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Pertinence of nano-enabled agrochemicals in plant-parasitic nematode control

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Abstract

Plant-parasitic nematodes are minuscule organisms, invisible to the naked eye, and are considered to be microscopic creatures. The severity of their impact is exemplified by the infestation of plant roots, resulting in a wide array of symptoms including stunting, wilting, yellowing, reduced flowering, fruit set, and fruit development, dieback, and in some cases, even plant death. In the tropical and sub-tropical climates, yield losses attributable tonematodes were estimated at 14.6% in the developing countries compared to 8.8% in developed countries with an average of 12.3%. In India, the annual estimated crop losses due to major plant parasitic nematodes are estimated to the tune of Rs. 242.1billion. Controlling these nematodes is a challenging task, as once they establish themselves in the soil, soil sterilization remains the only option. Conventional methods have proven inadequate in suppressing this pest, and fueled to search for new trends in pest control. Nanotechnology emerges as one of the endeavoring solutions to combat these pests. Potential nanomaterials and their customized products like nano-capsules, nanoparticles, and nano-suspension pesticides have currently been appreciated against plant-parasitic nematodes.

Keywords: Nanotechnology, plant-parasitic nematodes, nano-capsules, nano-suspension pesticide

Introduction:

Global agricultural production faces an ongoing reduction each year, primarily due to biotic stresses including fungi, virus, bacteria, protozoa and nematode attack. Plant-parasitic nematodes are one of the costly burdens of crop production. Ubiquitous in nature, phyto-parasitic nematodes are associated with nearly every important agricultural crop and represent a significant constraint on global food security. Nematodes are omnipresent in nature, and many of the species are parasitic to plants, causing enormous economic losses in various crops. Plant-parasitic nematodes (phyto-

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parasitic nematodes) invade the roots of plants and establish themselves to divert nutrients from the plant toward their own growth. Nematodes are multicellular animals of the phylum Ecdysozoa, and can shed their cuticle. Root-knot nematodes (*Meloidogyne* spp.), cyst nematodes (*Heterodera* and *Globodera* spp.) and lesion nematodes (*Pratylenchus* spp.) rank at the top of list of the most economically and scientifically important species due to their intricate relationship with the host plants, wide host range, and the level of damage ensued by infection. Recently, there has been extensive discourse surrounding environmental threats stemming from the excessive and inconsistent use of nematicides. In India, they are reported to cause an average crop loss of 21.3% annually (Kumar *et al.*, 2020). Typical nematode damage symptoms are a reduction of root mass, distortion of root structure, or enlargement of the roots (Sabry, 2019). Nematode damage of the plant root system also provides an opportunity for other plant pathogens to invade the root and thus further weaken the plant. Direct damage to plant tissues by shoot-feeding nematodes includes reduced vigor, distortion of plant parts, and death of infected tissues, depending upon the nematode species. These parasites destroy the plant by damaging its vascular tissue and interfering with the transport of nutrients or by creating open wounds that leave the plant susceptible to other pathogens.

Use of chemicals provides immediate effect to prevent pest population but in contrary, it is estimated that 90% of applied pesticides are lost during or after application (Worrall *et al.*, 2018) which leads to the contamination of environment. The cultural and biological approaches give slow results and sometimes are not even viable for intensive commercial agriculture. Searching for potential alternatives are therefore becoming a major concern in order to level up agricultural productivity as well as environmental sustainability. Use of nanoparticles in a sophisticated way is currently anticipated to work tremendously by overcoming the loopholes of old and inapt agrochemicals. The nanoparticles (NPs) have a high surface to volume ratio that increase their reactivity and possible biochemical activity. They act by disrupting multiple cellular mechanisms including membrane permeability, ATP synthesis, and response to oxidative stress (Kang *et al.*, 2012). NPs are advantageous due to their higher efficiency and longer shelf life. However, their environmental impact assessment needs to be conducted before commercialization.

Basis of nanotechnology: a promise to sustainable agriculture

The term "nanotechnology" was coined by Norio Taniguchi in 1974, and he defined nanotechnology as "the processing of separation, consolidation, and deformation of materials by one atom or one molecule". Nanotechnology is a branch of science dealing with synthesis and application of nano sized particles (having at least one dimension of 1-100 nm) of any material. A material acts differently when it is reduced to nano size and express some properties that completely lack in its bulk form. NPs have better chemical reactivity, biological activity, catalytic behavior and high mobility in the body of an organism including cellular entry. Additionally, metal NPs have easy surface modification chemistry, enabling the attachment of various molecules for targeted delivery and specific interactions (Dawadi *et al.*, 2021). NPs have a great degree of freedom that essentially relies on their uptake, absorption, and trafficking inside plants. NPs with different surface charge possess the differential capacity for aggregation and surface properties in comparison to their pristine counterparts. After entering into the plants, NPs are imperative to recognize the path that they follow to transport as it gives an idea of where these NPs might accumulate. Generally, NPs follow two important routes for moving up and down in a plant: the apoplast and the symplast. The symplastic pathway allows movement through the cytoplasm of adjacent cells (Roberts and Oparka, 2003), whereas the apoplastic pathway allows flow through the extracellular spaces involving cell walls of neighboring cells and xylem vessels (Sattelmacher, 2001). The cell-to-cell movement takes place through the passage plasmodesmata, serving as a cytoplasmic bridge to facilitate particle movement between neighboring cells.

Recently, nano-enabled smart agrochemical delivery systems using potential NPs as a carrier of active ingredients, are being continuously developed.

Nanotechnology for the management of plant-parasitic nematodes

Nanotechnology has a great impact on biological science including medicine, pharmacy, and agriculture. Recently, the rapid development in nanotechnology has opened a new avenue in order to better agriculture to improve the performance of conventional pesticide formulations through the construction of nanotechnology-based agricultural systems such as drug carriers and a controllable drug targeting and releasing system.

Currently, Fu *et al.* (2018), adopted flash nano-precipitation (FNP) to successfully produce abamectin-loaded nanoparticle suspensions with high drug-loading capacity (>40%) and encapsulation efficiency (>95%)

against the plant-parasitic nematode *Meloidogyne incognita*. Abdellatif *et al.* (2016), used green silver nanoparticles (GSN) synthesized and characterized by using the definite algal extract solution to control *M. javanica*. Cromwell *et al.* (2014), exposed second juvenile stage (J-2) of *M. incognita* to AgNPs in water at 30–150 mg/ml and reported that 99% of nematodes became inactive after 6 h of treatment. Thakur *et al.* (2018), used gold nanoparticles for the first time against plant-parasitic nematodes in India. Such findings truly reflect the importance of using natural products incorporated into nanotechnology to find safe and alternative nematicides.

Conclusion and future prospects

Pests, encompassing insects, mites, nematodes, and pathogens, pose a significant challenge to successful crop production. The regular use of pesticides has led to the emergence of resistance in numerous pests, leading to the accumulation of detrimental residues in food products and environmental contamination. Nanotechnology is a principal solution for this problem by using newpesticide formulations against the plant-parasitic nematodes. These nano-enabled formulations are eco-friendly and less toxic against non-target organisms. But the process of development for upscaling of nano-pesticide has not been widen yet. Currently, the understanding of characterization and detection of nanoparticles has fueled the urge of commercialization of nanostructured nematicides.

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