Chapter 10
Nanocarriers for Delivering Pesticides

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ABSTRACT

Nanocarriers have emerged as a promising solution for pesticide delivery, aiming to enhance efficiency, reduce environmental contamination, and improve targeted pest control. Traditional pesticide applications often result in excessive use, rapid degradation, and non-specific distribution, leading to environmental and health concerns. Nanocarriers, such as polymeric nanoparticles, lipid-based carriers, inorganic nanoparticles, and carbon-based materials, offer controlled release, enhanced bioavailability, and improved pesticide stability. These nanoformulations protect active ingredients from premature degradation, facilitate targeted delivery, and minimize off-target effects. Recent advancements in stimuli-responsive and biodegradable nanocarriers offer promising solutions for eco-friendly pest management. This review explores the types, synthesis, mechanisms, applications, challenges, and future perspectives of nanocarriers in pesticide delivery, emphasizing their potential in advancing precision agriculture.

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1.0 INTRODUCTION

Agriculture plays a crucial role in global food security, yet it faces persistent challenges due to pests, diseases, and environmental factors. Pesticides have been a vital component of modern agriculture, aiding in pest control and crop protection. However, conventional pesticide formulations often suffer from inefficiencies such as rapid degradation, leaching, and non-target effects, leading to environmental pollution and health risks. The excessive use of pesticides contributes to soil and water contamination, bioaccumulation in food chains, and resistance development in pests. These challenges necessitate the development of more efficient and sustainable pesticide delivery systems (Tudi et al. 2021).

Nanotechnology has emerged as a revolutionary approach to overcoming these limitations. The application of nanocarriers for pesticide delivery offers several advantages, including enhanced solubility, improved bioavailability, targeted delivery, and controlled release. Nanocarriers can encapsulate active pesticide ingredients, protecting them from premature degradation due to environmental factors such as UV radiation, oxidation, and microbial degradation. This encapsulation ensures prolonged pesticide activity, reducing the frequency of application and minimizing wastage. Additionally, nanocarriers enable the controlled and site-specific release of pesticides, reducing the impact on non-target organisms and promoting environmental sustainability (Kapeleka & Mwema, 2024).

Polymeric Nanoparticles: Biodegradable and biocompatible carriers, such as polymers like chitosan, polylactic acid (PLA), and poly(lactic-co-glycolic acid) (PLGA), are widely used in pesticide delivery systems due to their stability and ability to provide controlled and sustained release of active ingredients. These polymers protect pesticides from premature degradation and allow for gradual release, enhancing efficacy and reducing environmental impact. Additionally, carriers like liposomes and nanoemulsions are effective in delivering hydrophobic pesticides. They improve solubility and absorption while minimizing pesticide volatilization and degradation, thereby increasing the efficiency of pest control measures (Begines et al. 2020).

Inorganic Nanocarriers: Silica nanoparticles, metal oxides like zinc oxide and titanium dioxide, and clay-based nanomaterials have been investigated for their stability and capacity to facilitate sustained pesticide release. These inorganic nanocarriers offer advantages such as high surface area and tunable properties, enhancing pesticide loading and controlled delivery. Carbon-based nanocarriers, including carbon nanotubes and graphene oxide, have also gained attention for their ability to improve pesticide loading and targeted delivery. However, the environmental impact of these materials requires further study. Concerns include potential toxicity to non-target organisms and persistence in ecosystems. Comprehensive environmental risk assessments are essential to ensure the safe and sustainable application of these nanomaterials in agriculture (Yin et al. 2023).

Stimuli-responsive nanocarriers represent a significant advancement in pesticide delivery systems, offering controlled release mechanisms that respond to specific environmental triggers such as pH, temperature, or enzymatic activity. This targeted approach ensures precise application, enhancing efficacy while minimizing excess pesticide use and environmental impact. For instance, pH-responsive nanocarriers are designed to release their payload in environments with specific pH levels. In agricultural applications, these carriers can be engineered to degrade in the alkaline conditions of certain insect digestive systems, ensuring that the pesticide is released precisely where it is most effective. Similarly, temperature-sensitive nanocarriers utilize polymers that undergo structural changes in response to temperature fluctuations, allowing for controlled pesticide release during periods of increased pest activity. Enzyme-responsive carriers release their contents upon interaction with specific enzymes present in