Nanopesticides

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# Nanopesticides

From Research and Development to Mechanisms of Action and Sustainable Use in Agriculture



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This book is dedicated to those who made remarkable scientific discoveries and imagined their applications that ameliorate our lives and promote environmental sustainability

#### Foreword

One of the growing interest areas of nanotechnology applications is the development of novel formulations of pesticides that are more efficient, targeted, and release controlled. Such features may not only bring about cost savings but may also lower the overall use of pesticides and thus contribute towards reducing the negative impacts on human health and the environment. However, despite the novelty of the approach, only a few research groups have so far ventured into this area of R&D due to the current major gaps in knowledge. This book will, therefore, be useful in enhancing the understanding of fundamental concepts, underlying mechanisms, and state-of-the-art regarding nanopesticides.

The book is comprised of 11 chapters that are written by leading experts in their respective fields. It takes an account of the cutting-edge of the technology, gives pointers to the future directions of R&D, and identifies the areas where further research is needed. In describing the new technology, the authors have taken a balanced view by highlighting both the likely benefits and the potential risks of formulating pesticides at the nano-scale. In particular, the nano-scale formulation of natural pesticidal compounds, together with biodegradable polymers, can open up numerous new possibilities for the development of safer products for the control of a variety of pests of agricultural and public health importance. The Experts' perspectives on the novelty, the future prospects and trends of the technology, and regulatory aspects will be equally informative for the developmers, the regulators, and the users of nanopesticides.

In this context, Chap. 1 has looked into the use of natural degradable polyhydroxyalkanoates (PHAs) for the development of embedded extended-release formulations of herbicides and fungicides. It also provides example applications in laboratory soil ecosystems in wheat plant communities infected with *Fusarium sp.* and weeds.

Chapter 2 provides another interesting example of the development of smart formulations based on biodegradable and eco-friendly nano-chitosan and their application in fungal disease control.

The use of RNA interference (RNAi) is an interesting field of biotechnology that has also been studied for potential applications in pest control. However, such applications generally suffer from limitations in the delivery of dsRNAs to diffused and dispersed pest populations in the field. This is where the use of nano-carriers has been studied as a delivery vehicle for RNAi-based pesticides for the control of agricultural pests. Chapter 3 presents an overview of the literature on this topic, and discusses biosafety considerations in relation to the use of formulations based on nano-carrier containing RNAi.

Chapter 4 is focused on discussing the interaction of nanopesticides with plants. Such an understanding is fundamentally important to drive effective, safe, and sustainable application of nanopesticides in agriculture. Whilst the discussion centres around the conceptual basis, it also provides different examples of the uptake, mode of action, and effects of nanopesticides in the context of physiological and metabolic responses of plants exposed to nanopesticides. It also demonstrates prediction models that can provide a hint on the likely response of the plants to a specific type of nanopesticide.

Chapter 5 discusses the methods that can be used to study the behaviour and fate of nanopesticides in aquatic and terrestrial environments. It discusses the advantages and disadvantages of individual methods and highlights the important considerations that are needed due to the nano-scale characteristics of nanopesticides when using conventional environmental risk assessment methods.

Chapter 6 continues the theme of Chap. 4 to further discuss the interactions of nano-enabled agrochemicals with soil microbiome that plays a vital role in maintaining the soil quality as well as plant nutrition and health. Using examples of formulations based on nano forms of copper and silver, as well as nanocarriers of conventional pesticides, the chapter discusses the current state of knowledge in regard to the potential prospects and implications of nanopesticides for the soil microbiota.

Chapter 7 discusses bioactivity and environmental impacts of nano-formulated insecticides. Whilst the comprehensive overview presented in this chapter includes nano-formulation of synthetic pesticides, a particular focus is also on formulations of natural insecticidal compounds, the use of which can be expected to further minimize the environmental impacts. A similar theme is discussed in Chap. 8 in relation to the environmental toxicity of nanopesticides against non-target organisms. The comprehensive state-of-the-art overview concerns environmental safety of nanopesticides against non-target model organisms (microbes, plants, worms, insects, algae, daphnids, and fish). It also touches upon the various methods for characterization for the study of interactions of nanopesticides with biological and environmental systems, the use of nano-informatics, safety-by-design, environmental risk analysis and management for responsible development and regulation of nanopesticides.

Chapter 9 provides an overview of the aspects relating to environmental safety and regulation. Using a case study of nano-atrazine, the chapter discusses the current limited knowledge in relation to the behaviour and fate, and the potential adverse environmental impacts of nanopesticide formulations. It not only takes a note of the new advancements but also highlights the main challenges in regard to risk analysis of nanopesticides. This theme is further elaborated in Chap. 10 that discusses risk assessment of nanofertilizers and nanopesticides. The review shows that environmental and human health impacts of the nano-agrochemicals are of general concern. It highlights the scarcity of the relevant toxicological data to allow adequate risk assessment. The impact of the such knowledge gaps is considered a barrier to the development of regulatory policies, and, as a consequence, an obstacle to new marketable products.

Finally, Chap. 11 provides a market analysis of nanopesticides at different stages from R&D to the market. The market scenario depicts a continuous investment in the technology and innovation to develop more effective products, in a framework of mergers, ventures, and partnerships to accelerate the development and launch of the products. The analysis indicates that the development of nano-encapsulated pesticide formulations is currently an open field that can enable the development of new original materials and formulations. The overview identifies the current status and trends in the market, and provides a summary of the forthcoming technologies. It discusses the key challenges in the scale-up, and identifies encapsulation of microorganisms and dsRNA as new and emerging disruptive technologies.

In summary, the book provides an up-to-date account of the cutting-edge technology for the development of nanopesticides, its pros and cons, and potential applications in agriculture. It provides a balanced view of the innovations in this field in consideration of both benefits and risks. The book is highly commended to all those involved in R&D and safety/regulation of pesticides in an academic, research, industrial, or regulatory setting.

University of Chester Chester, UK Qasim Chaudhry

#### Preface

Nanomaterials have been contributing to agricultural science and technology in various phases of production and commercialization. Especially, nanopesticides can improve crop yields and are believed to reduce harmful effects on the environment. Their benefits may include better stability, permeability, and dispersion of the active ingredient, improved targeting to pest species, higher efficacy, decreased application doses, prevention of premature degradation, and increased environmental safety. Despite their promising use, it is necessary to study their accumulation in the environment and their impact on non-target organisms and consequently on biodiversity and human health. Nowadays, there is a lack of worldwide data on nanopesticide efficacy compared to conventional ones and on their environmental effects. Considering these facts, we discuss in this book some recent features of nanopesticide development, application, and toxicity evaluation. The book is organized into 11 chapters. Chapters 1-3 describe the use of different carriers for the controlled release of active ingredients aiming at agriculture applications. Chapters 4-6 describe some methods used to understand the fate and behaviour of nanopesticides in plants, soil, and water. Chapters 3 and 6 discuss their potential toxicity and impacts on the environment. Chapters 7 and 8 showed the potential toxicity of nanopesticides and their impacts on environment. Chapters 9 and 10 provide an overview of environmental safety aspects and regulatory issues regarding nanopesticides. Finally, Chapter 11 discusses the commercial aspects of nanopesticides in crop production.

In this context, with this book, we intended to contribute to a broader perspective of nanopesticide characteristics and risk assessment, regulation, application, and marketing.

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