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Nanobiotechnology: A New Paradigm for Crop Production and Sustainable Agriculture.

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ABSTRACT

Inflating food demand and frequent recurrence of environmental challenges requires the changes in agricultural practices, by development of new technologies and improvement of existing practices to enhance crop production without adversely effecting the environment and ecosystem. Over the last decade, the rapid growth and advancement of nanobiotechnological innovations have come up with huge potential in providing novel and better technologies in order to address various challenges facing by agriculture sector globally. The success of agricultural sustainability strictly linked with identifying new areas and technology development to address the issues like climate change, sustainable use of natural resources, accumulation of fertilizers and pesticides, declining soil health and other environmental challenges etc. Therefore the scientific community needs serious consideration in research and development in the area of efficient delivery system not only help in controlled and slow release of agrochemicals but also reduce the amount of agrochemicals applied in the field and economic loss. Nanotechnology offer potential and efficient delivery carrier system for regulated release of agrochemicals like nanofertilizers, nanopesticides, nanofungicides, nanoherbicides and plant growth regulators etc. In the last decade a polymer like chitosan has been identified as potential delivery vehicle for regulated release of diverse agrochemicals and genetic materials. The advances of nanobiotechnology not only enhance our understanding of crop biology which potentially enhances crop yield and nutritional values but also offers several green and novel technologies in sustainable agricultural practices. Despite availability of wide knowledge and applications of nanotechnology in different sectors there is marginal knowledge available in agriculture sector. The present compilation is focussed on to briefly discuss different nonmaterial based formulations and role of nanobiosensors and their application in amelioration of plant growth, crop production, crop protection and disease management to attain agricultural sustainability.

Keywords: Nanofertilizers, Nanopesticides, Nanofungicides, Sustainable agriculture.

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INTRODUCTION

Technology development and new innovations in present agricultural practices require serious consideration in order to achieve growing food demand and sustainable agriculture.

The increased dependency on chemical pesticides and fertilizers during the post green revolution has come up with several concerns associated with environmental issues, agricultural sustainability, health issues etc. due to over dependency on agro-chemicals. The continuous and indiscriminate application of fertilizers, chemical pesticides, herbicides and development of improved high yielding crop verities plays a crucial role in increasing the crop production and yield in developing countries. But in due course of time, yields of many crops have begun to decline or become stagnant possibly due to excessive and indiscriminate application of such chemicals which adversely affect the soil structure, fertility, mineral cycles, soil microbial flora, which further adversely affect the crop productivity therefore, to ensure the biosafety and sustainability, ecofriendly alternatives need to be explored[1,2]. With advancement of nanotechnology, it has shown tremendous beneficial potential in agriculture sector, with inclusion of innovative nanotechnological applications, this sector has annual growth is 25% (US$ 1.08 billion) and expected the global economic growth rate reaches to approx.US$ 3.4 trillion by 2020 if more advanced nanotechnological approaches would be adopted in agriculture [3,4]. Recently, The European Commission recognised nanotechnology as one of its six ''KeyEnabling Technologies'' which could be contributing toward sustainability in various sectors including agriculture sector, Although as compare to other industrial sectors, applications of nanotechnology in agriculture sector are still very naive and needs to be explore as new source in agriculture sector to make it viable commercially [5,6].

Nanotechnology exploits the properties of material which are acquired at atomic and nanoscale, where properties of compound differ from those at a larger scale. The development and innovations in this area attract large scale investment to develop nanomaterial with new properties. Nanotechnology provides the tools and technological platform to study the effect of nonmaterial on plant system. Application of nanotechnology in agriculture system needs identification of penetrance and transport of nanoparticles in plants in order to attain possible benefits of nanotechnology [7]. Primarily, the present agriculture system needs technology development toward sustainability, Nanotechnology aim to sustainable agriculture by regulated release of agrochemicals, minimize nutrient losses in fertilization, reduce amount of agrochemicals released into the environment and increase yields through optimized nutrient management. The development of technology in the direction of nanofabrication and characterization tools have helped enormously, which ease better understanding of plant pathogenic mechanism i.e., flagella motility and biofilm formation leading to development of better treatment strategy against plant diseases [8]. In the present scenario nanobiotecnnology has widens the knowledge by offering several new potential opportunities in various sectors including agriculture. Nanotechnology offer suitable and efficient delivery carrier system for regulated and sustainable delivery of agrochemicals like nanofertilizers, nanopesticides, nanofungicides, nanoherbicides and plant growth regulators etc. Nanoscale delivery system including different polymers and encapsulation, entrapment materials used to store and protect sensitive active ingredient from surrounding environment and ensure their sustainable release to the target in order to get maximum benefit. The controlled and slow release mechanism of active ingredient reduced the amount of agrochemicals used in agriculture thus environmental issues could be reduced to certain level in agricultural practices [9].Advances of nanotechnology helps to develop novel material with certain unique properties which are deviated from its bulk material. Therefore application of nanoparticles with diverse properties can be an effective instrument in agriculture sector for effective management. Nanoherbicides, nano-pesticide, nanofertilizers etc. which can sustainably disperse their content in optimum quantity to target cellular organelles in plants to achieve maximum benefit out of it with least effect on the environment and ecosystem . Although nanotechnology is widely explored in different sectors, however there is a wide knowledge gap of nanotechnology in agriculture sector and needs to be explored. The potential applications on nanoparticles (NPs) are still unexplored, especially their mechanism and role on plant growth and development [10, 11]. Improvement of plant resistance against plant diseases, target specific phytopathogens using procedures which involved nanofibres, NPs and nanocapsules to transfer and multiply genes certain set of genes could be a great approach using the nanotechnology [12,13,14]. Agriculture sector is currently perusing some of the nanotechnology based applications like Nanobiosensors and nano-based smart delivery systems to increase crop productivity, smart protection from crop pathogen attack, efficient use of water resources, optimized nutrient and agrochemical management and less nutrient loss etc [15, 16].

Nanofertilizers:

Conventional methods of application of fertilizers to increase the crop yield are inappropriate in current scenario in order to achieve the goals of sustainable agriculture. The prolonged and large scale application of chemical fertilizers not only damage the soil natural structure but also perturbs mineral cycle, soil microbial flora and soil organic matter etc. It has been corroborated that frequent and prolonged applications of nitrogen and phosphorus fertilizers are considered as one of the major anthropogenic factors which causes problems of eutrophication in both surface freshwater bodies and coastal ecosystems worldwide [17,18]. In this direction the applications of nanotechnology in agriculture sector could be a promising approach. Meticulous applications of improvised fertilizers using nanotechnoloy could be one approach which includes development of nanofertilizers which contribute significantly to improve crop production and meet the inflated food demand of the world's rapidly-growing population [19]. As far as application of conventional fertilizers is concerned they does not provide sufficient momentum to enhance crop production due to their low efficiency and limited management practices therefore, there is a constant need to work in the direction of research and development of fertilizers by applying applications of nanotechnology [20].The fact that there is poor fertilizer use efficiency by crops for about 20-50 percent for nitrogen and 10-25 percent for phosphorus fertilizers indicated that there is a wide room to enhance crop production by exploiting smart application of fertilizers exploiting nanostructured materials as fertilizers carrier referred as nanofertilizer, which are capable to release nutrient in controlled manner and increase crop yield by enhancing nutrient use efficiency and environmental cost of protection [21,22,23]. Development of nanofertilizers using applications of innovative nanotechnology potentially important and among the several strategies, encapsulation of fertilizers within a nanoparticle is one of them, which involves encapsulation of nutrient within nanoporous material coated with thin protective film of polymer or delivered as particle or emulsions of nanoscales dimensions [24].Fertilizer particles coated with nonmaterial help in controlled release of nutrients because of coated surface which hold the material more strongly than normal surface due to higher surface tension [25]. Moreover, the release of fertilizers in accordance with the pace of uptake by plants can be optimized by tagging nanofertilizer with nanosensor. This will not only help to prevent additional loss of nutrients to soil but also minimize the leaching, which avoids the interaction of nutrients with soil, microorganisms, water, and air thus reducing the transfer of nutrients and prevents eutrophication by (N) and phosphorus (P) fertilizers to ground water [20,26].

Moreover, nanofertilizers could be categorized in different classes based on macronutrient and micronutrient i.e., macronutrient nanofertilizers, micronutrient nanofertilizers, plant-growth-promoting nanomaterials and nutrient-loaded nanofertilizers [26].Among these categories macronutrient nanofertilizers are mainly consisted of one or more macronutrient elements (like N, P, K, Mg, and Ca) where as micronutrient nanofertilizers consisted of plant micronutrients which include iron (Fe), copper (Cu), zinc (Zn), manganese (Mn) and molybdenum (Mo) etc. although micronutrient are only required in trace amount but they are essential for optimum growth of plants along with macronutrients, Probably, by increasing the bioavailability of nutrients to plants even under adverse environmental conditions too. Hence, emphasis on the development of efficient and ecofriendly macronutrient (N and P) nanofertilizers should be given for sustainable crop production replacing with conventional N and P fertilizers. There are several reports which indicated that micronutrient-containing NPs could be better option to enhance plant growth and yield probably by better supply of nutrients to the plants. it is reported that foliar application of iron (Fe) nanoparticles at optimum concentration exhibit improved growth in soybean by increasing chlorophyll (Fe reduces chloretic symptoms) content [27] and increased yields (47% more in terms on number of pods) in black-eyed peas when applied solution of Fe-NPs in 500 mg/l concentration [28].Similarly other studies conducted using different nanoparticles like metallic Mn-NPs were better micronutrient which enhanced growth in root and shoot of mung bean (*Vigna radiata*) at the concentration of 20 mg/l [29]. Whereas significant growth in seedlings of mung bean and chickpea (*Cicer arietinum*) were reported on application of ZnO-Nanoparticle solution at low concentration (1 mg/l) [30].Similarly improved growth was reported in chickpea on application of Mo-NPs solution [31].Application of developed formulation of conventional fertilizers using the nanotechnology attributed several advantages to fertilizers including, sustained release of nutrient formulation matching with the pace of nutrient uptake by plants leading to effective nutrient uptake , enhanced solubility and dispersion for mineral micronutrients, extends effective duration of nutrient release and reduces fertilizer nutrients loss rate [21].

Nanopesticides, Nanoherbicides and Nanofungicides

In present agricultural scenario the conventional approaches used in agriculture for crop protection especially from pests and weed and abiotic stress management under integrated pest management and other practices are not adequate and indiscriminate application of bulk chemical pesticides, herbicides which not only reduces soil fertility but also adversely effects animals and human. Although several microbes were taken into account as bioinoculant for agricultural sustainability in earlier investigations [32].Nanotechnology opens up a wide opportunity in this area. It was estimated a substantial loss of crop productivity worldwide due to the insects, plant pathogen and weeds, which are responsible for crop loss by 14%, 13% and 13% respectively leading to the loss of approximately 2,000 billion dollars per year due to plant diseases [33].Therefore, plant pathogens especially belonging to the group of phytopathogenic fungi causes approximately $45 billion in crop losses every year in all over the world. Plant pathogens are able to contaminate any plant tissue at different stages of crop growth [34]. This loss may be brought down to substantial level by adopting nanotechnologies using insect pests management through the development and application of nanomaterial-based pesticides and insecticides formulations. However the crop productivity can be further enhanced by smart application of bio-conjugated nanoparticles (encapsulation) which allows the controlled release of nutrients, pesticides, herbicides, fungicides and water etc. to help plant protection against adverse stress conditions. Therefore, nanotechnology could be efficient alternatives for crop resilience against biotic and abiotic stress management in agriculture without harming the nature. Sustainable and controlled release of pesticides and herbicides, using nanotechnology has become critically important for promoting and development of eco-friendly and sustainable agriculture. It has been estimated that encapsulated pesticides and fertilizers in nanoparticles significantly reduce the amounts of pesticides or fertilizers applied by 70 or 80 percent in quantity and also reduces the cost and impact on the environment [35].

In the present scenario it is necessary to identify potential application of nanotechnology in efficient delivery of pesticides, herbicides and other agrochemical formulations using nanobased materials. Nanomaterial based formulations are critically important for enhancing the target specific efficacy of pesticides, herbicides or other agrochemical due to several factors like increased surface area, enhanced solubility, increased mobility and decreased toxicity and absence of organic solvents. It is noteworthy that nanomaterials can be exploited in various ways by encapsulation or entrapment on pesticides into suitable nanomaterial or adsorbed onto the nanomaterial, which causes the slow or delayed release of pesticides due to characteristic property of nanomaterials. The effective nanopesticide delivery techniques (i.e., nocapsules, nanocontainers, and nanocages) offer more environmental friendly approach than conventional approaches and reduce the dependences on organic solvents. The conventional approach of spraying pesticides causes large volume of pesticide loss due to spry drift due to tiny droplets and splash loss, however, naoparticle encapsulated or nanopesticides pesticides can overcome this loss in sizable volume [36].

In the recent years the considerable research on nanopesticides attracted the role of nanobiotechnology in crop protection [37]. The biological agents like bacteria, viruses and fungi could be potentially used as biocontrol tools against insect pests. However, such biological agents are prone for desiccation under diverse condition i.e., heat and UV radiations. Therefore, development and use of nano-formulations may strengthen the stability these biological agents. Therefore, over the last decade studies on the application of chitosan or clay as stabilizing and delivery agents offers an potential biocompatible and biodegradable nanomaterials and opens the wide opportunity in this direction to develop nanoformulations with biocontrol agents. Chitosan has shown its potential importance as carrier matrix for controlled delivery of active ingredients and genetic materials. Chtioson exhibits several features as carrier agent including nontoxicity, biocompatibility, biodegradability, and efficient adsorption capabilities. Therefore, chitoson offers the big advantage as protective reservoir for active agrochemicals and protect the active ingredients from surrounding environment [16, 38].

Recently nanofungicides emerged as a new type of biohybrid nanosized material that can offer an environmental friendly antimicrobial agent against different fungal pathogenic organisms to the plants and provides effective crop protection. Recently several studies were conducted to synthesize nanoparticles using combination of diverse nonpathogenic fungal species for silver, gold, goldsilver alloy, selenium, tellurium, platinum, palladium, silica, titania, zirconia, quantum dots, using acid, magnetite, cadmium telluride and uraninite nanoparticles, therefore use of nanofungicides, nanopesticides and nanoherbicides in agriculture sectors along with remote activation and monitoring of intelligent nano-delivery systems can help to reduce the amount of fungicides and pesticides in agriculture and enhance crops resilience to pathogens and pest[39].

The formulated hybrid nanofungicides not only use very small quantity of fungicides but also can be used effectively for longer duration of their application due to slow release and minimizing the effect of leaching, evaporation and photolytic, chemical hydrolysis and biodegradation . Recently conducted study indicated the potent antifungal activity of chitoson and Cu-chitosan against several plant pathogenic fungi i.e., *Alternaria alternata*, *Macrophomina phaseolina* and *Rhizoctonia* under in-vitro conditions and therefore offer eco-friendly crop protection from pathogenic fungi [40].

The development on potent nanoparticles and their use in plant crop protection could be an effective approach for effective control of plant pathogenic microbes, studies on several nanoparticles indicated that metal nanoparticles are potentially effective nanocides against various plant fungal pathogens [41]. Although, such nanofungicides are needed to be developed to display their fungicidal activity ones they are inside the targeted fungal [42]. The nanoparticles have a shown promising results in plant disease management as compared to application of conventional synthetic fungicides [43].There are several studies conducted individually or in combination that variety of different inorganic nanoparticles i.e., Ag, CuO, MgO and ZnO capable to exhibit antimicrobial activities in separately or conjugated with biopolymers [44].

Shah and Towkeer, (2010) studied that nanoparticles like zinc oxide (ZnO) and magnesium oxide (MgO) exhibited effective antibacterial activity and as anti-odour agents as well [45]. Application of naocapsules containing active ingredient has shown better absorption through cuticle and allows slow release of active ingredients to effectively target weeds. Therefore, the use nano-biopesticide could be more safe plants and eco-friendly than conventional chemical pesticide [46].Recently application of nanoformulation developed using chitosan/tripolyphosphate nanoparticles loaded with paraquat herbicide for control release and eco-friendly weed management were studied [47]. Poly (epsilon-caprolactone) nanoparticles loaded with atrazine herbicide could be an alternative technique in weed management with reduces effect on the environment [48].Nanosilver is well known and proven nanoparticles utilized for crop protection which exhibit strong broad spectrum of antimicrobial activities due to its high surface area and high fraction of surface atoms in contrast to its bulk [49,50]. Kim *et al*., (2012) observed the significant fungicidal effect of nano-size silver colloidal solution (100ppm of AgNPs) on plant pathogenic fungi grown on potato dextrose agar (PDA) and suggested the antifungal treatment on plants [51]. There are reports available that indicated that Ag NP can inhibit of fungal hyphal growth and conidial germination in *R.solani, S.sclerotiorum* and *S. ,minor , B.sorokiniana* and *M.grisea* under in-vitro conditions, although the efficacy is dose dependent, therefore restrict the fungal growth. [52, 53].

Weeds are among various factors which contribute substantially toward decreased crop development and yield and to overcome such crop yield loss herbicide are widely used. However the conventional method of spraying of herbicides not only kill weeds but also kill the crop plant if they get chance to affect crop plants at the same time large volume of pesticides wasted. In this direction application of nanoherbicide in the range of 1-100 nm provides a better solution as the nanoherbicides are very small in size and target specific. Nanoherbicides can be mixed easily with soil and can destroy the weeds from their roots to get better yield. Such nanoherbicides specifically target the weed from their roots and other food crops remain unaffected. Herbicides like atrazine; triazine could be encapsulated into nanomatrix to get efficient release to the plants. The enhancement of herbicide efficacy and absorption through the use of nanotechnology by combining active ingredient with smart delivery system could help to improve crop production without leaving toxic residues [54, 55]. Recent development and progress of nanobiotechnology in agro-biotechnological applications in agriculture sector has shown wide potential in addressing the problems associated with pests and pathogens, and loss of biodiversity and other environmental stress. Several studies revealed that nanotechnology could play a vital role in crop protection and soil systems. The study revealed that polymeric chitosan (78nm) nanoparticles and porous silica (15nm) exhibit controlled release of encapsulated pesticide and fertilizer. Moreover, the nanosized gold particles of 5-25nm were able to carry DNA efficiently to plant cells where as nanosensors based on iron oxide (30nm) could detect pesticides at minute levels. Which further assist in the development of precision farming by minimizing resource inputs and maximizing outputs in agricultural practices [56].

Nanoparticles as plant growth promoting agents

There are several reports indicated that plant growth can also be enhanced in response to the application of other types of nanoparticles also, which did not contain any essential plant nutrients, therefore different types of nanomaterials can use to synthesize nanoparticles by applying various techniques like polymerization, emulsification, oxido-reduction, ionic gelation etc. to increase productivity[57]. TiO_2 nanoparticles (Ti-NPs) and carbon nanotubes (CNTs) are most common example of such category. The study indicated that carbon nanotubes and nanoparticles of Au, SiO2, ZnO and TiO2 can potentially contribute to promote growth of plants by augmenting elemental uptake and nutrient use efficiency [58]. Although the effect of nanomaterials on plants depends on various factors like their composition, dimension size, surface charge, concentration and physiochemical properties. However effect also varies depending on the susceptibility of the plant species [59, 60].

The several potential applications of nanotechnology in agriculture sector were identified in order to achieve sustainable crop productivity like application of nanofertilizers, soil quality improvement by applying anozeolites and hydrogels which maintains crop plants even under adverse condition. Moreover, effective plant growth by application of nonnutrient nanomaterials (i.e. SiO_2, TiO_2 and carbon nanotubes) can be further improvised by using nanosensors [57].

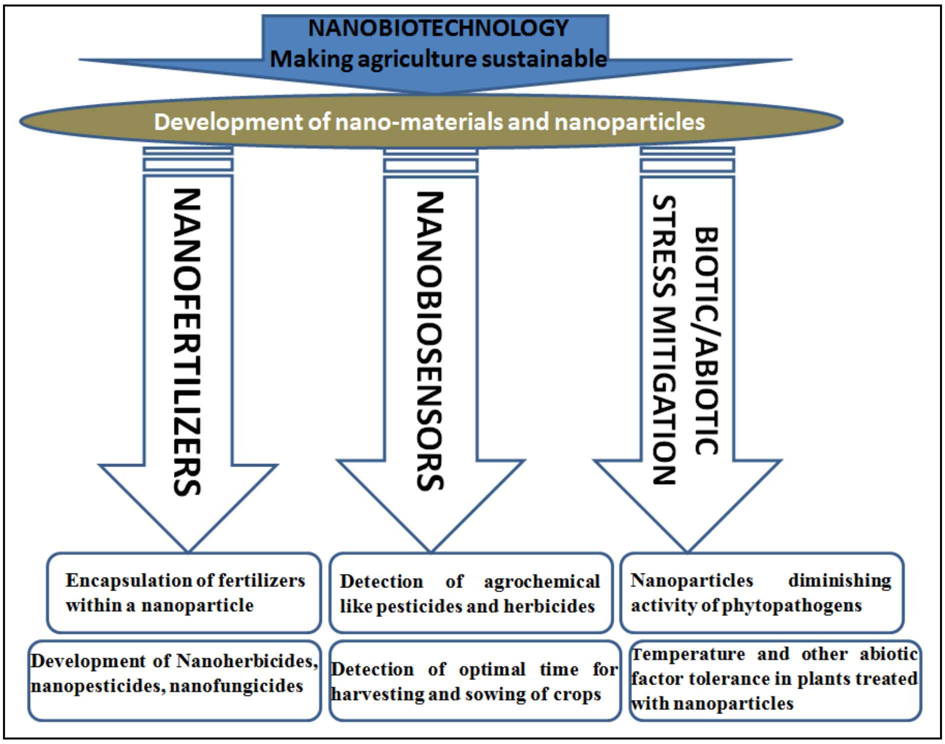

Figure1: Different aspects of nanobiotechnology in agricultural sustainability.

Nanoparticles in biotic and abiotic stress mitigation

Irrigation is one of the key components of agriculture sector which needs sufficient amount of fresh water and application of pesticides, fertilizers and other agricultural chemicals contributes significantly towards its pollution. However application of nanoporous materials could provide a considerable solution under drought stress conditions or under limited water state. Such nonporous materials are capable of storing water and water release from such nanoporous material can be controlled by wireless nanosensors depend on the different level of water stress or drought. Therefore, help in drought mitigation and reduced quantity of water use [61]. Nanotechnology has a wide scope in the direction of stress mitigation in crop plants and could be a promising tool for crop productivity and sustainable agriculture. Several studies indicated the application of nanoparticles could be an effective tool to enhance various crops resilience under abiotic and biotic stress (salinity, drought stress and phytopathogen stress.) in crop plants [62].

Application of silver nanoparticles exhibited plant growth promoting effect on lentil (*Lens culinaris* Medic) on various agronomic traits under drought stress. Moreover application of silver nanoparticles (AgNPs) could be attributed towards mitigating water stress mediating loss of plant growth and yield [63]. The mitigation of adverse effect of drought stress using foliar application of titanium nanoparticle (TiO2) on wheat and similarly iron (Fe) nanoparticles on goldasht spring safflower cultivars has shown promising results under drought stress[64,65].

Applications of Nano-SiO_2 particles in lentil (*Lensculinaris* Medik.) have shown potential increase in proline accumulation and upregulated antioxidant enzymes activity under salinity stress. Therefore application of Nano-SiO2 particles may be corroborated to enhance the abiotic stress tolerance in plants [66, 67].

Nanobiosensors

The fine tuning of technology and precision farming with the help of smart nanobiosensor and nanobased smart delivery systems could further increase crop productivity in agriculture sector. Exploiting unique chemical, physical and mechanical properties of nanomaterials and nanostructures (e.g. electrochemically active carbon nanotubes, nanofibers and fullerenes) have been recently used to develop highly sensitive bio-chemical sensors. Which have shown their importance in agriculture sector especially in soil analysis, bio-chemical sensing and control, precise and optimum delivery of pesticides, nutrients and water management. Nanosensors which detect soil moisture content in real time allows effective irrigation management system based on soil drying for sustainable irrigation system and effective utilization of water resource [68]. Nanobiosensors enable farmers with better agricultural management practices with reduced effective agricultural resource inputs especially by monitoring environmental variables and better management of time [61]. The nanosensors in present agriculture system could potentially used in effective management of different phased of crop cultivation, crop harvesting, food processing, food supply, packaging transportation and distribution [69]. In the recent advances of nanobiotechnology, nanobiosensors offer and efficient detection tools for wide variety agrochemicals (i.e., pesticides, herbicides, fungicides, insecticides fertilizers etc.), phytopathogens, soil moisture and soil pH etc., for effective management in order to enhance crop productivity [70].In the present scenario development and application of technology in agriculture sector has a wide scope, the use of cutting edge technologies in agriculture sector especially Geographic Information Systems (GIS) , Global Satellite-Positioning Systems (GPS) and Remote Sensing devices has proven to be an effective tool to remotely detect biotic and abiotic stress i.e., crop pests, drought, salinity etc.and allow timely management for farmers.

Nanobarcodes and nanoprocessing could be used to rapidly detect insects, diseases, pathogens, chemicals and contaminants hence helps in quick response to faster remediation treatments. The wide networks of wireless nanosensors devices installed in across the cultivated fields offers real-time monitoring of the crop progress and provide essential data like, moisture level, soil fertility, temperature, crop nutrient level , insects, phytopahtogens plant diseases and weeds leading to better agronomic practices along with controlled release of essential contents. Thus reducing the resource inputs and maximizing the yield with precise control [71]. Moreover the information obtained from nanobiosensors helps farmers to inform optimal time for sowing and harvesting of crop, time and for application of water , fertilizers pesticides and other treatments according to need by plant on the basis of physiological and environmental conditions. Thus help in enhancing crop protection, production and reduces environmental toxicity.

CONCLUSION

Over the last decade, there is a tremendous progress in the field of nanotechnology in various sectors. The rapid progress of nanotechnology led the development of nanometerials and nanoparticles for commercial applications. The applications of nanotechnology in agricultural sector put forward the mitigation of environmental challenges like drought, salinity and diseases etc. Technology development based on nanotechnology in the field of agricultural biotechnology could be a great help in addressing the issues of sustainability especially efficient utilization of natural resources and agrochemicals without effecting the crop productivity and environment. Biosynthesis of nanoparticles using biological system ,development of sensitive and effective delivery system, nanoencapsulation, nanofertilizers, insect pest management using nanoformulations of insecticides, herbicides , pesticides, fungicides etc. are primarily required attention towards their effective application in precision agriculture. The evolution of nanobiosensors for precise monitoring of environmental attributes and early diagnosis of disease, detection of agronomic traits and timely treatment based on plant specific physiology, pathology and environmental conditions may thrust upon for sustainable agriculture. Therefore, nanobiotechnology holds the bright future for modern agriculture.

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