A review on role of nanotechnology for sustainable agriculture to increase crop productivity.

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Abstract

Nanotechnology is a rising field in many research areas now a day. It brings up a vast scope in many areas like agriculture, food preservation, pharmaceuticals, etc. as the world population is increasing rapidly to cope with the rising demand for food. Nanotechnology is one of the most pioneering and promising technologies for the transformation of food and agro-industries. Nutrients in farms get depleted year after year due to the continuous farming system on particular farms. Although chemical fertilizers added regularly may sustain the yield, the quality of the yield gets affected nutritionally, which may seriously affect human health. One of the most promising ways to address the drawbacks of conventional agricultural methods is nanotechnology. Nanotechnology is a sustainable way of farming that improves the quality, quantity, and security of foods. The importance of Nano technological application in farming is to offer healthy and complete food from farm to fork including functional and neutraceutical foods and also to improve the efficacy, bioavailability, and nutritional status of food. Agro nanotechnology is proven to be an eco-friendly method of farming, using this technology decreases the toxicity of soil and increases its fertility. By incorporating innovative techniques to improve nutritional quality and food safety, the products obtained from the application of nanotechnology to agricultural and food systems might put farmers and manufacturers in a strong competitive position and benefit nearly everyone. Therefore, the use of nanoparticles as fertilizer enhances the growth, nutritional quality, affordability, and sustainability of the crop.

Keywords: Nanotechnology, Sustainable farming, Nano-fertilizers, Nanomaterial, Eco-friendly, Food production.

Introduction

The development of agriculture is a compulsory phenomenon for the purge of poverty and hunger which must be getting rid of the present situation. Therefore, we should have to take one bold step for agricultural development. In this world, mainstream peoples are below the poverty level and are being scatted in rural areas where agriculture enlargement has not so been effective. Different areas of nanotechnological applications in different sectors are shown in the fig. given below36.

Nowadays, the most vital obsession is to create flanked by, agriculture poverty and the nutritional process of getting food. Therefore, new technology should have to adopt that decidedly focuses on getting better agricultural production [1]. Recently, food and nutritional security are fully embedded in the novel knowledge. Agriculture development also depends on social inclusion, health, climate changes, energy, ecosystem processes, natural resources, good supremacy, etc., and must also be documented in specific target-oriented goals. Therefore, sustainable agricultural strengthens the practical opportunity to get rid of poverty and hunger of the people. Agriculture on the road to recovery, thus environmental performance is required and at the same time participation of food chain ecosystems is required in relation to agricultural food production [2].

The agricultural field is always at the utmost to feed the burgeoning population of humans and animals. Over the last decades, agriculture gets constant benefits from different innovative technological and synthetic agrochemicals like hybrid varieties, gene manipulation, synthetic fertilizers, and pesticides. However, every agrochemical is not environmentally friendly and has risky factors pollution in water and food products which threaten the environmental and human health, therefore specific supervision could permit to diminish these dangers [3]. Nanotechnology can handle the world's most problematic conditions such as water, energy, health, agriculture, and biodiversity. Nanotechnology is the branch of science that deals with the particles of Nano-meter (1–100 nm) dimensions. Because of their small size, they can simply enter in soil and assist the beneficial microbial population that is responsible for providing nutrition to plants through the mineralization of various micro and macronutrients [4]. Among the many developments, nanotechnology has

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been proven as one of the advanced technologies that can resuscitate agriculture and food demands. Morphology, type of functional group presents, coating, and concentration of NPs influence their absorption by plants. Nanoparticles (NPs) cover a variable array of materials and play a dynamic role in crop growth. Different plant varieties acted contrarily to similar kinds of NPs of diverse sizes and concentrations. Earlier, it has been detected that NPs can increase the agronomical, and biochemical parameters in different plants such as maize and beans. Applications of Nano pesticides and nano fertilizers can help enhance productivity without causing any toxic effect on soil.

Originally nanotechnology refers to the ability to project and construct by using tools and techniques being developed today for the completion of highly advanced products. Nanotechnology refers to the study, manipulation, and utilization of Nano-size materials for making different devices. Generally speaking, nanotechnology used to describe materials that are characterized by structural features ranging in size from 1 to 100 nanometers (nm). The brilliant concept of the Nano came up with the physicist Richard Feynman, Nobel Prize winner for Physics in 1965 when he said "there is plenty of room at the bottom" during a conference of the American Physical Society [5].

The first use of the term "nanotechnology" was by Norio Taniguchi in 1974 at the International Conference on Precision Engineering (ICPE). His definition referred to "production technology to get extra high accuracy and ultra-fine dimensions, i.e., the preciseness and fineness on the order of 1 nm (nanometer), 10−9 m in length"[6]

Nanostructured materials have indeed become a very active research field in the area of material science involving organic, inorganic, and composite materials that have a significant fraction of grain boundaries with a high degree of disorder of atoms along the grain boundaries and a large surface area to volume. The chemical composition of the phases and the interfaces between Nano grains must be controlled as well.

One of the most important characteristics of nanostructured materials is the significant dependence of certain properties upon the size in the Nano scale region. Earlier people believed that material properties can be changed only by varying the chemical composition. But later it has been found that the material properties can be tuned by varying the size of the material without changing the chemical composition. The transition from micron-sized particles to nanoparticles leads to several changes in their physical properties. The major change is the increase in the surface area to volume ratio, as the size of the particle moves to a regime where quantum confinement effects are predominant. These new properties or phenomena will not only satisfy everlasting human curiosity but also promise a new advancement in technology. Another very important aspect of nanotechnology is the miniaturization of current and new instruments, sensors, and machines that will have a great impact on the world we live in. Nanotechnology has an extremely broad range of potential applications from Nano scale electronics and optics, to Nano biological systems (Figure 1).

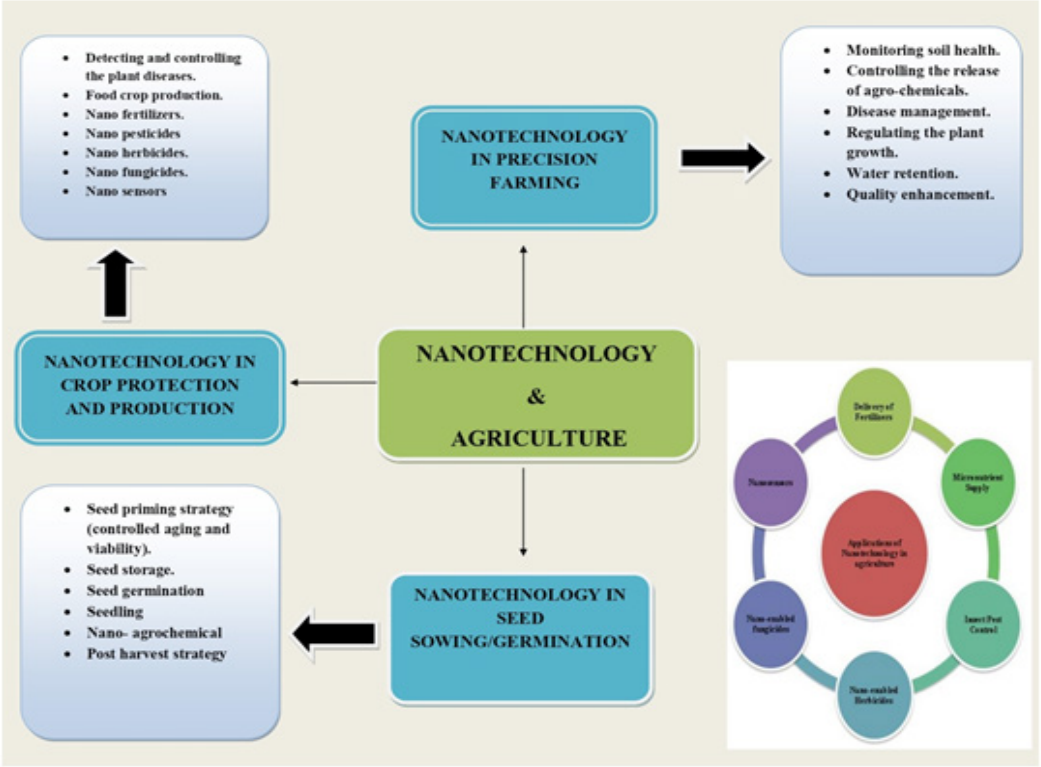
Over the last two decades, a significant amount of research has been carried out on nanotechnology emphasizing its numerous applications in the agriculture sectors [7]. Fertilizer application plays a pivotal role in increasing agricultural production; however, the excessive usage of fertilizers irreversibly alters the chemical ecology of soil, further reducing the available area for crop production. Sustainable agriculture entails a minimum use of agrochemicals that can eventually protect the environment and conserve different species from extinction. Notably, nanomaterial's enhance the productivity of crops by increasing the efficiency of agricultural inputs to facilitate site-targeted controlled delivery of nutrients, thereby ensuring the minimal use of agri-inputs. Indeed, the assistance of nanotechnology in plant protection products has exponentially increased, which may assure increased crop yield. Moreover, the major concern in agricultural production is to enable accelerated adaptation of plants to progressive climate change factors, such as extreme temperatures, water deficiency, salinity, alkalinity, and environmental pollution with toxic metals without threatening existing sensitive ecosystems [8].

Nanotechnology can transform the food and agricultural industry with new techniques for increasing the plant's ability to absorb nutrients, detecting diseases rapidly, and molecular operation of diseases. Nanotechnology is presently employed in a variety of fields, including food processing, packaging, and agricultural divisions to allow for the controlled delivery of pesticides and composts. Furthermore, nanotechnologies are used in a variety of fields, including insecticides, medicines, veterinary pharmaceuticals, animal feed, biocides, food, sanitation, and biotechnology.

The present study focuses on the relationship and use of nanotechnology and agriculture in the current scenario to increase crop production sustainably to meet the demand of the rising world population.

Nanotechnology and agriculture

Currently, the major challenges faced by world agriculture include changing climate, urbanization, sustainable use of natural resources, and environmental issues like runoff and accumulation of pesticides and fertilizers. These problems are further intensified by an alarming increase in food demand that will be needed to feed an estimated population of 6–9 billion by 2050. Furthermore, the world's petroleum resources are decreasing; there will be an additional demand for agricultural production as agricultural products and materials will soon be viewed as the foundation of commerce and manufacturing. In one fell swoop, new opportunities are emerging, e.g. generation of energy and electricity from agricultural waste but pending workable economics and encouraging policy [9]. This above-mentioned scenario of a rapidly developing and complex agricultural system is existing and greater challenges will be posed to the developing countries as, in developing countries, agriculture is the backbone of the national economy. They face many critical issues such as lack of new arable soil, reduction of the current agricultural land due to competing economic development activities, commodity dependence, poverty, and malnutrition, which need to be solved on a sustainable



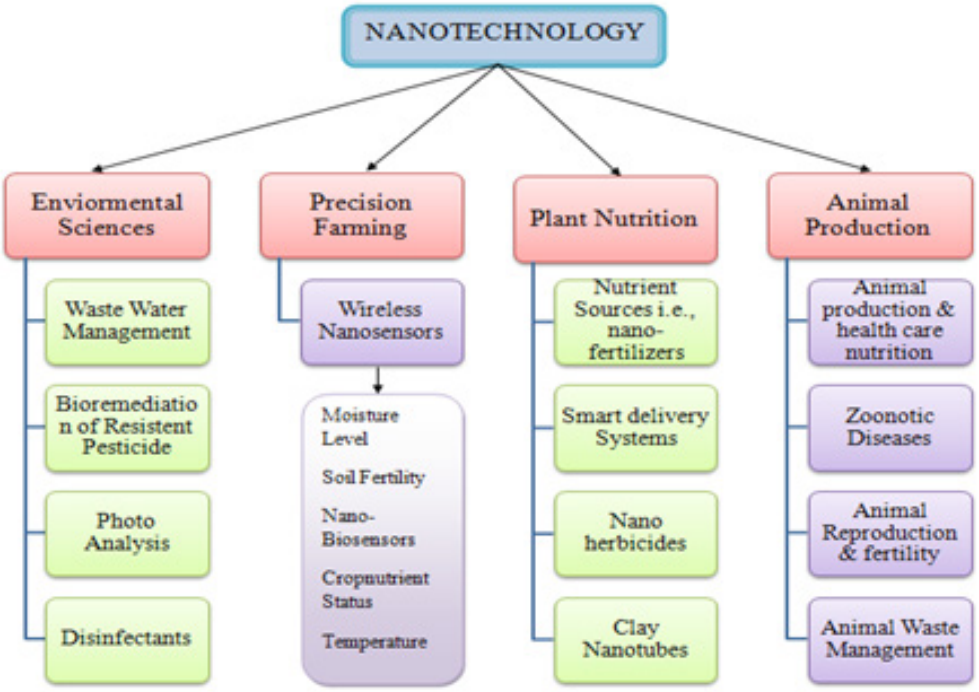


Figure 1: *Different areas of Nano technological applications in different sectors.*

basis. Profound structural changes in the agricultural sector have occurred due to the fast development of technological innovations, but these also pose challenges such as sustainable production considering food security, poverty reduction, and public health improvement. For developing countries, advancement in science and technology can offer potential solutions for discovering value addition in their current production systems.

Applications of Nanotechnology in Agriculture

Over time agriculture gets constant benefits from different technological innovations like hybrid varieties and synthetic fertilizers and pesticides. Now agricultural scientists are realizing that smart innovation like nanotechnology is strongly required for agricultural growth, to face the global challenges of food security and climate change. The importance of nanotechnology applications in the agricultural sector came

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only in recent years, but the research was started about half a century back [10]. The uses of nanomaterials are required for increasing fertilization (or fertilizer) use efficiency, yields, and reducing pesticide need; rapid and early pathogens and toxic chemical detection in food items; smart pesticides and fertilizer delivery systems; smart systems used for food packaging and processing; and regulating agricultural food security [11]. Agri- cultural productivity can be improved through nanomaterial-induced genetically improved animals and plants [12] site-specific drug and gene delivery of molecules at cellular/molecular levels in animals and plants [13] and nano-array-based genetic modification in animals and plants in stress conditions. Nanofilters or nanocatalysts can degrade and reduce existing pollutants and thereby pollution. In agriculture, nanotechnology can be used to produce slow-release nano fertilizers for fertilizer use by plants; nanoparticles encap- sulated pesticides for controlled and on-demand release; site-specific drug and nutrient delivery in fisheries and livestock; nanoparticles, nanobrushes, and nanomembranes for treatment of water and soil; cleaning and maintenance of fishponds; and nanosensors for assessing plant health and soil quality. Some recent breakthrough in nanotechnology in agriculture has been given in (Table 1).

Detection and control of the plant diseases

Nanoparticles may be useful in the treatment and monitoring of food crops diseases by targeting pathogens [14]. Some of the nanoparticles are nano-forms of carbon, silver, silica and alumina silicates that are used in control of crops diseases [15]. reported that nano silver is the most exploited nanoparticles in biological system. The capsulated nano silver removes unwanted microbes in planting soils and restricts several other plant diseases [16].

Food crop production

Globally, there is increasing demand for safe food due to the ever-increasing population. Thus, technological advancement is necessary for completing the demands of healthy food. Nanotechnology can be a boon in the current scenario and used in crop production and processing. Several studies have been carried out to determine the applicability of nanotechnology in the detection of chemical and biological compounds in many types of food crops [17]. Agro- nanotechnology focus on the sustainable food production and protection of food crops for both human nutrition and animal feeding and against pests and diseases [18].

Food security is one of the biggest issues for every country. In future global need of food and nutrition by 2050 will be increased by 70% from current levels in a sustainable way [19]. Thus, farmers must have new and innovative technologies and adopt modern farming practices to meet out the future challenges of agriculture based food production [20].

Nano-fertilizers

The augmentation of fertilizers in soil is essential to supplement the soil fertility for better yield of food crops [21]. However, the use of chemical fertilizers cause many adverse environmental effects and damaged the soil health. Thus, there is requirement a new cost effective ecofriendly technique for better crop production. In this context, the use of nano-fertilizers instead of using conventional fertilizers will assist in controlled release of nutrients in soil and prevent loss due to chemical fertilizers [22].

In nano-fertilization, nutrients may be entraped using nano-materials coated with a thin film or delivered as emulsions. The slow release of nutrients from nanoparticles coated

Table 1: *Nanotechnology in agricultural sectors.*

Areas of applications	Uses	References
Crop production		
Plant protection products	Nanoparticles encapsulated pesticides, nanocapsules, and nanoemulsions for controlled and on-demand release for better efficiency and disease pest control of plants	Anjali et al. (2012)
Nanofertilizers	Buckyball fertilizer nanoparticles, nanocapsules, and viral capsids for better nutrients absorption of plants and site-specific nutrient delivery	Anjali et al. (2012)
Precision farming	Nanosensors connected with global positioning system (GPS) navigation system for real-time monitoring of soil environments and crop growth, precise application of pesticidefertilizer and	Kalpana-Sastry et al. (2009)
Soil improvement		
Water/liquid retention	Nanomaterials like zeolites and nanoclays are used to hold water and liquid agrochemicals in soil for their subsequent slow release to plants	http://www.geohumus.com/us/ products.html
Water purification		
Water purification and pollutant remediation	Nanomaterials like nZVInanoclays and carbon nanotubes (CNTs) are used for filtering and binding of toxic substances and their subsequent removal from environments	McMurray et al. (2006)
Diagnostic		
Nanosensors and diagnostic devices	Nanomaterials and nanostructures like electro- chemically active CNTs and nanofibers are extremely delicate biochemical sensors used to closely assess environmental status, and growthconditions, plant	Vamvakaki and Chaniotakis (2007)
Livestock and fisheries	Nanoveterinary medicine like nanoparticles, buckyballs, dendrimers, nanocapsules used for drug delivery, nanovaccines; smart herds, cleaning fish ponds	Kalpana-Sastry et al. (2009)
Plant breeding		
Plant genetic modification	Nanoparticles loaded with desired DNA or RNA are delivered to plant cells for their genetic transformation or to trigger defense mechanism activated by pathogens	Torney et al. (2007)
Nanomaterials from plant		
Nanoparticles from plants	Production of nanofibers from bio-nanocomposite and Nanofibers from cotton waste and wheat straw and soy hulls for improved strength of clothing	Kalpana-Sastry et al. (2009)
Food industry	Use of silicate nanoparticles in airtight packag- ing of food products and nanosensors for con- tamination and pathogen determination in food	Kalpana-Sastry et al. (2009)

fertilizers increase the use efficiency of nutrient by crops [23]. reported the impacts of nano-fertilizers in sustainable agriculture. Several other researchers reported the possible use of nano-fertilizers as an alternative to conventional fertilization processes at low cost and in smaller quantity [24].

Nano-pesticides

In agriculture, pesticides or weedicides are used to control pests or weeds for increasing crop yield. However, they also damage the soil health. Nano-pesticide is an agro- chemical combination used to overcome the problems caused by conventional pesticides [25]. Several types of materials viz., surfactants, organic polymers and mineral nanoparticles that fall in the nanometer size range are used in formulation of nano-pesticides [26]. The new generation of nano- pesticides will be specific in action against insects and does not have any harm to other important insects of soil [27].

Nano-sensors

The crops growth depends on proper agro- climatic conditions. For effective protection of crops, the fast and sensitive sensors are required to detect plant pathogens. Nano- sensors can be use all over the agricultural fields for monitoring the fertility of soil and other agro climatic conditions [28]. Such measures will lead to enhanced crops yield at very low economy [29]. Researchers are working on nano systems for the release of fertilizers and pesticides as per agro-climatic conditions monitored by nano-sensors.

Nanotechnology is an eco-friendly and cost-effective technology for agriculture. It offers several benefits in agriculture such as the detection of pathogens, delivery of nano-pesticides to the specific target sites, and enhanced absorption of nutrients in plants. The applications of nanotechnology have great potential to meet the future agricultural challenges such as food security.

Nanotechnology and agricultural sustainability

In the era of climate change, Nano fertilizers improve plant nutrition and stress tolerance; therefore, valuable in promoting sustainability [30]. They reduce the investment on of fertilizers because the application in small amounts gives improved crop yields and concomitantly reduces transportation costs [31]. Nano fertilizers are used up by plants efficiently and leave very little residue in the soil, air, or ground water [32]. Nanofertilizers have benefited crop yield due to enhanced seedling growth, seed germination, nitrogen metabolism, protein and carbohydrate synthesis in cropS. Each nanoagricultural formulation has its own advantages. As every technology brings a positive change, there is a dark side to using nanotechnology in agriculture. In the pesticides sector, pesticides' active ingredients are lipid-soluble [33]. This limi

ts their bio-availability. Nano pesticides offer a solution to this problem due to their smaller particle size and therefore increased bioavailability. Solid and liquid formulations are available for pesticides. Wet Table Powder (WP) and Emulsifiable Concentrate (EC) are two formulations of currently existing pesticides. In this review, we have discussed nanotechnology applications to agriculture in the form of Nano fertilizers, Nano pesticides, and nanobiofertilizers. We touched upon the merits of the use of nanoparticles in agriculture and some unaddressed concerns. The use of nanotechnology in agriculture requires the availability of skilled manpower in areas where agriculture is mainstay. Educating farmers to ensure appropriate use of new technology also requires certain reforms at policy making levels in all agricultural nations across the globe [34].

The Impact of Nanotechnology on agriculture in Indian Scenario

Agricultural growth in India is showing a negative trend from 3.6% during 1985-95 to less than 2% in the decade 1995-05 against a targeted average annual growth of 4% for the agricultural sector to 2020. A particular area of concern is the production of food grains leading to mounting concerns about food security which is associated with the limited availability of land and water resources. The targeted growth in agriculture can be achieved only by increasing productivity and incomes per unit of these scarce natural resources through the effective use of improved technology. The national agricultural research continues to focus on the green revolution technology a model of breeding for short-duration high-yielding cultivars, irrigation, and intensive use of fertilizers and other agrochemicals [35].

Among the much advancement in science, nanotechnology is being visualized as a rapidly evolving field that has the potential to revolutionize agriculture and food systems and improve the conditions of the poor. Nanotechnology when applied as a tool, in tandem with other measures, can assist to address the world's most critical sustainable development problems in the areas of water, energy, health and environment, agriculture-biodiversity, and ecosystem management. Hence, it is considered paramount important the application of nanotechnology in the agri-sector to revolutionize the productivity of agricultural yield [36].

One of the key motivations for the application of nanotechnology research into agriculture and food systems in India could be its promising evidence of agricultural productivity in the future. This technology also helps in the genetic improvement of plants' delivery of genes and drug molecules to specific sites in the plant cellular system. The Nano-array-based gene technologies for gene expressions in plants and also in insect pest control may be achieved in stress conditions in developed countries. The potential is increasing with suitable techniques and sensors being identified for precision agriculture, natural resource management, and early detection of pathogens and contaminants in food products. Smart delivery systems for agrochemicals like fertilizers and pesticides, where smart systems integration for food processing, packaging, and other areas like monitoring agricultural and food system security also can take part.

Even though nanotechnology is an emerging field of science greatly exploited in different sectors mainly electronics, energy, environment, and health its application of nanotechnology in agriculture is rarely exploited in India and abroad though it has tremendous potential as a new effective tool in the agricultural

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field to gain solutions to unresolved field problems. This new technology, central to the green revolution adopts nano and micro or farm economics - which govern the use of inputs such as land, cultivar, labor, machinery, and chemicals balanced against profits from crop yields - and the nano, micro, and macroeconomics ensure better access to inputs and markets. The green revolution model did increase potential yields and farm incomes substantially, but it put less emphasis on the efficient and sustainable use of soil nutrients and water. The research in this sector in India is still at a preliminary stage and also at a conceptual level to understand realistic assessments. Critical evaluation and its potential assessment play a significant role before it could be used in many sectors. In the present century, one can propose providing good quality food based on agriculture with the application of green nanotechnology rather than the introduction of chemical synthesize nanomaterial.

However, the toxicological and eco-toxicological risks linked to this expanding technology ("emerging technology") cannot over-rules and need to be assessed carefully and critically as one must be very careful with any new technology to be introduced regarding its possible unforeseen related risks that may come through its positive potential suggesting understanding the potential opportunities and challenges. Naturally, the above mention facts help to propose that the microelement (nanoparticle) can execute its potential role in agriculture by producing a huge quantity of crops (in a macro form). However, it is also critical for the future of a nation to develop infrastructure either a trained workforce or a work environment in nano-technology .Further developments in nanotechnology in this sector can be expected to become the main economic driving forces in the long run and benefit consumers, producers, farmers, ecosystems, and the general society at large. The positive side of it is that the proposed technology will be boom and gloom to maintain the eco-factors of the agricultural field and the society in the future however needs a design of effective regulatory mechanisms and a strong governance system from authorities with the involvement of all stakeholders.

Conclusion

Agricultural production requires consolidative approaches to meet the rising burden of food demand. Nanotechnology has confirmed a well-built future to support plant growth and protection against biotic/abiotic stresses. The application of nano fertilizers and nanoparticles improved the plant health parameters and crop productivity and protection from plant pathogens. Agriculture nanotechnology is an environmentally sustainable and cost-effective technology. It has various applications in agriculture, including disease identification, application of nano pesticides to particular target locations, and improved nutrient absorption in plants. Nanotechnology applications offer a lot of potential for addressing future agricultural concerns like food security. With the advent of nanotechnology and the production of disease and stress-resistant plants, the agricultural industry has seen an increase in yield quantity and quality. The NPS may be administered to food products at various stages and do not interfere with their fundamental development. These contribute to the food's flavor, color, consistency, and nutritional content. Nanoparticles help in the elimination of contaminants in herbicides and pesticides by being incorporated during the production process and restricting the contaminant's respective sites and carriers.

We also need to have further more research on the disadvantages of nanotechnological applications in the area of agriculture like nanofertilizers, nanofungicides, nanoherbicides etc and their impact on human health.

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