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Use of nanotechnology in modern agriculture

[1]Ronit Ghosh, [1]Susmita Bakshi, [2]Parijat Bhattacharya and [2]Sahely Kanthal

[1]Department of Management, Swami Vivekananda University, Barrackpore, West Bengal, India

[2]Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

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Corresponding Author: Parijat Bhattacharya

Abstract

The undeniable global importance of agriculture lies in its role as a fundamental source of sustenance for humanity. Throughout history, pivotal shifts like the transition to settled farming and mechanization have significantly augmented agricultural production. The advent of the green revolution characterized by the adoption of technology and genetically modified crops, further elevated productivity, leading to a reduction in hunger and poverty. At the forefront of innovation, nanotechnology, which involves the manipulation of atoms on a minute scale, holds tremendous potential across various sectors, including agriculture. Nanoscience emerges as a beacon of hope in addressing contemporary challenges such as climate change, urbanization, resource management, and environmental concerns. Notably, nanofertilizers play a pivotal role in augmenting crop yields, diminishing reliance on chemicals, and mitigating environmental impact. Nanopesticides offer multifaceted benefits, including cost reduction and environmental protection. Nanoenabled agricultural packaging materials offer a range of significant benefits that enhance food safety, shelf life, and sustainability in the agricultural and food industries. Overall, nanoenabled agricultural packaging materials play a vital role in ensuring food security, reducing waste, and promoting sustainable agricultural practices in a rapidly evolving global food landscape. The imperative to develop a skilled workforce proficient in nanotechnology is crucial to its successful implementation. Equally important is raising public awareness, which not only spurs interest but also encourages innovation. However, its incorporation necessitates careful consideration due to potential unforeseen risks.

Keywords: Nanotechnology, agriculture, nanofertilizers, nanopesticides

1. Introduction

The agricultural practice, often referred to as "farming," encompasses the cultivation of specific crops and the raising of livestock with the aim of generating various essential products, including food, feed, and fiber. Agriculture serves as the cornerstone of many developing nations, directly and indirectly supplying sustenance to humanity. In the face of challenges such as climate fluctuations, resource and energy limitations, and the rapid expansion of the global population, food and water resources are experiencing unprecedented strains, drawing significant public attention to agricultural processes. Amidst a backdrop of resource depletion and the continual growth of the world's population, as noted by Brennan in 2012, agriculture's role as a primary food source is becoming increasingly critical. To address the demands of this expanding population, modern technologies have become indispensable in the realms of agriculture and food science, including nanotechnology and nano-biotechnology.

The term "nanotechnology" is derived from the Greek word "nano," signifying "dwarf," and typically denotes materials within the size range of 1 to 100 nanometers. Nanotechnology involves the manipulation or self-assembly of individual atoms, molecules, or molecular clusters to construct novel materials and devices with entirely distinct properties. This manipulation can be achieved through either a top-down approach, which involves reducing the size of existing structures to the nanoscale, or a bottom-up approach, in which individual atoms and molecules are manipulated to create nanostructures with properties closely resembling those found in chemistry or biology. One of the primary domains where nanotechnology finds application is in the production of food and agricultural products.

2. Concept

Nanotechnology, also known as nanoscience, encompasses the exploration and resulting applications emerging from the "nano" scale. The term "nano" is rooted in the Greek word "nanos," which translates to "dwarf," signifying dimensions that are a mere one billionth of a meter. To put this in perspective, the size of a hydrogen atom measures about 0.25 nanometers, illustrating that nanotechnology operates on the molecular and atomic scale. As per the European Union's 2011 definition, nanomaterials encompass natural or man-made entities whose external dimensions fall within the nanoscale range (1-100 nanometers) and exhibit a specific surface area per unit volume exceeding 60 square meters per cubic centimeter.

Furthermore, nanotechnology offers the potential for enhancing plant genetic material by precisely delivering drug molecules and genes to specific locations at the cellular level in both animals and plants. Traditional fertilizers have been supplanted by nanofertilizers, thanks to nanotechnology. These nano fertilizers have the capacity to

improve soil fertility, ultimately aiding in the mitigation of eutrophication and groundwater contamination.

3. Uses of nanotechnology in Agriculture

3.1. Nanopesticides

Nanopesticides refer to pesticides that are designed using nanomaterials for use in agriculture. These nanopesticides can take various forms, including being securely attached to hybrid substrates, enclosed within a matrix, or incorporated into functionalized nanocarriers that respond to external stimuli or enzyme-mediated triggers. The unique attributes of nanosized particles, including their size and shape, are believed to unlock novel approaches to pesticide applications within innovative carrier formulations. These carrier materials encompass a wide range of substances such as silica, lipids, polymers, copolymers, ceramics, metals, carbon, and others (Zulfiqar *et al*., 2019) [10].

3.2. Nanofertilizers

The controlled release of nutrients into the soil can be achieved through the application of nano-fertilizers, effectively preventing water pollution (Naderi and Abedi, 2012) [5]. Notably, the impact on maize growth was significantly altered when treated with TiO_2 nanoparticles, whereas the effect of bulk TiO_2 treatment was found to be negligible. TiO_2 nanoparticles enhance light absorption and diffusion within plants. Additionally, research has indicated that Silicon and Titanium nanoparticles compounds can boost nitrate reductase activity and improve the absorption capacity of soybean plants, thereby increasing their water and fertilizer utilization efficiency. Nano-fertilizers possess distinct attributes such as extremely high absorption rates, increased crop yields, heightened photosynthetic activity, and a substantial increase in leaf surface area (Iran Nanotechnology Initiative Council, 2009) [3]. Utilizing nano-fertilizers leads to enhanced nutrient efficiency, reduced soil toxicity, mitigating the adverse effects of excessive fertilizer application, and reduced frequency of fertilizer usage (Naderi and Shahraki, 2013) [6]. In a recent study, Sadaf *et al*. (2017) [9] explored the potential for improving wheat productivity and soil quality through the simultaneous application of biochars and chemical fertilizers (Sadaf *et al*., 2017) [9].

3.3. Nanotechnology and Agri-environment

The application of agrochemicals to boost crop yields often leads to the unintended release of harmful substances into the environment. Nowadays, nanotechnology holds promise for not only increasing crop yields but also remediating polluted groundwater and soil. Scientists have been investigating the current utilization of nanotechnology in agricultural environmental research, particularly focusing on the fate of nanomaterials in soil and water. The use of nanomaterials contributes to the improvement of environmental conditions and aids in the detection and remediation of contaminated areas. It's worth noting that only a limited number of nanomaterials exhibit potential toxic effects (Mura *et al*., 2013) [4].

4. Current Status of Nanotechnology in Agriculture

Over 60% of the global population relies on agriculture as their primary source of livelihood, making it the cornerstone of many developing nations. Nanotechnology is regarded as an innovative technology within the agricultural sector due to its capacity to facilitate precise delivery of nutrients and pesticides, leading to enhancements in crop yields and nutritional content. Additionally, it contributes to environmental remediation and offers a path to the cultivation of value-added crops. One common application of nanotechnology in agriculture is known as particle farming, a method in which plants are cultivated in specific soils to produce nanoparticles for industrial purposes. A study was conducted to extract gold nanoparticles by cultivating plants in soil rich in gold. These plants absorbed gold nanoparticles through their root systems, and upon harvest, the gold nanoparticles were separated from the plant material using mechanical means (Pandey, 2018) [7].

5. Advantages and disadvantages of Nanotechnology in Agriculture

Nanotechnology in agriculture holds the promise of delivering several advantages, but it also carries potential risks and drawbacks. Here are some examples:

5.1. Advantages

- Increased Crop Yields: Nanotechnology can enhance plant growth and yield, enabling farmers to boost food production while conserving land and resources.
- Reduced Pesticide and Fertilizer Use: Through precision delivery systems for pesticides and fertilizers, farmers can diminish the quantity of these chemicals required and minimize their environmental impact.
- Enhanced Food Safety: Nanotechnology facilitates the development of sensors and monitoring devices capable of detecting contaminants and pathogens in food, thereby improving food safety and reducing the risk of foodborne illnesses.
- Soil Remediation: Nanoparticles can effectively eliminate pollutants and heavy metals from soil, thereby enhancing soil quality and reducing crop contamination (Bhagat *et al*., 2015) [1]

5.2. Disadvantages

- Environmental Risks: The application of nanoparticles in agriculture may introduce environmental risks, such as soil contamination or unintended effects on non-target organisms.
- Health Risks: Our understanding of potential health risks associated with nanoparticle exposure, particularly in the long term, remains limited.
- Regulatory Challenges: The regulation of nanotechnology in agriculture is still evolving, making it challenging to assess the safety and effectiveness of new nanotechnology-based products.
- Ethical Concerns: Ethical concerns also arise regarding nanotechnology in agriculture, including its potential impact on small-scale farmers and the exacerbation of social inequalities (Pramanik *et al*., 2020) [8].

It is crucial to recognize that the risks and benefits of nanotechnology in agriculture depend on specific applications and the context in which they are employed. Further research, development, along with diligent regulation and oversight, will be vital in ensuring the safe

and responsible utilization of nanotechnology in agriculture.

6. Conclusions

In conclusion, the field of agriculture stands poised to harness the extensive potential of nanotechnology to revolutionize food production. The advantages and opportunities afforded by nanotechnology are profound. By implementing precision agriculture strategies underpinned by nanotechnological innovations, we can aspire to maximize crop yields while minimizing resource inputs through enhanced monitoring and targeted interventions. Nanotechnology equips crops with the capability to utilize water, pesticides, and fertilizers more efficiently, thereby bolstering the sustainability of agricultural practices. These advancements hold the promise of not only increasing agricultural productivity but also potentially benefiting farmers through improved food production. However, it is important to acknowledge that the integration of nanotechnology into agriculture is progressing at a measured pace. Nevertheless, ongoing efforts are dedicated to mitigating the adverse environmental and health effects associated with conventional agrochemicals. In this context, nanotechnology emerges as a powerful tool to enhance the properties of these substances for the sustainable advancement of crop production. As research and development continue to evolve in this field, the potential for nanotechnology to address agricultural challenges and contribute to global food security remains a compelling and exciting avenue for exploration.

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