Chapter 16
Risks and Concerns of Use of Nanoparticles in Agriculture

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1 Introduction

The act of agribusiness also called “farming/cultivating” is the most common way of cultivating food, feed, fiber, and various other desired items by the development of specific plants and the raising of animals/livestock (Acharya and Pal 2020). Farming is the foundation of most under-industrial/developing nations, and it gives food to people, straightforwardly and indirectly (FAO 2002; Patrick and Jeffrey 2015; Qadri 2018). The entire world populace will develop to an expected 8 billion individuals by 2025 and 9 billion by 2050, and it is broadly perceived that worldwide agricultural productivity should augment to take care of a quickly developing total populace (Ghasemzadeh 2012; Prasad et al. 2017). The FAO of the UN predicts that yearly meat production of 200 million tons will be needed by 2050 to fulfill the food needs achieved by expanding worldwide populace, and this anticipated expanding interest for meat put further pressure on horticultural/agricultural land because farmers need to develop crop yields to deliver animal feed (Ghasemzadeh 2012; Pandey 2018). Farming as a source of food is turning out to be progressively significant in a universe of decreasing assets and a steadily expanding

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worldwide populace (FAO/WHO 2010). Given the rising total populace, it is important to utilize the cutting-edge innovations like nanotechnology and nanobiotechnology in horticultural and food sciences. Nanotechnology has an enormous potential to revolutionize farming and associated fields, together with hydroponics and fisheries (Rajput et al. 2021a, b; Faizan et al. 2020; Usman et al. 2020a, b).

Nanoagriculture centers presently around targeted cultivating techniques that includes the utilization of nano-sized particles with novel properties to help in boosting of yield and animals' efficiency. The nanoscale is the size range from around 1 to 100 nm. At this size range, the laws of material science work in new ways that decides both the limitations and the chances of nanotechnologies and nanoscience in agribusiness and different allied branches (AE 2007; Ulbrich et al. 2016; Pathak 2019; Das and Pattanayak 2020; Das et al. 2020). The potential scopes/ chances related to nanotechnologies have prompted critical venture by government organizations, public research centers, colleges, and firms all through the world (Cobb and Macoubrie 2004; Scott 2007; Forsberg and de Lauwere 2013). Nanotechnologies incorporate the creation, formulation, synthesis of different nanoparticles, and their application to physical, chemical, and biological systems (Roco 2007, 2011). Horizon 3 estimates guarantee infinite utilizations of nanotechnology as an empowering innovation in different enterprises. As reported by Roco et al. (2010), the improvement of nanotechnology will have progressive impact on instrumentation, user facilities, computing resources, in silico assets, etc. in agriculture and allied areas (Fig. 16.1).

There is a various meaning of nanotechnology (NCI 2018): according to the National Cancer Institute "innovation improvement at the nuclear, atomic, or macromolecular capacity of about 1–100 nanometers to make and utilize designs, gadgets, system and frameworks that have novel properties." Thus, the National Cancer Institute described nanotechnology as "innovation or technology on the nanometer scale." The nanotechnology primarily defined as "invention and technology that is constructed from single atoms and which relies upon individual atomic particles for its work (enzyme)." In case the enzyme's quality changed, the transformed compound could conceivably work (Wolfenden and Snider 2001; Scott and Chen 2002;

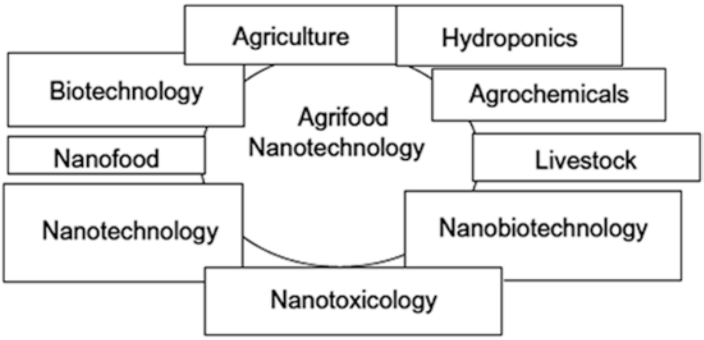

Fig. 16.1 Multidisciplinary nature of agriculture-food nanotechnology

NEHI 2008). Interestingly, whenever eliminated a couple of molecules from a mallet, it actually will work comparably well. This is a significant differentiation that has commonly been lost as the publicity about nanotechnology and utilized as a popular word for "little" rather than a particularly unique innovation (Chaudhry et al. 2005; Wu et al. 2020; Zhao et al. 2021).

Luckily genuine nanotechnologies are underway from the European Union-supported NanoHand project and reported that "nanotechnology contains the arising utilization of nanoscience" (ECCR 2004; EC 2009). The nanoscience is dealing with functional systems either dependent on the utilization of sub-units with specific size-dependent properties or of individual or joined functionalized sub-units (Brune et al. 2006; Raliya et al. 2013; Jeevanandam et al. 2018). The National Nanotechnology Initiative (NNI) thinks about "nanotechnology" just when nanotechnology instruments and ideas are utilized to concentrate on science, biology, and engineered biomolecules. The functionality of these synthesized particles is altogether different from those they have in nature and natural environment. The manipulation of these biological entities is finished by techniques more exact than should be possible by utilizing sub-atomic organic biomolecules, artificially synthesized or manufactured substance, and/or biochemical methodologies approaches that have been utilized for quite a long time in the biology research community (NCI 2018).

Somewhere else, nanotechnology is commonly defined as any innovation managing objects inside the 1–100 nm scale range (Elsabahy and Wooley 2012; Nicolas et al. 2013). Yet, without knowing what sort of items are 1–100 nm long, many individuals have a struggle in relating nanotechnology to its most efficient applications (Yadav and Upadhyay 2020a, b).

Nanotechnology shows a solid level of assembly with numerous different disciplines including information technology, biotechnology, animal husbandry, biomedicines, imaging, diagnostics, and food and agri-science (Groves 2008; Garcia et al. 2010; Ditta 2012; Pillai 2014; Pathak 2019; Singh et al. 2021a). With approaches and items emerging from innovation unions or technology convergences, it is enough hard to forecast and predict about its potential to transform and disturb ordinary living things. In the future, nanotechnology will not only ensure better livelihoods, but will help in solving problems nationally and internationally (Yadav et al. 2016, 2020; Yadav and Upadhyay 2020b).

Nanotechnology is becoming significant in fields like microelectronics, medical services, healthcare sectors, engineering, construction, and agriculture/farming (Joseph and Morrison 2006; Scott 2007; Singh et al. 2021a, b, c, d, e, f). The organic and naturally existing nanoparticles (nanoclay, tomato carotenoid lycopene, numerous synthetics obtained from soil natural matter, lipoproteins, exosomes, magnetosomes, viruses, ferritin) have different designs with multifacial biological role and natural jobs (Stanley 2014; Aggarwal et al. 2021; Tuli et al. 2021; Upadhyay et al. 2021a, b). Bio-nanoparticles are regularly biocompatible and have reproducible organization. The most possible and efficient biomedical utilizations of normal and modified bio-nanoparticles have been accounted by many schools in yesteryears (Singh et al. 2018, 2019, 2020a, b, c, d, e). "What would come about if we could put together the atoms individually the manner in which we need them?" asked Richard Feynman, in a deliberation of the American Physical Society held on 29 December 1959. This thought in the long run turned into an exploration field known as nanotechnology (Feynman 1960; Drexler 1992; Lewis 1993).

Nanotechnology deals with controlling, assembling, synthesizing, and rebuilding materials and gadgets on the size of particles and atoms of nanometer (Dan et al. 2020, 2021a, b; Rana et al. 2021). To know the feeling of the nanoscales, the width of the human hair is 80,000 nm, and the smallest things apparent with the exposed natural eye are 10,000 nm across. At nanoscales, the fundamental guidelines of chemical and physical science are not appropriate, and the same material may work entirely different. One suitable example of this innovation is the carbon nanotube invented in 1991, which is a couple of nanometers in dimensions but can conduct power better compared to copper, multiple times more grounded than steel, however just a 1/6th of its weight. Therefore, nanotechnology is a multidisciplinary field and portrayed as complementary integral, not cutthroat or competitive innovation (Lewis 1993; Jia 2005; Oberdörster et al. 2005; Priest 2006; Maynard 2007; Sozer and Kokini 2009; Raliya et al. 2013). As per an estimate, USD $40 billion were spent on various technologies and research related to nanotechnology by various agencies globally which further increased to USD $9.75 in 2009 (Gao et al. 2016; Harper 2017). Despite the huge speculation from government, private venture is relied upon to surpass public venture focusing on areas like semiconductors, drug and medical care, aviation, security, food, and agribusiness. BCC Research assessed that the worldwide market for items fusing nanotechnologies was roughly USD $15.7 billion by 2010, with figures to develop to USD $26.7 billion by 2015 with a compound annual growth rate (CAGR) of 11.1% from 2010 to 2015 (Harper 2017).

However, the worldwide market for nano-conductive materials should augment from $1.3 billion of every 2020 to $2.7 billion by 2025, at an accumulate yearly development rate (CAGR) of 15.3% during the time of 2020–2025 (BCC 2021). These estimates well established commercial nanomaterial applications, for example, nanocatalyst flimsy chips and membranes for catalytic converters, just as recent advances, for example, as nanoparticulate fabric treatments, rocket fuel additives, nanolithographic tools, and nanoscale electronic memory, health, energy, and the environmental remediation markets.

The agriculture and horticultural area are managing huge challenges like fast climatic changes, rapid diminishing soil characteristics, macro- and micronutrient deficit, and overuse of chemical fertilizers and pesticides, along with the presence of heavy metal in the soil (Chibuike and Obiora 2014; Prasad et al. 2017; Pandey 2018; Acharya and Pal 2020; Alengebawy et al. 2021). However, the worldwide populace increment has subsequently escalated food demand. Nanotechnology has colossally added to maintainable and sustainable farming by upgrading crop production, reestablishing and further development in soil quality (Pramanik and Pramanik 2016; Shang et al. 2019; Mali et al. 2020; Mittal et al. 2020). Nanotechnology is applied in different parts of farming, agriculture, viticulture, and horticulture as (a) nanopesticide applications for targeted delivery; (b) slow and controlled delivery of nanoparticles containing biofertilizers; (c) transport of hereditary materials for crop advancement; and (d) application of nanobiosensors for quick diagnosis of phytopathogens and other biotic and abiotic stresses. This article focuses on the risks and concerns of use of nanoparticles, nanosensors, nanotubes, nanofibers, and nanotechnology in agriculture.

2 Applications of Nanotechnology in Agriculture

The worldwide populace is projected to arrive at 8.5 billion by 2030, and the world should create basically half more food, to take care of around 9 billion individuals by 2050, as per the United Nations reports (Wiens 2016). Conversely, biodiversity, agri, and horticultural domains, seas, forests, and different types of natural resources, are being exhausted at an exceptional rate (Dewulf et al. 2015). Thus, expanding agricultural productivity, rural usefulness, and improving postharvest handling are fundamental to take care of a developing populace. For a long time, farmers have been endeavoring to increment agriculture yields by utilizing regular fertilizers, pesticides, and hybrid seeds. Worldwide environmental change is likewise causing a decrease in agricultural usefulness, due to the colossal modern growth (Bockstaller et al. 2008). Environmental effects on agribusiness can be evaluated utilizing agri-ecological markers to quantify the unfavorable impacts of editing and cultivating, for example, water and soil contamination, soil disintegration, and outflow of nursery gases.

Because of these natural emergencies, the expense of fundamental staples and the expansion in new food costs are unstable in nature, which will keep disturbing the normal populace. The world's food security will be at extraordinary danger, except if, what's more, until we advance agricultural practices and deal with our normal assets sustainably (Dasgupta et al. 2015). The nanotechnology had inescapable efficiency to give a valuable influence on a few areas, agribusiness, food handling, ranger service, natural issues, water industry, energy creation, and, also, economical use of waste resources. As of late, a wide scope of nanotechnology applications has been anticipated in agribusiness, in this manner drawing in serious innovative work rehearses at both scholastic and modern levels (Parisi et al. 2015). Nanotechnology has huge freedoms in different parts of agriculture going from production, assurance, reaping, and post gathering applications. In the accompanying area, uses of nanotechnology in agriculture are being examined.

2.1 Nanofertilizers

Advancement and application of modern sorts of synthetic manures utilizing inventive nanotechnology will possibly be powerful choices of altogether upgrading the worldwide agrarian creations expected to fulfill the future needs of the developing populace (Lal 2008). Moreover, the utilization of traditional fertilizers is hampered by the low effectiveness (simply 30–50%) and hardly any choices to improve the rates (Fageria 2009). Various studies shows that some designed nanomaterials can upgrade plant development in specific focus runs and could be utilized as nanofertilizers in farming to increment agronomic yields of harvests and additionally limit natural contamination. Nanofertilizers are classified as macronutrient nanofertilizers and micronutrient nanofertilizers, nutrient-loaded nanofertilizers, and plant growth-enhancing nanomaterials (Faizan et al. 2018).

Macronutrient nanofertilizers are artificially contained at least one macronutrient components (e.g., N, P, K, Mg, and Ca), in this way having the option to provide the requisite fundamental mega nutrients to floras. Enormous amounts of major fertilizers (primarily nitrogen and phosphorous composts) are utilized for yields of fundamental productivity. Smil (2002) assessed that nitrogen composts have shared an around 40% increment in proportionately food creation in yesteryears, demonstrating the basic job of the said synthetic manures in worldwide food creation. Besides, because of the low productivity (30–35%) and high utilization of these macronutrient composts, huge measures of these supplements (N and P) are shipped into surface and groundwater bodies, disturbing oceanic biological systems and undermining well-being of human and amphibian life. Consequently, a critical and basically fundamental exploration heading is to grow profoundly effective and harmless to the ecosystem ensuring safer climate.

Small-scale nutrients of plants incorporate Fe, Mn, Zn, Cu, and Mo. These nutrients are required in little amount for the profound growth and development of plants that in turn responsible for efficient and augmented plant productivity. These trace elements are usually amalgamated to the principal macronutrients as solvent salts for plant uptake. In any case, plant accessibility of the applied micronutrients might turn out to be low, and lack of micronutrient might happen in certain soils of alkaline pH, rough surface, or that containing lower soil matter (Fageria 2009). Apparently, theses trace elements along with nanofertilizers possibly enhance the bioavailability of necessary supplements to plants considerably under these most pessimistic scenario situations.

The NM-improved composts are characterized as those nanomaterials, which, when expanded with plant nutrient(s), can increment plant uptake proficiency of the nutrient(s) as well as diminish the unfriendly effects of customary fertilizer application; however those NMs neither contain nor give the designated nutrient(s). The main illustration of this kind is supplement of expanded zeolites. Zeolites' particles regularly don't happen at nanoscales. Yet, the arrangement of Al and Si in the three-dimensional system of SiO_4 and AlO_4 tetrahedra of zeolites makes channels and voids that are inside nanoscales (0.3–10 nm). Subsequently, zeolites are materials with nanostructures. It is a direct result of their extraordinary nano-permeable properties that zeolites frequently have incredibly high explicit surface region and high cation trade limit and are profoundly particular toward plant macronutrients (Liu and Lal 2015). These fundamental components might be traded onto zeolite trade destinations, where the supplements can be gradually delivered for plant take-up. There are a few reports archiving that utilization of some different sorts of NPs could likewise improve plant development somewhat, in spite of the way that these particles didn't contain any fundamental plant supplements. Commonplace instances of this sort are TiO_2 nanoparticles (Ti-NPs) and carbon nanotubes.

2.2 Nanopesticides

The help of nanotechnology in plant assurance items has dramatically expanded to accomplish higher yield. Over the years, crops were protected using huge amount and dose of fungicides, herbicides, and insecticides. Unfortunately, most of the pesticides get mixed with environment through various roots and leads to pollution and sometime even fails to control the pests (Pandey 2018). Indiscriminate use of pesticides not only financially burdens the farmers but also leads to environmental degradation. For optimum crop protection and maximum yield, pesticides should be active at their minimum concentration. Future research should be focused on these lines for optimum use of pesticides. One such technology is use of nanoparticles formulated with pesticides of choice. Nanoformulated pesticides are pesticides coated on nanoscale particles of various materials showing effective pesticide properties (Rai and Ingle 2012). The internal structure of the nanoparticles is known as core having effective concentration of pesticide, and capsulation materials are known as external phase (Fraceto et al. 2016). The advantage of nanoformulated pesticides is that this structure leads to sustained release of pesticides at requisite site without impacting the environment and other non-targeted crops. Nanobased pesticides have also other advantages like better transport, better solubility, better hardness, increased permeability, thermal stability, solubility, crystallinity, and also biodegradability essential for sustainable agro-environmental system.

Besides abovementioned advantages/promises, they also showed some concerns which need to be addressed properly. Copper-based nanopesticides like ($Cu(OH)_2$) have shown ill effects on spinach plants leading to change in there metabolic profiles and decreased level of antioxidants (ascorbic acid, α-tocopherol, 4-hydroxybutyric acid, ferulic acid) in plants with low amount of phenolic compounds also (Zhao et al. 2017). On the opposite, Petosa et al. (2017) reported that nanoformulations of pesticides lead to enhanced growth of plants with higher yield due to better transport of pesticides to target area. Further they reported that nanoformulations joining polymeric nanocapsules and the pyrethroid bifenthrin (nCAP4-BIF) show sustained release over the period of time and improved vehicle potential even upon the expansion of fertilizer in loamy sand soil immersed with artificial pore water containing Ca^{2+} and Mg^{2+} cations. This implies that nCAP4 could be a promising conveyance vehicle of pesticides like pyrethroid in plant security. This might be actually because of the expanded capability of scattering and wettability of nanoformulations that decrease natural dissolvable overflow and undesirable pesticide development. Besides, nanomaterials in pesticide detailing show some valuable properties like expanded firmness, porousness, warm dependability, dissolvability, crystallinity, and furthermore biodegradability fundamental for manageable agro-natural framework (Lu et al. 2002).

Further, numerous examinations have given proof that pesticide-based nanoparticles work best for plant-based systemic acquired resistance against pests. Enhanced capacity of pesticides to enter systemically in plant and reach up to cell sap has been reported by use of silica-based nanoformulations. These types of methods will help control biting- or sucking-type bugs like aphid (Li et al. 2007). Moreover, such nanoparticle-based and pesticide-based show enhanced protection against environmental factors like sunlight, etc. Further they have showed promising results for weed and disease management in agriculture. Various inorganic nanoparticles like, ZnO, Cu, SiO2, TiO_2, CaO, MgO, MnO, and Ag NPs play an important role toward control of microbial disease. Recently, ZnO nanoparticles successfully used to control fungal diseases caused by organism such as *Fusarium graminearum*, *Penicillium expansum*, *Alternaria alternata*, *F. oxysporum*, *Rhizopus stolonifer*, *Mucor plumbeus*, and *A. flavus* along with bacterial diseases caused by *Pseudomonas aeruginosa* (Servin et al. 2015; Shang et al. 2019). Hence, the nanomaterials in pesticides, fungicides, and herbicides have a huge extension in practical farming.

2.3 Nanobiosensor Use in Agriculture

Biosensors are electronic devices having receptor and transducer system with suitable biological component, being used to detect the various analytes (Sun et al. 2006). Nanobiosensors are latest edition of biosensor which are more versatile, connected to sensitized component to distinguish particular analyte at very low level through a physico-substance transducer. Nanobiosensors can help in early and rapid detection of analytes which may help to improve crop yields by appropriate management of water, land, fertilizers, and pesticides. High surface to volume proportion, fast electron-move kinetics, and high affectability and stability with longer life offer upper hands to nanobiosensors over regular and old age sensors (Mishra and Kumar 2009). They contain materials at miniscule level that perform as bioreceptor on a transducer which give signal to recognition component to recognize single or multiplex analyte. The major features of nanobiosensor are fictionalization, immobilization, and scaling down that incorporate biocomponents of a transduction framework into complex design to work on the scientific exhibition of NMs (Usman et al. 2020a, b). Their work dependent on turns off/on mechanism identifies analyte fixation inside parts per trillion (ppt) and limits the dissected network dependent on nano-definition.

Further, nanotechnology might be shaped and directed for constant observing of a varied range of pollutants of various origins including physical, chemical, and biological origins (Chen and Yada 2011). The continued use of chemicals to kill pests and insects in different farming exercises had made it important to investigate the new synthetic and physical composition of nanomaterials to foster creative devices for insecticide buildup location. These sensors made up at nanoscale are expected as scientific gadgets that will be requiring something like one detecting measurement no >100 nm, manufactured for checking physical as well as chemical properties on site for inaccessible locations and will provide more prominent affectability, small-scale detection, preciseness, quick recognition, and more versatility than regular discovery strategies (Fraceto et al. 2016; Kumar et al. 2015).

Besides rapid and accurate detection of pollutants at miniscule level, they can also be used measuring various parameters like moisture levels; soil and water pH; maturity index; climatic characteristics; nutritional status of crops, etc.; and amount that impacts the yields and quality of crops in order to support sustainable agriculture and enhanced productivity (Rai et al. 2012). The utilization of an organization of sensors, worldwide situating, and data frameworks through a farming region could instrument and write about various distinctive ecological, yield, and nuisance factors. Regulatory authorities and legislation can give the guides and rules to economical utilization of nanomaterials to identify, approve, and decrease their poisonous impacts in the entire environment (Iavicoli et al. 2017).

2.4 Nanotechnology for Bioremediation

Environmental contamination is perhaps the utmost complications faced by human race today (Das et al. 2015). Earth and water found beneath the earth surface are degraded by noxious contaminations by one or another natural or manmade sources at concentrations fit for presenting incredible danger to social well-being or the climate (Fu et al. 2014). Nanoscience has been seen as conceivably giving reasonable answers for these worldwide difficulties. Nanoscience-based procedures are state of art and economical techniques for the elimination of various contagions like heavy metals/metalloids, dyes, and organic contaminations (Li et al. 2016; Iavicoli et al. 2017; Thomé et al. 2015). Remediation through nanomaterial leads to detoxification of contaminations or change the contaminants to harmless level. These materials have exceptionally good strengths and adaptability for both on-site and uses at outdoor locations. NPs might have the option to get to tiny spaces in the subsurface and stay suspended in groundwater, accomplishing a more extensive appropriation contrasted with bigger, macrosized particles (Li et al. 2016). Remediation with use of nanoparticles can be effectively utilized for cleaning up of large-scale contaminated sites economically; not only it will clean the sites, but it will also reduce the time of cleanup processes. Further it will also help in elimination of need for treatment and disposal of contaminated soil.

A wide range of materials have been utilized effectively for remediation of various contaminants at nanoscale level. Out of these materials, zero-valent iron nanoparticle (ZVI-NP) has been generally examined, primarily because of its low poisonousness and minimal expense underway (Fu et al. 2014). These are electron-contributor particles that are primarily used for degradation of chlorinated compounds and the decrease of substantial metals through redox responses (Tosco et al. 2014). Further, they have been investigated for the removal of heavy metals like cadmium from aqueous solutions and chromium [Cr (VI)] from soil contaminated with tannery waste and wastewater (Singh et al. 2012). Not only from waste water were nanoparticles successfully used to increase the phytoremediation proficiency of heavy metals in tainted soils. Cadmium has been removed successfully from soybean plants using nanoparticles. TiO_2-based NPs have been successfully utilized for removal of Cd from plants and found to decrease the oxidative stress caused by Cd on soybean plants. Removal of lead by ryegrass (*Lolium temulentum* L.) from contaminated soils by using nano-hydroxyapatite and nano-carbon tubes has been reported by Liang et al. (2017). Similarly, various metal oxide-based NPs have been utilized for the expulsion of a few heavy metals and organic compounds. Iron oxide NPs have been largely utilized in the environmental field as anticipated adsorbents because of their redox cycle, particle trade, high proclivity for impurities, and attractive properties. Magnetite (Fe_3O_4), another member of the iron oxides, has been utilized for bioremediation (Lee et al. 2010).

Similarly, NPs can successfully be used in bioremediation of organic pollutants from soil. Further, impurities adsorbed to the NPs could be effectively taken up by plants all together with small-sized nanoparticles. Furthermore, modified membrane selectivity due to phytotoxic NMs may also work with take-up of natural toxins (Kah et al. 2019). De La Torre-Roche et al. (2012) studied the effect of fullerene introduction on accumulation of DDE (a metabolite of DDT) in plants like winter squash (*Cucurbita pepo* L.), soybean, and tomato (*Solanum lycopersicum* L.). Exposure of fullerene leads to increased uptake of DDE from 30% to 65%. They proposed co-take-up of NMs and pollutants as one of the potential instruments of improved take-up, as well as influencing the bioavailability/bioaccumulation of organic pollutants. After impurity removal, nanomaterials can be conveniently recuperated from liquefied media, making the cleaning system more practical. Despite the fact that likely valuable impacts on the eradication and change of noxious foreign substances have been proposed for nanomaterials, there is a still absence of data about their retrieval and reusability. The attention on materials life-cycle used for formulating nanoparticles starting from their entry into the environment not reported, how they are going to remove toxic substances etc., what will be their impact of various biological systems (Usman et al. 2016). All these concerns should be investigated on both the laboratory and pilot scale.

3 Fate of Nanoparticles in Soil and Transport in Plant

As NPs were added to soil for various purposes, they start connecting with soil particles, other materials in soils, and root exudates through the process of biotransformation (Shende et al. 2021; Rajput et al. 2018, 2021b). After establishing the connection, they move toward the aboveground parts of the plant. After entering soil, NPs can go through chemical and/or biological changes relying upon their tendency and on their communications with different soil parts (natural and inorganic). Various organic and inorganic particles including minerals and colloids intermingle with NPs which would prompt their segregation in solid and aqueous phase of soil system (Ben-Moshe et al. 2010). Accumulation is the chief interaction which happens unexpectedly when NMs are brought into the soil climate. Accumulation lessens the accessible exterior space of NMs which influences their usefulness. In addition, expansion in size of total will diminish their versatility in aqueous media and will influence overall purpose of NMs. There are two particular types of aggregation/accumulation which NPs face: aggregation between similar NMs known as homo aggregation and aggregation among NMs and one more molecule in environment (heteroaggregation), e.g., natural colloids, etc. known as heteroaggregation (Lowry et al. 2012). Restricted information is available with regard to destiny and conduct of NPs in the soil framework as the vast majority of the examination has been done in water frameworks and further investigation is required in this area.

Information available suggests that NP mechanisms like osmotic pressure and capillary forces help the NPs to enter into plant roots, or sometimes they directly enter root epidermal cells as root epidermal cells are semipermeable because of the presence of pores, but they stop the passage of NPs larger than 20 nm of size (Lin and Xing 2008). But larger NPs sometimes can initiate development of more novel and bigger pores in the epidermal cell which help their entry into plant system (Lin and Xing 2008). Once NPs cross the barrier of cell wall, they are apoplastically shipped through extracellular spaces to central vascular system and finally reach xylem. But it has been reported to reach up to central vascular system of plant; NPs have to cross the casparian strip barrier simplistically using the process of endocytosis, pore formation, and transport by binding to carrier proteins of the endodermal cell membrane (Tripathi et al. 2017).

Khodakovskaya et al. (2009) suggested that aquaporins and cell channels having pore sizes <1 nm that doesn't allow the NPs; notwithstanding some reports suggest that nanoscale tubes can control aquaporin pore size for penetration in plant cells. However, it has been suggested that aquaporin pore size can be regulated by carbon nanotubes for entry in plant cells. After their entry into the cytoplasm, NPs travel from one cell to another through the plasmodesmata (Tripathi et al. 2017). NPs which fail to enter into vascular system are reported to stay back at the casparian strip. NPs that have entered in the xylem are shipped to the shoots and consequently back to the roots by means of the phloem. Aggregates of NPs taken up by plants which have entered into the plants are found to be located inside the walls of epidermal cells and cytoplasm of cortical cells and furthermore in the nuclei (Reddy et al. 2016). Straight uptake of NPs can happen in seeds through parenchymatous intercellular spaces of the coat followed by dispersion in the cotyledon.

Organic matter, minerals, soil organisms, pH, temperature, and redox status of the soil are important parameters that impact the destiny of NPs applied through the soil route. Covering of NPs by parts of natural organic matter with reactive functional groups like carboxyl, amino, hydroxyl, and sulfhydryl; disintegration of NPs and release of ions; complexation and chelation with minerals and soil particles; and aggregation of NPs and degradation by soil microflora are a portion of the broadly detailed changes of NPs happening in soil. Reactions between the applied NPs and NPs normally framed in soil can contribute toward the adequacy of NPs as nanofertilizers, nanopesticides, etc. (Pérez-de-Luque 2017).

4 Risks and Uncertainties of Nanotechnology

Deliberate and greater contribution of nanotechnology into farming systems poses a number of queries in regard to the ecological fate and transportation of these materials into the climate that actually must be replied. Multifaceted applications of nanoparticles and its buildup and assimilation through everyday items have stressed the researchers and toxicologists. Noxious impacts basically rely upon nano-size measurement and cell association (Yang et al. 2017). It might lead to change in the genetic makeup and may influence the proteomic structure. As per one report, persistent use of ready to serve food varieties with NPs might apply imbalance on gut environment and may cause dysbacteriosis (Fröhlich and Fröhlich 2016). Other noted influences are reactive oxygen species (ROS) creation, DNA harm, genotoxic impacts, crucial organ harms in humans, etc. (Golokhvast et al. 2015). Generation of reactive oxygen species interferes with extracellular networks, bringing about oxidative pressure and toxicity to cell (Iavicoli et al. 2012). Impact of different consumed designed nanomaterials on cell expansion, apoptosis commencement, and pro-inflammatory and inflammatory cytokine release were additionally revealed in vivo, showing cytotoxicity of the liver, kidneys, stomach, and spleen (Ema et al. 2016). Additionally, nanoemulsion with lipophilic center has distinctive rate and degree of processing and adsorption in the gastrointestinal tract, which might make hurtful impacts due its compound nature as surfactant (Cushen et al. 2012). A few in vitro and in vivo examinations have demonstrated its cytotoxic consequences for various human organs; however clinical preliminary information for well-being and viability is as yet anticipated.

Further, clinical and cytotoxic biomarker studies are needed to detail the rules. Warning rules could be given for industrially accessible different food and agri-items with their conceivable hurtful impacts on long-term exposure. Progression of nanotechnology and its uses in food and agribusinesses suggested that nanoparticle ought to be chosen cautiously, dealing with the two, its advantage and disadvantage (Dasgupta et al. 2015). This appears to be a much more earnest issue to challenge seeing the huge number of nanoformulations conceivably utilized in the agricultural practice just as the doubts concerning potential connections with variable ecological components. These might incorporate the as yet unclear impact of normally happening ultrafine particles on the destiny of nano-agrochemicals; the doubts concerning the alterations brought about by maturing, soil, etc.; as well as those induced by the diverse work procedures adopted together with the difficulties in enumerating all these variables into an adequate risk assessment process (Mansoori 2017). In any case, these perspectives ought to be taken into cautious thought since they might influence the physico-substance portrayal of nanomaterials, changing their toxicological profile and consequently word-related dangers. Some of the major risks associated with use of nanotechnology are summarized below:

1. The danger in the area of nanotechnology is blended itself and ecological, health, industrial, and socioeconomic risks.
2. NPs will initiate toxicological consequences for a life form upon contact.

3. Because of the extraordinary potential for application in regions where the nanoparticles can come in direct individuals contact and can cause negative or unwanted harmful impacts.
4. Early exploration too demonstrates that nanoparticles influence various parts of the body where they might apply unfavorable impacts.
5. It is likewise that it could possibly disturb cell, enzymatic, and other organ-related abilities posing health hazards.
6. The nanoparticles are additionally non-biodegradable, and on removal, these arranged off materials may shape another class of non-biodegradable poisons.
7. Nanoparticles or the use of nanotechnology enhances the chance of environmental pollution (water, soil, air) and health hazards.
8. The nanotoxicity studies in agriculture are very limited, and it causes a potential risk to plant, microbes, animals, and even humans.
9. The nanotechnology creates the impression that the utmost danger is to the word-related health of the experts engaged with the formulation, packaging, and transportation of the nanomaterials.

5 Challenges and Barriers in Agro-nanotechnology

There are immense difficulties and constrains to be painstaking that facilitate the accountable commitment of nanotechnologies throughout diverse areas where these guarantees to make a huge commitment to usefulness, output, and effectiveness (Priest 2006; Chaudhry and Castle 2011). Several of these challenges are unified and contain:

- Synthesis and improvement of valuable practices for miniscule processes.
- Administrative, legitimate, governmental, ethical, and moral subjects.
- Contest with reputable miniscale innovations and techniques.
- Permit or grant of verification of nanotools idea, delivery pathways, and their outcomes.
- Intellectual right protection, copyright, patenting, and technology transfer division within organization.
- Potential intramural reluctance to accept nanotechnologies and nanotools within organization premises and businesses.
- Responsibilities and commission for Nanotechnology Research and Development in a pattern which are profoundly, effectively, and evocatively applicable to society and mankind.
- Monitoring of extensive production or price challenges.
- Requirement of interdisciplinary assets and investors.
- Health security, toxicity, and their effectual management of the possible dangers or risks of newly designed and developed nanomaterials.
- Community and consumer apprehension about security and involvement might hinder money-making interest and share in nanotechnology-oriented items.

The Australian Academy of Technological Sciences and Engineering (ATSE) has depicted the nanotechnology cascade significance since beginning with the creation of nanomaterials (nanoscale structures in natural and unprocessed forms) which then become nano-intermediates (transitional items with nanoscale properties) and lastly nano-empowered or nano-enabled items. Technique-based problems to be defeated to empower the formulation and manufacture of nanomaterials include efficient inspection of matters through synthesis, standardization, and effective and maintainable approaches for sequential and substantial production, along with thorough quality confirmation and control programs (ATSE 2008, 2013). The recurrent combination and enduring generations of innovative strategies for synthesis of imaginative, unique, and ground-breaking nano-objects into the prevailing production cycles will also necessitate to be addressed that may give confidence in the scale up of nanotech product synthesis into the coming days (Rose et al. 2007; Yang et al. 2009). Additional progress of material characterization techniques and nanoanalytics projects would too be needed to guarantee the forthcoming advancement of nanotechnologies (Naito et al. 2018; Lespes 2019).

Hodge et al. (2009) proposed that there are various administrative or regulatory difficulties or challenges to whom the society will confront in reference to nanotechnology (Bowman and Hodge 2007; Maynard et al. 2011; Moore 2013). A portion of these include large gaps in information and knowledge across different logical outskirts and technical frontlines. The replies are expected to discourse points raised in reference to the security of nanomaterials, along with the effect of newly designed nanomaterials via the material life-cycle. Considerable multidisciplinary research and investigation will be expected to address this information by nurturing proper metrology and norms for nanotechnologies. Efficient and successful strategies for estimating air, and waterborne nanomaterials are required to instituting and networking adequately the occurrence of administrative gaps and enact to current regulation (Kica and Bowman 2012; Allen et al. 2021). Viably evaluating legislative, administrative and regulatory systems, which might be practically acknowledging and recognizing qualities and shortcomings in various methodologies as well. The balancing financial, regulatory, and legislative assistance of government for nanotechnology are a foundation for future revolution, financial upliftment, policy making, and health security. Guaranteeing apposite spotless and trustworthy is going through all sectors of well-established and emerging nanotechnology guideline structures (Currall et al. 2006; Chaudhry et al. 2007; Siegrist et al. 2007a, b; Taylor 2008; Kumar et al. 2015).

6 Ethics of Nanotechnology in Agriculture

Nanotechnology is perceived as one of the vital technologies which has great possible benefits, and it has to be espoused with a cautionary standard, as that much is not known about its undevised effects on report of being new (Siegrist et al. 2007a, b). Although an excess of claims for nanotechnology in several fields and progressively more assertions are being used in the field of agriculture, and in reality, the common global population appears to know slightly about nanotechnology. Interestingly it was reported that a huge proportion of the US and the European general public have equitably very confined knowledge about the nanotechnology (Siegrist et al. 2008). So, it is clear that if public awareness of nanotechnology in such evolved societies where the literacy rates are relatively high is limited, then the situation is much worse in other parts of world that are also struggling with high illiteracy rates.

Nanotechnology inventions do not evoke arguments as biotechnology; maybe it is significant considering either similar solutions in the copyright law for the nanotechnology should be interject in the future. The nanotechnology is based on the methods and techniques of maneuvering matter on nanoscale, and it makes no difference either it is living or nonliving matter (Chaudhry et al. 2008). Public receptiveness of new technologies is the main feature of their development. The public should be conscious about the potential risks, benefits, and essential measures linked to the usage of nanotechnology. There are a number of reasons why implantation of nanotechnology in agriculture is still comparably at an early stage with other fields. The vital ones include lack of guidelines and unifying regulations on risk evaluation of nanotechnology and potential consumer health possibilities. In the face of potential risk levels that nanotechnology in the field of agriculture pose to the health of public and environment, people doubted that should the industry carry on using these nanosystems in spite of the unpredictability.

Nanotechnology has two greatest threats which are misuse and catastrophic accidents (Sozer and Kokini 2009). Several other ethical issues arise with development of nanotechnology like: Will it provide us more supernatural powers? It may head us to undetectable monitoring, and right to policy can be threaten. It has prospect to eliminate the other ethical issues (e.g., in plants target delivery of active ingredients can be done without damaging non-target plant tissue and also amount of chemical release in environment reduce). Public and related authorities wonder do they have a responsibility to help and provide other countries the technology (Marquis et al. 2009). General debate of people must be held and encouraged in a way to help the people in making an independent viewpoint. A significant role in this procedure should be played by the scientists, elucidating the process, principles, and applications of the nanotechnology among the people. The categorizing of agricultural crops having NPs should be supported to upgrade the free choice of use of these products by the people. It is essential for scientists to make a strong awareness among the people and forces that influence general public and also alert them about benefits and technological risks and failure. As a result, leadership and ethical personal decision-making will be developed in person to solve the problem of technological world (Smolkova et al. 2015).

7 Conclusions

Nanotechnology guarantees to further develop current agriculture practices through the upgrade of the executives and security of contributions to crops and other allied areas. The expected uses and advantages of nano-innovation are gigantic. Usefulness upgrade through nanotechnology-driven farming and expansion of result with minimization of contributions through better checking and designated activity is attractive. Nanotechnology empowers plants to utilize water, pesticides, and composts all the more proficiently. Nanotechnology use might carry possible advantages to growers through food production and to the food business through advancement of inventive items through food handling, protection, and bundling. Expected agri-food nanotechnology applications incorporate nanosensors/nanobiosensors for distinguishing microorganisms and for soil quality and for plant well-being observing, nanoporous zeolites for slow-discharge and productive measurements of water and composts for plants and of supplements and medications for animals, nanocapsules for agrochemical conveyance, making biofuels, nanocomposites for plastic film coatings utilized in food bundling, antimicrobial nanoemulsions for applications in cleaning of food, nanobiosensors for recognizable proof of microbe pollution, and further developing plant and creature reproducing.

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