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PHYTOCHEMICAL NANOPARTICLE AS A NOVEL APPROACH FOR NEURODEGENERATIVE DISEASES

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Abstract

Background: Neurodegenerative diseases, including Alzheimer's disease (AD) and Parkinson's disease (PD), are progressive disorders of the central nervous system characterized by complex pathological mechanisms such as oxidative stress, protein aggregation, neuroinflammation, and mitochondrial dysfunction. Despite extensive research, current therapeutic approaches remain limited to symptomatic management and fail to halt or reverse disease progression. Phytochemicals, naturally derived bioactive compounds from plants, have demonstrated significant neuroprotective properties due to their antioxidant and anti-inflammatory effects. However, their clinical application is restricted by poor solubility, low bioavailability, rapid metabolism, and limited ability to cross the blood–brain barrier (BBB). Recent advances in nanotechnology have introduced nanoparticle-based delivery systems as a promising strategy to overcome these limitations and enhance brain-targeted therapy. Study Purpose.

Objectives: This study aims to evaluate the therapeutic potential of phytochemicals in neurodegenerative diseases and to investigate how nanoparticle-based delivery systems can enhance their bioavailability, stability, and brain targeting. Additionally, it seeks to highlight recent advances in phyto-nanomedicine and identify future directions for developing effective treatment strategies for AD and PD.

Methods: This work is a narrative review based on a comprehensive analysis of recent peer-reviewed studies obtained from scientific databases such as PubMed, Scopus, and Google Scholar. The review includes in vitro, in vivo, and preclinical studies focusing on phytochemicals with neuroprotective effects and their incorporation into nanoparticle-based delivery systems. Different classes of phytochemicals and various nanocarriers, including lipid-based nanoparticles, polymeric nanoparticles, and liposomes, were analyzed in terms of pharmacokinetics, BBB permeability, mechanisms of action, and therapeutic outcomes.

Results: The reviewed studies demonstrate that phytochemicals exert significant neuroprotective effects by reducing oxidative stress, inhibiting amyloid-beta aggregation, preventing tau hyperphosphorylation,

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and modulating neuroinflammatory pathways. However, their therapeutic efficacy is limited by poor pharmacokinetic properties. Nanoparticle-based delivery systems significantly improve the stability, bioavailability, and BBB penetration of phytochemicals. These nanocarriers enable targeted drug delivery and controlled release, resulting in enhanced therapeutic outcomes in experimental models of AD and PD. Improved neuronal protection, reduced protein aggregation, and decreased inflammatory responses were consistently observed.

Conclusions: The integration of phytochemicals with nanoparticle-based delivery systems represents a promising and innovative approach for the treatment of neurodegenerative diseases. This strategy effectively addresses the major limitations of phytochemicals and enhances their therapeutic potential through improved brain targeting and multi-target mechanisms of action. Phyto-nanomedicine may offer a safer and more effective alternative to conventional therapies, with the potential to slow disease progression. Further experimental and clinical studies are required to validate these findings and support their translation into clinical practice.

Key Words: Nanocarriers, Phyto-nanomedicine, Brain drug delivery, Neuroprotection, Oxidative stress, Protein aggregation.

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