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Nano Biotechnology in Agriculture: Using Nanomaterials to Help Plants Grow and Tolerate Stress

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Introduction

Sustainable agriculture is an important part of the endeavor to meet the growing food demand of the world's population. Nanobiotechnology is a promising method for achieving long-term agricultural sustainability. Some Nanoparticles (NPs) having unique physiochemical properties, rather from operating as nano-carriers, inherently boost plant growth and stress tolerance. Nanoparticles' biological role is determined by their physiochemical features, application method (foliar delivery, hydroponics, soil), and concentration used. We examine the effects of various types, characteristics, and concentrations of nanoparticles on plant growth as well as abiotic (salinity, drought, heat, high humidity) factors.

The ability of nanoparticles to boost plant growth by having a beneficial influence on seed germination, root or shoot growth, biomass or grain yield is also taken into account. Researchers in and out of the nanobiotechnology sector will be able to better identify acceptable nanoparticles as starting materials in agricultural applications thanks to the information offered here. Finally, a change from testing/using existing nanoparticles to creating customised nanoparticles based on agriculture requirements will make nanotechnology more useful in sustainable agriculture.

By 2050, the global population is expected to reach almost 9.6 billion people, necessitating a 70-100% increase in agricultural productivity to meet food demand. However, the decreasing amount of arable land, water scarcity, climate change impacts, and the low use efficiency of present agrochemicals exacerbate abiotic and biotic stresses on crops, lowering yields. Salinity and drought, for example, cost billions of dollars in agricultural losses each year. As a result, increasing food production is a pressing concern. The development of stress-tolerant crop types has been gradual, and there are no commercially marketed robust salt-tolerant wheat cultivars.

At the same time, public worry about the safety of transgenic crops is widespread. To attain food security safely and sustainably, new technologies or approaches that protect plants from stress and improve the efficiency of pesticide usage are required. Nanotechnology is concerned with nanomaterials with at least one dimension smaller than 100 nm that can be altered at the atomic or molecular level. Among its numerous uses, agriculture is increasingly being investigated as a possible approach for promoting plant development and enhancing agricultural yields.

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Seed treatment and germination, plant growth and development, disease diagnostics, and harmful agrochemicals detection have all demonstrated promising benefits of tailored nanoparticles. As a result, plant Nano biotechnology may be able to increase long-term agricultural production through methods other than chemical and genetic modification. Nanoparticles (NPs) are effective nanocarriers for bioactive materials such as plasmid DNA and double-stranded RNA because to their tiny size, large surface area, and many binding sites. Single-Walled Carbon Nanotubes (SWCNTs) have recently been shown to transfer functional genetic material to chloroplasts and nuclei, respectively.

These findings showed that NPs can be used as a chassis for delivering functional genetic materials to a wide range of plant species. SWCNTs do not require agrobacterium infection, which is confined to a small number of plant species that can be genetically modified, or gene cannon bombardment, which is ineffective and causes plant damage. NPs can be loaded or encapsulated with standard agrochemicals or active substances to provide gradual, controlled, and targeted release in addition to acting as carriers for biomolecules.

In addition to acting as carriers, NPs offer unique optoelectronic, physiochemical, and catalytic characteristics that directly promote plant growth, enhance photosynthesis, and improve plant tolerance to biotic and abiotic stress. Nanoscale CeO_2 particles are excellent scavengers of reactive oxygen species due to their large number of surface oxygen vacancies that alternate between two oxidation states (Ce^{3+} and Ce^{4+}) (ROS). This antioxidant-enzyme-mimicking action can help plants improve their stress response and, as a result, their survival. Carbon-based nanomaterials have a lot of interesting properties. Drought, heat, excess salinity, cold, nutrient shortages, chemical toxicity (e.g., heavy metals), and oxidative stress are the leading causes of crop loss globally, reducing the average yield of most main agricultural plants by more than 50%. Plants experience morphological, physiological, biochemical, and molecular alterations as a result of abiotic stress, which negatively impact their growth, development, and productivity.

Upregulation of functional and structural protectants, such as suitable solutes (osmolytes) and antioxidants, is one of the most important mechanisms used by plants to improve their stress tolerance. Plants produce Reactive Oxygen Species (ROS) as a result of metabolic processes. During metabolic processes such as respiration and photosynthesis, plants produce ROS in chloroplasts, mitochondria, peroxisomes, and other cell locations. ROS are signalling molecules important in growth, development, and defence at low levels; nevertheless, excessive ROS accumulation in plants under stress causes damage to cell membranes, DNA, protein, and other cell components, resulting in cell death. Antioxidant enzymes such as Superoxide Dismutase (SOD), Catalase (CAT), Ascorbate Peroxidase (APX), Glutathione Reductase (GR), Glutathione Peroxidase (GPX), and Peroxidase (POD), as well as non-enzymatic low-molecular-weight metabolites, primarily scavenge ROS in plants (vitamin C, vitamin E, polyphenols).

ROS-scavenging metabolic pathways, such as shikimate-phenylpropanoid biosynthesis and ascorbate and aldarate metabolism, will be initiated in response to stress. Upregulation of these antioxidant pathways results in the production of ascorbic acid and polyphenols, which help to eliminate ROS and reduce oxidative stress. As a result, improving plants' ability to scavenge ROS, such as by the use of nanomaterials with antioxidant enzyme activity, may improve plant resistance to abiotic stress and hence reduce yield losses. As a result, plants modified with these NPs performed better under stress. The majority of crop production losses are caused by biotic and abiotic stressors. Because NPs have the potential to improve crop plant stress tolerance, they should be given top attention in study.