



Official publication of Pakistan Phytopathological Society

Pakistan Journal of Phytopathology

ISSN: 1019-763X (Print), 2305-0284 (Online)

http://www.pakps.com



GREEN SYNTHESIS AND CHARACTERIZATION OF SELENIUM NANOPARTICLES AND ITS APPLICATION IN PLANT DISEASE MANAGEMENT: A REVIEW

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ABSTRACT

Nanotechnology deals with the production of small-sized nanoparticles with sizes of 1-100 nm which play a substantial role in plant disease management and are synthesized utilizing chemical, physical and biological processes. Green synthesis has gained significance over other methods of synthesizing nanoparticles. These nanoparticles are characterized using different characterization techniques like UV.VIS, FTIR, SEM, TEM, DLS, XRD, EDX, Raman spectroscopy, and Zeta potential. Selenium nanoparticles over other nanoparticles play an important role in plant disease management by controlling various plant diseases like downy mildew of pearl millet, early blight of potato, and inhibiting various fungi like *Alternaria*, *Candida albicans*, *Pyricularia grisea*, and *Alternaria solani* on chili and tomato.

Keywords: Nanotechnology; Nanoparticles; Selenium nanoparticles; Green synthesis; Mechanisms.

INTRODUCTION

Nanotechnology plays a revolutionary role in science and technology by managing the materials at the Nanoscale. In fact, nanotechnology refers to any technology based on Nanosized materials having multiple applications in the actual world by encompassing the fabrication and application of physical, chemical, and biological systems from individual molecule to an atom into nano-sized material and uses this submicron-sized into these systems. This technology solves global problems and meets our needs (Nasrollahzadeh *et al.*, 2019). It deals with an extensive range of uses in agriculture, pharmacology, medicine, and other domains (Sinha *et al.*, 2017; Balaure *et al.*,

Submitted: January 30, 2022

Revised: May 17, 2022

Accepted for Publication: June 25, 2022

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2017). Nanotechnology enhances seed germination, and transfers target genes, Nano-biosensors, hormone delivery, and nano barcoding in agriculture, as well as reduces the emission of chemicals associated with agriculture (Hayles *et al.*, 2017). This technology is an art and science that manipulates matter into nanoscale sizes, characterizes, and then uses them for the desired purpose by controlling its shape and structure (Abobatta, 2018). It ranked at sixth as a revolutionary technology in this century (Mousavi and Rezaei, 2011). Nanotechnology is a type of applied technology that develops at the atomic level and then modifies it into a Nanostructure with unique qualities. It is becoming increasingly important in the domains of agricultural and medical sciences (Bayda *et al.*, 2020; Imani and Safaei, 2019). It has made it feasible to recognize the basic properties of an object at the atomic, molecular, and supramolecular levels.

Biotechnology provides role models and biosynthetic elements to nanotechnology, while nanotechnology

provides a different technological method for the discovery and creation of bioactive compounds (Keat *et al.*, 2015). The synthesis and application of materials whose atoms exist at the nanoscale, which is defined as a size of fewer than 100 nanometers, is known as nanotechnology. At the molecular and sub-molecular levels, this technology investigates electrical, optical, and magnetic activity, as well as structural behavior. It has the potential to revolutionize a variety of medical and biotechnological instruments and procedures by making them more portable, affordable, safe, and simple to use (Hasan S, 2015). Nanoparticles have unique properties as a result of their small size, which is why they have such a wide range of applications, but they also pose a serious environmental hazard. The number of studies examining the potential Ecotoxicity of nanomaterials has increased in the recent decade, with the purpose of understanding nanomaterials, despite their benefits, cause harm to the environment (Reboredo *et al.*, 2021). There are different types of nanoparticles including

metal nanoparticles, ceramic nanoparticles, and polymeric nanoparticles. For decades, noble metal nanoparticles have been created and studied. They've established a reputation in a range of fields, including homogeneous and heterogeneous catalysis, nanomedicine, and imaging (Peldon *et al.*, 2017). Their synthesis techniques have been fine-tuned to perfection, with precise control over particle size and shape (Peldon *et al.*, 2017). Ceramic nanocomposites have attracted a lot of attention in recent years because of their ability of increasing mechanical, thermal, and electrical properties when compared to ordinary ceramic matrix composites (Palmero, 2015; Rathod *et al.*, 2017). Nanocapsules and Nanospheres, which have different morphological structures, are both classified as nanoparticles. Polymeric NPs have shown a lot of promise in terms of delivering drugs to precise regions for the treatment of a range of diseases (Musumeci *et al.*, 2019).

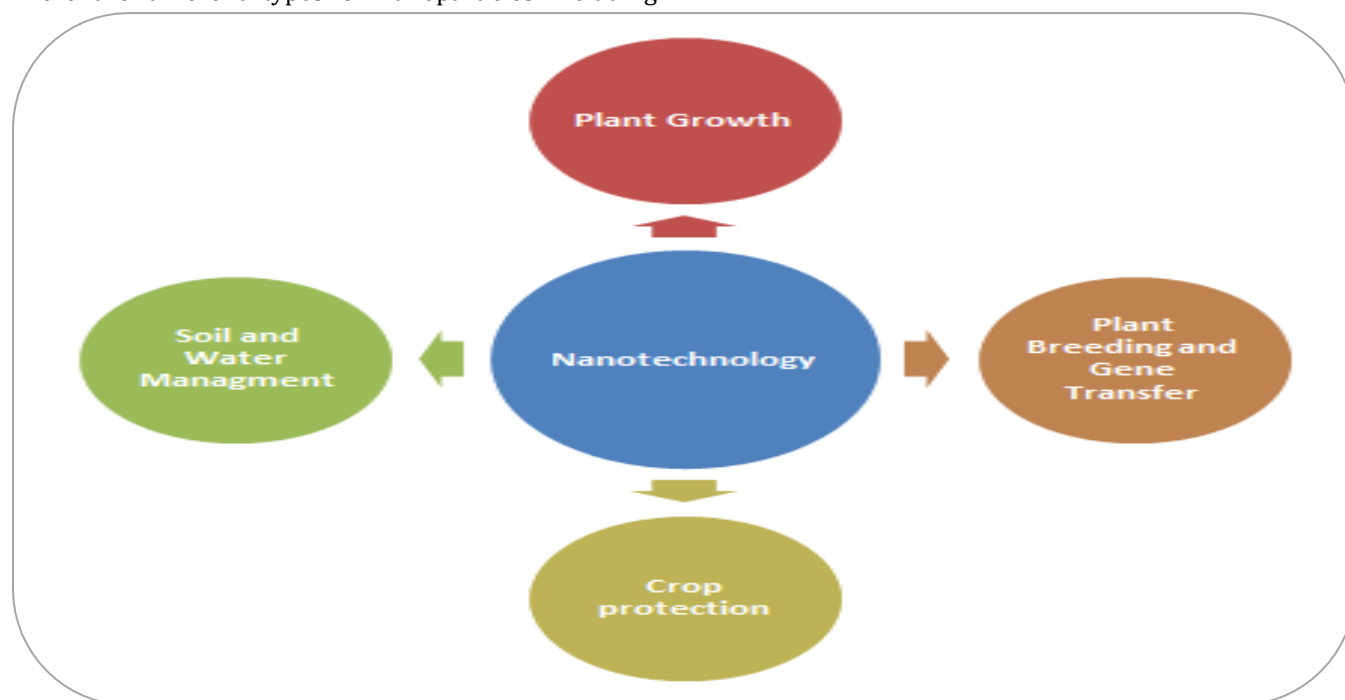


Figure 1. The significance of nanotechnology

Selenium (Se) is a critical element or micronutrient that must be monitored regularly in disease management (Menon *et al.*, 2017). Selenium, which is present in enzymes like glutathione peroxidase (GPx) as well as other seleno-chemical substances, is shown to boost chemotherapy efficacy by acting as a functional area of the redox center and excluding tissue destruction due to

reactive oxygen species (ROS) (Soumya *et al.*, 2018).

Nanoparticles are made through physical, chemical, or biological processes, with biological techniques involving plants or microbes being the most popular. The use of natural vegetation, microbes, microalgae, enzymes, plants, and plant extracts in the biofabricated protocol highlights the use of natural vegetation,

microbes, microalgae, enzymes, plants, and plant extracts, which provides a dependable, easy, and low-cost method with eco-friendly behavior, nontoxicity, and a stable nature and environmentally friendly results. (Menon *et al.*, 2019). Green source-mediated synthesis

allows for fine control of nanoparticle size and form because plants function as both stabilizing and reducing agents. Green nanoparticles have a much lower inhibitory effect than chemically produced nanoparticles.

Green Synthesis of SeNPs

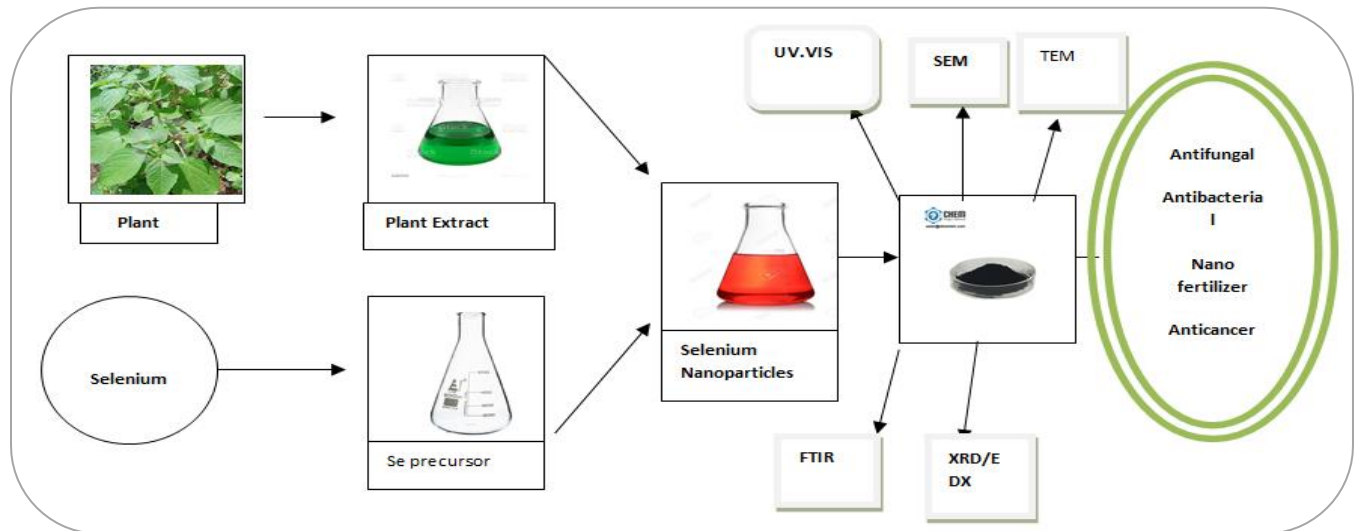


Figure 2. Bio fabricated SeNPs through Plant extracts, Characterization, and its Application

Plants play a fundamental role in the production of bio fabricated nanoparticle. Plants make metabolites, which aid in the breakdown of precursor molecules. In the production of nanoparticles, it also serves as a catalyst and stabilizer. Plants that contain selenium are primarily involved in the formation of SeNPs at first. Plants absorb selenium from the soil, which has been released by sediment rock. Plants that contain se can be divided into two groups: those that actively accumulate selenium in proportion to the quantity available in the soil (e.g. wheat), and others that actively gather selenium in vastly greater quantities than the soil

concentrations (e.g. wheat) (e.g. Astragalus sp.). Distinct plant species have different chemical kinds of Se, and the chemical type of Se regulates its bioavailability. Selenium can be securely contained within plant membrane-bound structures in various forms. Many of these methylated compounds necessitate the production of the enzyme seleno-cysteine-specific methyl transferase. SeNPs are produced by a variety of plants, including some that do not utilize selenium. Some examples include *Aloe vera*, *Withania somnifera*, *Diospyros Montana*, and *Trigonella foenum-graecum* (Subramani and Siphkema, 2019).

Table:1. Different plants parts used to Synthesized SeNPs along with their Size and Shapes

Sr. No	Salt	Plant Extract	Part of plant used	Size of NPS	Shape	Characterization	References
1	Selenium powder	<i>Clausen adentata</i>	Leaf	46.32 to 78.88 nm	spherical	SEM, EDX, XRD, FTIR, and UV-Visible Spectroscopy	Sowndarya et al, 2017
2	Selenious acid	<i>Moringa olifera</i>	leaf	3.5 nm	Spherical	SEM, TEM, DLS, UV.VISIBLE Spectroscopy and EDX.	Abu-Zeid <i>et al.</i> , 2021
3	Selenious acid	<i>Allium sativum</i>	Bulb	205 nm	Spherical	FTIR, EDX, XRD, SEM, RAMAN Spectroscopy, and DLS	Ezhuthupurakkal <i>et al.</i> , 2017
4	Sodium selenite	<i>Z.officinales</i>	Fruit	100 nm	spherical	UV. Visible spectroscopy, SEM, XRD, EDX, FTIR, Zeta Analyzer	Menon <i>et al.</i> , 2019
5	Selenium salt	<i>Ginkgo biloba</i>	Leaves	100 nm	spherical	UV. Visible Spectroscopy, SEM, Zeta Analyzer, XRD, EDX	Alsaggaf <i>et al.</i> , 2020
6	Sodium Selenite	<i>Pilargoniumzonale</i>	Leaves	50 nm	spherical	SEM, XRD, EDX, Zeta Analyzer	Fardsadegh <i>et al.</i> , 2019

7	Sodium Selenite	<i>Allium sativum</i>	Buda	79.60 nm	spherical	SEM, XRD, EDX, and UV. Visible spectroscopy	Ikram <i>et al</i> , 2020
8	Sodium Selenite	<i>Juglans regia L.</i>	Leaf	150 nm	Spherical	UV. Visible Spectroscopy, FTIR, TEM, Zeta Analyzer	Sheikhlou <i>et al</i> , 2020
9	Sodium Selenite	<i>Coffee bean</i>	Leaf	100 nm	Spherical	FTIR, TEM, UV. Visible Spectroscopy, DLS, Zeta Potential, SPR,	Abbasian and Jafarizadeh-Malmiri, 2020
10		<i>Ephedra aphylla</i>	Stem	13.95 to 26.26 nm	Spherical and tetragonal	TEM, Zeta Potential,	El- Zayat <i>et al</i> , 2021
11	Sodium Selenate	<i>Catharanthus roseus</i> ,	flower	32.02 nm	Spherical	UV. Visible Spectroscopy, LS, FTIR, SEM, TEM, EDAX,XRD,TEM,SPR	Deepa and Ganesan, 2015
12	Sodium Selenate	<i>Peltophorumpterocarpum</i>	flower	40.02 nm	spherical	TEM, EDAX, XRD	Deepa and Ganesan, 2015
13	Sodium Selenite	<i>Psidium guajava</i>	Leaves	8-20 nm	spherical	UV. Visible Spectroscopy, FTIR, TEM, SEM,	Alam <i>et al</i> , 2019
14	Selenium oxide	<i>Ziziphusspina-christi</i>	Leaves	20-45 nm	Spherical	UV, Vis. SEM, TEM, FTIR, XRD	Lashin <i>et al</i> , 2021
15	Selenous Acid	<i>Nilgiranthusciliates</i>	Leaves	N/A	N/A	UV. VIS. FE-SEM, HR-TEM,DLS, Zeta Potential, FTIR	Meena <i>et al</i> , 2021
16	Selenious dioxide, Sodium selenite	<i>O.tenuiflorum</i>	Leaves	15-20 nm	Spherical	UV.Vis. FTIR, XRD, SEM, EDAX	Liang <i>et al</i> , 2020
17	Selenious Acid	<i>Vitis vinifera</i>	Leaves	3-18 nm	Spherical	TEM, XRD, FTIR, XRAD, DLS,SEM, TEM	Sharma <i>et al</i> , 2014
18	Selenious Acid	<i>Carica Papaya</i>	Fruit	50 nm	spherical	UV. Vis., SEM, TEM,FTIR, XRD, DLS	Rajasekar and Kuppusamy, 2021
19	Selenious Acid	<i>Withania somnifera</i>	Leaves	45-90 nm	Spherical	UV. Vis. SEM, TEM FTIR, EDX, XRD	Alagesan and Venugopal, 2019
20	Sodium Selenite	<i>Cerpegia bulbosa</i>	leaves	55.9 nm	Spherical	UV.Vis. XRD, FTIR, FE-SEM, HR-TEM, DLS, Zeta potential	Cittrarasu <i>et al</i> , 2021
21	Sodium Selenite	<i>Citrus paradesi, Citrus Lemon</i>	fruit	1.5-2 nm	spherical	UV.Vis., FTIR, SEM, DLS, Zeta analyzer	Alvi <i>et al</i> , 2021
22	Sodium Selenite	<i>Fenneropens indicus</i>	Shell waste	6.8-58.2 nm	Spherical	UV. Vis. Zeta analyzer, SEM, TEM, DLS, FTIR	Alghuthaymi <i>et al</i> , 2021
23	Selenious Acid	<i>Fenugreek</i>	Seeds	50-150 nm	Oval	UV. Vis. SEM, TEM DLS, Zeta analyzer, FTIR, XRD	Ramamurthy <i>et al</i> , 2013
24	Selenium nitrate	<i>Solanumnigrum</i>	Dried Leaves	N/A	N/A	UV.Vis.	GOPLASAMY and Ramamurthy, 2020
25	Sodium hydrogen selenite	<i>Petroslenumcrispum</i>	Leaves	50-100 nm	Spherical	UV. Vis, DLS, AFM, FTIR,	Fritea <i>et al</i> , 2017
26	Sodium Selenite	<i>Hordeum vulgare. L</i>	Leaves	50-200 nm	Spherical	ICP-MS, UV. Vis. SEM, TEM, XRD	Habibi and Aleyasin, 2020
27	Sodium selenite	<i>Aloe Vera</i>	Leaves	9-58 nm	Spherical	UV. Vis, TEM, SEM FTIR, DLS	Jay and Shafkat, 2018
28	Sodium Selenite	<i>Azadirachta indica</i>	Leaves	153-278 nm	Spherical	Uv.Vis. SEM, TEM, XRD	Mullah <i>et al</i> , 2020
29	Sodium Selenite	<i>Camellia Sinensis</i>	Leaves	83-160 nm	spherical	UV. Vis, TEM, XRD, FTIR	Zhang <i>et al</i> , 2018
30	Sodium Selenite	<i>Bougavila spectabilis</i>	Flower	18-35 nm	Hollow crystal	UV. Vis. FTIR,XRD, SEM and EDAX	Deepa and Ganesan, 2015
31	Sodium Selenite	<i>Terminalia arjuna</i>	Leaves	10-80 nm	Spherical	SAED, AAS, SEM, FTIR, SEM, XRD, EDX and UV-Vis.	Prasad and Selvaraj, 2014
32	Sodium Selenite	<i>Diospyros Montana</i>	Leaves	4-16 nm	Spherical	UV. Vis, XRD, FTIR, TEM, SEM, DLS, Zeta potential	Kokila <i>et al</i> , 2017
33	Sodium selenite	<i>Allium sativum</i>	Leaves	7-48 nm	Spherical	SEM, TEM, UV. Vis. FTIR, EDAX	Jay and Shafkat, 2018
34	Sodium Selenite	<i>Capparis decidua</i>	Fruit	----	----	Uv. Visible Spectroscopy	Ali <i>et al</i> , 2020

Different plants used for the formation of SeNPs their size characterization techniques also their precursor and shapes of selenium nanoparticles are given in the table.

Characterization of SeNPs: UV-Visible spectroscopy is used to quantify Plasmon resonance and overall oscillations of conduction band electrons in response to electromagnetic waves to confirm the synthesis of NPs (Ingale and Chaudhary, 2013). It contains precise information about NP structure, size, aggregation, and stability (Zook *et al.*, 2011). When a specific wavelength of light is struck on NPs, it generates reverberation with electrons in the conduction band on the surface. Metallic NPs have discrete absorbance bands in their characteristic spectra; therefore each metal's NPs have a different range of absorbance peaks based on their size. The absorbance peak of gold NPs, for example, is between 500 and 550 nm, while the peak of silver NPs is between 400 and 450 nm (Haiss *et al.*, 2007; Rafique *et al.*, 2017). The absorption band of Cu-NPS ranges from 550 to 600 nanometers (Sun *et al.*, 2000). On a spectrophotometer, selenium nanoparticles in the range of 200 nm to 800 nm can be created (Kokila *et al.*, 2017). Scanning electron microscope (SEM) pictures with a resolution of 500 nm were taken (Hitachi s-3400N) and detectors containing secondary electron; semiconductor BSE (Quad type) were used to investigate the size and shape of SeNPs (Ramamurty *et al.*, 2013). This approach is used to get detailed surface information on NPS (Lindsay, 2010). Scanning tunneling microscopy was the first technique used to examine the morphology and size of nanostructures (STM). This method's main advantage is that it may be used on a broad variety of materials, including metals and semiconductors (Wysokowski *et al.*, 2013). This approach is used to get detailed surface information on NPS (Lindsay, 2010). Scanning tunneling microscopy was the first technique used to examine the morphology and size of nanostructures (STM). This method's main advantage is that it may be used on a broad variety of materials, including metals and semiconductors (Wysokowski *et al.*, 2013). TEM is the best of the regularly used techniques for determining the morphology of NPs. A beam of strong electrons is delivered through an ultrathin sample and interfaces, and the electrons are employed to generate a picture in this sort of microscopy. The electron beam exposes the crystalline specimen in TEM, the transmitted electrons are directed across the atomic sites, and the directed electron beam generates the image. The sample's planes' orientation about the electron beam determines the direction's intensity (Zhang *et al.*, 2003). The shape of selenium nanoparticles might be trigonal or spherical (Sarivastava and Mukhopadhyay 2003). FT-IR

spectroscopy was used to confirm the existence of functional groups that were predominantly involved in the bioreduction of SeNPs (Ramya *et al.*, 2015).

XRD was used to validate the synthesis of SeNPs in the film (Kalishwaralal *et al.*, 2017). This method is used to look at the structure of newly created NPs (Sun *et al.*, 2000). EDX analysis can be used to identify the qualitative and quantitative status of elements that may be involved in the formation of nanoparticles. The elemental content of selected areas inside SEM slices was examined using EDX microanalysis equipment. This study confirmed the high purity of the generated selenium nanoparticles.

According to EDX developed from Se nanoparticles, the Se-NPs were entirely composed of selenium. The C, O, Na, P, Cl, and Mg peaks were most likely caused by the glass underlay (Zhang *et al.*, 2011). DLS is a method for calculating the size and aggregation of nanoparticles. Photon correlation spectroscopy or quasi-elastic light scattering are other names for it. For analyzing colloidal solutions and macromolecules, it is a more powerful, sensitive, and faster equipment (Zanetti-Ramos *et al.*, 2009).

For Raman spectroscopy experiments, aqueous solutions of Se NPs were coated as thin films on small pieces of aluminum foil and dried in the air at ambient temperature. A Peak Seeker Pro 785 Raman spectrometer (Ocean Optics) was used to produce normal Raman spectra with a 785 nm excitation (30 mW; spectral range 150–2100 cm⁻¹) with a 785 nm excitation (30 mW; spectral range 150–2100 cm⁻¹). All spectra were averaged over ten separate runs, each with a 10-second acquisition time. The digital experimental spectroscopic data were analyzed and plotted using Microsoft Excel 2010. (Togarova *et al.*, 2018). The surface potential of SeNPs, which is linked to their stability in colloidal dispersion, was shown by the zeta potential (Chahabria and Desai 2016). The zeta potential is used to measure NP colloidal stability while also indirectly evaluating surface charge. It's a relationship between the external Helmholtz plane and the sheer surface's potential difference. The colloidal dispersion's storage capacity is taken into account while calculating zeta potential. To guarantee particle stability and avoid aggregation, high zeta potential values, whether positive or negative, should be attained. The value of zeta potential can then be used to estimate the extent of surface hydrophobicity. The zeta potential can also provide information about the way material is packaged inside nano-capsules or applied to the surface (Kadian, 2018).

Table: 2. Different Characterization techniques with properties to be Analyzed

Properties to be analyzed	Techniques for Characterization	Parameters	References
NP formation analysis	UV.Vis	Confirmation of SeNPs	Kokila <i>et al.</i> , 2017
Optical Characterization	DLS, UV.Vis.	Size distribution of NPs	Zanetti-Ramos <i>et al.</i> , 2009
Elemental analysis	EDX	Chemical Composition	Zhang <i>et al.</i> , 2011
Structural Analysis	XRD	Chemical Surface Analysis	Sun <i>et al.</i> , 2000
Size and Morphology analysis	SEM, TEM	Size and Shape	Behm <i>et al.</i> , 2013; Zhang <i>et al.</i> , 2003

Selenium Nanoparticles in Plant Disease Management:

Trichoderma spp. synthesizes selenium nanoparticles. Downy mildew disease is a disease that affects pearl millet. *Sclerospora graminicola* growth, sporulation, and zoospore viability were all inhibited by the nanoparticles, and the size of SeNPs had an inverse relationship with all biological activities. Early plant growth was improved and DM incidence was reduced more when SeNPs and *T. asperellum* were used together in the greenhouse than when they were used individually (Nandini *et al.*, 2017). SeNPs 0.5 g/ml, AgNPs 150 g/ml, and K2SO4 (2%) were used to manage Early Blight disease in potatoes to see how they responded

physiologically, and SeNPs 0.5 g/ml, AgNPs 150 g/ml, and K2SO4 (2%) showed disease severity (12.63%), but all plant parameters, including physiological parameters and yield, improved. According to the findings, AgNPs and SeNPs should be used as plant foliar to suppress plant diseases and improve plant yields (El-Batal A.I. *et al.*, 2016). Selenium nanoparticles (SNP) were commonly used as chemotherapeutic agents and environmental ameliorants, according to Guisbiers, G. (2017), but without concomitant biocontrol functions against fungal infections and mycotoxins.

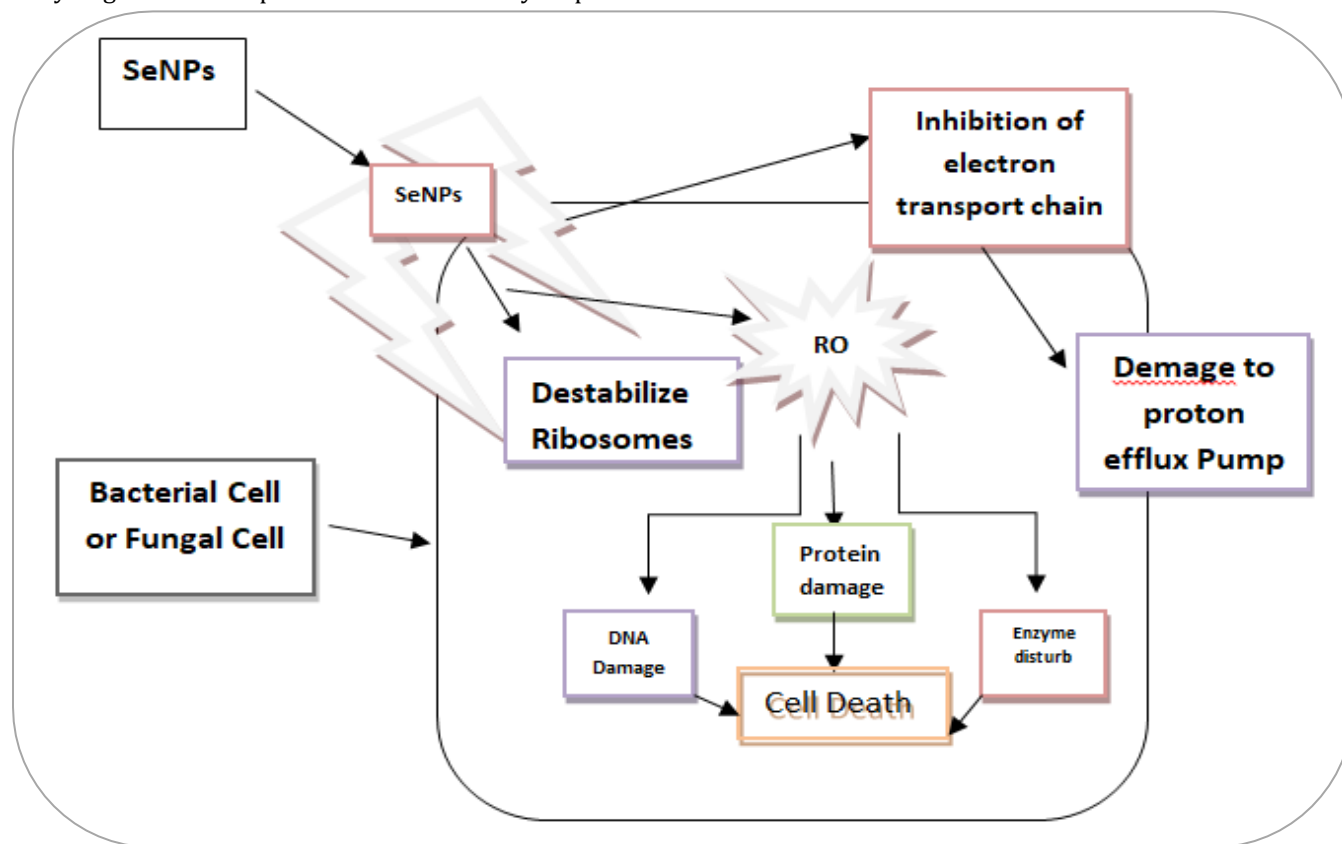


Figure 3. Mechanism of Action of SeNPS against microbial diseases in Plants

Antimicrobial (bacteria and/or fungal) mechanisms of several nanoparticles are depicted in this diagram. The direct contact of NPs with the bacterial and fungal cell

wall/membrane, as well as the inhibition of biofilm formation, has been attributed to their antimicrobial (bacteria and/or fungi) activity. NPS has significant

antibacterial/antifungal actions by inducing both innate and adaptive host immunological responses, producing harmful reactive oxygen species (ROS), and stimulating intracellular effects (e.g., enzyme disruption, DNA damage, and protein damage).

Alternaria toxins (reduction of 83 percent of TeA and 79 percent of AOH), fumonisin B1 (reduction of 63 percent of FB1), and deoxynivalenol (reduction of 76 percent of DON) were discovered to be efficient antifungal agents using selenium nanoparticles (D. Hu, *et al.*, 2019). *Candida albicans* biofilms were prevented using selenium nanoparticles created by femtosecond pulsed laser ablation in de-ionized water. By swapping Sulphur for selenium, advanced electron microscope images indicated that selenium nanoparticles cling easily to biofilms and then penetrate inside pathogens, causing cell structural damage. *Candida albicans* biofilm inhibition was accomplished at a concentration of only 25 ppm. Finally, crystallinity and particle size are two physical characteristics that have been shown to have a significant impact on *Candida albicans* survivability. The synthesized SeNPs from *Trichoderma atroviride* displayed high antifungal activity against *Pyricularia grisea* at concentrations of 50 and 100 ppm, respectively, and inhibited the infection of *Colletotrichum capsici* and *Alternaria solani* on chili and tomato leaves (Joshi *et al.*, 2019).

Antimicrobial activity of SeNPs against different phytopathogenic bacteria and fungi was reported by Srivastava and Mukhopadhyay, (2015) by using different SeNPs concentrations (100,100, 250 ug/ml) but 100 ug/ml showed best results in controlling 99% different bacteria like *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, and *Streptococcus pyogenes* and 500ug/ml SeNPs prevent the growth of phytopathogenic fungus *Aspergillus clavatus*.

Similarly, antimicrobial activity of SeNPs synthesized by Aloe Vera leaf extract was performed against disease-causing fungus and bacteria, Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) and fungus *Colletotrichum coccodes* and *Penicillium digitatum*. SeNPs showed effective bactericidal and fungicidal activity against these phytopathogenic bacteria and fungi (Fardasadeh and Jafarizadeh-Malimir, 2019).

Results confirmed that SeNPs synthesized by *Ceropegia bulbosa* tuber's aqueous extracts possess larvicidal activity. Menon *et al.* (2020) reported the antibacterial

activity of SeNPs against different phytopathogenic bacteria and *Klebsiella* sp showed the highest activity. Anchna *et al.* (2020) confirmed the cytotoxic activity and antimicrobial activity of SeNPs synthesized by garlic oil. Green synthesized selenium nanoparticles exhibited antimicrobial activity against gram-negative bacteria and yeast fungi *C. Albicans* ATCC10231 (Abbas *et al.*, 2021). Rajagopal *et al.* (2021) reported that Se NPs contained the maximum zone of inhibition in *E. coli* 17 ± 0.67 mm followed by *E. faecium* 15 ± 0.13 mm, *C. Albicans* 15 ± 0.32 mm and *S. aureus* 14 ± 0.93 mm. Therefore, it is proved that SeNPs possess maximum antibacterial activity as described. Antimicrobial activity of the selenium nanoparticles was done using a well diffusion technique against *Staphylococcus aureus* and *Bacillus subtilis*. The selenium nanoparticles synthesized in this process exhibited high antimicrobial potential against pathogenic bacteria (Jay and Shafkat, 2018). Hashem and Salem. (2021) reported that SeNPs contained minimal-inhibitory concentration (MIC) of SeNPs against *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Staphylococcus aureus* by using different concentrations of SeNPs 250, 31.25, and 500 $\mu\text{g mL}^{-1}$, while these concentrations were 62.5, 15.62, 31.25, and 7.81 $\mu\text{g mL}^{-1}$ were used against *Candida albicans*, *Aspergillus fumigatus*, *Aspergillus niger*, and *Aspergillus flavus* and obtained results supported the antimicrobial potentials of SeNPs against different phytopathogenic fungus and bacteria. Yilmaz *et al.*, (2021) reported the antimicrobial activity of Selenium nanoparticles using tarragon extract. SeNPs possessed highly antibacterial and antifungal activity by producing different inhibition zones ranging from 13 to 18 mm against the pathogenic bacteria and from 10 to 14 mm, 17–36 mm, 8–12 mm, 15–24.5 mm, and 9–14 mm, against *A. alternata*, *A. niger*, *A. parasiticus*, *B. cinerea*, *F. oxysporum*, and *P. chrysogenum*, respectively. Kokila *et al.* (2017) reported that Gram (+) *Staphylococcus aureus*, Gram (-) *Escherichia coli* (bacteria), and *Aspergillus niger* were all found to have considerable antibacterial action in the nanoparticles suspension (fungi). Gunti *et al.* (2019) reported that *Emblica officinalis* fruit extract mediated SeNPs possesses high antimicrobial activity against phytopathogenic fungi and bacteria. Mosallam *et al.* (2018) reported that SeNPs act as a strong antimicrobial agent by producing maximum zone of inhibition *Acinetobacter calcoaceticus* (15.0 mm ZOI) and *Staphylococcus aureus* (16.6 mm ZOI) were both

active against the SeNPs. SeNPs also inhibited *Candida albicans* (15.3 mm ZOI) and *Aspergillus flavus* (29.6 mm ZOI), both of which produce mycotoxin. In comparison to the common antibiotic Ciprofloxacin, different doses of SeNPs were employed for antimicrobial testing against *E. coli*, *M. luteus*, *B. subtilis*, and *K. pneumoniae*. SeNPs were found to have considerable antibacterial activity against all of the microorganisms tested. Finally, SeNPs derived from citrus fruits have the potential to be effective antibacterial options (Alvi *et al.*, 2021). Sarojini

et al. (2020) reported the antimicrobial activity SeNPs against *S. mutans* and *Lactobacillus* that produced a higher zone of inhibition than usual. Similarly, antifungal activity indicated a zone of inhibition against *Candida albicans* that was almost identical to the standard employed. SeNPs synthesized from *Psidium guajava* by using the agar well diffusion method to find the antibacterial effectiveness against *E. faecalis* (Migliani and Tan –Ishii, 2021).

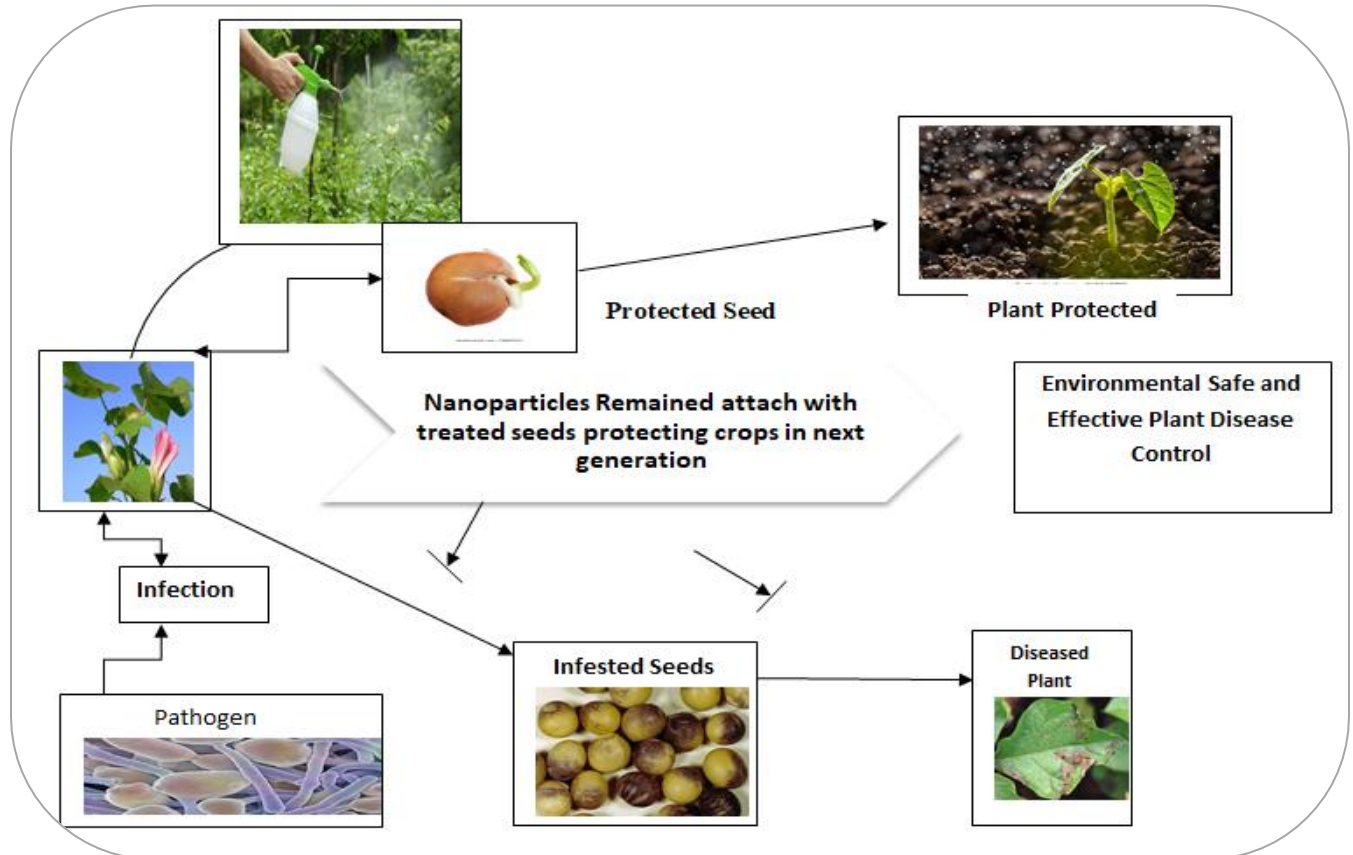


Figure 4. Effect on Plant with Nanoparticles and Without Nanoparticles Seeds treated with nanoparticles and seeds treated without nanoparticles result in the formation of healthy and unhealthy plants described in the diagram.

CONCLUSIONS

Selenium nanoparticles possess an antimicrobial property that enables them to fight against many fungal and bacterial diseases and can be used for the management of many plant diseases. Nanotechnology in terms of plant disease management is so effective and has an eco-friendly relationship. Using toxic and hazardous fungicides pollutes the environment and is expensive. Therefore, researchers should prefer nanoparticles as an alternative source of fungicides for combating plant diseases. Selenium nanoparticles, we

believe, will eventually take part in a major function in the suppression of plant diseases in both greenhouse and field environments. When compared to conventional metallic fungicides, one of the key benefits of employing nanoparticles in disease management is the significant reduction in inactive metals entering the environment. Researchers face a difficult challenge in that nanomaterials may function differently in diverse plant/disease systems, necessitating individual evaluations for each disease system. Due to the current agricultural issues, the advancement of Nano-enabled

disease suppression strategies will undoubtedly be a vital tool in the efforts to gain and maintain global food security.

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Contribution of Authors:

All authors contributed equally to this paper.