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Application of Nanotechnology in Crop Protection: Current Status and Future Prospects

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Introduction

Nanotechnology is the study and design of materials on the nanoscale, which is 1–100nm in size. The creation of new products based on nanoparticles (NPs) has been a scientific and technological priority in the last 20 years all over the world. This is owing to their unique qualities, which include a large surface area to volume ratio, cation exchange capacity and complexation, increased reactivity, unconventional structure, large ion adsorption ratio, and excellent stability and aggregation abilities. Nanoparticles, also known as nanomaterials or nanodevices, have been developed in a variety of industries, including medical, electronics, energy, genetics, and aeronautics. Today's agricultural experts are looking for more sustainable and less harsh ways to combat plagues and diseases, make better use of limiting resources like water, soil, and nutrients, and reduce pollution in rural areas. Finding innovative and low-cost investments in nanotechnology applied to crop production research and innovation could make a substantial contribution to this endeavor.

Nanotechnology has a wide range of applications in crop protection, but it is most commonly utilized to create slow-release encapsulating agrochemicals. New nanomaterials based on metallic, polymeric, and inorganic nanoparticles have been developed with the goal of improving intelligent nano systems that can absorb and immobilize nutrients and release them gradually in the soil to improve fertilizer efficiency. Furthermore, the advancement of nano sensors enables the identification of pests and illnesses in crops. Several types of metallic nanoparticles, including Ag, Fe, Cu, and Zn, can be utilized in two ways: as nano fertilizers to improve seed germination and plant growth, and as pesticides or fungicides to combat harmful bacteria and fungus.

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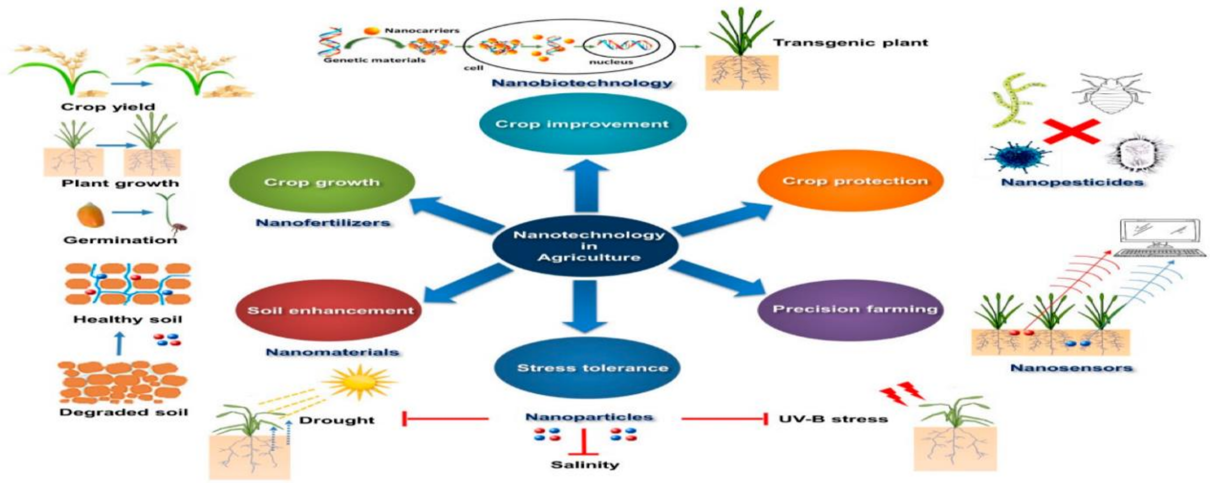

Fig.1

Nanotechnology as useful tool in agriculture

Nanoscience and nanotechnology are the most advanced modern agricultural technologies, and they will soon become a major economic force.Its uses include (a) pesticides and fertilizers formulated for crop improvement, (b) nano sensors and nano biosensors used to detect pathogens or hazardous residues, (c) nanocarriers used to improve genetic manipulation of plants and beneficial microorganisms, (d) plant disease diagnostics, (e) animal health and production, and (f) postharvest handling.

1. **Nano fertilizers for crops-**It is self-evident that healthy crops have a built-in ability to repel pests. As a result, before employing a biopesticide, biofertilizers should be used first. To improve the quality and yield of crops, traditional inorganic fertilizers are used. However, the hazardous influence on soil due to the toxic nature of these compounds impairs soil fertility, microbial population, and mineral content, resulting in lower crop yields. Nano fertilizers and nano insecticides have been established as sustainable approaches for precision farming as a result of the steady use of nanotechnology in agriculture over the previous decade. To adapt traditional dosages to more balanced doses, several manmade and natural nanoparticles, as well as the nanoencapsulation of nutrients in polysaccharide, mineral, or liposome nanocapsules, have been produced.Nano fertilizers are bulk or nano-sized compounds, primarily nutrients, that can be collected from various portions of plants to boost growth, production, and yield. Nano fertilizers, like ordinary fertilizers, can be applied directly to soil or foliage. The particles' small size permits them to enter the pores of roots and

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plants, and their reactivity and solubility are also advantageous. Some Nano fertilizers products have already been commercialized.1 Nano-GroTM (plant growth regulator and immunity enhancer)2. nano-Ag AnswerR (microorganisms, mineral electrolyte, and sea kelp)3. TAG NANO (NPK, PhoS, Zn, Ca, and others)4. protein lactogluconate; and 5. other micronutrients, probiotics, vitamins, seaweed extracts, and humic acid.

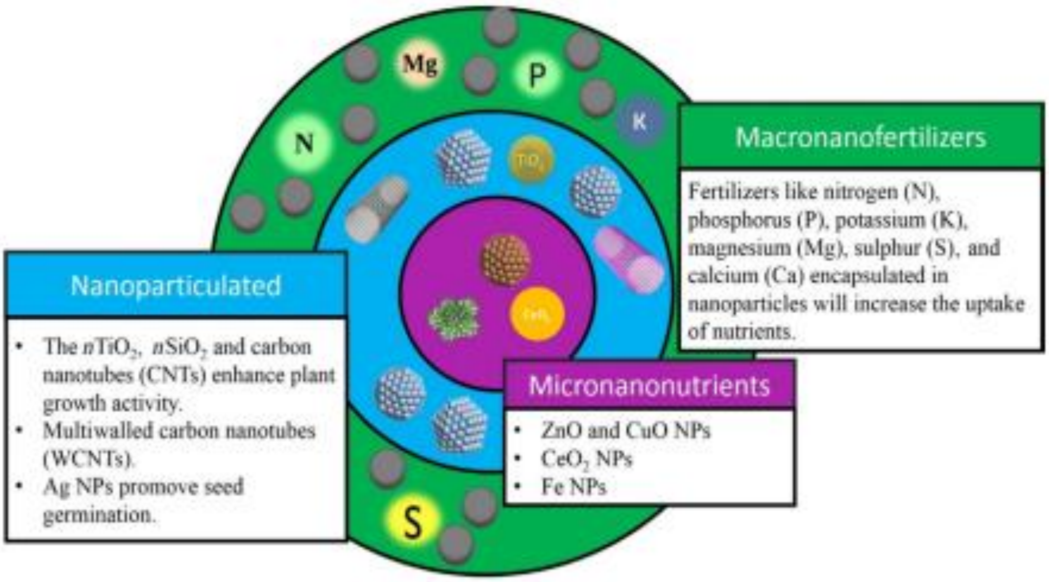

Fig.2 Nano fertilizers applied to agricultural crops

Nano fertilizers are divided into three types based on the nutrient requirements of the plant:

a. Macronanofertilizers
b. Micronanofertilizers
c. Nanoparticulated nano fertilizers

Macronanofertilizers are nanoparticles containing nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and calcium (Ca) that boost nutrient uptake in plants.Micronanofertilizers, such as ZnO and CuO NPs, have an effect on phytohormone responsiveness by raising plant growth rate.The addition of ZnO and CeO_2 NPs to cucumber plants (*Cucumis sativus)* modified the starch and carbohydrate content of the fruits, according to another study. Fe NPs boosted the chlorophyll content in the leaves of the black-eyed pea. Zinc oxide NPs were examined for their

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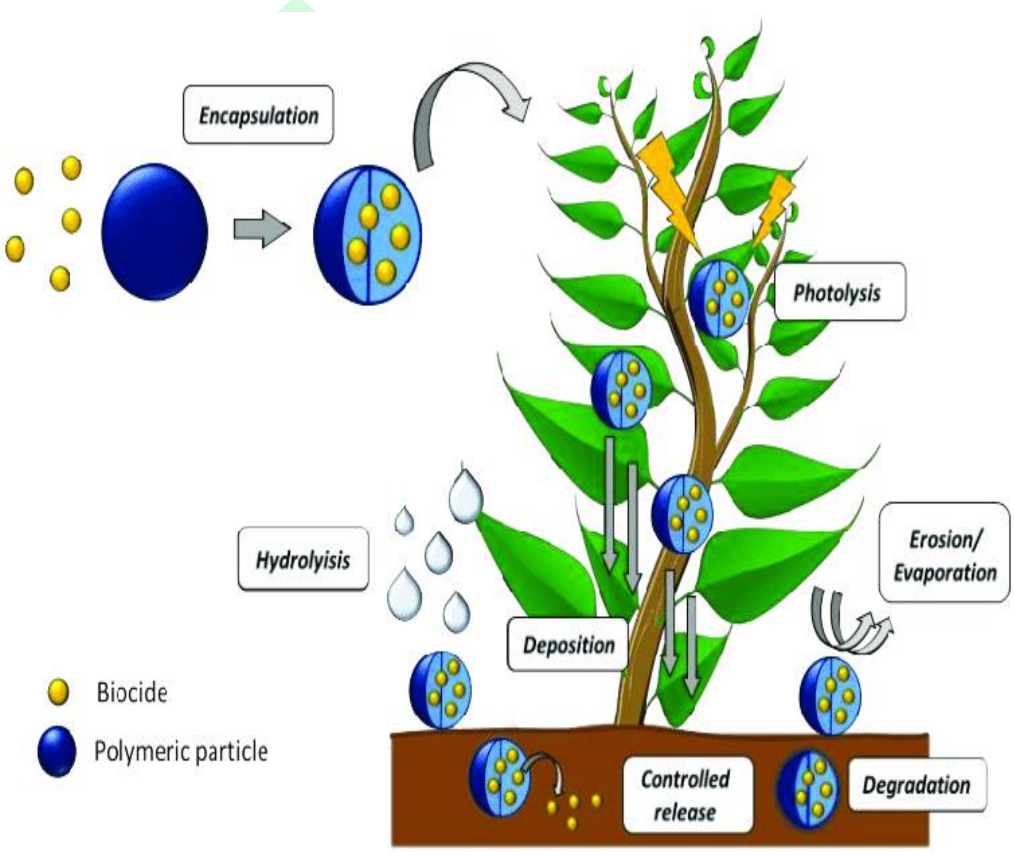
antibacterial action and potential as nano fertilizers stimulating germination, growth, and development.

2. **Nanotechnology for insect pest control-** Pest infestation is predicted to cause annual losses of 26–30 percent in barley, sugar beet, wheat, soybean, and cotton; 40 percent in rice; 39 percent in potatoes; and 35 percent in maize. Insect pests cause a 13 percent loss in crop yield, and over 3 billion kg of pesticides are sprayed each year to control pests. Chemical pesticides have a lot of disadvantages, including the fact that they are non-biodegradable and very hazardous to non-target creatures such as insect pollinators, birds, fish, amphibians, and humans. The goal of developing nano pesticides is to reduce or eliminate the use of pesticides derived from potentially harmful chemical compounds, which have been related to pest alterations, resistance, and detrimental environmental effects.

Several nanoencapsulation methods are microemulsion, nanoemulsion, nanodispersion, polymer-based NPs, solid lipid NPs, clay, layered double hydroxides, and metal-based nanoparticles.

Nanoparticle	Active Ingredient	Benefits
Amphiphilicmodified-N-(Octadecanol-1-glycidyl ether)-O-sulfate chitosan	Rotenone (insecticide for control of aphids ,thrips, acaroid)	Increased activity of rotenone to 13,000 times more than free rotenone in water
Nano and microemulsion system (oil in water)	β- Cypermethrin	Improved stability of the sprayed solution
Polyethylene glycol-coated nanoparticles	Garlic essential oil	Control of adult *Tribolium castaneum* with 80% efficiency
Alginate	Azadiractin	Neem oil emulsion
Alginate (emulsion)	Imidacloprid	Cytotoxicity in sucking pests

Nano capsules and nano spheres of poly-(ε-caprolactone) polymer	Extract of neem (*Azadirachta indica)*	The nano formulations showed high entrapment efficiency -529cy (>95%) and UV stability (30 times more compared to conventional products)



3. **Nanotechnology for plant diseases control**-Traditional pesticides are no longer effective against plant pathogenic bacteria and fungus. Due to their high adaptability to environmental changes, this has led to the hunt for more effective active chemicals, particularly in the case of plant pathogenic fungus. Growing food demand directly adds to the usage of 2 million tonnes of additional pesticides each year in the United States, Europe, and the rest of the globe: 24% in the US, 45% in Europe, and 31% in the rest of the world. Only about 0.1% of the approximately 3 million tonnes of active chemicals in pesticides are useful in crop protection; the remainder (99.9%) is lost due

to application mode (air, soil, water), deposition, and photodegradation. Nanoparticles used in plant disease control are;

A. Metallic nanoparticles

Silver nanoparticles and other metallic nanoparticles interact with cell membranes. Silver ions are used to attack human diseases because of their high reactivity and disruptive effects on bacterial and fungal cell membranes. Copper nanoparticles have been shown to exhibit antibacterial activity against a wide range of plant pathogenic bacteria and fungi in several investigations. Because of its distinctive features, such as a wide bandgap, antibacterial, optical, and catalytic efficiency, and a large active surface area, zinc oxide nanoparticles have a wide range of applications. When exposed to light, titanium dioxide NPs produce chemically reactive free radicals (hydroxyl and superoxide radicals), a photocatalytic process that impacts a variety of microorganism cells.

B. Biopolymer nanoparticles

Chitosan is a biological polymer made from chitin that has been N-deacetylated. It has a wide range of applications in agricultural nanotechnology since it is nontoxic, antibacterial, and biodegradable. The significant interaction of its cationic amino groups with biological components explains its antibacterial effect. Due to its limited solubility, chitosan has been chemically changed into triethylenediamine dithiocarbamate chitosan and o-hydroxyphenylaldehyde thiosemicarbazone, which has reduced biodegradability and enhanced toxicity.

Pathogen	Nanoparticles	Disease controlled
Bacillusmegaterium, Pseudomonas syringae, Xanthomonas oryzae	Silver nitrate	Bacterial blight in different plant species
Xanthomonas campestris	Nano silver	Significant reduction of cabbage black rot in a pot experiment
Xanthomonas	Nano copper	Pomegranate bacterial

axonopodis pv. *punicae*		blight
Sclerotinia homoeocarpa	Zinc oxide and silver	Dollar spot on cool-season turfgrasses
Rhizopus sp. Colletotrichum capsici , Aspergillus niger	Chitosan	Mycelial growth delayed in fungi

4. **Postharvest disease control using Nanotechnologies**-Decomposition causes a significant percentage of food loss both before and after harvest all around the world. The majority of these losses are caused by bacterial and fungal degradation.To enhance the postharvest life of fruits and vegetables, various nanotechnological products, such as nanofilms and nano sensors, can be used in postharvest management. Chitosan NPs, for example, have been used to improve chilli seed quality by altering the mycelial development of many fungus species. Antimicrobials have been developed using silver nanoparticles or nano silver (2.5nm). A combination of conventional fruit-coating material with a 1 percent concentration of nanosilver prevented the growth of *C. gloeosporioides*, which causes mango anthracnose, and resulted in considerable disease reduction as compared to control. Several studies on the production of nanolaminate coatings and how they might be combined into functional nanoparticulated nanomaterials for usage as carriers of additives or active substances have recently been published.

Conclusion

This article concentrated on specialized nanomaterial applications in crop protection. The benefits of adopting nanotechnologies to preserve crops and aid enhance crop yields were validated by a number of spectacular and instructive studies. In the future, however, further research and development in agronanobiotechnology for food security will be necessary. However, some concerns have been raised about their usage in agriculture, particularly in terms of their toxicity, which has the potential to harm human health and the environment; these concerns must be addressed. It is important to note that while the examination and implementation of nanomaterials in agricultural soils

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could be extremely beneficial in alleviating the present global food shortage, such materials could also pose a threat to the environment.As a result, toxicity level studies must be continually examined and improved. It is critical to remember that individual experiments must be conducted for each scenario, and generalizations about the effects of artificial nanomaterials on crops, as well as their impact on human and environmental health, should be avoided.