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ORIGINAL PAPER

Applications of nanotechnology for plant disease management

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INTRODUCTION

Global climate changes, mainly caused by human activities, have accelerated in the past 200 years (Velásquez et al., 2018), characterized by increased global average temperature, increased CO2 concentration in the environment, and frequency and adversity of extreme weather events (Fischer and Knutti, 2015). The agricultural sector is most negatively influenced by rapidly changing climate, since it directly depends on climatic conditions affecting crop growth and productivity (Schroeder et al., 2013; Naithani, 2016). The second most influencing factor is plant pests and pathogens. It cause significant reductions in crop production, with estimated global losses of 20%–40% per year. Current pest management relies heavily on the application of pesticides, as well as insecticides, fungicides, and herbicides. In spite of many advantages, like high availability, fast action, and reliability, chemicals have harmful side effects towards non-target organisms, the resurgence of the pathogen population, disease dynamics, and the development of resistance. Furthermore, it is estimated that 90% of applied chemicals are lost during or after application. As a result, there is an increased motivation to develop cost-efficient, high-performing pesticides that are less harmful to the environment. The challenges faced by plant pathologists and other agriculturalists are daunting. However, nanotechnology stands as a new weapon in our arsenal against these mounting challenges in disease management and plant health. The utilization of nanotechnology in plant disease management, diagnosis, and genetic transformations is still in its infancy and has only begun to be explored in the plant pathology literature.

MECHANISM OF NANOTECHNOLOGY

The word "nano-technology" was first termed by Norio Taniguchi in 1974, though it was not widely known. Nanotechnology has led to the development of new concepts and agricultural products with immense potential to manage the above mentioned problems. There are two different mechanisms to protect plants by the use of nanoparticles: (a) nanoparticles themselves providing crop protection, or (b) nanoparticles as carriers of existing chemicals or other actives, such as double-stranded RNA (dsRNA), and can be applied by the method of spray application or drenching/soaking of it into seeds, foliar tissue, or roots. Nanoparticles, as carriers, can provide several benefits, like (i) increased shelf-life, (ii) improved solubility of poorly water-soluble pesticides, (iii) less toxicity, and (iv)increased site-specific uptake into the target pest. Another possible benefits of nano-carrier include an increase in the efficacy of the activity and stability of the nanopesticides under environmental pressures (UV and rain), significantly reducing the number of applications, thereby decreasing toxicity and reducing their costs (Figure 1).

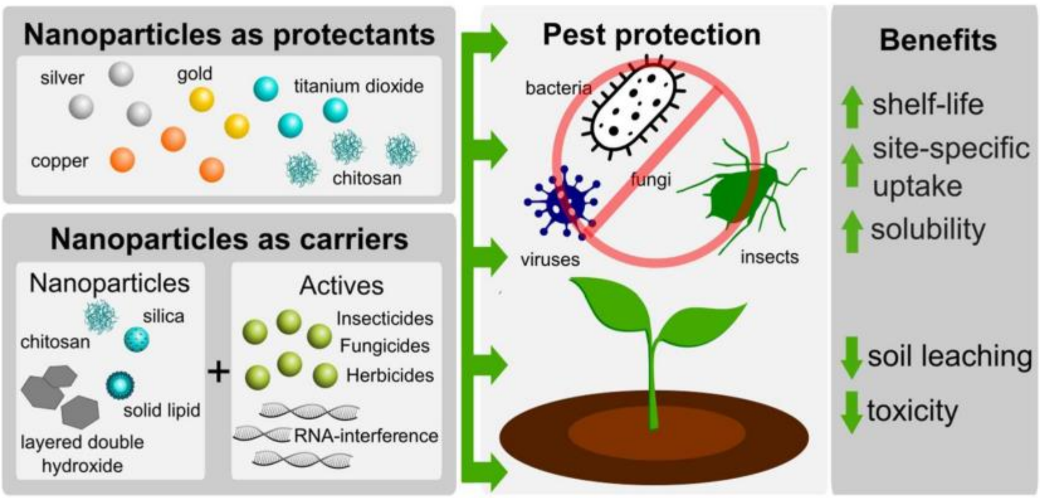

Figure 1. Nanomaterials as protectants or carriers to provide crop protection. This schematic shows different nanomaterials as either protectants or carriers for actives such as insecticides, fungicides, herbicides, or RNA-interference molecules, targeting a wide range of pests and pathogens. It also highlights the potential benefits of nanomaterial applications, such as improved shelf-life, target site-specific uptake, and increased solubility, while decreasing soil leaching and toxicity.

USE OF NANOMATERIALS AS ANTIMICROBIAL AGENTS

There are several uses of NMs in plant protection, but the most efficient use of them seems to be as an antimicrobial agents for disease management practices to improve crop health. The most extensively examined and explored nanomaterials used as antimicrobial agents are nanoparticles (NPs) of metals such as silver (Ag), copper (Cu), and zinc (Zn); and carbon- and polymer-based NMs. (Baker *et al.*, 2017).

Application of silver nanoparticles for controlling plant pathogens is the most investigated area given the historically known antimicrobial activity of Ag (Richards, 1981). It was experimentally found that the foliar application of 100 ppm Ag-dsDNA-GO on tomato seedlings, in greenhouse condition, significantly reduced the disease severity of bacterial spot as compared with untreated plants, with results similar to conventional bactericides (Kocide 3000+mancozeb) treatment. Meanwhile, no trace of toxicity on plant leaves was observed. These results highlight the benefit of nanoscale silver in managing Cu-tolerant phytopathogens, given the comparable similar efficacy to the commercial marketed products, and remarkably low dose and toxicity. Likewise, Giannousi *et al.* (2013) found that Cu-based nanoparticles (Cu_2O, CuO, and Cu/Cu_2O) were more effective against *Phytophthora infestans* on tomato, at a lower copper weight content when compared with the registered marketed commercial copper-based products, and did not cause any permanent damage/harm to the plants. Undoubtedly, the design and synthesis of multifunctional nanocomposites will be very attractive and lucrative in the coming years. Studies have also highlighted the benefits of nanomaterials on plant beneficial microbes, which could be further explored for plant disease suppression and also the possibility of integration of biocontrol agents in nanoformulation for improving crop health. Nanomaterials will play a vital role in reducing the new challenges currently faced in disease management and the severe environmental impact of chemical-based fungicides/bactericides.

CONCLUSIONS AND FUTURE OUTLOOK

Nanotechnology can provide solutions for agricultural applications and has the potential to revolutionize the existing technologies used in disease management. Development of nano fungicides can offer unprecedented advantages like (i) increased solubility of poorly water-soluble pesticides,(ii) improved bioavailability and efficacy of pesticides when loaded onto nanoparticles and reduced pesticide toxicity, (iii) enhanced shelf-life and controlled delivery of actives, (iv) target-specific delivery of the active molecules and pH dependent release, (v) smart delivery of RNAi molecules for disease management, (vi) nanoparticles as carriers to slow down degradation of active molecules and improve the formulations' UV stability and rain-fastness, (vii) nanofungicides to improve the selective toxicity and overcome pesticide resistance.

In conclusion, material scientists and biologists need to work closely and bring in complementary expertise from various fields, in order to have a deeper understanding of the fundamental interaction mechanisms in a complex bio-nano system. A comprehensive understanding about the structural properties of the nanoparticles, such as morphology, size, functional groups, and active adsorption/loading capacity, may provide a useful guide as a starting point for the rational choice of suitable nanoparticles. It is also important to select a reliable and reproducible system to conduct biocompatibility and efficacy studies at the cell, organism, and pest–host ecosystem levels, aiming for as-close-to field conditions as possible. The research and development landscape for agricultural nanotechnology is very promising, as the possibilities offered by nanoparticles for developing efficient products are being actively explored. It is believed that multidisciplinary and collaborative research will provide a concrete platform to bring the applications of nanotechnology for plant protection a reality.

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