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Review of Nanotechnology's Potential in Agricultural Applications

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ABSTRACT

Nowadays, the fundamental concept of nanoscience and nanotechnology is used in a variety of fields for a numerous reasons, purposes, and applications at Nano scale. This is an interdisciplinary subject, and its applications include engineering, biotechnology, biomedical instruments, and composite materials; however, nanotechnology has recently become most imperative and exciting in the field of agriculture. Nanotechnology and nanoscale materials have the potential to provide solutions to many significant challenges confronting our farmers. This review paper summarizes some of the most promising and significant nanotechnology applications in agricultural products such as nanopesticides, nanourea, nanosensors, and other nanoscale processes. The current review concentrates on technical and financial challenges confronting achievement of nanotechnology in rural community development.

1. Introduction

The vast majority of Indians live in rural areas. Agriculture is regarded as the backbone of most developing countries, including India, with more than 60% of the population relying on it for living [1]. Climate change, urbanization, sustainable use of natural resources and environmental issues such as runoff and pesticide and fertilizer accumulation are now major challenges for global agriculture. These difficulties are exacerbated by an alarming increase in food and its product demand, which will be required to feed an estimated 6-9 billion people by 2050 [2]. In general, most farmers live in rural areas, which are less developed and have a lack of technical knowledge and materials when compared to urban areas [3]. Furthermore, when compared to urban areas, rural areas have poor living conditions [2, 4]. The majority of farmers in rural areas have completely adhered to old conventional means and methods in their regular agricultural activities and work. However, reflective structural changes in the agricultural sector have occurred as a result of the rapid growth of technological innovations, but these also pose challenges such as sustainable production while considering food security, poverty reduction, and public health improvement [4]. The rural economy is primarily dependent on agriculture, fisheries, animal farming, food processing, and so on. As a cutting-edge technology, nanotechnology should be applied to the entire agricultural value chain, fisheries, and animal farming to have a significant impact on the rural economy. For developing countries, advancements in science and technology can provide prospective results for discovering value additions in their current manufacturing systems [6]. The main reason for using fertilizer in agriculture is to provide full-fledged macro and micro nutrients that soil typically lacks. Fertilizer accounts for 34 to 40% of crop productivity, but some fertilizer directly affects plant growth [6]. To address these drawbacks more effectively, nanotechnology may be one source. Given that fertilizers are the primary concern, developing Nano-based fertilizers would be a novel technology in this field. Fertilizers are sprayed in a variety of ways, including soil, leaves, and even aquatic environments; these inorganic fertilizers are supplied in equal ratios to provide three main components, nitrogen, potassium, and phosphorous. For example, nanotechnology applications could have a significant impact on all aspects of agricultural food, including food production, nutrition, processing, food safety, packaging, and transportation. Nano is derived from the Greek word Nano, which means dwarf or small. Nanotechnology includes the manipulation of matter with at least one dimension of approximately 100 nm. One nanometre is one billionth of a metre in length. (1nm=10^{-9} meter). In comparison, the average thickness of a human hair is between 60,000 and 100,000 nm. Nanotechnology encompasses the development and application of functional nano structured materials, devices, and systems with novel characteristics and properties. As a result, advancements in nanotechnology may provide appropriate solutions to many challenges confronting rural communities today, as well as add significance to their current lifestyles and livelihood [7]. A nano fertilizer increases nutrient use efficiency by three times and provides stress tolerance. Nanotechnology can be used on any crop. Nanotechnology increases bio source use and eco-friendliness in nature, builds carbon uptake, and improves soil aggregation. These Nano fertilizers will have a slow and targeted efficient release because they contain nutrients and growth promoters encapsulated in nano scale polymers. Nanotechnology is the collection of information about atoms at the Nano scale level, with consideration for physical, catalytic, optical, and magnetic properties [8] and product quality. As a result, the prospects offered by nano science and technology to extend the shelf life of food and agricultural products, detect pathogens, control pests and toxins, and improve drinking water quality are promising for rural applications. The main advantages of using nanotechnology in agriculture include increased yield and product quality. When compared to the requirements and costs of chemical fertilizers, Nano fertilizers are economically cheaper and require less. Farmers later discovered that nitrogen uptake is the primary cause of low crop yield [7-8]. Some novel Nano materials have been developed for crop growth development, environmental monitoring, nano fertilizer and pesticide development, food quality and safety monitoring, and rural technology transformation. The purpose of this paper is to provide a summary of potential agricultural applications of nanotechnology. A brief introduction to nanotechnology and nanostructured materials is also included. Various types of Nanomaterials and their agricultural applications are discussed. Finally, the paper concludes with a discussion of the potential challenges of nanotechnology in terms of implementing this emerging technology for agricultural applications [9].

2. Nanotechnology and Nanomaterials

Nanotechnology is defined as the manipulation and control of materials in the Nanoscale region with at least one dimension in the range of 1 to 100 nm, so that any object with three dimensions x, y, and z and any of

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these dimensions having a distance less than about 100 nm (10^{-7} metre) is referred to as a nanomaterial [10, 11]. Other intriguing aspects of Nanomaterials include their small size, high specific surface area, deep access to cells and organelles, a variety of physical and chemical properties, and the ability to change these properties depending on the application [12]. Nanotechnology is a novel and rapidly developing field of study in the interdisciplinary fields of basic sciences, medicine, engineering, and so on [13]. Nanoscience is capable of dealing with materials at the molecular level, resulting in exceptional systems with fundamentally new molecular organization [14]. Furthermore, any nanomaterials physical and chemical properties are entirely determined by its morphology, size, and composition. Nanomaterials properties can act as a bridge between atoms and bulk material. Mechanical strength, thermal properties, electrical conductivity, and optical properties may not be the same at the Nanoscale as they are in bulk materials. Nanomaterials exhibit appealing properties for potential applications in a wide range of fields, including consumer products, energy generation from various sources, agro industries, water treatment, environmental science, animal farming, and health care products [15].

2.1 Types of Nanomaterials

- Nanomaterials are classified based on the number of dimensions that are not limited to nanoscale range (<100 nm):
- Zero-Dimensional (0-D): All dimensions are in the nanometre range. For example, silver nanoparticles, gold nanoparticles, magnetic nanoparticles, and so on (Figs. 1 and 2) [16] .
- One-Dimensional (1-D): any two dimensions of nanoparticles are a few nanometres apart. Nanotubes, nanowires, and etc.
- Two-dimensional (2-D): Only one dimension is less than 100 nm, while the other two aregreater than 100 nm. For example, nano layers, such as nano coatings & nano films.
- Three-dimensional (3-D) materials: 3-D materials are not confined to the nanoscale in any dimension and contain nanoparticle dispersions.
- Multiphase, multilayer, and many polycrystalline materials with dimensions of 0D, 1D, and 2D nanomaterials are examples [17].

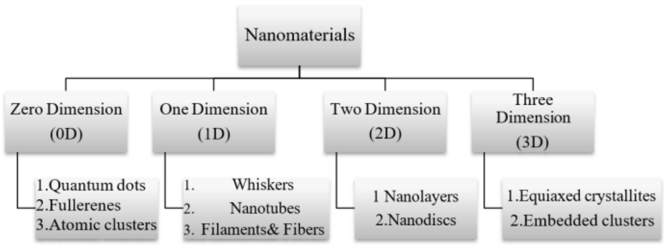

Fig. 1 Classification of nanomaterials

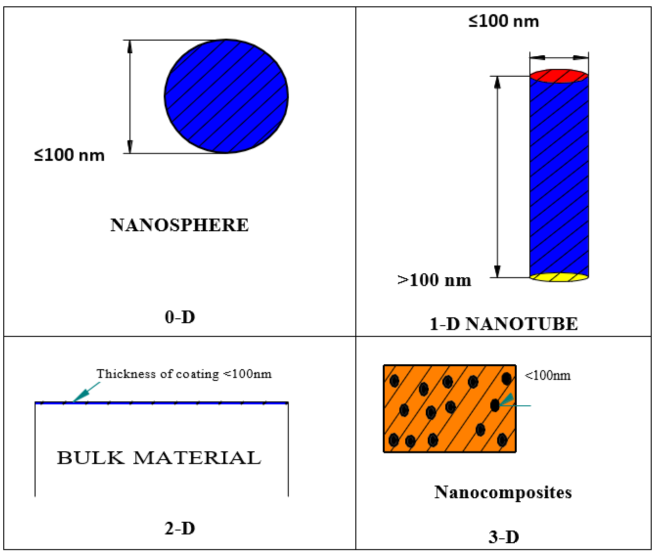

Fig. 2 Types of nanostructured materials

2.2 Nanomaterials Preparation

Nanostructured particle materials are ultra-small particles ranging in size from 1 to 100 nm. This dimension has a high surface-area-to-volume ratio and a large interfacial area. Bottom-up and top-down approaches can be used to create nanostructured materials (Fig. 3) [18, 19].

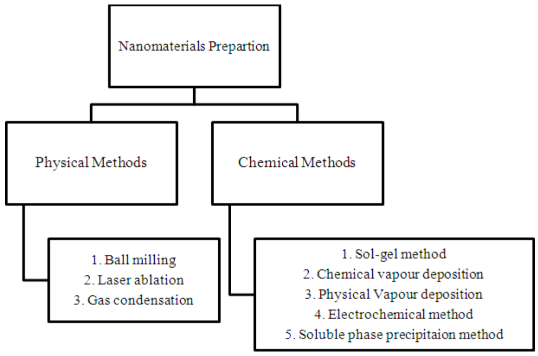

Fig. 3 Methods of preparation of nanomaterials

2.3 Nanomaterials Characterization

Scanning Electron Microscope (SEM), Transmission Electron Microscopy (TEM), X-ray diffraction (XRD), Raman spectroscopy, and infrared spectroscopy can all be used to characterize nanomaterials (IR). SEM and TEM techniques are commonly used to characterize the morphology of nanomaterials [20, 21].

3. Nanotechnology Applications in Agriculture

Agriculture and food production are vital to human health. Nanotechnology is a new and promising method for agricultural sectors and food production processes (Fig. 4) [22]. Nano-formulated agrochemicals such as nano fertilizers, Nano pesticides, Nano biocides, Nano-based veterinary medicines, and nano sensors for improved efficacy, precise control of agrochemical applications (e.g., slow and controlled release of pesticides or fertilizer) to reduce overdose, toxic effect are some of the major applications of nanotechnology in agriculture [23].

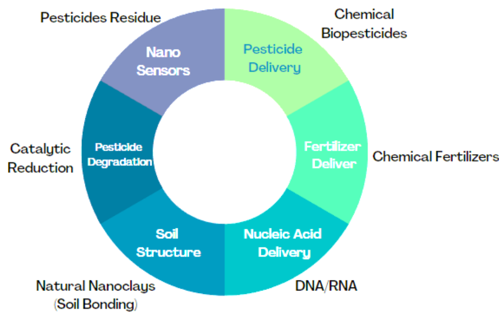

Fig. 4 Potential applications in agriculture [6]

Nanotechnology applications in the field of materials and biomass conversion technologies useful in agriculture are the foundation of providing food, feed, fire, fiber, and fuels. Food demand will skyrocket in the coming years, while natural resources such as land, water, and soil fertility will be insufficient [24, 25]. Because of limited reserves of fuel such as natural gas and petroleum, the cost of production inputs such as chemical fertilizers and pesticides is expected to rise at an alarming rate. To avoid such problems, a number of cutting-edge techniques for improving precision farming practices, known as nanotechnology, are now available [26, 27].

3.1 Nano Fertilizer

A nano fertilizer is a product that can supply micronutrients to crops via Nano-sized packages (nano encapsulated, nano emulsion, products, etc.) that are coated with thin protective coatings. Nano fertilizers release micronutrients on demand, reducing waste by preventing them from converting prematurely into chemical/gaseous forms [9, 28, 29].

3.2 Nano Smart Pesticides

By continuously and slowly discharging active ingredients, Nano smart pesticides provide better perception to pest-affected matters, avoiding phytotoxicity on the crop caused by complete herbicides against parasitic weeds [12] practices that will enable precise control at the nanoscale [27, 30].

3.3 Nano Urea

A half-liter of nano urea (Fig. 5) [30] solution is equivalent to 50 kg of the market's existing crystal form urea. The surface area to volume ratio

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of Nano urea is greater than 10,000 times that of conventional urea (Table 1). During the spraying of Nano urea solution to the crop, nanoparticles can easily dissolve from the surface to the crop route, allowing for complete absorption of nano particle nutrients, as well as increased soil fertility and crop yields [30].

Table 1 Relationship between cluster size (nm) and surface area (%)

No	Cluster Size (nm)	Surface area(% increase)
1	20	15
2	10	25
3	5	50
4	2	90
5	1	100

Nano urea, developed by the Indian Agriculture Firm IFFCO, is an innovative Agri-input based on nanotechnology [14, 15] that provides nitrogen to plants in various forms. Nano urea is a long-term solution for Indian farmers to transition to smart agriculture and combat climate change. These meet the plant nutrient requirement as a fertilizers [16, 17] because nano urea is bio available to plants due to its required particle size of about 20-50 nm and greater surface area (10,000 times greater than 1 mm urea prill) and quantity of particles (55,000 nitrogen particles over 1 mm urea prill) [30].

Fig. 5 Images of IFFCO Nano urea and its benefits [31]

As a result, nano urea increases crop accessibility by more than 80%, resulting in increased nutrient use effectiveness [30]. Furthermore, nano urea helps to reduce the environmental footprint by reducing nutrient loss from agricultural fields through liberation and gaseous excretions, which used to cause pollution and climate change [20].

3.3.1 Benefits of Nano Urea Increased Crop Yield

IFFCO nano urea elements are easily accessible to crops due to their small size and higher surface area to volume ratio. Higher crop yields are observed as a result of improved chlorophyll and photosynthesis in leaves, as well as an increase in root biomass and the number of effective tillers/branches, among other things. According to 11,000 field trials conducted across India during 2019-20, average crop yield growth of up to 8% has been observed [22]. Income: According to agriculturalist field trials, there has been a decrease in input costs, an increase in crop yield, and an improvement in crop quality. Improved food quality: Crops collected with IFFCO nano urea are safe to eat. Nutritional quality of harvested yield is higher in terms of protein and nutrient content [23].

3.3.2 Reduced Use of Chemical Fertilizers

- IFFCO nano urea validates the use of bulk nitrogenous fertilizers such as urea.
- Foliar application of nano urea at critical crop growth stages effectively meets nitrogen requirements.
- A bottle (500 mL) of IFFCO nano urea can potentially replace at least one bag (50 kg) of conventional urea [30].

3.3.3 Reduced Use of Chemical Fertilizers

- Agriculture sustainability and environmental care can be confirmed by using IFFCO Nano Urea.
- IFFCO Nano Urea manufacture is energy and resource friendly.
- It reduces surplus application of bulk urea and associated volatilization, as well as leaching and run off losses.
- Agriculture sustainability and environmental safety can be established through the use of IFFCO's Nano Urea Production. Nano urea is both energy and resource efficient [30].

3.3.4 Simple to Store and Transport

- When it comes to bulky nitrogenous fertilizers like urea, IFFCO nano urea is essential in small quantities.
- Farmers can easily carry in bottles of nano urea physically over bulky Urea heavy 50 kg bags, which have a significant impact on relative logistics and warehousing costs [30].

3.4 Smart Dust

We can use the smart dust technology for monitoring several parameters like humidity, temperature and perhaps insect and disease infestation to create dispersed intelligence in vineyards and orchards [26].

3.5 Clay Nanotubes

Clay Nanotubes have been developed as carriers of pesticides for little cost, extended release and improved contact with plants, and they will decrease the amount of pesticides by 65 to 80%, hence reducing the cost of pesticide and also the influence on water streams [27].

3.6 Nano Sensors

Nanotechnology applications are also being developed to increase soil fertility and crop production. Nano sensors can also monitor crop and animal health and magnetic Nano-particles could remove soil contaminants further, Lab on chip technology also could have significant effects on developing nations [28].

4. Conclusion

The current paper provides an overview of the potential of nanotechnology development for agricultural applications for human welfare and a sustainable environment. Several research findings have revealed how nanoparticles and nanostructures increase various properties due to their larger surface area, small size, and highly catalytic nature. This evolving technology is regarded as an innovative key to developing agricultural production by implementing nutrient efficiency and increasing plant protection practices; additionally, nanotechnology may have real answers to various agriculture problems such as enhanced crop varieties, plant safety, disease identification, and plant growth monitoring. The agricultural sector offers substantial visions for the growth of the agricultural sector through innovative applications and the probability of products and increased global crop production volumes to feed the world population in later decades. One of the challenges and risks for the use and applications of nanomaterial and various nano particles like Zn, TiO_2, SiO_2, Au and MgO may be health issues due to easy penetration through cells. It may cause complications for human health and the environment.

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