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The Key Benefits and Application of Nanotechnology in Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The science of controlling materials at the nanoscale is known as nanotechnology. Working with the smallest particles conceivable gives rise to aspirations for increasing agricultural production by running into issues that can't be solved traditionally. In the management aspects, attempts are made to restore soil fertility by releasing fixed nutrients, as well as to boost the efficacy of applied fertilizer with the aid of nano clays and zeolites. With the aid of nano biosensors and satellite systems, the input requirements for crops are determined in controlled environments for agriculture and precision farming based on needs, and the necessary quantities are given at the appropriate times and locations. To combat the issues of managing perennial weeds and depleting the weed seed bank, nano herbicides are being developed. By using targeted delivery, slow/controlled release, and conditional release mechanisms, nanostructured formulations could more accurately time the release of their active ingredients in response to biological needs and environmental cues. According to studies, using nano fertilizers improves the efficiency with which nutrients are used, lessens soil toxicity, reduces the frequency of treatment, and minimizes any potential side effects from overdosing. Because of this, nanotechnology, especially in underdeveloped nations, has tremendous potential for attaining sustainable agriculture. To increase agricultural productivity, new technologies are frequently used in agriculture. Employing nanoparticles in agriculture is known as "nanoagriculture," and these particles will have positive effects on crops.

Keywords: Nanotechnology; agriculture; nano fertilizer; nano application; agrochemicals; crop production.

1. INTRODUCTION

The growth of nanotechnology and the creation of new nanomaterials and nanodevices present opportunities for novel uses in biotechnology and agriculture. Materials with at least one dimension smaller than a few hundred nanometers are considered nanoparticles because they are small enough to fall inside the nanometric range. It has been widely reported that nanotechnology has the potential to change the fields of health care, textiles, materials, information and communication technology, and energy [1,2]. The use of nanotechnology in the food and agricultural industries is currently receiving attention. The potential benefits of investing in agriculture and food nanotechnologies range from increased food quality and safety to lower agricultural inputs, enhanced processing, and greater nutrition. Even though the majority of funding is concentrated in rich nations, recent research developments hint at possible agricultural, food, and water safety applications that might have a big impact on rural communities in poor nations. The focus of this review is on contemporary methods of nanotechnology that are utilized to manage water, pesticides, restrictions on the use of chemical pesticides, and the potential of nanomaterials in sustainable agriculture management [3,4].

The enormous field of nanotechnology in the twenty-first century is having a big impact on the world's economy, industry, and people's lives. It focuses on the consequences for human well-being of the physical, chemical, and biological features of materials at the nanoscale (1-100 nm). A nanomaterial is a substance that includes particles having at least one dimension that ranges in size from 1 to 100 nm. Its capacity to manipulate and/or create matter at this scale leads to the creation of fresh and inventive properties that can be used to tackle a wide range of technical and societal problems. Developing nations like China have hurriedly completed their research on the delivery of agricultural pesticides using nanotechnology, and in the following five to ten years, field applications are anticipated. However, several elements, including market demand, profit margin, environmental advantages, risk assessment, and managerial practices in the context of other competing technologies, are crucial to their success. The importance of agriculture to all human communities is now more apparent than ever thanks to the growing global population [5,6]. Every human has a basic and essential need for food, and agriculture both directly and indirectly contributes to this need. In developing nations, expanding the agricultural sector is viewed as crucial to achieving development goals. It is clearer than ever before that new technology must be used in the agriculture sector following years of the green revolution and a drop in the agricultural product ratio to the global population increase. India is one of many developing nations whose economies are based largely on agriculture, and where the bulk of the population depends on it for survival. Indian food production has reached a level of self-satisfaction as a result of the green revolution of the 1960s. Globally, food security is a top priority, and both the public and the government have been working to solve this difficult issue. Modern science and technology have made it possible to transform the situation for the better [7,8]. The use of technology has brought advantages in resolving the farm situationThe agricultural industry has been able to respond to the rising demand for agricultural products because of a wide array of agricultural research systems, robust extension apparatus, and government policies (Ali et al. 2014). However, recent decades have seen several challenges for agriculture, including farm losses, low soil quality, the emergence of new disease strains, global warming, and climate change. The increased demand for food caused by population growth makes it necessary to place an increasing emphasis on the study and creation of new technologies. It is important to generate new technology and spread it through the growth of human resources. To address the issues of increasing global food security and climate change, continuous innovation is very necessary [9,10]. To do this, new science and developing intermediate technologies must be added to the traditional research methodologies. Agriculture has profited from numerous technical advances over the years, including the manufacture of hybrid crops, synthetic chemicals, and biotechnology. At the moment, scientists are looking into nanotechnology as a potential new source of agricultural improvements. The primary goal of research on agricultural nanotechnology applications has been to find answers to a variety of agricultural problems, such as sustainability, better seed quality, and increased productivity. In agriculture, nanomaterials might be more useful for managing nutrients and water, delivering active ingredients, and other tasks where more conventional approaches have fallen short. By fusing DNA with nanoparticles, genetic engineering, a process that has proven very popular in synthetic biology, has also found a place in nanotechnology.

Nanotechnology is the process of developing and using materials, tools, and systems by manipulating the characteristics and molecular structure of matter at the nanoscale. In the emerging and fascinating topic of nanotechnology, recent developments in nanotechnology are combined with biology, particularly with molecular and cell biology.

2. DEFINING NANOTECHNOLOGY IN AGRICULTURE

The interdisciplinary field of nanotechnology has been explored by professionals in a variety of applied sciences, including chemists, physicists, biologists, doctors, and engineers. Nanotechnology refers to focused research and development aimed at comprehending, manipulating, and measuring materials with atomic, molecular, and supermolecule dimensions. Nanotechnology is described as the study of matter at length scales of around 1-100 nanometers, where peculiar physical characteristics enable innovative uses.

2.1 Regarding Size and Dimension, this Definition is a Little Rigid

The ability of the materials to solve problems may have been stressed further. From the perspective of agriculture, other definitions of nanoparticles include "particulate between 10 and 1,000 nm in size dimensions that are simultaneously colloidal particulate." The science of creating and developing machines with every atom and chemical connection accurately specified may be summed up as nanotechnology. It is not a collection of specific methods, tools, or goods, but rather the range of talents we will possess when our technology approaches the boundaries established by atomic physics. The goal of nanotechnology is to accomplish matter control what computers did for our control of information. Drexler believes that the creation of the "assembler" is the ultimate goal of nanomachine technology. A nanomachine called the assembler is created to work with matter at the atomic level. The emerging uses of nanotechnology in agriculture will continue to rely on the material's capacity for problem-solving and are unlikely to slavishly stick to the top limit of 100 nm. This is because nanotechnology for agricultural applications will have to address the substantial inherent flaws and complexity of farm production systems (such as extremely low input use efficiency), which may require nanomaterials with flexible dimensions but still perform tasks in agricultural production systems effectively. In contrast, nanoparticles may function well in tight-knit production systems centered in factories.

3. THE KEY BENEFITS OF NANO-TECHNOLOGY APPLICATIONS

The research and development pipeline currently available has the potential to improve agriculture's productivity, boost yields and product quality, and thus boost nutritional benefits. Nanosensors, nano agricultural chemicals, soil-cleaning nanoparticles, nanopore filters, nanoceramic devices, and nanoparticles are all being used or tested in developed nations. Nanosensors, which may be able to identify chemical contaminants, viruses, and bacteria, nano delivery systems, which may deliver medications or micronutrients precisely at the right time and to the right part of the body, as well as nanocoatings and films, nanoparticles, and quantum dots, are just a few of the applications that are anticipated for use in food and agriculture (Bouwmeester et al., 2009). Numerous papers have discussed the enormous potential of agricultural and food nanotechnology in developing nations. Applications of nanotechnology that show promise address the issues of low input usage efficiency, drought stress, and high soil temperature.

Nanoscale agrichemical formulations can boost productivity and cut down on waste. Additionally, yields could be improved and water could be saved by using nanoporous materials that can store water and gently release it as needed. Aflatoxin is a fungal toxin, and studies have shown that using nanotechnology to lessen its effects raises the weight of food animals. Agriculture's potential use of nanotechnology is expanding (Shi et al., 2006).

According to Barik et al. (2008), the bio-remediation of polluted environments, biocides, and antifungals on textiles are more ambitious uses of nanoparticles.

Another area where nanomaterials can be very useful is photocatalysis in agriculture. Various titanium dioxide (TiO2) nanostructures and

As photocatalysts, zinc oxide (ZnO) has received extensive research (Ullah and Datta, 2008). Pesticide chemicals are converted into comparatively innocuous molecules like CO_2, N_2, and H_2O. Photocatalysis is also being used to remove pesticides and herbicides from soil and plants. Dichloropyrifos, one of the common pesticides, is an example of a carbamate insecticide that mineralizes in the presence of ZnO and TiO_2. There have been reports on the usage of nanotubes and thin films of nanostructures in addition to nanoparticles for the degradation of insecticides.

4. BENEFITS OF NANOTECHNOLOGY

- Post-harvest control
- Animal health, animal breeding, and poultry production.
- Diagnosis for plant diseases.
- Nanotechnology for genetically modifying plants.
- Application of nanosensors in crop protection to detect disease and pesticide residues.
- The application of fertilizers and insecticides to crops using nanoformulations of agrochemicals.
- Precision farming methods also increase crop yields without harming the soil or the water.
- Additionally, nitrogen loss through emissions, leaching, and soil microbes may be reduced.

5. APPLICATIONS OF NANO-TECHNOLOGY IN AGRICULTURE

Products made from nanotechnology that are used in agriculture are essential for improving plant development and crop productivity.
They are a preferable option for farmers over traditional chemicals and methods because of several characteristics, including their small size, portability, ease of handling, long-term storage, high effectiveness, and nontoxicity. Globally, the commercialization of nanotechnology is now booming.

Studies on the effectiveness of nanosilver against the phytopathogen Colletotrichum gloeosporioides have recently been conducted. Other than their antibacterial properties, the other nanoparticles (carbon nanotubes, Al_2O_3, CeO_2, TiO_2, ZnO, Zn, Al, Si, Cu, and Fe) have also been reported to have negative impacts on plant growth.

Sometimes, the growth of helpful soil bacteria, such as Pseudomonas putida KT2440, is impacted by the nanoparticles.

The use of environmentally friendly pesticides was the main focus of various research teams. For the use of antimicrobial agents to protect crops from various illnesses, herbicides and nanoparticle-based pesticides like chemical pesticides have been investigated.

The antifungal properties of nanoparticles can be used to make insecticides that contain them.

Due to its many benefits over other nanoparticles including TiO_2, Al_2O_3, ZnO, gold, zinc, and copper, as well as its differences from other inorganic nanoparticle-based antibacterial treatments, a variety of researchers have extensively investigated silver.

Precision farming generally represents a change in farm management philosophy. The amount of fertilizer and chemical pesticides required for each farm area will be determined with the use of nanosensors. As a result, there will be optimal input use, safe goods, and greater economic efficiency. Farmers can maintain their farms with precise control and timely plant requirements reports thanks to nanosensors. Precision farming could make better use of agricultural natural resources like water, fertilizers, and chemicals with the aid of nanosensors and nano-based smart delivery systems. Farm managers might remotely find crop pests or signs of stress like drought through the use of nanomaterials, global positioning systems, and satellite photography of fields. Pesticide sprays or irrigation levels would automatically be adjusted once a pest or a drought were recognized. Plant viruses and the amount of soil nutrients can also be detected using field-distributed nanosensors. Plants will quickly and completely absorb nano fertilizers. To reduce environmental pollution and fertilizer consumption, nano-encapsulated slow-release fertilizers have also gained popularity. Super water adsorbents, which are products of nanotechnology, play a significant role in the preservation and storage of water in arid and semiarid areas.

Nanotechnology has a wide range of uses some of the production of strong mechanical components with the use of nano-coating and the use of bio-sensors in smart machines for mechanical-chemical weed control; application in machine structure and agricultural tools to increase their resistance against wear and corrosion and ultraviolet rays; production of nano cover for bearings to reduce friction; the creation of alternative fuels and the reduction of environmental pollutants through the use of nanotechnology. The genetic makeup of crop plants can be altered using nanotechnology, which aids in crop plant improvement (DeRosa et al., 2010; Jones, 2006).

The wide spectrum of special and advantageous nanotechnology has many uses in the fields of electronics, energy, biology, and even agriculture.

Since nanotechnology is incorporated into every system conceivable related to agriculture in the twenty-first century, it has drawn increasing interest on a global scale. When scientists discovered that conventional farming techniques couldn't boost crop yields while also preserving ecosystems by using less water, fertilizer, and pesticides, nanotechnology in agriculture was born.

The growth of precision farming and sustainable agriculture may be greatly aided by nanotechnology. The need for improved agricultural yields by a population that is always expanding is driving up the usage of nanotechnology in agricultural science. Additionally, nanotechnology in agriculture may offer technologies for precision farming that use sensors and monitoring equipment to maximize crop productivity, hence increasing global food production and having a favorable impact on the agricultural sector. The numerous uses of nanotechnology in the agriculture industry are depicted in Fig. 1 above. The next subsections will provide a quick overview of each application.

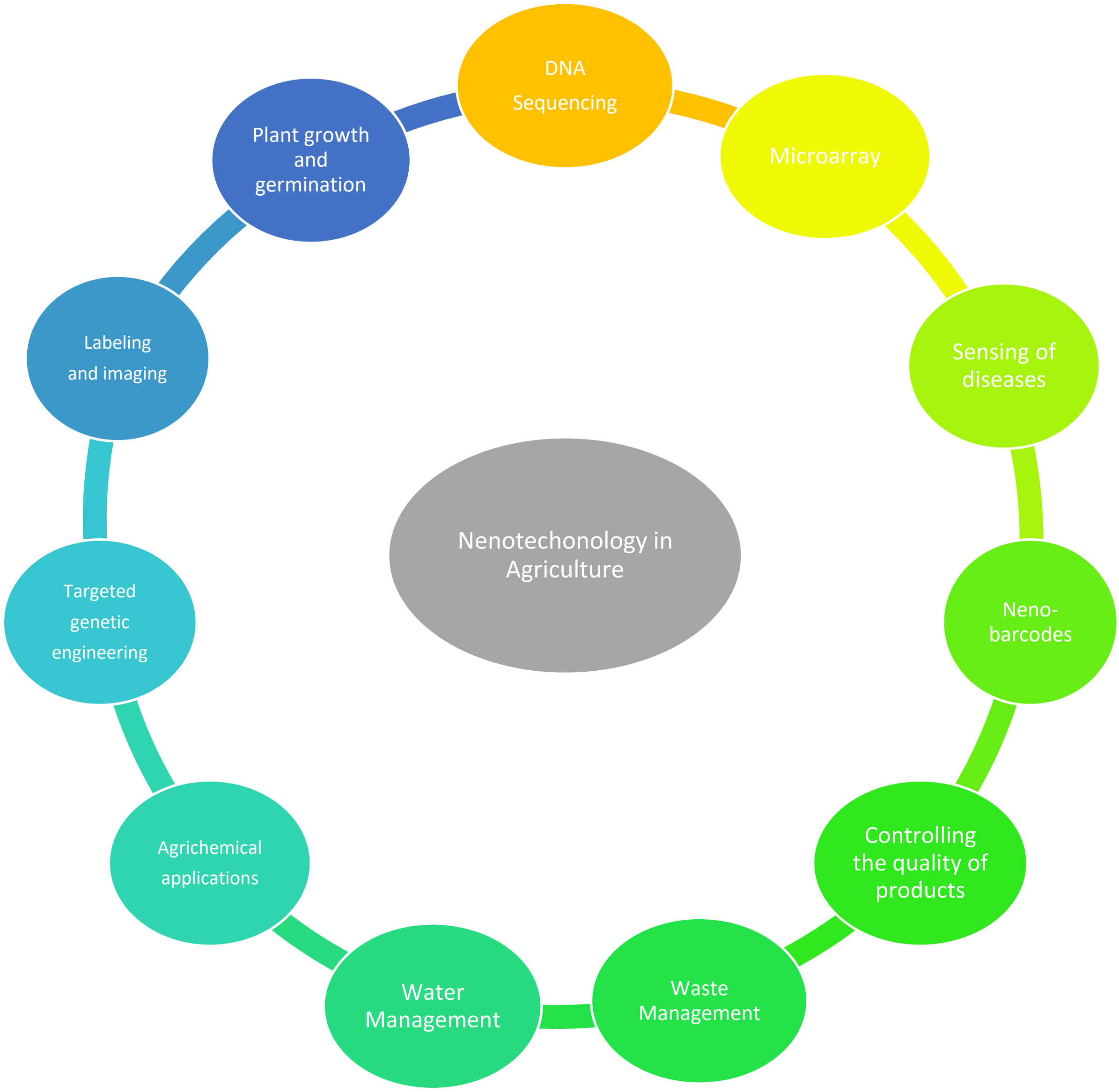

Fig. 1. Google Source of the nanotechnology applications in agriculture

6. CONCLUSION

Finally, it should be noted that the era of nanotechnology is rapidly developing and will be widely used in sustainable agriculture.

Due to mass production and rising demand for nanoproducts, nanotechnology has sparked a revolution.

Nanotechnology has greatly benefited the agricultural sector by creating xylem vessels, nanoscale transporters, and biosensors.

These are some of the most significant advances in nanotechnology that have influenced the modernization of the agricultural industry.

The use of nanoparticles as smart delivery systems is a particularly intriguing application of nanoparticles in the field of life sciences. This study aims to present several approaches for the analysis of nanoparticles delivered into plants, the identification of plant illnesses, and the usage of such nanoparticles in particular plant tissues. The findings give up a wide range of opportunities for employing nanoparticles in agronomy and general plant study.

Their effectiveness, safety, and acceptability are all improved by nanotechnology, which also helps to lower the overall cost of healthcare. This essay addressed how nanotechnology might be used in the agricultural sector. We talked about DNA sequencing and molecular biology and concluded that genomics plays a crucial role in making the fusion of nanotechnology and biotechnology possible.

Protein, DNA, and other profile arrays reveal how pesticides, plant diseases, and other compounds interact with one another.

The results of this investigation will aid in crop improvement. We also discussed how this technology is applied to agricultural enhancement, plant disease, and nanobiotechnology. The full magnitude of nanotechnology uses in agriculture is finally examined in detail. We conclude that nanotechnology is crucial to crop yield development and provides us with significant financial gain. Nanotechnology offers enormous potential for use in agriculture. Agriculture-related nanotechnology applications have only recently been studied. However, given that conventional farming methods are becoming less and less effective and that human requirements have outgrown the capacity of the terrestrial ecosystem, we are left with no choice but to investigate the use of nanotechnology in all facets of agriculture. nanotechnology, nanoformulation of fertilizers, surveillance and control of pests and diseases, molecular understanding of host-parasite interactions, development of next-generation pesticides and safe carriers, preservation and packaging of food and food additives, strengthening soil, and nutritional quality are just a few of the areas where nanotechnology promises to break through. An in-depth knowledge of science, fabrication, and material technology, as well as a grasp of the agricultural production system, are prerequisites for working with nanotechnology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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