



Nano-Technology Based Pest Management in Vegetables

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Over the past few decades, the need to boost total agricultural output has increased the significance of pesticides in order to ensure enough food availability and sufficiency for the expanding world population. In India, nearly 15–25% of annual food production is lost due to insect pests and diseases significantly affecting vegetable crops, which are highly susceptible to biotic stresses. Since the scope for expanding cultivable land is limited, improving productivity per unit area remains the most viable strategy to meet rising food demands. This has traditionally relied on high-yielding cultivars, fertilizers and chemical pesticides. However, increased crop intensification often leads to higher pest incidence, thereby escalating pesticide usage. The conventional insecticides have a number of significant drawbacks, including high dose per unit crop, drift risks, operational risks, residues in vegetables and the environment, as well as an adverse effect on non-target vegetation and non-target species. Therefore, such pesticides need to be replaced with a different pest management method in vegetables.

One of the more technically sound solution to shortcomings of above problem is the use of nano-technology. Chemicals used to protect vegetables called nano-pesticides either contain an active ingredient or a carrier molecule that was created using nanotechnology. The word "nano" is of Greek origin, and it actually means "dwarf." The main goal of developing nanopesticides is to increase a chemical's effectiveness while reducing the environmental risks associated with a pesticide active ingredient. The advantage in this case is the particles' extremely small size. A nanometer is one billionth of a metre, and the size of a nanoparticle typically ranges from 1 to 100 nanometers. When particles are thus small, a significant surface area is reached, increasing the amount of insecticides that come into touch with pests. Nanoparticles can penetrate because of their incredibly small size and form. Nanopesticide formulations include the active component, the carrier molecule, and surfactants, just like regular pesticide formulations. The main advantages of these nanoparticles are the increased solubility of the active components, improved formulation stability, gradual release of the active ingredient, and increased mobility brought on by the smaller particle size and greater surface area. With nanoparticles as opposed to bulk materials, the mechanism of action against the targeted pests is anticipated to be improved. Additionally, nano-formulations have increased soil qualities, uniform leaf coverage and systemic features that promote their beneficial application in agriculture. Improved soil interaction, efficient delivery, and better plant uptake make nano-based pest management a sustainable and innovative approach for vegetable crop protection. Thus, nanoformulations represent a next-generation strategy that addresses the limitations of conventional pesticides while promoting environmentally safer and residue-conscious vegetable production systems.

Nanoemulsion: In a nano-emulsion, the active ingredient of the chemical is disseminated as nanosized droplets in water, with surfactant molecules constrained at the pesticide-water interface. This type of emulsion is more prevalent than an oil-in-water (O/W) emulsion.

Based on the number and kind of surfactants, nano-emulsions are further divided into thermodynamically stable and kinetically stable categories. It is a thermodynamically stable nano-emulsion if the pesticide is only partially soluble in the aqueous phase and a stable emulsion spontaneously forms when the pesticide, surfactant, and water components are mixed together. The pesticide and surfactant initially form a two-phase system due to the insolubility of the active ingredient; however, continuous shearing causes them to mix, and pesticide droplets in the nano-emulsion will remain dispersed for a long time and are therefore considered to be kinetically stable. For instance, a nanoemulsion of neem oil in water has been created utilising Tween 20 as the surfactant for the control of insects.

Nano-suspension: A pesticide is dispersed as solid nanoparticles in aqueous media to create nano-suspensions, also known as nano-dispersions. The surfactant molecules are constrained at the particle surface in nanodispersions, with the non-polar sections interacting with the solid pesticide and the polar portions extending into the aqueous solution. For instance, scientists have created aqueous dispersions of nano-permethin, novaluron, and cypermethrin.

Polymer-based nanoparticles: Active chemicals in pesticides are primarily released to the target location slowly and under regulated conditions using polymer-based pesticide nanocarriers. Additionally, they can function as a reservoir for protection and to enhance dispersion in watery conditions. This category includes items like nano-encapsulation, nanospheres, nano-gels, nano-fibers, etc.

Nano-encapsulation: A heterogeneous reservoir type structure, nano-capsules or nano-encapsulation have an inner central cavity that restricts the hydrophobic or hydrophilic active ingredient, and are encircled by a polymer coating or membrane. This formulation offers protection for the neem-azadiractin formulation's active component. For instance, acetamiprid and imidacloprid, two neonicotinoid insecticides, have been produced as controlled-release nanoformulations.

Nanospheres: In homogeneous vesicular formations called nanospheres, the bioactive component is evenly distributed throughout the polymer matrix. For instance, nanospheres of polymer-stabilized bifenthrin are being created.

Nanogels: These are additionally referred to as hydrogel nanoparticles. These are created by cross-linking hydrophilic polymeric particles, which absorb more water as a result. Consider chitosan nanogel as an illustration.

Nano-fibres: Thermally induced phase separation and electrospinning are used to create nano-fibres. For the control of a variety of lepidopteran insect pests, scientists have created electrospun nano-fibers that are loaded with the chemical (Z)-9-dodecenyl acetate, which is a component of pheromones and becomes embedded in the polymer matrix.

The following are the main benefits of using nano-pesticides over conventional pesticides

- The majority of nano-pesticide formulations are extremely target specific, making nanotechnology a tool for creating novel eco-friendly pesticide formulations.
- In general, controlled release and targeted distribution of nanopesticides can increase pesticide utilisation while lowering residue and pollution. For instance, nano-microcapsule formulations have gradual release and protective performance due to the use of high polymer materials to deliver pesticides that are light-sensitive, thermo-sensitive, humidity-sensitive, enzyme-sensitive and soil pH-sensitive. These systems ensure gradual release and enhanced stability under field conditions, which is particularly beneficial in vegetable crops requiring repeated protection.
- Nano-pesticide formulations increase droplet adherence to plant surfaces (lower drift losses), which enhances the dispersion and bio-activity of pesticide molecules' active ingredients (a.i.). Since they are smaller than conventional pesticide formulations (such as DDust, G-Granule, P-Pellet, EC-Emulsifiable Concentrate, WP-Wettable Powder, WDG-Water Dispersible Granule, etc.), nano-pesticides have improved droplet ductility,

wettability, and target adsorption when applied to fields, which makes them more effective and environmentally friendly.

- Nano-pesticides are remarkable tools for creating a sustainable and eco-friendly agricultural system since they cut down on total chemical use, hazardous residues and improve crop protection. Their improved delivery efficiency supports safer vegetable production systems with better residue compliance.

Some limitations on the use of nano-pesticides

- It is not yet fully recognised what risks nanoparticles (nano-pesticides) may present to the environment and human health.
- Since nano-pesticides appear to be far more persistent and harmful than their conventional equivalents, nano-pesticides may also result in new types of contamination of soils and rivers.
- Therefore, a deeper comprehension of what happens to and how nanopesticides behave after application is needed. Before deciding to use new technology extensively, it is a good idea to take all essential safety precautions.