polymer film (Al-Bataineh et al., 2022). FeONPs with, materials like polyvinylpyrrolidone (PVP), or polyethene glycol (PEG) increased the antiviral properties (Kumar et al., 2014). CuNPs-C-PLA nanocomposite films, good antibacterial action was exhibited by the NPs against Pseudomonas sp. (Longano et al., 2012).

Conclusion

Self-sterilizng packaging are widely used in areas where pathogenic microbes are present. This seems to be a clever solution to any pandemic breakdown. Almost all the metal NPs follow the similar mechnism of producing ROS in order to cause cell death for both bacteria and fungi. AgNPs are extensively used in commercial packaging and have increased the shelf-life of food products. Works of literature on the AuNPs in this subject are very few which might be because of its high cost. MgONPs exhibited practically significant properties when reinforced into a PLA film. Being safe and nontoxic, ZnONPs are being used in the packaging industry currently. Copper-reinforced cellulose nanocomposite packaging materials that were developed showed good biocidal activity against E.coli. Titanium Dioxide, Tin(IV) Oxide and Ferrous Oxide NPs prove to be good choices for producing a self-sterilizing packaging material.

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