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Nanotechnology and Its Applications in Crop Improvement

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In the web of life, where the complexity of biological systems meets the precision of engineering, nanotechnology emerges as a transformative force that significantly affects Science and Agriculture.

As we know agriculture is one of the main pillars of developing countries with which more than 60% of the population depends on agriculture for their livelihood. Nanotechnology offers a transformative approach to agriculture by leveraging nanoscale material and techniques to enhance crop productivity, improve nutrient uptake, mitigate environmental stresses, and combat plant diseases (Bowen et al., 1992). This article explores the role of nanotechnology in modern agriculture, shedding light on its applications and the utilization of nanomaterial-based formulations for various purposes.

Potential applications of nano-technology in crop improvement

With emerging challenges in agriculture, there is a growing interest in using nanotechnology. The objectives of employing nanotechnology in agriculture are to enhance crop yield and optimize resource utilization. Specific applications of nanotechnology in agriculture encompass:

1. **Nano-genetic Manipulation of Crop:** Nano-genetic manipulation of crops uses nanoparticles (triggering gene expression in plants) and nanofibers (for efficient genetic material to plant cells), replacing traditional methods like gene guns.
2. **Agricultural Diagnostics and Drug Delivery:** Nanotechnology aids in the precise delivery of drugs, nutrients, and agrochemicals to plants, combating diseases using materials like carbon, silver, silica, and aluminosilicate nanoparticles. Carbon nanofibers strengthen natural fibers, while silver nanoparticles serve as effective pesticides.
3. **Nano-biosensors:** Nano-biosensors have revolutionized farming practices by detecting analytes at low concentrations (Joyner and Kumar, 2015). Integrated with computers, electronics, and nano-sciences, these devices monitor soil conditions, crop health, and pest presence in real time (Liu et al., 2005). Wireless nano-sensor networks provide vital data for optimal crop management, aiming to boost productivity while minimizing inputs.
4. **Nano-particles as Fertilizers:** Nanoparticles enhance plant growth and soil health. Unlike conventional fertilizers, nano-fertilizers upgrade soil systems without degrading fertility. This innovation aligns with precision farming, employing technologies like slow release, quick release, and pH adjustment. Nano-urea boosts grain yield by 10.2% and nitrogen fertilizer efficiency by 44.5% compared to traditional urea. Nano-fertilization treatments show an 11.6% yield increase over conventional methods. Encapsulation delivers nutrients at the nanoscale level.
5. **Nanoparticles as Pesticides:** Nano-pesticides offer a potent solution to control pests efficiently while minimizing environmental impact (Afrasiabi et al., 2012). By diluting pesticides with Nano-treated water, their effectiveness increases, reducing the quantity of

chemicals needed and cutting costs in half compared to conventional methods. Nano-encapsulation enhances insecticidal value by sealing active pesticide ingredients with a thin protective coating, improving effectiveness and decreasing environmental hazards. For instance, "Halloysite" clay nanotubes serve as carriers for pesticides, significantly reducing the required amount of chemicals.

6. **Nano-herbicides:** Nano-herbicides eliminate weeds without leaving toxic residues, blending with soil particles to prevent resistant weed growth. They target specific receptors in weed roots, inhibiting glycolysis and preventing new weed growth from viable underground plant parts.
7. **Smart Dust:** Smart dust consists of nano-sensors scattered across fields, capable of wireless communication to relay information on parameters like temperature, humidity, and nutrients. These sensors can anticipate environmental changes and alert farmers in advance. By utilizing gas sensors, smart dust can also assess pollutants in real-time, particularly when connected to GPS for precise tracking.
8. **Controlled Environment Agriculture (CEA):** Smart sensors and delivery systems aid in combating crop pathogens and contaminants in agriculture. Nanostructured catalysts enhance pesticide and herbicide efficiency, reducing the doses needed. Nanotechnology indirectly protects the environment by using alternative energy sources and filters to reduce pollution (Chen et al., 2014). CEA optimizes crop production through advanced hydroponic methods in a controlled environment. Computerized systems monitor and regulate localized crop environments, providing a platform for integrating nanotechnology into agriculture.

Expected Consequences of Nano-Technology

Nano-technology holds the great potential in agriculture but may poses potential risks to human health and the environment (Hong et al., 2013).

- One of the primary concerns associated with nanoparticles in soil is their uptake and accumulation in plant tissues and water systems which could negatively impact soil as well as humans.
- Health and safety risks for workers and consumers exposed to nanoparticles as they can enter the human body through inhalation, swallowing, skin adsorption, etc.
- In humans it leads to decreased cell viability; produces oxidative stress and damages the DNA.
- Due to small size and unique shape, they can move freely in the human body. Sometimes they can penetrate the blood-brain barriers.
- It is challenging to remove nanoparticle residues by simple rinsing methods (Coles and Frewer, 2013).

Nanotechnology has found many applications in agricultural applications such as nanofertilizers, nano biosensors, nanopesticides, and as environment remediation agents. Though, a strong understanding of nanomaterials fate and impact on the environment remains a major challenge in agricultural sciences.

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