PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.3027

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REVIEW ARTICLE

Nano-technology as an eco-friendly approach in agriculture

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ARTICLE HISTORY
Received: 14 December 2023
Accepted: 17 July 2024

Available online
Version 1.0 : 28 December 2024

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Roy B, Pal AK. Nano-technology as an eco-friendly approach in agriculture. Plant Science Today (Early Access). https://doi.org/10.14719/pst.3027

Abstract

Global food security is now the most challenging issue due to the limited natural resources, low productivity of food crops in the agricultural sector, rapid climate changes and huge population growth. Researchers are trying to adopt newer innovations and technologies to increase the production of food crops to meet the demand. Nanotechnology is one of the most challenging technologies that could enhance the productivity of crops in sustainable agriculture, giving importance to nano-fertilizers, nano-pesticides, nano-biosensors and nano-material-based remediation strategies. The physical and chemical processes to produce nanoparticles (NP) have a detrimental effect on the ecosystem. Thus, green synthesis of NPs using various microorganisms offers a more promising and sustainable alternative. Nanotechnology is very promising as it has many potential benefits like improvement of food quality, minimization of agricultural inputs and enrichment of plants by absorbing nutrients from the soil. Nanoparticles can be used as nanofertilizers, distinct agrochemical carriers and site-targeted or regulated nutrition delivery with improved crop protection. The potential of nanomaterials offers a new green revolution in sustainable agriculture.

Keywords

food security; green nanoparticles; nano-biosensors; nano-fertilizers; nanomaterials; nano-pesticides; nano-technology

Introduction

The demand for food security leads to sustainable development in agriculture through technological innovations (1) throughout the world. Global food security facing challenges throughout the world due to the limited natural resources and the huge population growth demanding the development of agriculture which must be beneficial from the economic and environmental standpoint (2). So, the development of sustainable agriculture is essential to reduce hunger and poverty in rural areas as well as new scientific inventions are needed to get better food production for the global population (3). Global agriculture is facing numerous challenges due to rapid changes in climate. Actually, sustainable agricultural growth depends on nanotechnology and the term proposed by Prof. Norio Tanaguchi (1974) (4). The protection of the environment from the pollution and conservation of different species from extinction is the main target in the development of sustainable agriculture and the innovation of nanotechnology provides a big opportunity to meet the global food demand (5).

Nanotechnology is the science of small particle study between 1-100 nanometers (6). Small size with a greater surface area of different metallic nanoparticles such as silver, gold and zinc has unique characteristics that are useful in medicine, pharmacology, water treatment, industry, anti-cancer, anti-tumor, textile engineering, electronic, surgical devices and biomedical, food processing and packaging, agriculture as nano fertilizer, nutrient delivery, etc. (7).

Green Nanoparticles

Nanoparticles can be generated under the processes of photochemical reactions, simple erosions and volcanic eruptions. Those nanoparticles that are derived from plants and microorganisms having an eco-friendly nature are green nanoparticles (NPs) (8).

Different algae, fungi (9), bacteria, Actinomycetes (10) and a group of plants (11) are used to produce nanoparticles in the procedure of Nano-biotechnology. Gold nanoparticles are produced from *Medicago sativa* and *Sesbania* plant spices whereas inorganic nanoparticles composed of nickel, cobalt, zinc and copper can be produced inside plants like *Brassica juncea*, *Medicago sativa* and *Helianthus annus* (12). Some microorganisms like *Verticillium* sp., *Aspergillus flavus*, *Aspergillus furnigatus*, *Phanerochaete chrysoparium* and *Fusarium oxysporum* are used for the biosynthesis of nanoparticles containing metal sulphide (12). Green nanotechnology can reduce emissions of greenhouse gases. The nanomaterials that may be synthesized from plant materials are known as green nanotechnology (12). Nanomaterials support eco-friendly sustainable development in the field of green nanotechnology.

Different oxidation and reduction reactions were observed between metallic ions and biomolecules that are secreted by microbial cells like sugars, carbohydrates, proteins and enzymes to produce NPs. (13). However, different microbes produce different NPs via different synthesis pathways. Sulfur-containing proteins or DNA are supposed to be used by bacteria to reduce silver, while fungi employ carboxylic group reduction or nitrate-dependent reductase to manufacture extracellular and intracellular AgNPs (14). The intracellular NPs are expensive due to the cost of extra separation and purification steps. The morphological character of NPs can be altered by different experimental parameters like pH, aeration, reactant concentration, salt content, temperature and reaction time (15) whereas these parameters should be under precise control for the betterment.

Smart delivery through nanoparticles

Nanotechnology provides us the sustainable growth in agriculture by following better management practices and conservation procedures with low wastage of agricultural materials (16). The transport of DNA molecules, organic molecules and agrochemicals are very essential in agricultural farming for sustainable agricultural development (17). For sufficient plant growth, agrochemicals are required in effective concentration but there are losses of chemicals due to leaching by photolysis or by degradation of microbes also (18). The controlled delivery of sufficient quantities of agrochemicals on the large surface is possible through the nanoparticles where micronic or submicronic particles get incorporated into agrochemicals by various tactics like capsulation, absorption and surface ionic or weak bonding attachment of nano-martix with effective ingredients (19).

Nano-fertilizers

The increasing world population may reach near about nine billion within 2050 and the future population demands 60-100 % more food (20). But practically the agricultural yield declines due to loss in soil fertility due to lack of proper farming practices. As a result, 40 % of the world's agricultural field is being degraded (21). Generally, one-third of crop productivity mainly depends upon the use of fertilizers whereas the rest is based on agricultural inputs (21). The nutrient use efficiency of fertilizers that are used directly into the soil or sprayed upon the leaves mostly depends upon the concentration of applied fertilizers to move the target sites (22), whereas a very low amount of fertilizers can reach the target site due to loss of chemicals, drift, runoff, hydrolysis, evaporation, photolytic or degradation of microbes also (23). The use of huge fertilizers causes an imbalance in the inherent nutrients of the soil but also causes contamination of drinking water due to the leaching of toxic chemicals into the water (22). Whereas, most of the chemicals remain in the soil and may create adverse effects in the environment that can hamper the growth of flora and fauna (24). Nanotechnology can play an active role in crop productivity through the control of efficient nutrients required for plant growth and it also monitors the quality of water and pesticides for sustainable agricultural growth (12).

There are wonderful changes in agriculture throughout the world as nano-fertilizers are being used to reduce so many problems in agriculture and to meet the demand for food crops (25). Actually, the nano-fertilizers can be generated with special attention to control the release of nutrients and to reduce the various losses during the leaching of chemicals or evaporation (26). Nanofertilizres are so many types depending on their actions (27).

The nano-fertilizers are obtained after the encapsulation of nutrients with nanomaterials which are generated by the use of both physical and chemical approaches. The targeted nutrients are encapsulated within the nanoporous materials or coated by a polymeric film-like substance which is thin-layered and delivered as particles with nano-scale dimension (28).

It has been noticed that the grain yields of rice, spring maize, soybean and winter wheat have been increased after the application of carbon nanoparticles together with fertilizers also (29). The use of porous nanomaterials like zeolites, clay or chitosan can control the uses of nitrogen and also accelerate the nutrient uptake process in the plant body (30, 31).

Several micronutrients such as manganese, boron, copper, iron, chlorine, molybdenum and zinc can play a vital role in crop productivity and the deficiency of those micronutrients can reduce the crop productivity which ultimately affects human health due to intake of micronutrient-deficient food materials (32, 33). It has been observed that the use of nano-zinc oxide enhances the shoot and root elongation side-by-side with the rate of photosynthesis and the fresh dry weight of the plant also increases (34).

Nanopesticides

More than 90 % of conventional pesticides that are used in agriculture may be lost in the environment causing serious environmental depletion and health hazards. The development of nano-materials brings new areas in plant protection where nano-formulation of pesticides containing a very tiny number of particles may act as ingredients of pesticides that are very effective (35). The nano-encapsulated pesticides with slow-releasing properties that can promote solubility, specificity, stability and permeability also (36) and these nano-encapsulated pesticides have a positive environmental impact which increases crop protection.

Fusarium wilt in lettuce and tomato in many nations may be controlled by the application of NPs. It was reported that MgONPs can be effective in controlling green peach aphids in a greenhouse habitat (37).

Plant adaption against progressive climate change

Progressive global climate change leads to food insecurity for the growing population as the available resources are limited and the adaptation of plants in existing sensitive ecosystems is very vital (2). Plants are facing continuous environmental stresses. To overcome this stress and to regularize various functions like control of the enzymatic system of the plant body, regulation of plant hormone and regulation of uptake of toxic metal gene expression, several research efforts have been granted under sustainable agricultural systems (38) to reduce the adverse effects of climate. The adverse environmental situation like salinity stress reduces the production of food crops by approximately 23 % of cultivated land throughout the world (39). It has been noticed that the foliar application of nanoparticles like iron sulfate ($FeSO_4$) gives a better response in sunflower cultivars under salinity stress (40). The application of nano-material shows a better response in various cases like the foliar spray of nano-Si at 2.5 mM concentration in rice plants shows a positive response under Cd stress by controlling the accumulation of Cd (41). The nano -Si fertilizers can also reduce heavy metal accumulation which occurred in the case of conventional fertilizers (42). The potential use of nano-materials shows promising effects in the plant protection field which is environment-friendly in nature (8). The various nano-fertilizers have been applied to various plant species but their response on plants depends upon the plant species, stage of plant growth and the composition of applied nano-materials (31).

Nanotechnology in abiotic stress management

Different abiotic stresses like salt and drought hampered plant growth and productivity (43). Nanobiotechnology can be an alternative to reduce plant stress management from the last few decades. Nanobiotechnology is presumed to improve plant physiology and molecular and biochemical processes to increase plant vigor and yield. Moreover, it can help the plant to fight against environmental factors.

Future trends and Challenges

The use of nano-sensors is very useful to check the crop growth and the conditions of soil, deficiency of micronutrients and macronutrient status, disease development and determination of toxicity that would provide us protection from environmental depletion. The development of bionic plants is very unique in which the nanoparticles are inserted into the choloplastic cells of living plant parts that develop self-powering plants having big potentials as they are able to communicate as infrared devices (44, 45) which is very useful in farming management. It was shown that the implementation of single-wall carbon nanotubes (SWNTs) can able to increase the electron transfer rate of light-mediated chloroplasts *in vivo* conditions which is a very intelligent application (46). Another interesting area of research has been shown, where a gold electrode nanosensor with copper nanoparticles was used to identify the pathogenic fungus spread out by controlling the salicylic acid level in the case of oil seed crops (47). So, the application of nano-sensors brings a new window for future research.

Green synthesis of NPs is a possible and environment-friendly approach for agricultural applications, such as nanopesticides, nanofertilizers and nanobiosensors. As the behaviors of these NPs in the ecosystem are not predictable and metallic NPs can be detrimental to the growth of many harmful bacteria, they can also be harmful to other neutral microbes in nature. So, it is very critical to asses more prominent ways to apply these NPs in agriculture in a sustainable manner. However, the application and toxicological screening of nanotechnology should have adequate regulations and legislation.

Table 1. Green biosynthesis of NPs using bacteria.

Bacteria	Nanoparticle	Morphology of the nanoparticle	Size (nm)	Reference
Aeromonas sp. SH10	Silver	-	6.4	(48)
Bacillus cereus	Silver	Spherical	20-40	(49)
Bacillus megatherium D01	Gold	Spherical	1.9 ± 0.8	(50)
Clostridium thermoaceticum	Cadmium sulfide	Amorphous	-	(51)
Corynebacterium sp. SH09	Silver	-	10-15	(52)
Desulfobacteraceae	Zinc sulfide	Spherical	2-5	(53)
Desulfovibrio desulfuricans	Palladium and selenium	-	-	(54)

Desulfovibrio vulgaris	Gold, uranium and chromium	-	-	(55)
Desulfovibrio magneticus strain RS-1	Magnetite	Crystalline	Up to 30	(56)
Escherichia coli	Cadmium sulfide	Wurtzite crystal	2-5	(57)
Escherichia coli	Silver	Spherical	8-9	(58)
Escherichia coli DH5*α*	Silver	Spherical	10-100	(59)
Escherichia coli DH5*α*	Gold	Spherical, triangular and quasi-hexagonal	25 ± 8	(60)
Escherichia coli MC4100	Gold	Spherical, triangular, hexagonal and rod shape	Less than 10 to 50	(61)
Geobacillus sp.	Gold	Quasi-hexagonal	5-50	(62)
Geovibrio ferrireducens	Gold	-	-	(63)
Klebsiella aerogenes	Cadmium sulfide	Crystalline	20-200	(64)
Lactobacillus strains	Silver	Crystalline, hexagonal, triangular and Cluster	15-500	(65)
Lactobacillus strains	Gold	Crystalline, hexagonal, triangular and Cluster	20–50 and above 100	(65)
Lactobacillus strains	Silver-gold alloys	Crystalline and cluster	100–300	(65)
Lactobacillus strains	Titanium	Spherical	40–60	(66)
Lactobacillus casei subsp. *casei*	Silver	Spherical	25–50	(67)
Magnetospirillum magnetotacticum	Magnetite	Cluster (folded-chain and flux-closure ring)	-	(68)
Nocardiopsis sp. MBRC-1	Silver	Spherical	~45	(69)
Plectonema boryanum UTEX 485	Gold	Cubic and octahedral Platelet	~1–10 and 10 to 6000	(70)
Pseudomonas aeruginosa	Gold	-	15–30	(71)
Pseudomonas aeruginosa	Lanthanum	Crystalline and needle-like	-	(72)
Pseudomonas fluorescens	Gold	Spherical	50–70	(73)
Pseudomonas putida NCIM 2650	Silver	Spherical	~70	(74)
Pseudomonas stutzeri AG259	Silver	Hexagonal, equilateral triangle, crystalline silver and monoclinic silver sulfide acanthite	35–46 and up to 200	(75)
Rhodobacter sphaeroides	Zinc sulfide	Spherical	Average diameter of 8	(76)
Rhodopseudomonas capsulata	Gold	Nanoplate and spherical	10–20	(77)

Conclusion

At present sustainable agriculture is a promising way to provide human food that should take modern knowledge to bring green revolution in the agricultural field to meet the global food demand. The target of nano-materials used in sustainable agriculture is to minimize nutrient losses and to increase the production of food crops. More emphasis should be given to reducing the gaps in our knowledge regarding the properties of different nano-materials and their use as every scientific innovation is being targeted to meet the demand of human welfare. The advancement of nanotechnology in environmental protection and to generate quality food products brings new hope for global food security.

Acknowledgements

The authors would like to acknowledge the financial help from DST-PURSE programme of Department of Science and Technology, GOI, India.

Authors' contributions

BR designed the manuscript. BR and AKP wrote the manuscript.

Compliance with ethical standards

Conflict of interest: The authors have no conflict of interest.

Ethical issues: None

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