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Outlooks of Nanotechnology in Organic Farming Management

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ABSTRACT

Technological advances are getting monitored with time, and science suggests nanotechnology as the emerging future. This even holds correct with human food consumption for health benefits, where organic farming is a better solution for the rising population and is even supported by major countries instead of using chemical fertilisers and pesticides. Nanotechnology provides a platform where nanoparticles help in better management for organic farming by using it as nano fertilisers, nanocides, nano biosensors, nano growth promoters, etc. These nanomaterials can be synthesised by three different mechanisms namely; chemical, physical, and biological methods. Since the chemical and physical mode of synthesis does not follow the criteria of organic farming and have their drawbacks. Hence, the biological method, also known as the green synthesis of nanomaterials fulfills the requirement of organic farming and has achieved the attention of researchers. Extracts of plant parts (stems, roots, leaves, flowers and, fruits) and different microbes, including bacteria, fungus, and mycorrhiza can be used as a base material for the synthesis of nanoparticles under green synthesis mode. The vision behind the green synthesis of nanoparticles was to curb the hazardous effects of chemically synthesised nanoparticles. In the present review, green synthesis of major elements of organic farming namely; nano fertilisers, nano-pesticides, and nano growth promoters, their modes of transportation, their advantages, and disadvantages in organic farming are discussed.

Keywords: Nano-fertilisers; Nanocides; Nano-plant growth promoters; Organic farming

1. INTRODUCTION

Agriculture is the main pillar of developing countries and provides food for a healthy life. The current population of the world is 7.6 billion, with 11.2 billion anticipated by 2100[1]. As land scarcity, water scarcity, and dependence on traditional crops are important challenges in the current agricultural landscape, only technology interventions can meet the need for quality and quantity food for the targeted population. Although, in the 1960s "Green revolution" and in the 1980s Genetically Modified Crops[2,3,69] enhanced the overall crop production, but simultaneously these chemical and gene editing-based practices caused damages to the environment and created an imbalance in the ecosystem. To counteract these effects, demand for organically farmed goods has risen in recent decades. The health benefits of organically cultivated food, as well as food safety concerns, triggered the start of the second green revolution. Organic food production is defined as "Cultivation without the application of chemical fertilisers, and synthetic pesticides or genetically modified organisms, growth hormones, and antibiotics"[4]. Northbourne coined the word "organic" in his book "Look to the Land," published in 1940. According to Northbourne, 'There should be a biological unit in the farm; it must be alive, and must possess a balanced organic life.' He also termed organic farming as 'An ecological production management system that advances and amplifies ecosystem, biogeochemical cycles, and soil biotic properties'[5].

In The World's Organic Agricultural Land, India holds 8th position whereas it secures 1st position in terms of a total number of producers with 4339184.93 ha area under the organic certification process and 3496800.34 MT production of ratifying organic products. Oil Seeds, Millets, Fiber, Sugar Cane, Cereals, Cotton, Pulses, Tea, Coffee, Fruits, Spices, Dry Fruits, Vegetables, Aromatic & Medicinal Plants, processed foods, and so on are all classified as organic products. Madhya Pradesh has the most organically certified land of any Indian state, followed by Rajasthan, Maharashtra, Chhattisgarh, Himachal Pradesh, Jammu & Kashmir, and Karnataka. Sikkim made the incredible achievement of converting its whole cultivable land (more than 75000 acres) to organic certification in 2016 (FIBL & IFOAM Year Book, 2020). Nanomaterials have transformed modern agriculture methods, assisting in the solutions of conventional farming challenges while also enhancing organic farming applications. Nanomaterial's large area-to-volume ratio and new physicochemical features have received much interest and have been implemented into a wide range of sectors, including chemistry, pharmaceutical research, diagnosis, therapeutics, and agriculture[6-7]. Nanotechnology

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refers to a group of technologies that deal with manipulating matter on a 1–100 nanometre scale. Particles smaller than 100 nm sizes exist in an intervening zone between discrete/independent atoms or molecules and the correlating bulk material, causing drastic changes in the substance's physical and chemical properties. Nanomaterials can be created in three ways: physically, chemically, and biologically[8]. An important goal of this review is to focus on the green synthesis of nanoparticles and applications in crop security for the long-term sustainability of agriculture and the environment.

2. GREEN SYNTHESIS OF NANOPARTICLES

Nanoparticles of desired shapes and sizes can be produced chemically and physically[9], but the formation of nanoparticles by the chemical method leads to the formation of toxic compounds with harmful effects whereas those produced by physical methods are too expensive to opt for[10]. These demerits lead to the development of nanoparticles by using green and environment-friendly modes. The Green approach for the synthesis and characterisation of nanoparticles has emerged as an outstanding division of nanotechnology, especially for

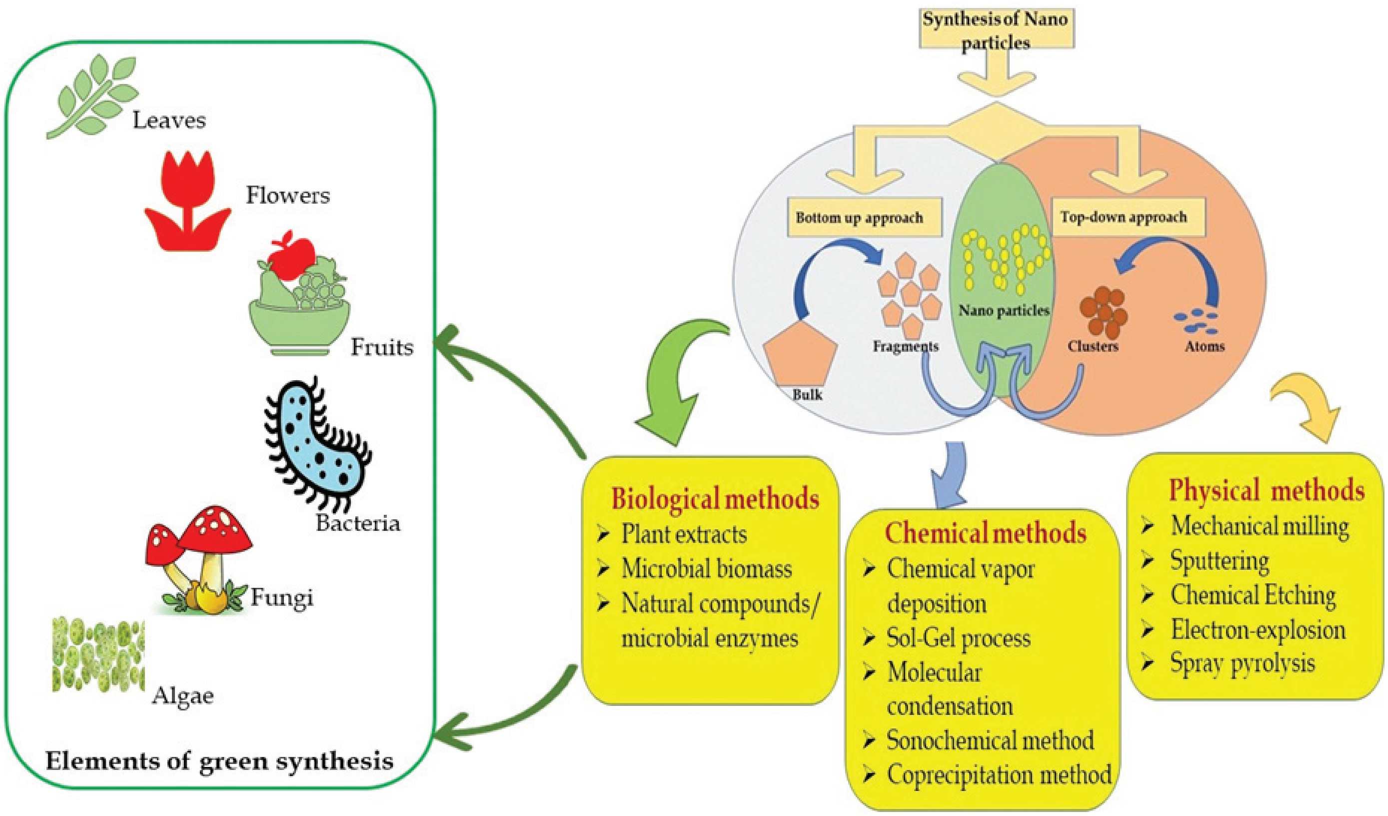

Figure 1. Synthesis of nanoparticles.

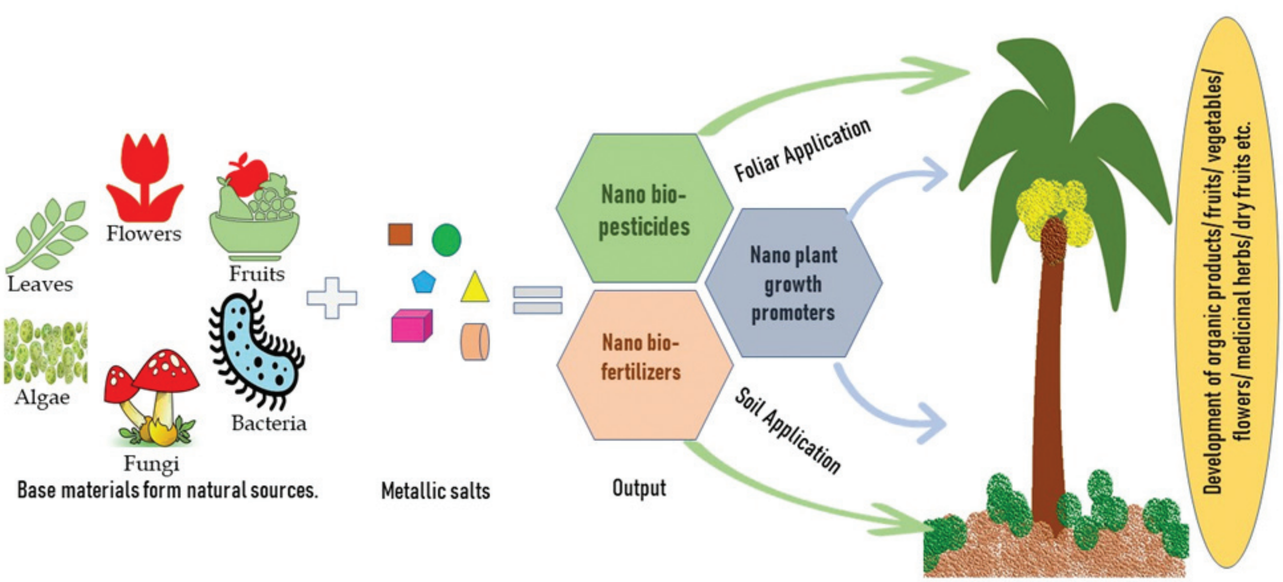

Figure 2. Green synthesis of nanoparticles and their application in organic farming.

Table 1. Application of nanoparticles in organic farming synthesised through green synthesis.

Nano-fertilizers	Size	Source	Effective on	References
Zn	< 100 nm	Basil Plant extract	Basil Plant	12
Cu	< 100 nm	Basil Plant extract	Basil Plant	12
Fe	1.45-2.20 nm	Zeolite	-	13
Fe	< 20 nm	Leonardite potassium humate	Soyabean	14
Fe/Mn	< 25 nm	Bacteria supernatant containing auxin complex (indole-3-acetic, IAA)	-	15
Mn (II/III)	44 nm	Leaf extract of Adalodakam	-	16
MgO	38 to 57 nm.	*Enterobacter* sp. RTN2	*Oryza sativa* L.	17
Cu–Zn/CNFs	34/98 nm	PVA-Starch	Garden soil	18
Ca-P/Nano-NPK/ Urea-NPK		Biomimicking of bone composition	Wheat	19
Nano-pesticides				
Ag	< 100 nm	*Passiflora foetida*	-	20
Ag	70-140 nm	Leaf aqueous extract of *Manilkara zapota*	*M. domestica*	21
Ag	-	Peepal tree, *Ficus religiosa* (FR) and banyan tree*, Ficus benghalensis*	*Helicoverpa armigera*	22
Cu	15.67–62.56 nm	Aqueous extract of *Metarhizium robertsii*	*Anopheles stephensi*, *Aedes aegypti*, *Culex quinquefasciatus*, *Tenebrio molitor*	23
Au	< 100 nm	*Simarouba glauca*	Gram positive and Gram negative bacteria	24
Zn	76.2 to 183.8 nm	*Aspergillus niger* biomass	*Holotrichia sp.*	25
Zn	21.3 nm	*Pongamia pinnata* leaf extract	*Callosobruchus maculatus*	26
N-Doped		Plasma assisted		27
Zn	21-35 nm	*Bacillus cereus* RNT6	*B. glumae* and *B. gladioli* (Pathogen of rice plant)	28
Nano-plant growth promoters				
Zn(II) complex	<20nm	*Trichderma longibrachiatum*	*Vicia feba*	29
Ag complex	3.63–8.68	Polysaccharides of Chlorella vulgaris	*Triticum vulgare* and *Phaseolus vulgaris*	30
Ag complex	25 to 50 nm	*Bacillus siamensis* strain C1,	Rice seedlings	31
FeO	20–80 nm	*Cassia occidentalis* L. flower extract	Pusa basmati rice seeds	32
Nanohydroxyapatite	30 ± 5 nm	*Bacillus licheniformis*	Soil application	33
Nano-TiO_2	20-30 nm		*Oryza sativa L*	34

noble metals such as Au (Gold), Ag (Silver), Pt (Platinum), Pd (Palladium), Fe (Iron), etc. Among all silver nanoparticles is most widely developed and used in the green synthesis method.

Synthesis of nanoparticles can be done by using two different approaches, i.e. (1) Top-Down approach: It is used to develop smaller devices/components by using larger ones to direct their assembly (2) Bottom-Up approach: It is used to arrange smaller components into more complex assemblies. Green synthesis methodology follows the bottom-up approach to synthesize nanoparticles (Fig. 1).

The fundamental idea of nanoparticles synthesis by green mode was first given by Raveendram *et al.* (2003)[11] where β-D-glucose was used as a reducing agent and starch as a capping agent for the preparation of silver nanoparticles. Green synthesis can be done by using various plants of medicinal or ornamental importance, microbes including bacteria, fungus, mycorrhiza, etc., and spices as well (Fig. 2). The vision behind the green synthesis of nanoparticles was to curb the hazardous effects of chemically synthesised nanoparticles and to form biologically beneficial, sustainable, and economical ones. To achieve this goal, the use of supreme/absolute solvent systems and organic/biological resources is required. In this regard, nanotechnology can be helpful by providing smart delivery systems for sustainable development[70]. Here, we outlined the current status of research on the green synthesis of metal and metal oxide nanoparticles used as nano-biofertilisers; nano-biopesticides, and nano-bio-plant growth promoters. (Table 1).

3. NANO-BIOFERTILISERS

With the breakthrough of the Green Revolution, the use of chemical fertilisers was adopted. Since then, the use of chemical-based fertilisers has been practiced to increase the quality, quantity of crops along with soil fertility, which led to the incorporation and persistence of chemicals in the soil as well as in the environment at a hazardous level[35-36].

Though these chemical fertilisers enhanced and enriched the soil fertility and crop production but also caused problems like soil acidification, water, and soil salinity, disturbance of the rhizosphere or micro-biota of the soil, formation of herbicide-resistant species and superweeds, invasion of alien species, and loss of biota of soil and traditional crop plants, leaching and runoff chemicals in water reservoirs which ultimately lead to the soil and water pollution[37-38]. All these problems drew huge concern among scientists and ecologists to find alternatives for chemical fertilisers and were replaced by biofertilisers[39-40].

In general, for the synthesis of nano-fertilisers, selected species of microorganism (specifically used in the formation of bio-fertilisers) is grown in specific nutrient under ambient physical conditions. Once, a microorganism is achieved in an exponential phase in the growth cycle, biomass is collected and filtered out. The filtrate is used for the preparation of nanoparticles. In the case of the synthesis of nanoparticles through plants, extracts of leaves, fruits, flowers, roots, or stems are used. Different extraction methods can be used to prepare plant extract, in which secondary metabolites secreted from plant parts are present. These secondary metabolites reduced the salts and enhanced the formation of nanoparticles. Hence, nano- biofertilisers can be produced by exploiting biological materials like microbes or plant extracts[41].

Plant cell walls have pore diameters ranging from 5 nm to 20 nm, so it restricts the entry of those agents which have diameters more than the mentioned range, even if nanoparticles having a larger diameter than pore diameter could not easily pass through and reach the plasma membrane[42]. Several factors are responsible for the penetration, migration, and cumulation of nanoparticles such as the species of plants, duration, environment for survival, and the physicochemical properties, functionalisation, solidity, and the mode of delivery of nanoparticles.

Many authors have reported the uptake of nanoparticles into plant cells through aquaporins, ion channels, or endocytosis, by forming complexes with membrane transporters or root exudates[43]. Moreover, uptake of nanoparticles is affected by the type of growth medium, plant species targeted, and the size of nanoparticles. This is supported by the findings of Solanki *et al.*,[44] reported that higher uptake of magnetite nanoparticles was observed in *Cucurbita maxima* (pumpkin) when the plant is grown in a hydroponic medium, whereas no uptake was achieved in plants grown in soil. Simultaneously, the absence of the same nanoparticles was recorded in treated lima beans. Later, a study by Wang *et al.*[45] reported that because of the large size of magnetite nanoparticles, the plant cell wall of pumpkin restricted the entry of nanoparticles. Nanoparticles can be coated with the nutrients by any of the following modes.

- Absorption on nanoparticles
- Attachment on nanoparticles mediated by ligands
- Encapsulation in a nanoparticulate polymeric shell
- Entrapment of polymeric nanoparticles
- Synthesis of nanoparticles composed of the nutrient itself.

Nano-biofertilisers could be applied to plants in the following ways by (1) Directly by dusting or mixing the bio-fertilisers with the seed while they are in dry condition (2) In slurry form, while seeds are in wet condition or may be suspended in water (3) Seeds can be encapsulated with the coating of nanoparticles or nano-biofertiliser (4) foliar application (5) applied through seed soaking (6) Mixed in the soil, (7) Through aeroponics, and (8) Through hydroponics[46-47]. Despite several benefits, there are certain demerits of using the Nano fertilisers, like (1) There might be a possibility of development of plant toxicity by the formation of Reactive Oxygen species (ROS) which might cause DNA damage or deterioration of proteins and lipids. (2) It might cause damage to the whole plant or its parts. (3) The crop quality may be compromised. (4) Impaired growth of seeds and rooting or shooting (5) There might be a reduction in biomass. Yet these impairments can be corrected by the use of certain enzymatic or non-enzymatic defense systems[48-51].

4. NANO PESTICIDES

Crop plants are constantly being challenged in nature with various biotic stresses resulting in numerous diseases ranging from bacterial, fungal, and viral[52]. Several management practices have been given, such as the *in-silico* approach, RNAi-mediated resistance, but nanotechnology also plays a wide role in disease management[53]. The development of nano pesticides by exploiting nanotechnology showed greater and newer characteristics like tremendous strength, higher electrical conductivity, and chemical reactivity.

The general mechanism of synthesis of Nano-pesticides through the green synthesis method is similar as described in the synthesis of nano-fertilisers earlier; while for their controlled release formulations, different types of nanomaterials are used such as; nano polymers, nanospheres, nanogels, nano capsules, and micelles. However, the encapsulation of the pesticide is essential for its controlled release as well as to minimize its toxic effects.

Through this process development of pesticides-loaded nanoparticles; insecticides-loaded nanoparticles; herbicides-loaded nanoparticles; fungicide-loaded nanoparticles have been reported by several authors. In 2012, Adak *et al.*[53] demonstrated that in aqueous media, nano-micellar aggregates could be assembled by using certain amphiphilic copolymers synthesised from polyethylene glycol (PEG) and various aliphatic diacids which were used to generate the CR formulations of imidacloprid through the encapsulation technique.

Characterisation of nano pesticides formed is done by using techniques like Infrared (IR) spectroscopy, Dynamic Light Scattering (DLS), and Transmission Electron Microscope (TEM). The formation of nano pesticides using the Controlled Release Formulations (CRF) was used by Wilkins in 2004[54] where he mentioned that it can be achieved by two methods, i.e. Chemical and Physical. The chemical method engages the formation of covalent bonds between the bioactive compounds and the coating agent. There can be intermolecular interactions that can also be made possible by immobilizing the bioactive agent within the coating agent. Whereas, in the Physical method the mixture of bioactive compound and coating polymer is used either in form of a chain or in form of a globule. The CRF approach is widely used for nano- pesticide preparation and application to plants because the components used here possess the ability to regulate and protect the slow and steady release rate of the compound in a definite period to its site[54].

Few examples of nanoparticles used in varied forms can be quoted, such as the use of pheromones from the fruit fly in controlling the pest attack were done by preparing a nanogel from Methyl Eugenol (ME), a pheromone that was easy to handle and can be transported without refrigeration against *Bactoceradrosalis*[55]. Pesticides used in the form of nanotubes filled with alumina silicate were found to stick to the plant surface while the components of the nanotubes stuck to the insect hair and ultimately entered their body by affecting their physiology[56].

Due to the specific shape, size, and confirmation of nano pesticides they exhibit distinct physical, chemical, and biological properties[57] along with many advantages over commercial pesticides like (1) Hydrophobic pesticides in form of microencapsulation can be applied to target pathogens which help in their slow release with longer persistence (2) Due to longer persistence, the amount required also gets minimized as there is no need of applying the nano pesticides multiple times (3) Preparations containing insoluble compounds get dispersed more rapidly as they get to interact with the target insects in a more effective manner due to their solid nature, which also reduces the leaching and run-off with water (4) Minimum requirement of bioactive compounds per unit area so cost also gets reduced (5) Since the nano-pesticides are applied directly to the soil instead of spraying, so there are lesser chances of getting any irritation or infections to the humans (6) It also minimizes the chances of phytotoxicity and adverse effects on the environment as well as to the non-target plants and organisms[58-59].

Instead of providing huge advantages, nano-pesticides can pose a threat to plants or microbes or animals and humans in some or another way. The exposure of skin may show a localised infection to the site of contact or it may mix with the bloodstream and can cause many diseases. Hence, it can be concluded that the use and launch of the nano-pesticides in the form of nanotubes, nanogels, nano capsules, should be done before their proper testing as they can be harmful to the organisms as well as to the environment.

5. NANO-PLANT GROWTH PROMOTERS

Sustainable agriculture requires the use of the minimal agrochemicals feasible to secure the environment and save many species from extinction. Nanomaterials, for example, improve crop yield by strengthening the regulation of agricultural processes, allowing for the intended and managed distribution of nutrients with the least use of agronomics. Nanoscience is a new scientific revolution that entails the creation of opportunities for a variety of low-cost nanotechnological approaches for improved seed sprout, growth and development of the plant, and acclimatisation in different habitats. Seed sprout could be a critical stage in a plant's alternation of generations, as it aids seedling development, survival, and population dynamics.

Seed germination, on the other hand, is strongly influenced by a variety of factors, like environmental factors, genomic traits, water content, soil quality, and richness[60]. In this concern, many studies have demonstrated the use of nanomaterials, improving germination as well as plant growth, and development. Details of the green synthesis of nanoparticles as plant growth promoters are depicted in Table 1.

Despite a large volume of research on nanomaterial-stimulatory effects on germination, the processes by which nanomaterials enhance germination are still unknown. Nanomaterials have been shown in a few studies to penetrate seed coats, promoting water absorption and consumption, stimulating the enzymatic system, and, in turn, improving development and seedling growth[61]. The mechanism for transportation of nanomaterials in seed cells is not known yet but few authors partially explain that nanomaterials have the potential to absorb nutrients and water that help to increase the strength of roots with enhanced enzymatic activity[62]. Moreover, the research on the slow and controlled release or controlled loss of plant growth promoters performed in water and soil has confirmed that nanomaterials remain in the soil and water during the full period of cultivation, which promotes germination, growth, flowering, and fruiting[63].

6. SETBACKS FOR NANOTECHNOLOGY

Practicing the synthesis and use of nanoparticles by using biological agents serve several advantages over the chemical one, such as nanoparticles are very small in size (of nm range), possess high structural integrity, cost-effective, non-corrosive, and non-hazardous nature[64], highly stable with long persistence in the soil, easy product recovery, environmentally safe and beneficial to soil microbes as well as humans, can be coated or encapsulated with reducing agents which limit their rate of solubilisation, the potency of slow and steady release in soil and supplied gradually to plants. Nanotechnological developments though helpful in many ways, but posed many threats to the environment as well as to plants, soil, and ultimately to humans and animals[65]. So, there are various demerits of using nanoparticles for sustainable agriculture. Some are briefly mentioned below: (1) The use of nanoparticles for agriculture can enter into the food chain and ultimately to the gut of animals or humans (2) The bioengineered or genetically modified nanoparticles are comparatively more toxic when used (3) The bioaccumulation, biomagnification, and eutrophication are certain phenomena which may occur while practicing the use of nanoparticles in soil (4) It causes the toxicity of cell i.e. Cytotoxicity at the cellular or genetic levels (5) Cytotoxicity occurs majorly because of the formation of reactive oxygen species (ROS) which are responsible for the cellular and molecular level damage (6) These are responsible for decreasing the biomass of plants by reducing the growth of leaves (7) Reduction in seed germination and growth of roots are also found to be affected by the use of nanoparticles (8) Increased persistence of the nano/biofertiliser in the soil also leads to the disturbance of the microflora of the soil and the rhizosphere (9) Disturbance in the rhizosphere pose threat to their ability of atmospheric N_2 fixation and P and K solubility which in turn declines fertility of the soil (10) Through soil, nanoparticles find their route to enter into the plant cell either by xylem or phloem and can affect the membrane integrity of the cell also[64,66-68].

7. CONCLUSION

Nanotechnology with much advancement served as a tremendous tool to synthesise the nanoparticles either by the chemical, physical or biological method. In the course of further studies, scientists concluded that chemical methods are highly toxic for nanoparticle formation; as they liberate many harmful chemicals while their formation. Also, physical methods are too expensive to use in agricultural fields. Hence, biological methods are frequently used nowadays to tackle various harmful agricultural pests/pathogens. Nanotechnology provided a huge room for the development of components highly useful for the revolution in the organic farming sector by the innovation of biologically based fertilisers of nanoscale and implementing them for the advancement in the quality and quantity of crops and that of soil as well. The growing need for more food and sustainable organic farming leads to the development of things like nano fertilisers, nanocides, nano biosensors, nano-plant growth promoters, and many more. So, to implement the use of such nanoparticles to meet the higher crop yield and soil fertility without much harm to soil microbes and herbivores, and other animals, it is necessary to check their concentration and the level of modification before using them for organic farming.

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