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Current Scenario and Future Perspectives of Nanotechnology in Agriculture

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ABSTRACT
Nanotechnology has drawn a lot of interest in recent years due to its wide applications in various sectors like medicine, materials, catalysis, agriculture, etc. The realization that traditional agricultural technologies would not be able to further enhance productivity or repair ecosystems harmed by existing technologies to their pristine form led to the first attempts to use nanotechnology in agriculture. The nano-chemicals can improve fertilizers, insecticides, and plant growth. Insects, fungi, and weeds are among the plant pests that can be controlled using nanomaterials in recent years. In the food industry, nanoparticles play a key role in the production of foods that are high-quality and nutritious. The rising need for food worldwide has led to the widespread usage of fertilizers. The widely used chemical fertilizers may promote plant growth and production but harm the environment, our soil, and consumer health because they are made of nanoparticles that contain both macro- and micronutrients and are controlled in their delivery to the plant rhizosphere, Nano fertilizers are among the most intriguing alternatives to conventional fertilizers. Millets are said to be a miracle crop that has improved food production through their nutritional values and also resistance to a variable climate. With the growth of the population in the near future, it will be a challenging task to feed them. Through the use of nanotechnology to enhance productivity and decrease yield losses, the Millet can prove to be a better option in terms of its production and nutritional requirements. Millet production along with the application of nano fertilizers can revolutionize food scarcity due to the rising population, both by yield and quality. There are various types of nanomaterials like nano fertilizers, nano pesticides, etc which can be used to enhance the yield and nutritional requirement. The use of nanotechnology can be used either at one stage or at all stages of crop production i.e., from seed to post-harvesting. The property of either colloid formation or through the technology of 'nano-encapsulation' is used to employ the approach of nanotechnology on crops.
Key words: *Nano fertilizers, Chemical fertilizers, Nanoparticles, Slow-release fertilizers, Controlled release fertilizers*

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INTRODUCTION

Nanotechnology is an innovative solution to the global problem of food scarcity. However, the use of nanomaterials in agriculture has started since 1999 [1,2,3]. It is an emerging technique to resolve agricultural problems in the form of nano fertilizers (NFs), seed enhancement through nano primers, nano pesticides (NPs), nano biosensors, and nanoparticle remediation of problem soils. The advent of this technology in agriculture is a result of the stress faced by the world in food production due to climate change, burgeoning population, plant and soil stress conditions, and so on. Minor millets were introduced as a miracle crop and contributed well to improving food productivity. These are especially known for their nutritive values and antioxidant properties [4]. Nowadays, small millets are classically grown and consumed specifically by farmers in Asia and Africa region [5]. Due to its hardiness and climate resilience, small millets are known as crops of the future. These include the millet varieties of Kodo (*Paspalum scrobiculatum*), finger (*Eleusine coracana*), proso (*Panicum miliaceum*), barnyard (*Echinochloa esculenta*), foxtail (*Setaria italica*), and small (*Panicum sumatrense*). These six tiny millets may be used to make pulverized flour for human use as well as animal feed. They can also be used to make alcoholic beverages.

Due to their nutritional richness and antioxidant activity [6], they are highly valued and perceived as superior to those crops that have high carbohydrate content like paddy and wheat [7]. These millets require less fertilizer for their establishment and growth and are resistant to various other biotic and abiotic stresses. Many reports have been published that they are having a high degree of pest resistance and good long-term shelf life [8,9]. Millets have the capacity to withstand adverse climatic conditions and are capable of fulfilling the balanced dietary requirements of human beings.
According to the data received from the Food and Agriculture Organization [10], there will be an increase of about 10 billion people by 2050. Meeting the food requirements of these people along with the existing population will be a challenging task for everyone. To overcome this problem, the researchers have to make some affirmative changes in the global food production system. Minor millets have already been present in the food production system dating back to ancient times and most of the people who are residing in arid and semi-arid zones of the world have included millets in their staple diet [11].These are considered neglected crops and generally apprehended by farmers to replace classical crops with millets due to their low yield as compared to other grain crops [11,12,13]. Millets enhancement through nanomaterials can be a better option than the conventional approach to decrease the yield losses and damages caused by biotic and abiotic factors. Several types of nanomaterials have been used for specific cereal crop requirements to enhance yield and other quality parameters. While, seed priming with nano fertilizers responded well in increasing the nutritive value of crops like Mung, Maize, and Rice [14]. Treatment of small millets with nanomaterials will enhance the nutritive value, yield, and other agronomic parameters, which can contribute to the improvement of food productivity and security. The idea of writing this review is to collect the information regarding enhancement of minor millets through nanomaterials and to provide complete reference material to the researchers who are involved in the studies of nanotechnology; especially in terms of minor millets. Enhancement of millet through this novel technique will surely contribute to hunger management and alleviate poverty and malnutrition.

NFs Revolution

Agriculture has advanced throughout humankind's development. With traditional agricultural practices, conventional agriculture mandates the routine application of fertilizers [15], which may significantly increase crop growth, yield, productivity, and nutritional value [16]. Thus, from the time of the green revolution, chemical fertilizers have been essential to the development of current agricultural practices. Agriculture underwent significant mechanization in the early 20th century, but in the following decades, new technologies like marker-assisted breeding and the transgenic way of crop production were created [17]. Even though these developments have greatly increased crop yield, they also have several negative consequences on the environment and the soil's nutritional value [18]. They also reduce the resilience of plants to infections and pests. More than 50% of the chemical fertilizers and pesticides that are used are thought to go wasted because they build up in the soil and water through leaching and mineralization. In the past 10 years, there have been a lot of studies done on natural fertilizers, microbiomes, and soil quality as a result of the increased awareness of the negative impacts of fertilizers [19].
In the current day, nanotechnology and its related applications have become extremely important since this field of technology has significantly changed modern science [20]. To permit regulated release and gradual diffusion into the soil, nutrients are encapsulated with nanomaterial to create Nano fertilizers. The application of Nanoscale fertilizers may aid in preventing nutrient loss through leaching/runoff and slow down its rapid deterioration and volatility, thus improving the soil's fertility and nutrient quality and boosting crop yield over time. In addition to all the other benefits, they need to be applied to soil in a comparatively small amount, which makes them easier to apply and costs less to carry. However, using Nano fertilizers has some restrictions and drawbacks, much like using other types of fertilizers [17].
Modern agriculture needs Nano-fertilizers because they have the right formulations and delivery systems to enable the best absorption and utilization by plants [21,22,23]. By investigating NPs composed of various metals and oxides of metals for use in agriculture, these Nano scale fertilizers improve nutrient usage efficacy and the quality of the environment by reducing nutrient losses owing to leaching and avoiding chemical modifications [24,25]. Due to their smaller size and potential for distinct absorption dynamics from mass particles or ionized salts, Nanoscale particles have several advantages over larger particles. Because Nano-fertilizers have been shown to promote productivity by assuring controlled transfer/gradual breakdown of nutrients and lowering fertilizer application with an improvement in NUE, their use may increase the efficiency of nutrient delivery to plants. By physical or chemical techniques, Nano-fertilizers are made smaller and their surface-mass ratio is enhanced, allowing roots to absorb more nutrients.

Synthesis
Nanotechnology is the management and control of form and size at the nanometer scale used in the production and use of devices. It has opened the path and made it possible to employ "smart fertilizer," or materials with nanostructures, as fertilizers [26]. Silica, iron, oxides of zinc, cerium, and aluminum, and dioxide of titanium, the gold nanorods, ZnCdSe/ZnS core-shell, InP/ZnS core-shell, and Mn/ZnSe quantum dots are examples of nanomaterial constituents. The usefulness of Nanomaterials as plant Nano fertilizers for its development depends significantly on their size, composition, concentration, and chemical characteristics, as well as the kind of crop. When suspensions ofNP that contains these Nano fertilizers react with water, nutrients are released into the soil. Such fertilizers can be either Polymer-coated or made of thin coatings to enclose the NPs to prevent undesirable nutritional losses [27].
The application of nano fertilizers that make use of the special qualities of NPs can increase the effectiveness of nutrient usage. By adding nutrients alone as well as in a mixture to the adsorbents with Nano-dimensions, Nano fertilizers may be created. The target nutrients are loaded as it is for cationic nutrients, while the anionic nutrients are added following surface modification to produce the nanomaterials utilizing physical and chemical techniques [28].
Depending on what nutrients are needed for plant development and growth, Nano fertilizers can be made in three different ways: Nanoscale coating fertilizers, Nanoscale additive fertilizers, and Nanoporous compounds [29]. Hydroxyapatite-containing Nano fertilizers are nutritional delivery mechanisms that are Nano-enabled, possess a large surface-area-to-volume ratio, as well as are capable of supplying both phosphorus and calcium to plants.
Role of Nano fertilizers in agriculture
To evaluate their potential use in enhancing plant growth and productivity, a variety of organic, inorganic, and hybrid NP-based fertilizers have been used for a variety of plants. These enhance the quality of the soil, environment, and nutrients as well as the plants' ability to hold onto water and their antibacterial activity. Si-based fertilizers, such as Si dioxide NPs, can enhance seedling and root growth as well as plant disease resistance, nitrate reductase activity, and water and fertilizer absorption capacity. Ti-based fertilizers, including Ti dioxide NPs, improve plant growth, water retention, and photon energy transfer. While Ag NPs considerably boost seed germination potential, Zn oxide NP fertilization significantly increases growth and biomass output. Fe and its oxide ($Fe2O3$) NPs boost biomass, photosynthetic rates, and chlorophyll content, improving the growth of plants.
Carbon-based NPs like Carbon nanotubes, multi-walled Carbon nanotubes, and single-walled Carbon nanotubes can increase growth, elongation of roots, crop production, biomass, and the quality of seeds [30,31]. Similar enhancements in biomass, chlorophyll content, and phenological growth have been reported for Mg oxide NPs [32], Mn NPs [33], and Cu-chitosan [25]. Ce oxide NPs increase plant growth and yield [34]
Role in Hydroponic Plants
Due to a shortage of space, hydroponics is being used to develop a large number of plants and crops. It is not uncommon to utilize Nano fertilizers to promote the development of crops cultivated hydroponically. Plants cultivated hydroponically have magnetic NP traces in their stems, leaves, and roots, but plants cultivated in sand or soil do not exhibit similar signals, suggesting negligible particle absorption. However, studies on zucchini seed germination and growth of roots in a hydroponic medium containing ZnO NPs found no adverse effects, despite nanoscale Zn and ZnO decreasing germination of seed in ryegrass and maize. Soybean plants cultivated hydroponically ingested ZnO NPs in their Zn2+ oxidation state.
Nano-biosensors for soil-plant systems
To perceive the chemical and physical features of an agent in the presence of living or organic recognition components and identify if there isa particular biological analytic, a hybrid system of receptor and transducer known as a "biosensor" is utilized. The next generation of biosensors, known as nano biosensors, are smaller and connected to sensitized components to detect specific analytics at deficient concentrations using a physicochemical transducer. Early detection and quick decisions to increase agricultural yields through proper water management, terrain, fertilizers, and pesticides may be made using nano-biosensor technology. Nano biosensors provide significant benefits over traditional and last-generation sensors [35], including a high surface-to-volume ratio, quick electron-transfer dynamics, high sensitivity, stability, and extended life.
Among pesticides, organo-phosphates, neonicotinoids, carbamates, and atrazine are considered to be the main classes, and because soil homogeneity is poor, their leftovers, even at low concentrations, endure longer in soil. Nano-biosensors that employ piezoelectric transducers and have antigen-antibody interaction, enzyme activity suppression, and binding properties of nanomaterials are used to detect

these pesticides [36], and specific antibodies. However, the effectiveness of these nano-biosensors may differ depending on the detection limit and the high cost associated with developing antibodies, which are only available for about 10% of the 800 active ingredients in pesticides [37,38]. These factors may limit their commercial application. Therefore, pre-treatment and repetitive sampling is required to increase the effectiveness of these nano-structured biosensors. The most extensively used fertilizer for agricultural production is urea, which is also a source of the water pollutants nitrate, nitrite, and urease that cause eutrophication and have negative environmental effects. [39,40].

The mechanistic approach of Nano fertilizers utilization

To reduce loss of nutrients, eutrophication, and water and air pollution, NFs can release their active components into the soil gradually and under-regulated conditions [41]. Because NFs have greater efficiency, reliability, accessibility, and utilization than CFs due to their large surface area-to-volume ratio, the latter provides a framework for creating sustainable and innovative nutrition delivery systems.

Nutrients like N, P, and K can be provided as nanoemulsions either by foliar or soil application of NFs (as shown in Fig. 1), by being covered via thin films of polymers or enclosed in nanomaterials.

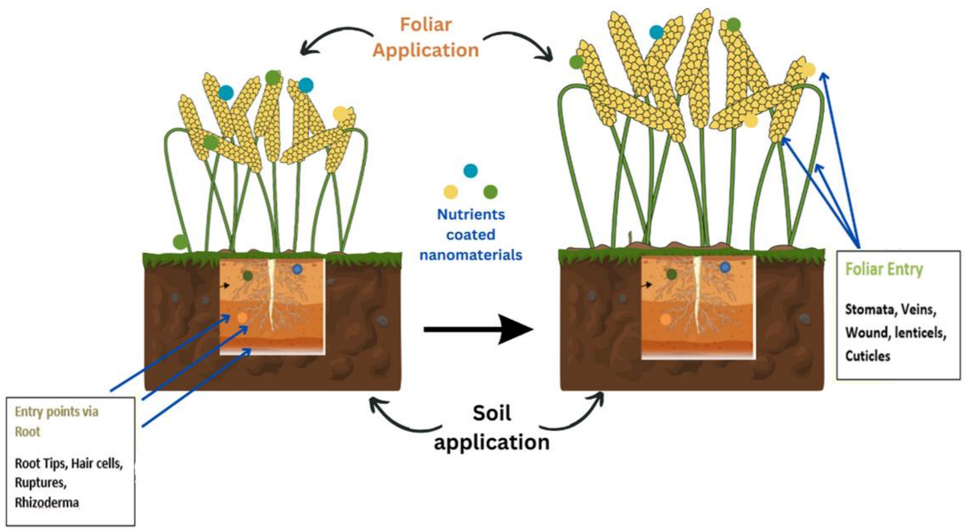

Fig. 1, Nanomaterials, loaded with nutrients, delivering appropriate nutrients for the growth, productivity, and functioning of plants, applied via foliar and roots (Soil).

The NPs components can include the oxides of zinc, cerium, and aluminum, and dioxide of titanium, the gold nanorods, ZnCdSe/ZnS core-shell, InP/ZnS core-shell, and Mn/ZnSe quantum dots [42]. The size, concentration, content, and chemical characteristics of the nanomaterials, as well as the crops, have a significant impact on the effectiveness of utilizing them as NFs on plant growth [43]. The nutrients released into the soil that the crops require happen when NP suspensions containing NFs react with water. To avoid unfavorable nutrient losses, the NFs polymer coating or the thin film encapsulation of NPs might delay interaction with water and soil.

Since traditional fertilizers have poor absorption efficiency, they must be administered in considerable quantities. Low nutrient absorption efficiency and fast transformation into chemical forms, that plants are unable to utilize, are the two primary problems with phosphorus- and nitrogen-based fertilizers [24]. Due to the rise in eutrophication and the release of hazardous greenhouse gases, this has had a severe effect on soil health and the ecosystem. The slow release of nutrients using NFs may help to increase the effectiveness of nutrient utilization without any associated negative consequences [44]. NFs can be applied via foliar or directly to plants to promote growth. NFs may be an ideal choice for preventing eutrophication and increasing the effectiveness of nutrient usage in agriculture [45,46,47]. Depending on their makeup and interactions with the soil, the organic and inorganic elements in the soil might alter the impact of the applied NFs. Aggregation happens initially when NFs are introduced to the soil, which lowers the scope of action [48], and the aggregates become less mobile as they get bigger in porous materials. As a result, the mobility of the NPs can be increased or decreased depending on the degree of organic material in the soil as a whole, the surroundings, and the chemical characteristics of the NFs. The anatomical vie of NFs root application has been shown in Fig. 2.

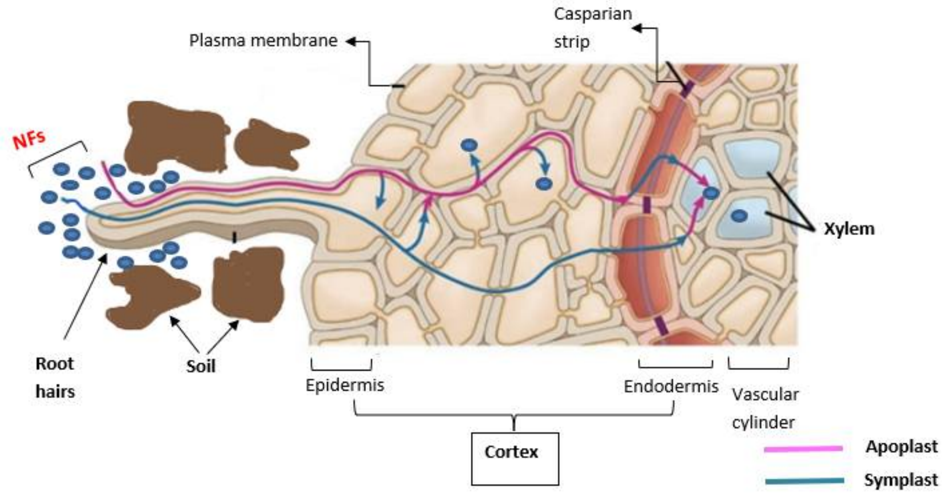

Fig. 2 The anatomical view of the mechanism of NFs uptake in Root

In Zn-deficient soil, scientists [49] found that adding ZnO NPs to other fertilizers increased the production of barley by 91% and enhanced nutrient use efficiency (NUE) compared to control, but bulk ZnSO4 only increased productivity by 31%. Moreover, nano-composite fertilizers have demonstrated favorable effects on rhizosphere microbes by encouraging the production of secondary metabolites that enhance plant development by encouraging bacterial colonization of the surface of the root.

Controlled or Slow-release fertilizers

Fertilizers coated with NPs are seen as viable alternatives to traditional fertilizing techniques since they gently release nutrients to plants, preventing nutrient loss [50]. NPs have been created to distribute fertilizers to plants precisely, slowly, and effectively, enhancing the nutrient availability to plant pores at the nanoscale [51]. SRFs and CRFs, which have been created to reduce fertilizer usage and minimize ecological pollution and contamination without sacrificing great yields, have become green fertilizers that are eco-friendly for agriculture.

SRFs/CRFs have been created to have all the crucial characteristics of fertilizers [52], including high solubility, stability, effectiveness, controlled release, increased targeted action, and resistance to damage from photolysis and hydrolysis. SRFs of many sorts have been created and tested, including those based on nano-zeolite and biochar- [53,54]; as well as those coated with natural or organic polymers including chitosan, starch, and cellulose.

Although SRFs release nutrients more gradually than CFs do, the frequency, pattern, and length of the release all rely on the weather, the temperature of the soil, and moisture levels. NPK fertilizers which are encapsulated in a carboxymethyl cellulose-based nanocomposite with polyvinylpyrrolidone were shown to have a water retention capacity in the soil and excellent slow release of nutrients [55]. lately, SRFs prepared with cellulose-graft-polyacrylamide/hydroxyapatite mixtures have been shown to successfully synchronize the release of NPK fertilizers into water hyacinth [56]. Similar to this, biochar-based nanocomposites increase soil fertility and supply nutrients for a longer time by minimizing environmental problems like eutrophication and runoff. A simple classification of CRFs has been shown in Fig 3.

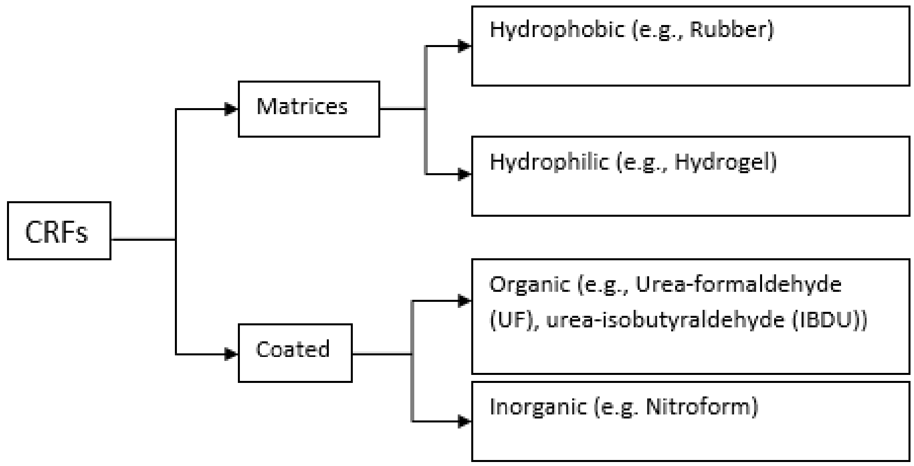

Fig. 3, A simple classification of Controlled Release factors (CRFs)

Uptake and translocation mechanism

The root's epidermal cell wall and the plant's cell membrane are both penetrated by the nanoparticles via a complex series of steps that allow them to pass through the vascular bundle (xylem), move through the stele, and finally reach the leaves. To pass through the complete cell membrane, however, nanoparticles pass through cell membrane pores that are particular in size [57]. Before reaching the stele, nanoparticles passively integrate through the apoplast, a component of the endodermis [58]. In addition to other biological processes like signaling, reusing, and plasma membrane regulation, active transport accounts for the bulk of the ways that nanoparticles reach cells. [59,60].

Application of Nanomaterials in Small Millets

Nanomaterials have potentially been utilized in improving yield, resistivity, and, nutrition enhancement. Detailed information on the types of nanomaterials used in millets is given below:

Nanofertilizers (NFs):

Numerous fertilizers come from phosphate, urea, and ammonium salt complexes, which should not be applied directly to crops. The gradual release of fertilizers may benefit from the use of nanomaterials. Due to the high surface tension, the surface coating of nanomaterial on fertilizer particles binds the material from the plant more firmly. So fertilizers with sulfur Nano-coating are very useful for crop production. Nano coating offers surface protection for bigger particles since the durability of the coating decreases the rate of fertilizers' disintegration. [61]. The resourceful studies on the use of NFs in millets specifically in minor millets are very limited. A recent study reported a 4.2% higher increase in the average yield of pearl millets by applying nitrogen and zinc NFs along with organic practices in a study performed in Haryana, India [62].

Nanotechnology in crop production:

In India, fertilizers are crucial to the production of food grains, particularly since the start of the "green revolution" era. Nitrogenous fertilizer used in excess has an impact on the groundwater. With a nitrogen fertilizer consumption rate of 20–50% and a phosphorus fertilizer usage efficiency of 10–25%, the application of NFs causes an accumulation of nutrients in solids. In reality, nanotechnology has reduced the price of environmental protection while opening up new potential to enhance nutrient efficiency. Nanocomposites and fertilizers with slow release from the nanoscale are fantastic substitutes for soluble fertilizers. As crops develop, nutrients are produced more slowly, but most of them may be absorbed by plants without going to waste. So NFs technology is very innovative but its use in small millets is scantily reported in the literature [63]., though it was reported in a study that the application of zinc nanoparticles size ranged from 15-25 nm significantly improved grain yield of pearl millet up to 37% [64]. The results propound that the increase in yield is due to enhanced cell metabolic activities caused by NFs penetration through stomatal openings.

Nanotechnology in seed science:

The entire potential of seeds can be achieved with the application of nanotechnology. It takes a lot of work to produce seeds, especially for crops that are wind-pollinated. By determining the pollen loads that may cause contamination, genetic purity can be guaranteed with precision. Pollen flight is influenced by air temperature, humidity, wind speed, and crop pollen output. Bio-nanosensors used to identify polluted pollen can help identify possible contamination and then reduce it. By employing the same method, it may be possible to prevent field crops from becoming infected by pollen from genetically engineered plants. The seeds are infused with novel genes and offered for sale. Nano barcodes [65] that are encodable, machine-readable, robust, and sub-micron-sized tangents might be used to track sold seeds. The application of insecticides and herbicides has been revolutionized by technologies like encapsulation and controlled release techniques. Smart seeds are seeds that have been nano-encapsulated with a particular bacterial strain. Thus, it will lower the seed rate, guarantee a good field stand, and enhance crop performance. Coating seeds with a nanomembrane that senses water availability and only permits germination when the conditions are right, aerial dispersal of seeds coated with magnetic particles, detection of moisture content during storage to take appropriate precautions to reduce damage, and use of bioanalytical are some other techniques being used. Nanosensors are some of the thrust areas of research which are possible to understand and determine seed aging [66].

Nano pesticide:

Pest populations can be reduced to the point at which management is no longer effective economically thanks to pesticide persistence throughout the early stages of crop growth. Therefore, one of the most practical and economical ways to manage insect pests is to utilize active substances on the surface that is being treated. A nanotechnology strategy called "Nano-encapsulation" can be utilized to increase the insecticidal value by shielding the active component from harmful environmental factors and fostering persistence. A thin-walled sac or shell (protective covering) is used to encapsulate the active components in nano encapsulation. Insecticides, fungicides, and nematocides can be nano-encapsulated to create formulations that effectively control pests without leaving behind residues in the soil. Because the amount of product that is truly effective is at least 10-15 times lower than that administered with conventional formulations, nano-pesticides will minimize the rate of administration. As a result, a significantly smaller amount may be needed to provide much better and extended control. For extended release and better interaction with plants, clay nanotubes (hallo site) have been created as pesticide carriers at a cheap cost. Through their use, there can be a reduction in the quantity of pesticides, by 70–80%, lowering the cost of pesticides with little influence on water streams. [8]

The fate of Nanomaterials (NMs) in the soil:

Natural colloids, organic fractions, and mineral fractions may interact with nanomaterials, causing their separation in the soil system's solid and aqueous phases [67,68]. Since the majority of research has been done in water systems, there is little information available regarding the fate and behavior of nanomaterials in soil systems. Some soil suspension studies have mostly been used to infer how NMs behave in soil systems. NMs can change physically, chemically, or biologically as they reach the soil, depending on their makeup and how they interact with different soil elements (both organic and inorganic). The primary physical process that arises on its own, when such NMs are added to the soil environment is called aggregation. The accessible area of NMs is decreased by aggregation, which has an impact on their reactivity. Additionally, when the aggregate grows larger, its ability to move in porous medium decreases, which will have an impact on the NMs' responsiveness and behavior. [48]. There are 2 forms of aggregation: homoaggregation between the same NMs and hetero-aggregation between NMs and another particle in the environment (hetero-aggregation) e.g., natural colloids [48,69]. Although there was more homo-aggregation (78 ± 16.2%) than hetero-aggregation (22 ±2.2%) when using TiO_2 nanoparticles (1.0 g) at greater concentrations than kaolin clay (0.13 g), the ratio of homo- to hetero-aggregation varied when phosphate or E. coli were present. For instance, the presence of E. coli caused these values for $nTiO_2$-$nTiO_2$ homoaggregates and that of $nTiO_2$-kaolin lead to heteroaggregates to alter to 51.3 7.9% and 43.7 13.1%, respectively [70]. By using an electron microprobe [71], it was discoveredthat soil colloids were highly deposited Zn oxide nanoparticle carriers, and the aggregates were visibly linked to the soil clay minerals. As a result, hetero-aggregation is more inclined to determine how NMs behave in natural environments. Despite these defenses, homoaggregation was the main topic of most aggregation investigations. Furthermore, hetero-aggregation has often been studied in the presence of fewer quantities of natural colloids and high concentrations of NMs [69].

Influence of nanomaterials on plants:

Several nanoparticles have expanded applicability in vitro culture after interacting with plants. For instance, compared to other ZnO forms, the usage of Zn as a ZnO nanomaterial had a more noticeable impact on the development of tobacco (Nicotiana tabacum L.) or physiological characteristics. When given to the calli as NMs, they acquired more Zn. Depending on the concentration and type of the applied nanomaterial, changes occur in plants [72], including the encouragement of calli development and the production of additional protein [73]. Consequently, the impact of nanomaterials on plants can either be beneficial or hazardous [72,74]. Nano-growth stimulants enhance seed germination [74] and subsequent development phases [75]. For example, treating soybean seeds with nano-TiO_2 and nano-SiO_2 boosted the activity of the nitrate reductase, which subsequently in turn promoted seed germination; applying both NMs together was more advantageous [76]. Spinach development was enhanced (An increase of 44% in dry weight over the control) by treating the seeds with TiO_2 (0.25%) nanoparticles, which also increased the rate of photosynthesis [77]. Pre-germinated wheat seeds were submerged in a solution of multiwall carbon nanotubes (MWCNTs) for 4 hours, which accelerated root development and increased vegetative biomass.

Limitations of NPs/NFs use

There are certain toxicity-related hazards associated with using NPs as fertilizers to boost agricultural productivity and enhance the accessibility of plant nutrients. Additionally, there are holes in the study, the law, and adequate monitoring that prevent the widespread use of NFs. Since these tiny particles may more easily enter biological systems and provide serious risks, it is yet unclear how poisonous, safe, and how NPs will affect the environment [62]. NPs produced by physical and chemical processes are more hazardous than those created by biological methods. Moreover, compared to metals and metal oxide NPs, organic NPs are less harmful to soil microbes. NPs are used to supply nutrients to plants, but their nano-toxicity is still a worry for both people and the environment. When there is widespread application of them under various pedo-climatic conditions around the world, NFs are more expensive than conventional fertilizers, which is a major obstacle. This is also true of their lack of uniformity and recognized formulation, which causes differing effects on identical plants in different areas.

CONCLUSION

Nanotechnology has found many applications in agricultural applications such as nano fertilizers, nano pesticides, nano biosensors, and environmental remediation agents. However, a firm understanding of nanomaterials' fate and environmental impacts remains a major challenge in agricultural and environmental sciences. Application of NMs may help improve the growth and yield of crop plants, but the response may vary as per plant species. The foreseeable future agricultural production is millets. It is a prospective crop for agriculture because of its benefits to farmers, cultivation, and to human health. Due to its little water impact and adequate climatic requirements, millet is the ideal crop to be planted. Millets are a profitable crop and the advantages they provide make them a potential source of future global food security. Together with the use of millets and the application of nano fertilizers can revolutionize food production in the near future.

The efficiency and behavior of nanomaterials can be tailored by tuning the properties and stability of nanomaterials. Nanotechnology offers a wide range of uses in agriculture, including nano biosensors, nano pesticides, nano fertilizers, and nano environmental remediation agents. The agronomic and environmental disciplines still face significant difficulties in fully comprehending the fate of nanomaterials and their effects on the environment. Crop plants may grow and produce more when NMs are applied, although each plant species may respond differently. By modifying or altering the characteristics and stability of nanoparticles, the effectiveness and behavior of such materials may be changed. Site-specific fertilizer and nutrient delivery by NPs with formulations that are controlled to release (CRFs) have been demonstrated to enhance plant nutrition and growth in fertilizers based on nanotechnology Although the use of these methods for agriculture continues to be in its infancy, it has the potential to alter agricultural systems, particularly in light of issues with the application of manure. One example of the unique qualities that improve the catalytic activity of NPs in comparison to regular nanomaterials is the capacity to modify the geometry, size, as well as chemical composition of the surface of NPs to operate as nano-alloys, heterodimers, & core shells. A targeted nano fertilizer was developed as a breakthrough in the design of materials and consumer product creation. Using various nano fertilizers can significantly increase agricultural output by reducing fertilizer costs and emission risks. Nanofertilizers offer targeted dispersion and regulated release because of their improved solubility, reactivity, and capacity to penetrate the cuticle. Nanofertilizers can also improve crop growth, yield, quality, and nutrient usage efficiency by lowering stress caused by abiotic factors and metallic toxicity. However, rather than emphasizing the advantages and effectiveness of the technology, more focus is being placed on the concerns connected with its use and restricted use.

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