Chapter 12

Biosynthesis of Nanoparticles by Microorganisms and Applications in Plant Stress Control

Khaled M. A. Ramadan and Hossam S. El-Beltagi

Contents

K. M. A. Ramadan (✉)
King Faisal University, Central Laboratories, Riyadh, Saudi Arabia

Agricultural Biochemistry Department, Faculty of Agriculture, Ain-Shams University, Cairo, Egypt
e-mail: kramadan@kfu.edu.sa

H. S. El-Beltagi
Agricultural Biotechnology Department, College of Agriculture and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia

Biochemistry Department, Faculty of Agriculture, Cairo University, Giza, Egypt

H. I. Mohamed et al. (eds.), *Plant Growth-Promoting Microbes for Sustainable Biotic and Abiotic Stress Management*,
https://doi.org/10.1007/978-3-030-66587-6_12

Abbreviations

AgNPs	Silver nanoparticles
AuNPs	Gold nanoparticles
BacMPs	Bacterial magnetic particles
BMs	Bacterial magnetosomes
BRECs	Bovine retinal endothelial cells
CdS NPs	CdS nanoparticles
CSE	Cell-soluble extract
GTPase	Guanosine triphosphatase
HRP	Horseradish peroxidase
mAbs	Monoclonal antibodies
MRI	Magnetic resonance imaging
MTB	Magnetotactic bacteria
PHB	Polyhydroxybutyrate
TEM	Transmission electron microscope

1 Introduction

Nanotechnology's future applications and advantages in agriculture are immense. This involves the treatment of insect pests by new nanomaterial insecticide formulations (Ragaei and Sabry 2014). One nanometer is understood to be a milliard of a micrometer or a million of a micron. That is around 1/80,000 of human hair diameter or ten times hydrogen atom diameter. American scientists assert that "There is plenty of space at the bottom," which was also held as a way of paying attention to the nanotechnological field. Feynman (1960) discovered technique through which it is possible to manipulate single atoms and molecules, utilizing series with specialized instruments to construct and manage a limited range of necessary scales, etc. In this context, Feynman suggested that the shift in magnitude would lead to scaling problems in various physical phenomena: gravity became less relevant, and surface tension and the attraction of van der Waals might be more relevant. Many experiments on nanoparticles have shown their efficacy toward plant diseases, insects, or other threats. Therefore, such nanoparticles were still only used to repel insects, but also to prepare new products, such as pesticides and insecticides (Prasad et al. 2017a, b). But safety for plants to plants for metal-based nanostructures with far larger volume-to-volume particle size and with specific antimicrobials compared with their bulk materials is one of the latest with the rapid advancement of nanotechnology, and their special properties expand the use of a range of carbon nanomaterials (CNMs). The use of a buckyball molecule fullerene (C60) is, for example, commonly available in computers and aircraft airframes and as drug delivery carriers in the form of biomedicine and carbon nanotubes (CNTs) (Ngan et al. 2015; Liu et al. 2015). These have thoroughly studied interactions between CNMs and plants. In 30-day experiments with hydroponic tension, for instance, graphene concentrations ranging from 250 to 1500 mg/L inhibited wheat growth (Zhang et al. 2016). A great number of physical, electronic, biological, or hybrid methods depend on the fabrication of various classes of nanoparticles. Although organic compounds are most common throughout the production of nanoparticles, the use of dangerous substances severely restricts their medicinal use, especially in medical practice (Liu et al. 2011). Hence, it is of utmost importance that to extend their biomedical applications, healthy, nontoxic, and environmentally friendly approaches are developed for the production of nanomaterials. Synthesizing microorganisms with nanoparticles is one of the choices. The nanoparticles generated by biogenic enzyme process greatly outweigh those generated by chemical processes in many respects. Although the latter is capable of producing large amounts of nanoparticles of given size and shape in a reasonably short period, they become complex, obsolete, expensive, and ineffective and produce dangerous radioactive waste that is dangerous not only to the environment but also to public health. Usage of costly chemicals is avoided via an enzyme solution, and most suitable "green" pathway wasn't as energy-intensive and environmentally friendly as chemical route. A biogenic method is again confirmed by the fact that in varying temperature, pH, and pressure conditions, most bacteria exist. These procedures provide greater catalytic reaction, increased surface area, and enhanced interaction among enzyme and metal ion as a result of the bacterial cell membrane (Bhattacharya and Mukherjee 2008). Nanoparticles are biosynthesized as microorganisms take target ions out of the atmosphere and then transform metal into elemental metal by enzymes formed by cell activity. Depending on where nanoparticles are made, intracellular and extracellular synthesis can be categorized. Throughout the existence of enzymes, the intracellular process is the transport for ions to produce nanoparticles by bacterial cell. Extracellular nanoparticle synthesis includes capturing metal ions on the cell surface and decreasing the amount of ions when enzymes are present (Zhang et al. 2011). To biosynthesize nanoparticles, a number of applications have been used, like selective drug carriers, cancer treatment, gene therapy and DNA sequencing, antiviral activities, biosensors, reaction-enhancing rates, and isolation monitoring.

The objectives of this chapter highlight the extensive properties of inorganic nanoparticles and the synthesis of metal, oxide, sulfide, and other conventional nanoparticles among different species of microorganisms. It will also discuss the proposed pathways for the biosynthesis of inorganic nanoparticles. Size/shape and stabilization of synthesized nanoparticles were affected. Pharmaceutical formulations include such nanoparticles, crop protection, and antibacterial agents. Synthesized biometallic nanoparticles are also investigated by manipulating *Penicillium* species and their uses in pharmaceutical applications (Fig. 12.1).

2 Metallic Nanoparticles

Table 12.1 summarizes several standard nanoparticles made through microorganisms.

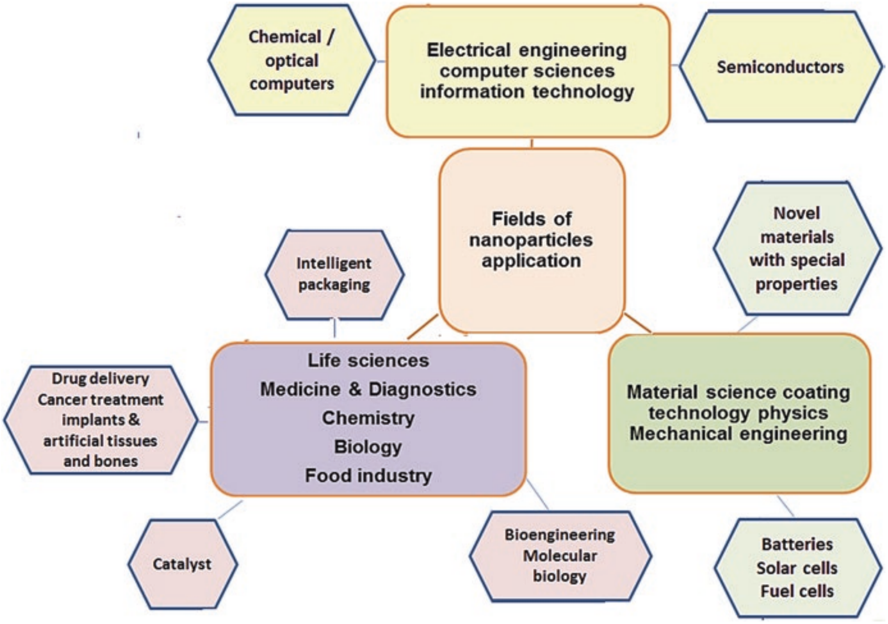

Fig. 12.1 Fields of application of nanoparticles

2.1 *Gold Nanoparticles*

In chemistry, Au nanoparticles get a long and glorious background to Roman times, wherein they were being used for aesthetic reasons to dye glasses. AuNPs were already used centuries earlier for the treatment of different diseases. Previous study recorded that colloidal gold substances had distinct characteristics than mass gold, which launched the modern era of AuNP synthesis (Hayat 1989). Because of the increasing need to improve environmentally sustainable material synthesis technologies, nanoparticles have received considerable attention as evolving bionanotechnology (overpass of nanotechnology and biotechnology). Extracellular production by *Fusarium oxysporum* fungus and actinomycete sp. with gold nanoparticles has been documented in previous research. Intracellular synthesis of *Verticillium* sp. fungal gold nanoparticles has been reported (Ahmad et al. 2003a). Southam and Beveridge (1996) showed nanoscale gold particles could be readily caused inside microbes by cells with Au^{3+} ions. The gold monodisperse nanoparticles were synthesized with *Rhodococcus* sp. alkalotolerant within extreme biological regulation, like alkaline conditions and environments with marginally greater temperatures (Ahmad et al. 2003b). Lengke et al. (2006a, b) have submitted Au complexes to synthesize filamentous cyanobacteria in various shapes, including spherical, cubic, and octahedral, and to research the mechanisms of nanostructure formation. There have been studies of the development of nanocrystals and nanoalloys using *Lactobacillus* (Nair and Pradeep 2002). Table 12.1 summarizes some other typical microorganism-formed gold nanoparticles (Konishi et al. 2007a; Singaravelu et al. 2007).

Table 12.1 Metal nanoparticles synthesized by microorganisms

Microorganisms	Products	Culturing temperature (°C)	Size (nm)	Shape	Location	References
Sargassum wightii	Au	Not available	8–12	Planar	Extracellular	Singaravelu et al. (2007)
Rhodococcus sp.	Au	37	5–15	Spherical	Intracellular	Ahmad et al. (2003a)
Shewanella oneidensis	Au	30	12 ± 5	Spherical	Extracellular	Suresh et al. (2011)
Plectonema boryanum	Au	25–100	<10–25	Cubic	Intracellular	Lengke et al. (2006a)
Plectonema boryanum UTEX 485	Au	25	10 nm–6 μm	Octahedral	Extracellular	Lengke et al. (2006b)
Escherichia coli	Au	37	20–30	Triangles, hexagons	Extracellular	Du et al. (2007)
Yarrowia lipolytica	Au	30	15	Triangles	Extracellular	Agnihotri et al. (2009)
Pseudomonas aeruginosa	Au	37	15–30	Not available	Extracellular	Husseiny et al. (2007)
Pseudomonas rhodesiae	Ag	37	20–100	Spherical	Extracellular	Hossain et al. (2019)
Pseudomonas sp. and *Achromobacter* sp.	Ag	37	20–50	Spherical		Kaur et al. (2018)
Rhodopseudomonas capsulate	Au	30	10–20	Spherical	Extracellular	He et al. (2007)
Shewanella algae	Au	25	10–20	Not available	Intracellular	Konishi et al. (2007a, b)
Brevibacterium casei	Au, Ag	37	10–50	Spherical	Intracellular	Kalishwaralal et al. (2010)
Trichoderma viride	Ag	27	5–40	Spherical	Extracellular	Fayaz et al. (2010)
Bacillus licheniformis	Ag	37	50	Not available	Extracellular	Kalimuthu et al. (2008)
Bacillus siamensis	Ag	37	25–50	Spherical	Extracellular	Ibrahim et al. (2019)
Escherichia coli	Ag	37	50	Not available	Extracellular	Gurunathan et al. (2009)
Shewanella loihica PV-4	Au	30	10–16	Spherical	Extracellular	Lv et al. (2018)
Corynebacterium glutamicum	Ag	30	5–50	Irregular	Extracellular	Sneha et al. (2010)
Trichoderma viride	Ag	10–40	2–4	Not available	Extracellular	Fayaz et al. (2009)
Ureibacillus thermosphaericus	Au	60–80	50–70	Not available	Extracellular	Juibari et al. (2011)

(continued)

Table 12.1 (continued)

Microorganisms	Products	Culturing temperature (℃)	Size (nm)	Shape	Location	References
Bacillus cereus	Ag	25	18–39 1	Spherical	Extracellular	Ahmed et al. (2020)
Aspergillus fumigatus	Ag	25	5–25	Spherical	Extracellular	Bhainsa et al. (2006)
Aspergillus niger	Ag	25	10–100	Spherical	Extracellular	Al-Zubaidi et al. (2019)
Verticillium sp.	Ag	25	25 ± 8	Spherical	Extracellular	Senapati et al. (2005)
Fusarium graminearum	Ag	25	20–45	Spherical	Extracellular	Ibrahim et al. (2020)
Fusarium oxysporum	Ag	25	5–50	Spherical	Extracellular	Senapati et al. (2005)
Trichoderma harzianum	Ag	25	11–13	Spherical	Extracellular	El-Moslamy et al. (2017)
Trichoderma hamatum	Au	25	5–30	Spherical, pentagonal, and Hexagonal	Extracellular	Abdel-Kareem and Zohri (2018)
Streptomyces griseus	Cu	25	5–50	Spherical	Extracellular	Ponmurugan et al. (2016)
Neurospora crassa	Au, Au/Ag	28	32, 20–50	Spherical	Intracellular Extracellular	Castro-Longoria et al. (2011)
Shewanella algae	Pt	25	5	Not available	Intracellular	Konishi et al. (2007a, b)
Enterobacter sp.	Hg	30	2–5	Spherical	Intracellular	Sinha and Khare (2011)
Shewanella sp.	Se	30	181 ± 40	Spherical	Extracellular	Lee et al. (2007)
Escherichia coli	CdTe	37	2.0–3.2	Spherical	Extracellular	Bao et al. (2010)
Yeast	Au/Ag	30	9–25	Irregular polygonal	Extracellular	Zheng et al. (2010)
Fusarium oxysporum	Au-Ag alloy	25	8–14	Spherical	Extracellular	Senapati et al. (2005)
Penicillium duclauxii	Ag	25	3–32	Spherical	Extracellular	Almaary et al. (2020)
Setosphaeria rostrata	Ag	25	2–50	Spherical	Extracellular	Akther and Hemalatha (2019)
Pyrobaculum islandicum	U(VI), Tc(VII), Cr(VI), Co(III), Mn(IV)	100	N/A	Spherical	Extracellular	Kashefi and Lovley (2000)
Desulfovibrio desulfuricans	Pd	25	50	Spherical	Extracellular	Lloyd et al. (1998)

2.2 Silver Nanoparticles

Ag nanoparticles exhibit Gram-positive bacteria with effective antimicrobial activity, particularly multiresistant strains such as *Staphylococcus aureus* which is resistant to methicillin, as its bulk counterpart (Panacek et al. 2006). The secrets of nature have contributed to the production of advanced nanoparticles through biomimetic approaches. Researchers have long made efforts to use microorganisms to manufacture as many silver nanoparticles as possible to create eco-friendly nanofactories. Various microbes are recognized as reducing Ag^+ ions in silver nanoparticles, and most are spherical particles (Fayaz et al. 2010). Klaus et al. (1999) showed that when *Pseudomonas* bacterium is extracted from silver mine, while put within a solution containing aqueous silver nitrate, *stutzeri* AG259 played a significant function throughout the decrease of Ag^+ ions as well as in production with well-defined silver nanoparticles and separate topography of bacteria within periplasmic space. AgNPs were produced as a film or formed in liquid or collected onto their cell surface when fungi *Verticillium* or *Fusarium oxysporum* were used (Jain et al. 2011). Table 12.1 lists some other microorganism-developed silver nanoparticles (Kalimuthu et al. 2008; Gurunathan et al. 2009; Sneha et al. 2010; Fayaz et al. 2009; Kalishwaralal et al. 2010; Castro-Longoria et al. 2011; Juibari et al. 2011). Synthesized AgNPs by Hamouda et al. (2019) demonstrated good antibacterial activity toward multidrug-resistant bacteria (*Bacillus cereus*, *Escherichia coli*) and anticancer activity toward cell lines of human (breast, colon, liver). Low concentrations of hemolytic activity of AgNPs have been studied and reported as nontoxic to human RBCs. Furthermore, the dynamics of absorption and cytotoxicity of these AgNPs have been studied in the cell lines of breast cancer, enabling them to be shown to be good antibacterial agents, with further proof of the different behavior of AgNPs to cause toxicity in cells and bacteria when collected at pH 7 or 8. Moreover, the theoretically unlimited source of the reducing agent (i.e., leaf extract obtained from agricultural processing waste) and its negligible environmental impact constitute another strength of this method (De Matteis et al. 2019; Tanase et al. 2019). It has been shown that the combination of $AgNP_{bio}$ and simvastatin may be a great future option for bacterial infection control, where lower doses of $AgNP_{bio}$ with the same antibacterial activity are needed when combined with simvastatin (Figueiredo et al. 2019). Also, the synthesized silver nanoparticles had a strong antibiofilm property and were also found to be biocompatible with the red blood cell lysis assay and their association with peripheral mononuclear blood cells and 293 cells of the human embryonic kidney. *Mesoflavibacter zeaxanthinifaciens* is therefore found to be an excellent source of exopolysaccharide synthesis that assists in production of silver nanoparticles (Oves et al. 2019).

2.3 Alloy Nanoparticles

Using alloy nanoparticles in catalytic reactions, electronics, and optical substances and coatings is of great interest. *Fusarium oxysporum* production of bimetallic Au-Ag alloy and argued that secreted NADH cofactor is a significant determinant of the composition of Au-Ag nanoparticles (Senapati et al. 2005). Au-Ag metal nanoparticles, biosynthesized by yeast cells, have been studied (Zheng et al. 2010). Nanoparticles of the Au-Ag alloy were commonly produced by extracellular phase, microscopically characterized by fluorescence and electron microscopic transmission, or generally existed as irregular polygonal nanoparticles. Electrochemical research has shown vanillin sensors have been able to enhance electrochemical reaction of vanillin at least five times by changing glass carbon electrodes based on Au-Ag metal nanoparticles. Au-Ag alloy nanoparticles from fungal strains have been used in *Fusarium semitectum* core-shell synthesis of nanoparticles and been very stable for several weeks (Sawle et al. 2008).

2.4 Other Metallic Nanoparticles

It is understood that heavy metals are life-threatening to microorganisms. Microbial tolerance to many other toxic metals is in nature due to its chemical detoxification or even cell-dependent ion excretion by protein complexes acting as ATPase, chemical cations, or anti-transporter protons. Solubility changes play a crucial role as well in resistant bacteria. Konishi et al. (2007b) studied the use of *Shewanella* algae, a metal ion-reducing bacterium, to obtain platinum nanoparticles. In most cells of *Shewanella* by time lactate was delivered as an electron donor, aqueous $PtC_{16}b_2$ ions in elemental platinum were reduced to room temperature and neutral pH within 60 min. Platinum nanoparticles of about 5 nm were found in periplasm. Sinha and Khare have shown that *Enterobacter* sp. can synthesize mercury nanoparticles (Sinha and Khare 2011). Cultivation conditions (pH 8.0 and lower mercury concentrations) facilitate the synthesis of uniformly sized, spherical, and monodispersed 2–5 nm intracellular mercury nanoparticles. Many of heavy metals with hydrogen as an electron donor of the anaerobic hyperthermophilic microorganism *Pyrobaculum islandicum*, like U(VI), Tc(VII), Cr(VI), Co(III), and Mn(IV), have been reported to be reduced (Kashefi and Lovley 2000). In palladium nanoparticles, sulfate-reducing bacteria, *Desulfovibrio desulfuricans*, or metal ion-reducing bacteria *sulfur* can be synthesized. Table 12.1 also lists some other nanoparticles formed by microorganisms (DeWindt et al. 2005; Lee et al. 2007; Bao et al. 2010).

3 Oxide Nanoparticles

Oxide nanoparticles are an essential type of microbial compound nanoparticles. The biosynthesized oxide nanoparticles from both sides have been investigated in this section: magnetic oxide nanoparticles or nonmagnetic oxide nanoparticles. In Table 12.2, many examples of magnetotactic bacteria (MTB) shown in development of nanoparticles of magnetic oxide and biological systems for the production of nanoparticles of nonmagnetic oxide are summarized.

3.1 Magnetic Nanoparticles

Owing to its peculiar microstructure and properties, such as magnetic nanoparticles, strong forces, and its potential to widespread implementation in fields of biological isolation and biomedicine, superparamagnetic nanoparticles become new materials discovered. It is known that magnetic nanoparticles are Fe_3O_4 (magnetite) and Fe_2O_3 (maghemite). Targeted treatment of cancer (magnetic hyperthermia), stem cell filtering and manipulation, drug delivery guidance, gene therapy, DNA sequencing, and magnetic resonance imaging (MRI) have been actively investigated (Fan et al. 2009). Magnetotactic bacteria produce intracellular magnetic particles containing iron oxide, iron sulfides, or either. To differentiate between them and artificially synthesized magnetic particles (AMPs), these particles were pointed as bacterial magnetic particles (BacMPs) (Arakaki et al. 2008). Its associations with bacterial links are presumed to function like biological compass points that allow bacteria to move to oxygen gradients in aquatic environments under geomagnetic field of Earth (Blakemore 1975). BacMPs, as they can be surrounded through biological membranes composed primarily of lipids and proteins, could be quickly spread into aqueous media. In addition, individual BacMPs with better magnetic characteristics involve individual magnetic field or magnetite (Thornhill et al. 1995). Since the first magnetotactic bacteria study in 1975, numerous morphological forms have been described and observed in numerous aquatic environments, including cocci, spirals, vibrants, ovoid bacteria, and multicellular bacteria, with specific characteristics (Spring and Schleifer 1995). For example, magnetotactic cocci showed a high diversity and distribution and were often found on aquatic sediment surfaces. Identification of such type of bacteria shows that it is microaerophilic, including the coccus strain cultivated by magnetic MC-1. In the case of *Vibrio* bacteria, three optional anaerobic marine vibrating forms were extracted from freshwater salt marshes. As part of *Alphaproteobacteria*, these bacteria are known to belong to *Rhodospirillaceae* family, and truncated hexoctahedron-type BacMPs have been synthesized to evolve heterotrophically and organically with chemo. On the other side, parts of the *Magnetospirillaceae* family are present in sediments containing fresh water. In this family, significant amounts of previously isolated magnetotactic bacteria have been detected by utilizing culture medium and magnetic isolation methods. The first family member was isolated from strain MS-1 of *Magnetospirillum magnetotacticum*, while the physiological and genetic features of strain MSR-1 of *Magnetospirillum gryphiswaldense* were also well studied. AMB-1 was discretionary magnetotactic anaerobic spirilla, separated by Arakaki et al. (2008). After 2000, several new magnetotactic bacteria were discovered in different ecological settings. Several of freshly described magnetotactic bacteria were recorded in Table 12.2. Uncultured magnetotactic bacteria were found in distinct environments (Lefevre et al. 2010a). Mesophilic bacteria are the most common cultivated magnetotactic bacteria, which appear to grow less than 30 °C. The majority of uncultivated magnetotactic bacteria is 30 °C and below. Thermophilic magnetotactic bacteria are described in only few studies. Each of magnetotactic bacteria known as HSMV-1 is identified in samples

Table 12.2 Oxide nanoparticles synthesized by microorganisms

Microorganisms	Products	Culturing temperature (°C)	Size (nm)	Shape	Location	References
Shewanella oneidensis	Fe_3O_4	28	40–50	Rectangular, rhombic, hexagonal	Extracellular	Perez-Gonzalez et al. (2010)
QH-2	Fe_3O_4	22–26	81 ± 23 × 58 ± 20	Rectangular	Intracellular	Zhu et al. (2010)
Recombinant AMB-1	Fe_3O_4	28	20	Cuboctahedral	Intracellular	Amemiya et al. (2007)
Yeast cells	Fe_3O_4	36	Not available	Wormhole-like	Extracellular	Zhou et al. (2009a)
Yeast cells	$FePO_4$	36	Not available	Nanopowders	Extracellular	Zhou et al. (2009b)
WM-1	Fe_3O_4	28	54 ± 12.3 × 43 ± 10.9	Cuboidal	Intracellular	Li et al. (2007)
Shewanella oneidensis MR-1	Fe_2O_3	25	30–43	Pseudohexagonal/irregular or rhombohedral	Intracellular	Bose et al. (2009)
HSMV-1	Fe_3O_4	63	113 ± 34 × 40 ± 5	Bullet-shaped	Intracellular	Lefevre et al. (2010a)
Saccharomyces cerevisiae	Sb_2O_3	25–60	2–10	Spherical	Intracellular	Jha et al. (2009)
Lactobacillus sp.	$BaTiO_3$	25	20–80	Tetragonal	Extracellular	Jha et al. (2010a)
Lactobacillus sp.	TiO_2	25	8–35	Spherical	Extracellular	Jha et al. (2010b)
Fusarium oxysporum	TiO_2	300	6–13	Spherical	Extracellular	Bansal et al. (2005)
Fusarium oxysporum	$BaTiO_3$	25	4–5	Spherical	Extracellular	Bansal et al. (2006)
Fusarium oxysporum	ZrO_2	25	3–11	Spherical	Extracellular	Bansal et al. (2004)
Streptomyces spp.	CuO	25	78–80	Spherical	Extracellular	Hassan et al. (2019)

of springs in which temperatures varied between 32 and 63 °C (Lefevre et al. 2010b). TEM images of the untouched HSMV-1 cell discovered single polar flagellum and single bullet-shaped magnetosome string. The average number per cell of magnetosome crystals is 12 ± 6 and 113 ± 34 nm by 40 ± 5 nm. Report's findings indicate that certain magnetotactic bacteria may at least indicate mild thermophilicity. Under conditions where magnetotactic bacteria are present and are expected to develop as high as 63 °C and where *Magnetosome magnetitis* (Magnetosomes are membranous structures present in magnetotactic bacteria) is deposited, maximum temperature level has been extended (Lefevre et al. 2010b). The use of yeast cells as a template has been reported to synthesize magnetic Fe_3O_4 materials with a mesoporous structure (Zhou et al. 2009a, b). Table 12.2 (Amemiya et al. 2007; Li et al. 2007; Bose et al. 2009; Perez-Gonzalez et al. 2010; Zhu et al. 2010;) mentions several other magnetic oxide nanoparticles.

3.2 Nonmagnetic Oxide Nanoparticles

Many oxide nanoparticles, including TiO_2, Sb_2O_3, SiO_2, $BaTiO_3$, and ZrO_2 nanoparticles, were also investigated in addition to magnetic oxide nanoparticles (Jha et al. 2009). A green, cheap-cost, repeatable biosynthesis induced by Sb_2O_3 nanoparticles of *Saccharomyces cerevisiae* has been described (Jha and Prasad 2010). The synthesis was carried out in compliance with room temperature. Analysis has shown that the Sb_2O_3 device is a 2–10 nm spherical aggregate (Jha et al. 2009). For processing of SiO_2 and TiO_2 nanoparticles of soluble SiF62- and TiF62-anionic complexes, *Fusarium oxysporum* (Fungus) is used. *F. oxysporum* 4–5 and 3–11 nm were also prepared from tetragonal $BaTiO_3$ and quasispheric ZrO_2 nanoparticles in size (Bansal et al. 2004, 2005, 2006).

4 Sulfide Nanoparticles

As quantum dot fluorescent biomarker and cell marking agent, sulfide nanoparticles have been strongly bounded to fundamental and technological research for its fascinating, innovative, optical, and electronic characteristics, in addition to oxide nanoparticles (Yang et al. 2005). Microorganisms have nanocrystal CdS synthesized, and it constitutes one typical form of sulfide nanoparticle. It was found that *Clostridium thermoaceticum* would aggregate CdS both on cell surface and in $CdCl_2$ media in existence of cysteine hydrochloride in raising environment, most likely serving as a sulfide source (Cunningham and Lundie Jr 1993). *Klebsiella pneumoniae* was reported to create CdS (20–200) nm of on cell surface, exposing growth environment to Cd^{2+} ions. Intercellular nanocrystals, consisting of rootite chrystal phase were formed, while *E. coli* incubates $CdCl_2$ and Na_2SO_4 (Sweeney et al. 2004). Depending on cell growth process, nanocrystal formation differs greatly and increases by approximately 20 *Escherichia coli* cultivated in stationary stage relative to that produced in retard logarithmic period. *S. pombe*, *C. pombe*, and *S. glabrata* (yeasts) were used in the production of CdS nanoparticles with intracellular cadmium mixture. PbS and ZnS nanoparticles have been designed and synthesized using biological systems. ZnS with 2–5 and 8 nm mean diameter intracellular nanoparticles were used with *Desulfobacter* and *R. sphaeroides* (Bai et al. 2006). The use of *Rhodobacter sphaeroides*, whose diameters are regulated by culture time, was also used to synthesize PbS nanoparticles (Bai and Zhang 2009). For extracellular development of sulfide metal nanoparticles, eukaryotic organisms like fungi have been reported for being ideal candidates (Ahmad et al. 2002). Certain stabilized metal-metal sulfide nanoparticles like CdS, ZnS, PbS, and MoS_2 may be formed extracellularly by fungus *Fusarium oxysporum* when exposed to aqueous metal sulfate solution. Quantum dots were produced from Cd^{2+} ion interaction to sulfide ions supplied via reduction of sulfide ions. Other types of sulfide nanoparticles were magnetic Fe_3S_4 or FeS nanoparticles. Uncultured magnetotactic bacteria have documented the development of Fe_3S_4 (Bazylinski et al. 1995). A sediment sample of magnetotactic bacteria was analyzed, and about 105 cells are collected the following purification by racetrack treatment. In uncultured cells, magnetosomes showed extended rectangular shapes. The overall amount of magnetosomes in each cell was around 40, and they have been usually observed with big groups of cells. Magnetosomes forming a chain-like structure were detected alongside major clusters. Sulfate reduction bacteria may generate magnetic FeS nanoparticles (Watson et al. 1999). Table 12.3 shows many sulfide nanoparticles formed via microorganisms.

5 Other Nanoparticles

A broad range of species from organic/inorganic composites in biological systems, are utilizing biopolymers, like microbial cells and protein, with organized structures. In addition to the above mentioned nanoparticles, microbe synthesis has been reported as $SrCO_3$, $PbCO_3$, $CdCO_3$, PHB, CdSe, and $Zn_3(PO_4)_2$ (Table 12.4). $SrCO_3$ crystals were produced with ionic Sr^{2+} ions while incubating demanding fungi (Rautaray et al. 2004). Researchers assume even through fungal development of *Fusarium oxysporum* in higher cognitive superstructures, protein excretion modulated the morphology and hierarchical assembly of strontianite crystals. Through yeast biotemplates, zinc phosphate nanopowder was produced (Pandian et al. 2009). Production of $Zn_3(PO_4)_2$ particles with a butterfly-like microstructure between 10–80 nm diameter and 80–200 nm in length was shown. It has been demonstrated that *Fusarium oxysporum* in extremely luminescent room temperature would synthesize CdSe quantum dots (Yan et al. 2009).

Table 12.3 Sulfide nanoparticles synthesized by microorganisms

Microorganisms	Products	Culturing temperature (°C)	Size (nm)	Shape	Location	References
Multicellular Prokaryotes	Fe_3S_4	25	Not available	Not available	Intracellular	Lefevre et al. (2010b)
Uncultured Magnetotactic Bacterium	Probably polyphosphate	Not available	Not available	Rectangular	Extracellular	Arakaki et al. (2010a, b)
Rhodopseudomonas palustris	CdS	30	8	Cubic	Intracellular	Bai et al. (2009)
Coriolus versicolor	CdS	25	100–200	Spherical	Extracellular	Sanghi and Verma (2009)
Lactobacillus	CdS	25–60	4.9 ± 0.2	Spherical	Intracellular	Prasad et al. (2010)
Yeast 1	CdS	25–60	3.6 ± 0.2	Spherical	Intracellular	Sweeney et al. (2004)
E. coli	CdS	25	2–5	Wurtzite crystal	Intracellular	Sweeney et al. (2004)
Rhodobacter sphaeroides	ZnS	Not available	10.5 ± 0.15	Spherical	Extracellular	Bai et al. (2009)
Sulfate-reducing bacteria	FeS	Not available	2	Spherical	Extracellular	Watson et al. (1999)

Table 12.4 Other miscellaneous nanoparticles synthesized by microorganisms

Microorganisms	Products	Culturing temperature (°C)	Size (nm)	Shape	Location	References
Fusarium oxysporum	$PbCO_3$, $CdCO_3$	27	120–200	Spherical	Extracellular	Sanyal et al. (2005)
Fusarium oxysporum	$SrCO_3$	27	10–50	Needlelike	Extracellular	Rautaray et al. (2004)
Brevibacterium casei	PHB	37	100–125	Not available	Intracellular	Pandian et al. (2009)
Yeasts	$Zn_3(PO_4)_2$	25	10–80 × 80–200	Rectangular	Extracellular	Yan et al. (2009)
Fusarium oxysporum	CdSe	10	9–15	Spherical	Extracellular	Kumar et al. (2007)

6 Mechanism of Nanoparticle Synthesis by Microbes

Different microorganisms have numerous pathways of nanoparticle creation. Nanoparticles, though, are usually shaped as follows: metal ions first were trapped in microbial cells or on the surface. Then, trapping metal ions in existence of enzymes was limited to nanoparticles. In fact, in two distinct ways, microorganisms affect mineral formation. At any point, you can change a solution's composition to oversaturate it or undersaturate it. Another way for microorganisms to affect mineral formation is through organic polymers that could affect nucleation by encouraging (or preventing) stabilization of first mineral seeds (Benzerara et al. 2010). Potential mechanisms for the production of some common nanoparticles were discussed in this section: gold and silver, heavy metals, and magnetic and sulfide nanoparticles. The basic process for intracellular creation of silver and gold nanoparticles from *Verticillium* sp. or algal biomass has not been entirely known. However, the observation in which nanoparticles have grown on mycelium surface rather than in the solution supports the following hypothesis: first electrostatic interactions of ions with the overlooked cell wall of carboxylated groups of enzymes have captured fungal cells on the surface. The metal ions were then reduced to nuclei of gold or silver, which were then produced further by reduction and aggregation (Sneha et al. 2010). It was suggested that nitrate reductase enzyme can synthesize nanoparticles of B silver (Kalishwaralal et al. 2008). Nitrate ions activate this enzyme and silver ions are reduced into silver. Reducing enzyme metals in electron shuttles is a potential way of minimizing silver ions. Nitrate reductase enzymes based on NADH and NADH-reliant enzymes are the essential factors for metal nanoparticle formation. NADH and NADH-reliant enzymes, especially nitrate reductase, are considered to be secrets for *Bacillus licheniformis*, which may be essential for biosynthesis of Ag^+ to Ag^0 or continued development of silver nanoparticles (Husseiny et al. 2007). Molecular and proteomic response to hazardous conditions in metalloplastic microorganisms can lead to the development of heavy metal nanoparticles (Reith et al. 2007). Toxic effect of the microorganisms on its survival is caused by strong metal ions like Ag^+, Cd^{2+}, Co^{2+}, CrO_4^{2+}, Cu^{2+}, Hg^{2+}, Pb^2, Ni^{2+}, and Zn^{2+}. To counteract certain impact or precisely control metal metabolism, microorganisms develop molecular and proteomic reactions (Nies 1999). Microbes have many essential genes of metal tolerance that allow cell removal through a range of techniques, including complexity, excretion, or limitation of precipitation. In conditions that require large amounts for moving ions of heavy metal, as mine waste dumps and metalworking plant flows including natural sedimentary areas, metallophilic microbes thus flourish (Tang et al. 2005). A multistage method is thought to be a molecular mechanism of BacMP biomineralization. First sage is cytoplasmic membrane invagination, which is a predecessor to BacMP membrane (Arakaki et al. 2008). The mechanism for envelope formation remains unknown. Vesicular pathways for magnetotactic bacteria were more likely similar to other eukaryotes, or precipitation is controlled by particular GTPase. In a linear cytoskeletal filament chain, vesicles which were formed were then assembled. Aggregation of iron ions in vesicles is the second stage in BacMP biomineralization. The movement of foreign iron is internalized by proteins and siderophores. An oxidation-reduction mechanism strictly controls internal iron. Closely bound BacMP proteins activate and/or regulate magnetized nucleation of crystal in the final step. Magnetite generation functional roles can be performed by different membrane proteins of BacMP. This requires iron supersaturation deposition, preservation of conditions of reduction, and iron oxidation to reduce or dehydrate ferrihydrate to magnetite (Arakaki et al. 2008). This implies mineralization. Perez-Gonzalez and the staff recently suggested a new possible *Magnetitis synthesization* method that uses both passive and active *Shewanella oneidensis* (Spring and Schleifer 1995). Secondly, Fe^{2+} activity occurs as a terminal electron admitter, as bacteria use ferrihydrite, and the cell pH value may be increased by the amino acid bacterial metabolism. Localized accumulations of Fe^{2+} and Fe^{3+} on a network, bacterial surface wall, cell compositions, or cell particles allow a passive mechanism to be precipitated by magnetite system to supersaturate magnetite process. It was proposed that the production of CdS NP was due to disulfide (cystine) bridges that could be related to slashing of S–H bonds or creation of new nanoparticle surface bonds, namely, Cd-thiolate ($Cd–S–CH_2COOH$) S–Cd-bond complex (Sanghi and Verma 2009). Cadmium thiolate group CoOH interacts with hydrogen bond, not with NH_2 protein. CdS-capped nanoparticles also bind to hydrogen bond groups of NH_2 (Tang et al. 2005). A coordinated link between oxygen Cd^{2+} ion atom was created by one of the carboxylic oxygen group atoms, COOH, thus competing with the thiol group to construct surfaces with CdS nanoparticles (Lover et al. 1997). In general, microbes synthesize nanoparticles by implanting metal ions, followed by enzyme reduction, on cell surfaces (extracellular) or in cells (intracellular). Using fungal cellular structure and cell membrane sugars, these metal ions can be absorbed and reduced. With different microorganisms, mechanisms of synthesis of nanoparticles differ. Three options, for example, consist of an extracellular synthesis of nanoparticles, i.e., action by both electron shuttle quinones or nitrate reductase. *Penicillium* and many other fungal species have initiated the synthesis of nitrate reductase (Deepa and Panda 2014). Nitrate reductase activity was conducted using 2,3-diaminophthalene nitrites (Kumar et al. 2007). Oxysporum is associated with quinone extracellular shuttle, NADPH-dependent reductases, and nitrate reductase. Studies have shown AgNP production is generated earlier with 33 kDa protein and then with protein capping agent (free amine groups and cysteine) that maintains NPs of *Aspergillus flavus* (Soni and Prakash 2011). Metal ions were trapped firstly in the cell surface of fungi by electrostatic activity by intracellular synthesis and later reduced with enzymes inside the cell wall, contributing to NP construction and production (Singh et al. 2014). Silver nanoparticles involved in nitrate reductase enzyme *Bacillus licheniformis* are synthesized. NADH and NADH-based enzymes essential for Ag^+ bioreduction and subsequent production of AgNPs secrete *Bacillus licheniformis* (Husseiny et al. 2007). Reduction of Ag + requires a process of reducing electron shuttle enzyme to metallic silver by convincing nitrate ions and silver ions. Strong metal nanoparticles (Co^{2+}, $CrO_4{}^{2+}$, Pb^{2+}, Zn^{2+}, Hg^{2+}, Cd^{2+}) synthesize genetic and proteomic reactions that specifically control metal homeostasis and fight harmful effects (Reith et al. 2007). *Shewanella oneidensis* synthesis, moreover, involves active and passive pathways. Owing to

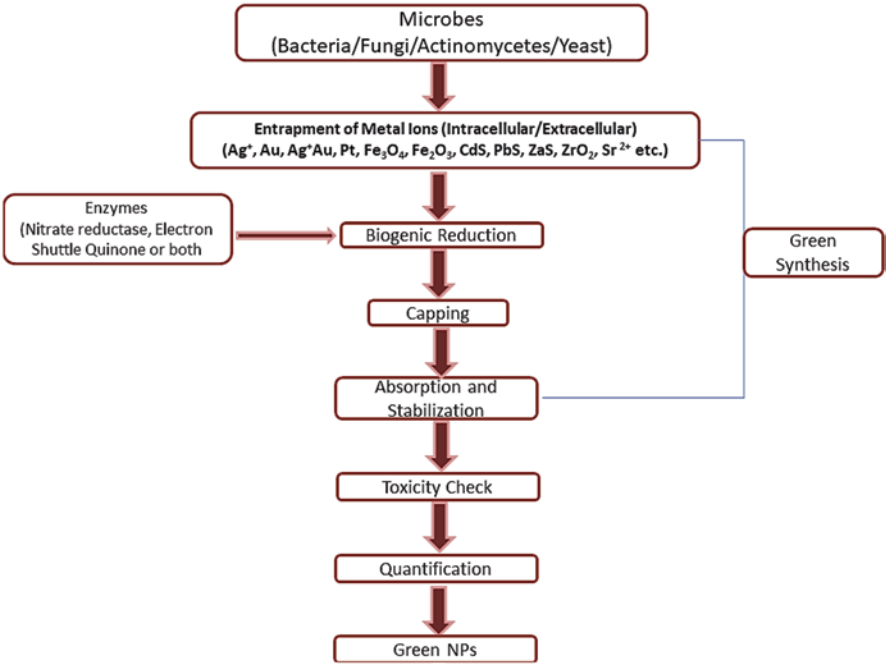

Fig. 12.2 Microbial synthesis of nanoparticles

amino acid metabolism and efficient Fe^{2+} growth, pH value rises, accompanied with active Fe^{2+} or Fe^{3+} levels that enable magnetite process to aggregate, *if* ferrihydrite is used by bacteria. The research was conducted on the production of disulfide (cysteine) cross-section CdS NPs that cause S–H bond divide and the new model nanoparticle complex ($Cd–S–CH_2COOH$) (Sanghi and Verma 2009). Acid carboxylic COOH groups with a hydrogen bond resulted in CdS nanoparticle capping bonds with NH_2 groups (Tang et al. 2005), cadmium-thiolate complex reaction. A coordination connection between Cd^{2+} and oxygen atoms has been generated by one carboxylic atom (–COOH) that competes to thiol for building nanoparticles on CdS surfaces (Li et al. 2007). Covalent binding to nanoparticles of carboxylic acids while still inhibiting the growth of surface oxides that minimize the magnetic characteristic of cobalt can induce biocompatibility. For the rational design of such entities, recognizing the origin of acid-metal interaction is important, but possibly most experimentally a difficult stage (Farkas et al. 2020) (Fig. 12.2).

7 Regulation of Nanoparticle Size and Morphology

It's so well established that electronic and optical characteristics of nanoparticles depend enormously on their size and shape. Significant attention was paid to monitoring the scale, shape, and media support for nanoparticles. Special emphasis has recently been put in the form regulation, as it also allows properties to be optimized to the highest degree of versatility, which gives particles their distinctive character. Although physical and chemical techniques are capable of generating, over a short time, significant quantities of nanoparticles of certain size and shape, these techniques are complex and present certain disadvantages, such as the development of radioactive waste that is hazardous not just to the environment but even to public health. Microbes that are considered to have been efficient green nanofabrics can regulate the size and shape of biological nanoparticles. Two fungal cultures of gold nanoparticles of different morphologies and sizes, *Verticillium luteoalbum* and one labeled isolate 3–6 (Gericke and Pinches 2006), were found to have an intracellular synthesis. Particle formation rate and particle size may be manipulated to a certain degree by manipulating parameters such as exposure times to pH, temperature, gold, and $AuCl_4$. As demonstrated by electron microscopy scans, numerous morphologies of particles were present, including circular, triangular, hexagonal, and other shapes. Shape and size of particles ranged dramatically from several nanometers to around 100 nm. Their observations often found that particles of spheres seemed to be lower than particles of triangles and hexagons. During the study, screened bacterial cultures appeared to intracellularly synthesize thin, nearly homogenous gold nanoparticles. Particles were mainly noticed in the cell cytoplasm, with most spherically shaped particles. Gurunathan et al. (2009) investigated optimal process requirements to complete AgNP production and particle size reduction. In a synthesis of AgNPs, process temperatures and pH values have been used to detect optimum conditions, various mediums, and media of varying $AgNO_3$ concentrations. A nitrate medium with a 5 mM $AgNO_3$, a reaction temperature of 60 °C, and a pH of 10 was described as the maximum synthesis subject. It took only 30 min to achieve more than 95% conversion using *Escherichia coli* supernatant culture under these optimum conditions. The rate of synthesis of identical particles obtained using chemical methods is comparable or faster. Average particle size can be tuned by varying the $AgNO_3$ concentration, temperature of reactions and pH from 10–90 nm. During the synthesis of the Pt nanoparticles, the cell-soluble extract (CSE) might decrease the Pt(IV) into nanoparticles that were stable by means of binding protein and exhibit both g in solution. Strong initial Pt(IV) levels seemed to have led to more regular and geometric particles. More hydrochloride (pH to 4) was produced inside the system at high initial amounts of Pt(IV), leading to precipitation of biocomposites of nanoparticle proteins and consequently a reduction in the level of soluble particle size in colloids. Besides, without cellular restrictions, high size and type variations of protein-stabilized biogenic Pt(0) nanoparticles can be synthesized. Magnetotactic bacteria create uniform size and morphological iron oxide magnetic particles. Magnetite shaped by magnetotactic bacteria takes different forms such as cuboid, rhombic, and rectangular shape of a bullet. A high degree of biological regulation has been observed in various species-dependent crystal morphologies and structures (Amemiya et al. 2007). It is discovered that Mms6 is a big protein closely linked to *Magnetospirillum magneticum* AMB-1, the surface of bacterial magnetites (Arakaki et al. 2010a). With a uniform cuboctahedral morphology, protein was shown to intercede the creation of magnetite crystals. Formation of magnetite with synthetic peptides imitating Mms6 protein was examined. A spherical structure of 0.70–0.90, similar to one of the bacterial magnetites and particulate matter formed by the Mms6 protein, was demonstrated by particles synthesized with short peptides comprising the Mms6 C-terminal acid region. Also, if other peptides are added in production, rectangular morphology was observed with circularities of 0.60–0.85 (Arakaki et al. 2010b). The same group developed an additional method for highly controlled synthesis of magnetite crystals using the recombinant magnetotactic bacterial protein Mms6 in aqueous solutions at reduced temperatures. Crystallographic study of magnetite crystals reveals that Mms6 mediates the development of a peculiar crystal shape of magnetite particles with narrow-scale distribution close to that seen in magnetic bacteria. Mms6 aggregates have a high affinity for iron ions in aqueous solution and have motif sequence in many biomineralization scaffold proteins, close to other organisms. If compared to Mms6, crystals have identical sizes (20 nm) and morphologies (cuboctahedral). This means that Mms6 has a direct impact through the synthesis process on size and shape of nanoparticles (Amemiya et al. 2007). Particle size control for other nanoparticles has also been seen. For instance, Yan et al. (2009) find that yeast induction is an efficient way of achieving a small diameter distribution of zinc phosphate powders. To prevent the large accumulation of $Zn_3(PO_4)_2$ particles to completely control particle size and shape, their method used the yeast feature in reaction mechanism.

8 Nanoparticle Applications

Nanomedicine is a booming scientific area with a vast potential to improve human disease diagnosis and care (Fadeel and Garcia-Bennett 2010). The most widely used nanomedicine nanoparticles are fluorescent biologic labeling, drug/molecular delivery agents, as well as tissue engineering (Tian et al. 2008), heat tumor destruction (hyperthermia), MRI contrast enhancement, and phagokinetic analysis (Parak et al. 2002). Many reviews and research articles have been published that analyze nanoparticles' applications in biomedicine (Piao et al. 2011). Though biosynthesized nanoparticles are relatively new, research has been initiated on applications in drug delivery, cancer care, genetic modification and DNA sequencing, antimicrobials, biomaterials, and response enhancement.

8.1 Antibacterial Agent

Silver-based antiseptics were stressed in recent times due to proliferation and rise of microorganism resistance to various antibiotics. The use of *Trichoderma viride* fungus in silver nanoparticles was biosynthesized (Fayaz et al. 2010). Aqueous silver (Ag+) ions were found to be decreased in solution when exposed to *Trichoderma viride* filtrate, resulting in production of pretty stabilized AgNPs. Nanoparticles have also been tested with multiple antibiotics for increased antimicrobial activity toward Gram (positive and negative) bacteria. With the existence of AgNPs, antibacterial efficacy of erythromycin, chloramphenicol, ampicillin, and kanamycin toward test strains has been improved. Strongest enhancement effect of ampicillin against test strains was detected. Results showed greater antimicrobial effects in combination with antibiotics with AgNPs and offered valuable insight into the production of new antibacterial agents. Duran et al. (2007) have demonstrated that extracellularly generated silver nanoparticles utilizing *F. oxysporum* could be integrated through woven materials in an effort to avoid or decrease contamination with infective bacteria like *S. aureus*. Silver nanoparticles of *Acalypha wilkesiana* (AW-AgNPs) demonstrated substantial repression toward dominant Gram-negative and Gram-positive selected bacteria. Therefore, AW-AgNPs may be suggested as a potential antimicrobial and therapeutic agent against multidrug-resistant pathogens (Dada et al. 2019). The key components of AgNPs, CuONPs, AuNPs, and ZnONPs have been updated and commonly used for therapeutic and medicinal purposes (e.g., as antibacterial, antifungal, antiviral, anti-amebial, anticancer, anti-angiogenic, anti-inflammatory factors). These particles were suggested as alternatives to standard antibiotics to overcome bacterial resistance due to their excellently described antibacterial activity toward Gram (positive and negative) bacteria. Nanoparticles utilize mechanisms involved that differ from traditional therapies, with the benefit of becoming effective toward antibiotic resistance bacteria which have already formed, as well as by attacking several biomolecules that compromise resistant strain growth (Sánchez-López et al. 2020).

9 BM-NPs: Synthesized as Antimicrobial, Antiviral, and Scolicidal Potential from *Penicillium* Species

There have been studies of silver nanoparticle (AgNPs) biosynthesis caused by *Penicillium citrinum* (Yassin et al. 2017). Biogenic AgNPs toward aflatoxinic *A. flavus* were also tested. Biogenic AgNPs toward aflatoxinic A. flavus var. columnaris isolated from sorghum seeds were also tested for antifungal activity (Fig. 12.3). They showed that action of AgNPs toward *Aspergillus flavus* varied from 20.28 to 50.00%, and 224.5 to 4001.8 ppm were calculated at ED50 and ED95, respectively. Such antifungal activity was linked to the cell membrane and cytoplasm modification, membrane permeability, and DNA energy depletion. In extracellular biomimetic synthesis, AgNPs induced by *Penicillium chrysogenum* strain FGCC/BLS1 have been reported (Saxena et al. 2017). Their analysis showed potent antibacterial activity of AgNP at 100 ppm and antifungal activity at 100 ppm toward *E. coli*, *K. pneumoniae*, and *S. aureus* against phytopathogenic fungi *sclerotiorum*. In hemolytic test with a dose of 10 ppm in red blood cells, no cytotoxicity was observed. Exceptionally, biogenic synthesis of gold nanoparticles in an extracellular approach with *P. funicular* BL1 in 18–28 nm range has been documented

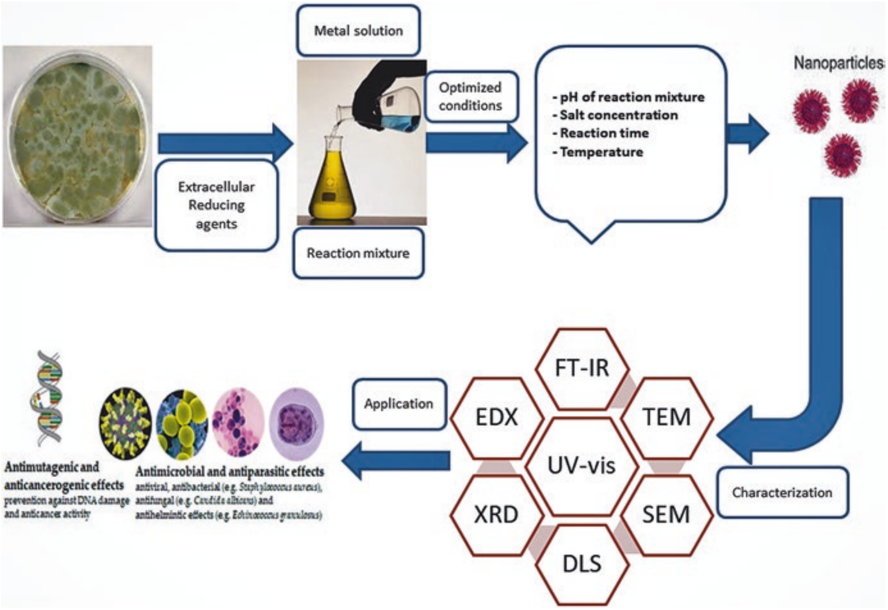

Fig. 12.3 A modern version of pharmaceutical nanobiotechnology and the interface of nanotechnology, bacteria, and pharmaceutical ability

(Maliszewska et al. 2017). They demonstrated a photodynamic inactivation of *Candida albicans* planktonic and biofilm cells in combination with synthesized biogenic AuNP exposure to rose bengal (RB). AuNPs showed no unusual murder of Xe lamp glare exposure to *Candida albicans*. However, killing was shown to be a fair efficiency of *Candida albicans* when RB and biogenic NPs are administered together like photosensitizing agent. Combination of RB and AuNP showed that 4.7 log10 and 4.89 log10 had decreased CFUs, which were 99.91 and 99.99%, while 98.21 and 99.37% were killed by RB alone after the same time. Furthermore, by using Penicillium spp. biosynthesized AgNPs. in an extracellular way (Verma et al. 2013). Maximum antibacterial activity in AgNPs was observed in *Bacillus* and *Pseudomonas* spp., accompanied by *E. coli* and *Salmonella* spp. at concentrations of 1 mg/mL if used in conjunction with tetracycline, and maximum inhibition was observed in *Salmonella*, *Pseudomonas*, and *Escherichia coli*. A research was performed using a disc diversion approach for *Pseudomonas aeruginosa*, *Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Candida albicans* to determine antimicrobial activities of biofabricated AgNPs of *Penicillium aculeatum* Su1. In either study, 200 μg/mL AgNPs had strongest antibacterial effect on all listed strains compared to 100 μg/mL AgNPs with a big variation relative to 50 and 200 μg/mL $AgNO_3$ (Osman et al. 2015). Notably, Solanki et al. (2016) extracellularly synthesized AgNPs *using Penicillium brevicompactum* between 6.28 and 15.12 nm. All through research, antimicrobial activity of biofabricated AgNPs has been evaluated utilizing disc-diffusion methods for clinically isolated pathogenic bacteria such as

E. coli, *S. aureus*, and *P. aeruginosa*. They found that regardless of whether AgNP concentration improved, a dose-dependent zone of inhibition often increased. The inhibition zone for the 10 μL concentration between 7 and 16 mm was found in depth, while for the 20 μL concentration, the inhibition region was significantly found between 9 and 28 mm. In addition, Khan and Jameel (2016) extracellularly biosynthesized AgNPs with *Penicillium fellutanum* within a domain of 10–100 nm. Antifungal activity was assessed through the use of discharge assays against *Candida glabrata*, *Candida albicans*, and *Candida tropicalis*, though $AgNO_3$ solution was not found to inhibit the region. Ammar and El-Desouky (2016) have also documented biosynthesis induced by HA_2N *Penicillium* expansion between 14 and 25 nm. For *A. ochraceus* and *A. niger* with disc-diffusion process, researchers even searched for an antifungal role for biogenic AgNPs. In particular, at concentration of 9 μg AgNPs in A, maximum inhibition level was observed in *Aspergillus niger*. Moreover, AgNPs with culture medium concentration of 220 μg/100 mL were found to cause, with 52.18% decrease percentage, the most important mycotoxin produced by *Aspergillus ochratoxin*, called *Aspergillus ochraceus*. Majeed et al. (2016) have documented an extracellular approach of biomimetic synthesis of AgNPs ranging from 30 to 60 nm. Appraised antibacterial activity of AgNPs using *Proteus vulgaris*, *Staphylococcus aureus*, *Escherichia coli*, and *Vibrio cholera* diffusion methods. For disc-diffusion research, every disc was saturated for 20 μg/mL of AgNPs. Antibiotics such as amoxicillin, carbenicillin, cefixime, ofloxacin, and piperacillin were contrasted with AgNPs. Antimicrobial activity of Ag nanoparticles recorded strong via a zone of inhibition for *E. coli*, *V. cholera*, *P. vulgaris*, and *S. aureus*. Amusingly, Ag nanoparticles strengthened their antibacterial efficacy in combination with the aforementioned antibiotics. Moreover, Sarsar et al. (2015) recorded biogenic AgNP production utilizing 5–25 nm range of *Penicillium atramentosum* KM filtrate extract. *Aeromonas hydrophila*, *Bacillus cereus*, *Enterobacter aerogenes*, *Micrococcus luteus*, *Staphylococcus aureus*, and *Salmonella typhimurium* disc-diffusion process tested antibacterial activity. Significant antimicrobial activity toward *Bacillus cereus* has been observed. A considerable surface area was provided as AgNPs, contributing to its connection to the cell wall, increasing the integrity of cell membranes causing apoptosis, and the authors advocate it for stronger bacterial communication. It also showed a substantial increase of antibacterial activity of microgravity-synthesized AgNPs than of usual gravity-synthesized AgNPs (Sheet et al. 2017). A research was carried out by Ali et al. (2014) that otherwise recorded antimicrobial activity for AgNP extracellular/intracellular production using *Pseudomonas citreonigrum* with micro-dilution technique toward *B. subtilis*, *S. aureus*, *S. typhimorium*, *E. coli*, and *P. aeruginosa* and demonstrated antifungal effect toward *Aspergillus* utilizing micro-dilution technique. In this research, the antiviral effect toward type 2 herpes virus and the cytotoxicity toward three cancer cell lines were also seen. Significant antiviral activity at concentrations of 50 μg/mL, medium antiviral activity at concentrations of 25 μg/mL, or poor performance at concentrations of 12.5 μg/mL has been seen in extracellular environment-generated AgNPs, while far poorer results were found in intracellular AgNPs at concentrations of 50 and 25 μg/mL. Authors proposed throughout viral membrane whether disulfide linking areas in the glycoprotein subunit would interact with AgNPs smaller than 10 nm in size because of their surface plasmon vibration and broad efficient dispersion cross-section including its individual AgNPs. It is important to remember that *P. aculeatum* used a mean diameter of about 60 nm and good scolicidal effect toward *Echinococcus granulosus* protoscolices. Extracellular biosynthesis of AuNPs is documented (Barabadi et al. 2017). Their results show that after 120 min of exposure, the scolicidal behavior of AuNPs was equal to that of AgNP, selenium NPs, 20% $AgNO_3$ at 20 min, and isotonic saline at 20%.

Synthesis of extracellular AgNP has been recently documented by Sheet et al. (2017) to assess its biological and physicochemical role, using microgravity and ordinary conditions. Findings indicate cytotoxic effects of microgravity-synthesized ANPs on cancer cells are much greater than standard severity-synthesized ANPs. In the range of 4–55 nm of exploited *Penicillium aculeatum* Su1, extracellular biosynthesis of AgNPs was stated (Ma et al. 2017). This research revealed that biosynthesized AgNPs are far more biocompatible with human bronchial epithelial cells than $AgNO_3$ and were substantially dose-determined toxic to A549 cells via IC_{50} of 48.73 μg/mL, reflecting a potential impact on human pulmonary adenocarcinoma cell proliferation. Moreover, cytotoxic activity of AgNPs was biosynthesized with the use of *Penicillium* spp. in vitro in a sample. Cell lines with human colon adenocarcinoma (HT-29) ranging from 5 to 100 μg/mL were tested in contrast to normal Vero cell lines. Findings showed that AgNPs of IC50 had a cytotoxic effect of 30 μg/mL to HT-29, while IC50 was anticipated to be far greater than 50 μg/mL for the standard Vero cell line (Verma et al. 2013). Also, a research study found that biogenic AgNPs provided cytotoxic effects on the A549 cancer cell line, whereas their toxicity was significantly lower at the same level as the usual Vero cell line. Expansion of AgNPs by active oxygen species, which causes oxidative damage that induces higher levels of necrosis at higher levels and not just affects critical enzymes, was explained by researchers (Majeed et al. 2016). Ali et al. (2014) also reported intracellular/extracellular AgNP biosynthesis by using *P. citreonigrum* throughout the order of 10–50 nm. AgNPs were tested for cytotoxicity on (breast, colon, liver) cell lines. In dramatic terms, extracellular AGNPs showed significantly greater inhibition effect of three cancer cell lines than intracellular NPs. For this relation, researchers indicated that interruptions of AgNPs in the mitochondrial breathing chain might contribute to ROS, which interrupts ATP production and leads directly to DNA damage. Furthermore, Vazquez-Muñoz et al. (2019) provide a deeper understanding of the complementary mechanism of AgNPs and antibiotics to effectively fight antimicrobial pathogens to alleviate current crises due to antibiotic resistance, particularly those with multidrug-resistant microorganisms.

10 Microbial-Based Crop Safety Nanoparticle Applications

Through the manufacture of nanomaterials, the distribution of inorganic fertilizers and biopesticides to agriculture or a fully qualified approach to gene transfer, nanobiotechnologies, including detection and control for phytopathogens and food safety against infections, can be widely used (Fig. 12.4). Nanoparticle crop protection applications are considered effective if they stay active in extreme conditions like temperature variations, target pathogen penetration, tolerance to phytopathogens, cheap cost of formulation preferably in advanced mode of action, and social and economic advantages (Smith et al. 2008). In growing effectiveness and stabilization of utilized cells and enzymes, nanoparticles play a pivotal role. Nanomaterials result from biomolecular integration (enzymes, metabolites, etc.) or full cell hybrid systems with different agricultural uses (Bailey et al. 2010). Microbe-integrated nanoparticles gain from improved biological efficacy, fast fixation over the wide surface region, increased bioavailability and versatility, reduced toxicity, and improved mass delivery systems. Next NPs are trapped and nanomaterials are fused, and active ingredient is released in a controlled manner. The use of NP aids would involve a tailored distribution strategy based on the actions and environmental conditions of phytopathogens. For instance, DNA-coated AuNPs have been utilized as a shot to bombard plant and tissue cells to induce gene transfer in gene gun protocol (Vijayakumar et al. 2010). Microbes (bacteria, fungi) and its metabolites (enzymes, inhibitors, antibiotics, toxins) have been able to use biocontrol factors to protect plants or to improve the productivity of plants for years.

Coating of polymeric NPs provided advanced pathways for improving efficiency and stability of biocontrol agents, as gravity preparations for formulations supplied to targeted pathogens with a directed distribution system. Besides, trapped nanomaterial products can support the growth of soil and plants (Peteu et al. 2010). Fungal biological control factors are highly precise and are widely available without ingestion, for mass manufacturing by contact. Many fungal genotypes (*Beauveria*, *Nomuraea*, *Verticillium*) spread infection via conidia, requiring humidity to allow host pathogenesis to germinate (Kulkarni et al. 2008). To stabilize *Myrothecium* complex enzymes, nanoformulation with chitosan and montmorillonite clay NPs was produced and demonstrated for *Fusarium* spp. *Gossyphilous Phenacoccus* and biocontrol, with a sluggish discharge of enzymes (cotton mealybug). Antifungal hydrolases and enhanced chitina and chitosanase enzymes are induced by Chito nanoparticles handled with curcuma plants to protect plant host that have made them resistant to turmeric red *Pythium aphanidermatum* rhizome (Anusuya and Sathiyabama 2013). Silica-based NPs (60 nm) packed with fluorescent dye and covalently linked with microbe surface antigen-specific antibodies are sensitive. Copper is converted through metal NPs by popular plant species (*Phragmites australis* and *Iris pseudacorus*) if produced using endomycorrhizal fungi in polluted soil (Manceau et al. 2008). The inhibition efficacy of Ag_2S nanocrystals and $ZnTiO_3$ was higher. In corn-treated plants by silica NPs, greater tolerance to *F. oxysporum* and *A. niger* has been exhibited (Suriyaprabha et al. 2014). TiO_2 NPs have improved

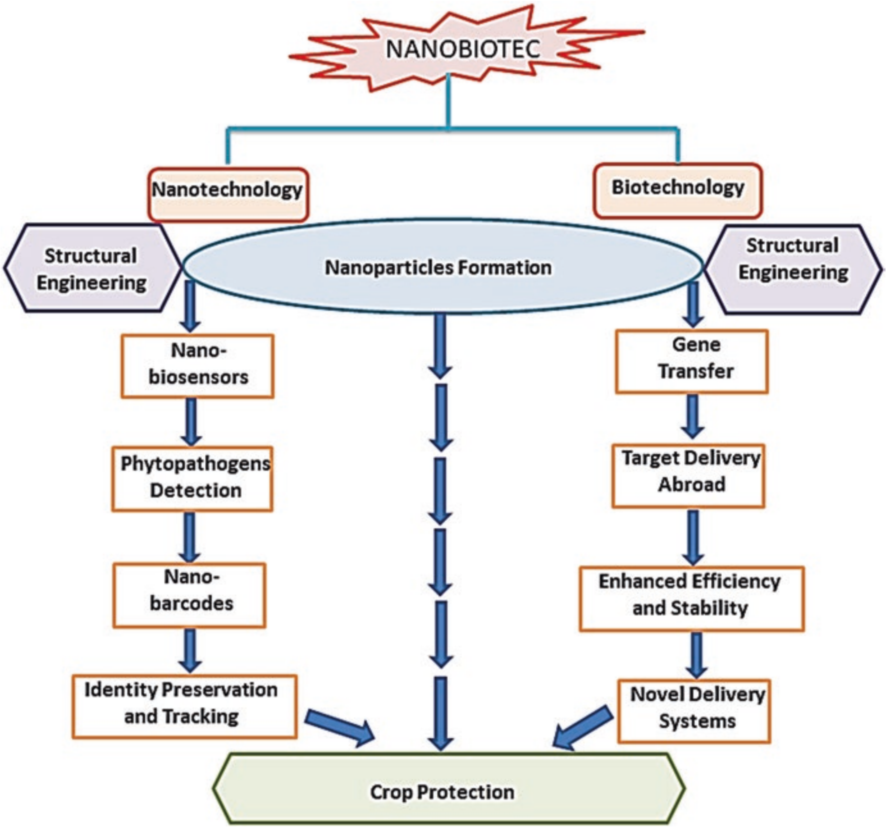

Fig. 12.4 Overview of the impact of nanoparticles on crop protection

and provided defense toward *Alternaria brassicae* (*Bacillus amyloliquefaciens*) in *Brassica napus* rhizosphere (Palmqvist et al. 2015). Zinc oxide NPs showed that conidium and *Penicillium expansum* conidium were inhibited, resulting in fungal mat absence (He et al. 2010). Magnetic reverse of nanoparticles is an extremely precise and sensitive approach. To detect *Prunus necrotic ringspot virus* promptly, reverse transcription loop-mediated isothermal amplification (RTLAMP) was established (Zong et al. 2014). Incubated under atmospheric conditions with combination of $CdCl_2$ + $SeCl_4$ and $CdCl_2$ + $TeCl_2$ by electron transmission microscopy (TEM) and electron diffraction under specific conditions, high fluorescence CdSe QDs and CdTe QDs are metabolized by *F. oxysporum* (Shaligram et al. 2009). Yeast cells have also been used for nanoparticle cadmium telluride (CdTe) biosynthesis QD of tunable fluorescence emission (Nayak et al. 2010). To reduce time to classify unique phytopathogens, the nucleic acid sensor bound to quartz crystal microbiological sensor surface could be coupled with rapid PCR protocols (Maliszewska et al. 2013). Through the use of AgNPs, nanobiotechnology has lately become more effective toward multiple phytopathogens. AgNP interaction with microbes increases because of a higher surface-to-volume proportion and hence greater permeability (Kim et al. 2008). This reduced solution results in the production of highly stable AgNPs with sizes of 5–40 nm when aqueous silver (Ag^+) ions are treated with *Trichoderma viride* filtrate (Fayaz et al. 2010). Antibiotic mixture with AgNPs has been tested to have a stronger antimicrobial effect on many types of bacteria (Aziz et al. 2014, 2015, 2016). Infection of *S. aureus* pathogens in textiles for extracellularly formed AgNPs containing *F. oxysporum* was reduced (Duran et al. 2007). Highest inhibition of disease was also found in *Colletotrichum* species (*C. acutatum*, *C. gloeosporioides*, *C. higginsianum*, *C. nigrum*, *C. orbiculare*, *C. dematium*) or cucumber, pumpkin, and powdery mildew. DNA-directed AgNPs can be removed by *Xanthomonas perforans* leaf spot disease (Ocsoy et al. 2013).

In other studies, biogenic silver nanoparticles have impregnated and reported superior antibiotic disc activity (chloramphenicol) with two pathogenic bacteria *Abelmoschus esculentus* and *Citrullus lanatus* (*Citrobacter freundii* and *Erwinia cacticida*) diseases (Paulkumar et al. 2014). Substantial antifungal effect toward spot blotching disease in wheat induced by *Bipolaris sorokiniana* has been metabolized and illustrated (Mishra et al. 2014). X*anthomonas axonopodis* fluorescent silica nanoparticles (FSNP) were correctly demonstrated in tomatoes and peppers in conjunction with antibody molecules to prevent *vesicatoria* that cause bacterial spot disease (Mishra et al. 2010). Nanoparticles include antibodies used to detect *Xanthomonas axonopodis* (Yao et al. 2009). Ag nanoparticles increasingly attracted researchers worldwide for their antimicrobial agents so their production is more cost-effective and competitive for plant disease control. If utilized in consortiums with several other nanocrystals, numerous studies have shown powerful effects on AgNPs. With the use of Ag-SiO_2 NPs, *Botrytis cinerea* has been reduced by significant antifungal activity (Oh et al. 2006). Ag nanoparticles have been tested toward *Phoma glomerata*, *Phoma herbarum*, *Fusarium semitectum* for antifungal activity with fluconazole spp., *Trichoderma*, and *C. albicans* through disc-diffusion method (Gajbhiye et al. 2009). Throughout the type of *Colletotrichum gloeosporioides* (competence of anthracnosis), *B. sorokiniana*, *M. grisea*, and *S. cepivorum*, sclerotium-forming phytopathogenic fungi, the existence of AgNPs has been significantly inhibited. AgNP fungistatic and fungicidal action against Ambrosian fungus *Raffaelea* spp. and *Fusarium culmorum* was examined, as well as some pathogenic yeasts (*Candida albicans*, *Candida parapsilosis*, *Candida tropicalis*) (Kasprowicz et al. 2010). Inhibition effect has shown to be 15 mg of AgNP toward *Alternaria alternata*, *Botrytis cinerea*, *Curvularia lunata*, *Macrophomina phaseolina*, *Sclerotinia sclerotiorum*, and *Rhizoctonia solani*.

11 Conclusion

Nanomedicine is a thriving scientific area with enormous potential for human diseases to be properly diagnosed and treated. Biological synthesis of microbial nanoparticles for “green chemistry” is considered safe, nontoxic, and environmentally acceptable. Depending on the location of intracellular and extracellular production of nanoparticles, microorganisms, like bacteria, leaves, fungi, and actinomycetes, may be used. Shape and size of nanoparticles in intracellular particle form could be manipulated to a certain degree using control factors like pH, temperature, substrate concentration, and exposure time. The study is presently being performed to monitor molecular and proteomic microorganisms. These techniques and their industrial use in medicine and health care are expected to be applied on a large scale in the next few years, with latest developments and ongoing attempts to increase the efficiency of particulate synthesis and to explore biomedical applications. Over the last decade, there have been huge advances in the field of nanoparticles developed by the microorganism and their applications. However, to improve synthesis and track size and morphology of particles, a lot of work needs to be done. Compared with the physical and chemical process, it is recognized that production of nanoparticles with microbes (several hours, even some days) is a really slow process. Reducing time of production would make this path even more appealing. Particle size and monodisperse particles are two main concerns in the assessment of nanoparticle synthesis. Efficient particle size and monodisperse regulation must therefore be thoroughly examined. Several studies have shown that after a certain period, nanoparticles produced by microorganisms can decompose. The stability of biological nanoparticles therefore needs further research and should be improved. Because particle shape control in the physical and chemical production of nanoparticles is indeed research subject, biological mechanisms with the ability to specifically regulate particle shape would seem to have significant benefits. Adequate control of particle size and monodisperse particle may be given with varying conditions like microorganism type, microbial growth phase, growth medium, synthesis, pH, substratum concentrations, target nanoparticles' origin compound, temperature, process period, and nontarget ion addition. Biosynthesis methods are also beneficial, as nanoparts are mostly covered by lipid molecules, which give biological stability and solubility, which is important for biomedical applications and other synthetic processes for bottling. Research is currently being conducted to control genomic and proteomic cells. Shorter response period and high composition efficiency are being achieved with a deeper understanding of the system of molecular and cellular synthesis, particularly separation and characterization for those molecules responsible for nanoparticle depletion.

References

Abdel-Kareem MM, Zohri AA (2018) Extracellular mycosynthesis of gold nanoparticles using Trichoderma hamatum: optimization, characterization and antimicrobial activity. Lett Appl Microbiol 67:465–475

Agnihotri M, Joshi S, Kumar AR, Zinjarde S, Kulkarni S (2009) Biosynthesis of gold nanoparticles by the tropical marine yeast *Yarrowia lipolytica* NCIM 3589. Mater Lett 63(15):1231–1234

Ahmad A, Mukherjee P, Mandal D et al (2002) Enzyme mediated extracellular synthesis of CdS nanoparticles by the fungus, *Fusarium oxysporum*. J Am Chem Soc 124(41):12108–12109

Ahmad A, Senapati S, Khan MI, Kumar R, Sastry M (2003a) Extracellular biosynthesis of monodisperse gold nanoparticles by a novel extremophilic actinomycete, *Thermomonospora* sp. Langmuir 19(8):3550–3553

Ahmad A, Senapati S, Khan MI et al (2003b) Intracellular synthesis of gold nanoparticles by a novel alkalotolerant actinomycete, Rhodococcus species. Nanotechnology 14(7):824–828

Ahmed T, Shahid M, Noman M, Niazi MBK, Mahmood F, Manzoor I, Zhang Y, Li B, Yang Y, Yan C et al (2020) Silver nanoparticles synthesized by using *Bacillus cereus* SZT1 ameliorated the damage of bacterial leaf blight pathogen in rice. Pathogens 9:160

Akther T, Hemalatha S (2019) Mycosilver nanoparticles: synthesis, characterization and its efficacy against plant pathogenic Fungi. BioNanoScience 9:296–301

Ali FT, El-Sheikh HH, El-Hady MM, Elaasser MM, El-Agamy DM (2014) Silver nanoparticles synthesized by Penicillium Citreonigrum and Fusarium moniliforme isolated from El-Sharkia, Egypt. Int J Sci Eng Res 5(4):181–186

Almaary KS, Sayed SRM, Abd-Elkader OH, Dawoud TM, El Orabi NF, Elgorban AM (2020) Complete green synthesis of silver-nanoparticles applying seed-borne Penicillium duclauxii. Saudi J Biol Sci 27:133–1339

Al-Zubaidi S, Alayafi AA, Abdelkader HS (2019) Biosynthesis, characterization and antifungal activity of silver nanoparticles by *Aspergillus niger* isolate. J Nanotechnol Res 1:23–36

Amemiya Y, Arakaki A, Staniland SS, Tanaka T, Matsunaga T (2007) Controlled formation of magnetite crystal by partial oxidation of ferrous hydroxide in the presence of recombinant magnetotactic bacterial protein Mms6. Biomaterials 28:5381–5389

Ammar HAM, El-Desouky TA (2016) Green synthesis of nanosilver particles by *Aspergillus terreus* HA1N and *Penicillium expansum* HA_2N and its antifungal activity against mycotoxigenic fungi. J Appl Microbiol 121:89

Anusuya S, Sathiyabama M (2013) Effect of chitosan on rhizome rot disease of turmeric caused by Pythium aphanidermatum. ISRN Biotechnol 305349:1–5

Arakaki A, Nakazawa H, Nemoto M, Mori T, Matsunaga T (2008) Formation of magnetite by bacteria and its application. J R Soc Interface 5(26):977–999

Arakaki A, Masuda F, Amemiya Y, Tanaka T, Matsunaga T (2010a) Control of the morphology and size of magnetite particles with peptides mimicking the Mms6 protein from magnetotactic bacteria. J Colloid Interf Sci 343(1):65–70

Arakaki A, Shibusawa M, Hosokawa M, Matsunaga T (2010b) Preparation of genomic DNA from a single species of uncultured magnetotactic bacterium by multiple-displacement amplification. Appl Environ Microbiol 76(5):1480–1485

Aziz N, Fatma T, Varma A, Prasad R (2014) Biogenic synthesis of silver nanoparticles using Scenedesmus abundans and evaluation of their antibacterial activity. J Nanoparticles 2014:689419. https://doi.org/10.1155/2014/689419

Aziz N, Faraz M, Pandey R, Sakir M, Fatma T, Varma A, Barman I, Prasad R (2015) Facile algae-derived route to biogenic silver nanoparticles: synthesis, antibacterial and photocatalytic properties. Langmuir 31:11605–11612

Aziz N, Pandey R, Barman I, Prasad R (2016) Leveraging the attributes of Mucor hiemalis-derived silver nanoparticles for a synergistic broad-spectrum antimicrobial platform. Front Microbiol 7:1984. https://doi.org/10.3389/fmicb.2016.01984

Bai HJ, Zhang ZM (2009) Microbial synthesis of semiconductor lead sulfide nanoparticles using immobilized *Rhodobacter sphaeroides*. Mater Lett 63(9–10):764–766

Bai HJ, Zhang ZM, Gong J (2006) Biological synthesis of semiconductor zinc sulfide nanoparticles by immobilized *Rhodobacter sphaeroides*. Biotechnol Lett 28(14):1135–1139

Bai HJ, Zhang ZM, Guo Y, Yang GE (2009) Biosynthesis of cadmium sulfide nanoparticles by photosynthetic bacteria *Rhodopseudomonas palustris*. Colloids Surf B Biointerfaces 70(1):142–146

Bailey KL, Boyetchko SM, Langle T (2010) Social and economic drivers shaping the future of biological control: a Canadian perspective on the factors affecting the development and use of microbial biopesticides. Biol Control 52:221–229

Bansal V, Rautaray D, Ahmad A, Sastry M (2004) Biosynthesis of zirconia nanoparticles using the fungus *Fusarium oxysporum*. J Mater Chem 14(22):3303–3305

Bansal V, Rautaray D, Bharde A et al (2005) Fungus-mediated biosynthesis of silica and titania particles. J Mater Chem 15(26):2583–2589

Bansal V, Poddar P, Ahmad A, Sastry M (2006) Room-temperature biosynthesis of ferroelectric barium titanate nanoparticles. J Am Chem Soc 128(36):11958–11963

Bao H, Lu Z, Cui X et al (2010) Extracellular microbial synthesis of biocompatible CdTe quantum dots. Acta Biomater 6(9):3534–3541

Barabadi H, Honary S, Mohammadi MA, Ahmadpour E, Rahimi MT, Alizadeh A, Naghibi F, Saravanan M (2017) Green chemical synthesis of gold nanoparticles by using *Penicillium aculeatum* and their scolicidal activity against hydatid cyst protoscolices of *Echinococcus granulosus*. Environ Sci Pollut Res Int 24:5800

Bazylinski DA, Frankel RB, Heywood BR et al (1995) Controlled biomineralization of magnetite (Fe_3O_4) and greigite (Fe_3S_4) in a magnetotactic bacterium. Appl Environ Microbiol 61(9):3232–3239

Benzerara K, Miot J, Morin G, Ona-Nguema G, Skouri-Panet F, Ferard C (2010) Significance, mechanisms and environmental implications of microbial biomineralization. Compt Rendus Geosci 343(2–3):160–167

Bhainsa KC, D'Souza SF (2006) Extracellular biosynthesis of silver nanoparticles using the fungus Aspergillus fumigatus. Colloids Surf. B Biointerfaces 47:160–164

Bhattacharya R, Mukherjee P (2008) Biological properties of naked metal nanoparticles. Adv Drug Deliv Rev 60(11):1289–1306

Blakemore R (1975) Magnetotactic bacteria. Science 190(4212):377–379

Bose S, Hochella MF, Gorby YA et al (2009) Bioreduction of hematite nanoparticles by the dissimilatory iron reducing bacterium *Shewanella oneidensis* MR-1. Geochim Cosmochim Acta 73(4):962–976

Castro-Longoria E, Vilchis-Nestor AR, Avalos- Borja M (2011) Biosynthesis of silver, gold and bimetallic nanoparticles using the filamentous fungus *Neurospora crassa*. Colloids Surf B Biointerfaces 83(1):42–48

Cunningham DP, Lundie LL Jr (1993) Precipitation of cadmium by *Clostridium thermoaceticum*. Appl Environ Microbiol 59(1):7–14

Dada AO, Adekola FA, Dada FE, Adelani-Akande AT et al (2019) Silver nanoparticle synthesis by *Acalypha wilkesiana* extract: phytochemical screening, characterization, influence of operational parameters, and preliminary antibacterial testing. Heliyon 5:10

De Matteis V, Rizzello L, Ingrosso C, Liatsi-Douvitsa E, De Giorgi ML, De Matteis G, Rinaldi R (2019) Cultivar-dependent anticancer and antibacterial properties of silver nanoparticles synthesized using leaves of different *Olea europaea* trees. Nano 9:1544

Deepa K, Panda T (2014) Synthesis of gold nanoparticles from different cellular fractions of *Fusarium oxysporum*. J Nanosci Nanotechnol 14:345–3463

DeWindt W, Aelterman P, Verstraete W (2005) Bioreductive deposition of palladium (0) nanoparticles on *Shewanella oneidensis* with catalytic activity towards reductive dichlorination of polychlorinated biphenyls. Environ Microbiol 7(3):314–325

Du L, Jiang H, Liu X, Wang E (2007) Biosynthesis of gold nanoparticles assisted by Escherichia coli DH5α and its application on direct electrochemistry of hemoglobin. Electrochem Commun 9(5):1165–1170

Duran N, Marcato PD, De Souza GIH, Alves OL, Esposito E (2007) Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment. J Biomed Nanotechnol 3(2):203–208

El-Moslamy SH, Elkady MF, Rezk AH, Abdel-Fattah YR (2017) Applying Taguchi design and large-scale strategy for mycosynthesis of nano-silver from endophytic *Trichoderma harzianum* SYA.F4 and its application against phytopathogens. Sci Rep 7:45297

Fan TX, Chow S.K, Zhang D (2009) Biomorphic mineralization: from biology to materials. Progress in Materials Science 54(5): 542–659

Fadeel B, Garcia-Bennett AE (2010) Better safe than sorry: understanding the toxicological properties of inorganic nanoparticles manufactured for biomedical applications. Adv Drug Deliv Rev 62(3):362–374

Farkas B, Terranova U, de Leeuw NH (2020) Binding modes of carboxylic acids on cobalt nanoparticles. Phys Chem Chem Phys 22:985–996

Fayaz AM, Balaji K, Kalaichelvan PT, Venkatesan R (2009) Fungal based synthesis of silver nanoparticles—an effect of temperature on the size of particles. Colloids Surf B Biointerfaces 74(1):123–126

Fayaz AM, Balaji K, Girilal M, Yadav R, Kalaichelvan PT, Venketesan R (2010) Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria. Nanomed Nanotechnol Biol Medicine 6(1):e103–e109

Feynman RP (1960) There's plenty of room at the bottom. Eng Sci 23:22–36

Figueiredo EP, Ribeiro JM, Nishio EK, Scandorieiro S, Costa AF et al (2019) New approach for simvastatin as an antibacterial: synergistic effect with bio-synthesized silver nanoparticles against multidrug-resistant bacteria. Int J Nanomedicine 14:7975–7985

Gajbhiye M, Kesharwani J, Ingle A, Gade A, Rai M (2009) Fungus mediated synthesis of silver nanoparticles and their activity against pathogenic fungi in combination with fluconazole. Nanomedicine 5:382–386

Gericke M, Pinches A (2006) Biological synthesis of metal nanoparticles. Hydrometallurgy 83(1–4):132–140

Gurunathan S, Kalishwaralal K, Vaidyanathan R et al (2009) Biosynthesis, purification and characterization of silver nanoparticles using *Escherichia coli*. Colloids Surf B Biointerfaces 74(1):328–335

Hamouda RA, Hussein MH, Abo-elmagd RA, Bawazir SS (2019) Synthesis and biological characterization of silver nanoparticles derived from the cyanobacterium Oscillatoria limnetica. Sci Rep 9:1–17

Hassan SE, Fouda A, Radwan AA, Salem SS, Barghoth MG, Awad MA, Abdo AM, El-Gamal MS (2019) Endophytic actinomycetes *Streptomyces* spp mediated biosynthesis of copper oxide nanoparticles as a promising tool for biotechnological applications. J Biol Inorg Chem 24:377–393

Hayat MA (1989) Colloidal gold: principles, methods, and applications. Academic Press, San Diego

He S, Guo Z, Zhang Y, Zhang S, Wang J, Gu N (2007) Biosynthesis of gold nanoparticles using the bacteria Rhodopseudomonas capsulate. Mater Lett 61(18):3984–3987

He L, Liu Y, Mustapha A, Lin M (2010) Antifungal activity of zinc oxide nanoparticles against *Botrytis cinerea* and *Penicillium expansum*. Microbiol Res 166:207–215

Hossain A, Hong X, Ibrahim E, Li B, Sun G, Meng Y, Wang Y, An Q (2019) Green synthesis of silver nanoparticles with culture supernatant of a bacterium *Pseudomonas rhodesiae* and their antibacterial activity against soft rot pathogen *Dickeya dadantii*. Molecules 24:2303

Husseiny MI, El-Aziz MA, Badr Y, Mahmoud MA (2007) Biosynthesis of gold nanoparticles using *Pseudomonas aeruginosa*. Spectrochim Acta A 67(3–4):1003–1006

Ibrahim E, Fouad H, Zhang M, Zhang Y, Qiu W, Yan C, Li B, Mo J, Chen J (2019) Biosynthesis of silver nanoparticles using endophytic bacteria and their role in inhibition of rice pathogenic bacteria and plant growth promotion. RSC Adv 9:29293–29299

Ibrahim E, Zhang M, Zhang Y, Hossain A, Qiu W, Chen Y, Wang Y, Wu W, Sun G, Li B (2020) Green-synthesization of silver nanoparticles using endophytic Bacteria isolated from garlic and its antifungal activity against wheat Fusarium head blight pathogen *Fusarium graminearum*. Nanomaterials (Basel) 10:219

Jain N, Bhargava A, Majumdar S, Tarafdar JC, Panwar J (2011) Extracellular biosynthesis and characterization of silver nanoparticles using Aspergillus flavus NJP08: a mechanism perspective. Nanoscale 3(2):635–641

Jha AK, Prasad K (2010) Ferroelectric $BaTiO_3$ nanoparticles: biosynthesis and characterization. Colloids Surf B Biointerfaces 75(1):330–334

Jha AK, Prasad K, Prasad K (2009) A green low-cost biosynthesis of Sb_2O_3 nanoparticles. Biochem Eng J 43(3):303–306

Jha AK, Prasad K (2010a) Ferroelectric $BaTiO_3$ nanoparticles: biosynthesis and characterization. Colloids Surf. B Biointerfaces 75(1): 330–334

Jha AK, Prasad K (2010b) Synthesis of $BaTiO_3$ nanoparticles: A new sustainable green approach. Integrated Ferroelectrics 117(1): 49–54

Juibari MM, Abbasalizadeh S, Jouzani GS, Noruzi M (2011) Intensified biosynthesis of silver nanoparticles using a native extremophilic *Ureibacillus thermosphaericus* strain. Mater Lett 65(6):1014–1017

Kalimuthu K, Suresh Babu R, Venkataraman D, Bilal M, Gurunathan S (2008) Biosynthesis of silver nanocrystals by *Bacillus licheniformis*. Colloids Surf B Biointerfaces 65(1):150–153

Kalishwaralal K, Deepak V, Ramkumarpandian S, Nellaiah H, Sangiliyandi G (2008) Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. Mater Lett 62(29):4411–4413

Kalishwaralal K, Deepak V, Ramkumarpandian S et al (2010) Biosynthesis of silver and gold nanoparticles using *Brevibacterium casei*. Colloids Surf B Biointerfaces 77(2):257–262

Kashefi K, Lovley DR (2000) Reduction of Fe(III), Mn(IV), and toxic metals at 100°C by *Pyrobaculum islandicum*. Appl Environ Microbiol 66(3):1050–1056

Kasprowicz MJ, Kozio M, Gorczyca A (2010) The effect of silver nanoparticles on phytopathogenic spores of *Fusarium culmorum*. Can J Microbiol 56:247–253

Kaur P, Thakur R, Duhan JS, Chaudhury A (2018) Management of wilt disease of chickpea in vivo by silver nanoparticles biosynthesized by rhizospheric microflora of chickpea (Cicer arietinum). J Chem Technol Biotechnol 93:3233–3243

Khan JN, Jameel N (2016) Antifungal activity of silver nanoparticles produced from fungus, *Penicillium fellutanum* at different pH. J Microb Biochem Technol 8:440

Kim KJ, Sung WS, Moon SK, Choi JS, Kim JG, Lee DG (2008) Antifungal effect of silver nanoparticles on dermatophytes. J Microbiol Biotechnol 18:1482–1484

Klaus T, Joerger R, Olsson E, Granqvist CG (1999) Silverbased crystalline nanoparticles, microbially fabricated. Proc Natl Acad Sci USA 96(24):13611–13614

Konishi Y, Ohno K, Saitoh N et al (2007a) Bioreductive deposition of platinum nanoparticles on the bacterium Shewanella algae. J Biotechnol 128(3):648–653

Konishi Y, Tsukiyama T, Tachimi T, Saitoh N, Nomura T, Nagamine S (2007b) Microbial deposition of gold nanoparticles by the metal-reducing bacterium Shewanella algae. Electrochim Acta 53(1):186–192

Kulkarni SA, Ghormade V, Kulkarni G, Kapoor M, Chavan SB, Rajendran A et al (2008) Comparison of Metarhizium isolates for biocontrol of Helicoverpa armigera (Lepidoptera: Noctuidae) in chickpea. Biocontrol Sci Tech 18:809–828

Kumar SA, Ansary AA, Abroad A, Khan MI (2007) Extracellular biosynthesis of CdSe quantum dots by the fungus, *Fusarium oxysporum*. J Biomed Nanotechnol 3(2):190–194

Lee JH, Han J, Choi H, Hur HG (2007) Effects of temperature and dissolved oxygen on Se(IV) removal and Se(0) precipitation by Shewanella sp. HN-41. Chemosphere 68(10):1898–1905

Lefevre CT, Abreu F, Lins U, Bazylinski DA (2010a) Nonmagnetotactic multicellular prokaryotes from low-saline, nonmarine aquatic environments and their unusual negative phototactic behavior. Appl Environ Microbiol 76(10):3220–3227

Lefevre CT, Abreu F, Schmidt ML et al (2010b) Moderately thermophilic magnetotactic bacteria from hot springs in Nevada. Appl Environ Microbiol 76(11):3740–3743

Lengke MF, Fleet ME, Southam G (2006a) Morphology of gold nanoparticles synthesized by filamentous cyanobacteria from gold(I)-thiosulfate and gold(III)-chloride complexes. Langmuir 22(6):2780–2787

Lengke MF, Ravel B, Fleet ME, Wanger G, Gordon RA, Southam G (2006b) Mechanisms of gold bioaccumulation by filamentous cyanobacteria from gold(III)-chloride complex. Environ Sci Technol 40(20):6304–6309

Li W, Zhou L, Yu P, Zhu M (2007) A Magnetospirillum strain WM-1 from a freshwater sediment with intracellular magnetosomes. World J Microbiol Biotechnol 23(10):1489–1492

Liu J, Qiao SZ, Hu QH, Lu GQ (2011) Magnetic nanocomposites with mesoporous structures: synthesis and applications. Small 7(4):425–443

Liu Y, Page Z, Ferdous S, Liu F, Kim P, Emrick T, Russell T (2015) Dual functional zwitterionic fullerene interlayer for efficient inverted polymer solar cells. Adv Energy Mater 5(14):1500405

Lloyd JR, Yong P, Macaskie LE (1998) Enzymatic recovery of elemental palladium by using sulfate-reducing bacteria. Appl Environ Microbiol 64(11):4607–4609

Lover T, Henderson W, Bowmaker GA, Seakins JM, Cooney RP (1997) Functionalization and capping of a cds nanocluster: a study of ligand exchange by electrospray mass spectrometry. Chem Mater 9(8):1878–1886

Lv Q, Zhang B, Xing X, Zhao Y, Cai R, Wang W, Gu Q (2018) Biosynthesis of copper nanoparticles using Shewanella loihica PV-4 with antibacterial activity: novel approach and mechanisms investigation. J Hazard Mater 347:141–149

Ma L, Su W, Liu JX, Zeng XX, Huang Z., Li W, Liu ZC, Tang JX (2017) Optimization for extracellular biosynthesis of silver nanoparticles by Penicillium aculeatum Su1 and their antimicrobial activity and cytotoxic effect compared with silver ions. Materials Science and Engineering C: Mat Biol Appl 77:963–971

Majeed S, Abdullah MS, Dash GK, Ansari MT, Nanda A (2016) Biochemical synthesis of silver nanoparticles using filamentous fungi *Penicillium decumbens* (MTCC-2494) and its efficacy against A-549 lung cancer cell line. Chin J Nat Med 14:615

Maliszewska I, Juraszek A, Bielska K (2013) Green synthesis and characterization of silver nanoparticles using ascomycota fungi *Penicillium nalgiovense* AJ12. J Clust Sci 25:989–1004

Maliszewska I, Lisiak B, Popko K, Matczyszyn K (2017) Enhancement of the efficacy of photodynamic inactivation of candida albicans with the use of biogenic gold nanoparticles. J Photochem Photobiol 93:1081

Manceau A, Nagy K, Marcus M, Lanson M, Geoffroy N, Jacquet T et al (2008) Formation of metallic copper nanoparticles at the soil-root Interface. Environ Sci Technol 42:1766–1772

Mishra AN, Bhadauria S, Gaur MS, Pasricha R (2010) Extracellular microbial synthesis of gold nanoparticles using fungus *Hormoconis resinae*. J Microbiol 62:45–48

Mishra S, Singh BR, Singh A, Keswani C, Naqvi AH, Singh HB (2014) Biofabricated silver nanoparticles act as a strong fungicide against *Bipolaris sorokiniana* causing spot blotch disease in wheat. PLoS One 9(5):e97881

Nair B, Pradeep T (2002) Coalescence of nanoclusters and formation of submicron crystallites assisted by lactobacillus strains. Cryst Growth Des 2(4):293–298

Nayak RR, Pradhan N, Behera D, Pradhan KM, Mishra S, Sukla LB, Mishra BK (2010) Green synthesis of silver nanoparticle by *Penicillium purpurogenum* NPMF, the process and optimization. J Nanopart Res 13:3129–3137

Ngan CL, Basri M, Tripathy M, Karjiban RA, Abdul-Malek E (2015) Skin intervention of fullerene-integrated nanoemulsion in structural and collagen regeneration against skin aging. Eur J Pharm Sci 70:22–28

Nies DH (1999) Microbial heavy-metal resistance. Appl Microbiol Biotechnol 51(6):730–750

Ocsoy I, Paret ML, Ocsoy MA, Kunwar S, Chen T, You M, Tan W (2013) Nanotechnology in plant disease management: DNA directed silver nanoparticles on graphene oxide as an antibacterial against *Xanthomonas perforans*. ACS Nano 7:8972–8980. https://doi.org/10.1021/nn4034794

Oh SD, Lee S, Choi SH, Lee IS, Lee YM, Chun JH, Park HJ (2006) Synthesis of ag and Ag-SiO2 nanoparticles by y-irradiation and their antibacterial and antifungal efficiency against *Salmonella enterica* serovar Typhimurium and *Botrytis cinerea*. Colloids Surf A 275:228–233

Osman ME, Eid MM, Khattab OH, Abd-El All SM, El-Hallouty SM, Mahmoud DA (2015) Spectroscopic characterization of the effect of gamma radiation on the physical parameters of biosynthesized silver/chitosan nano-particles and their antimicrobial activity. J Chem Biol Phys Sci 5:2643

Oves M, Rauf MA, Hussain A, Qari AH, Parwaz Khan AA et al (2019) Antibacterial silver nanomaterial synthesis from mesoflavibacter zeaxanthinifaciens and targeting biofilm formation. Front Pharmacol 10:80

Palmqvist NGM, Bejai S, Meijer J, Seisenbaeva GA, Kessler VG (2015) Nano titania aided clustering and adhesion of beneficial bacteria to plant roots to enhance crop growth and stress management. Sci Rep 5:10146

Panacek A, Kvitek L, Prucek R et al (2006) Silver colloid nanoparticles: synthesis, characterization, and their antibacterial activity. J Phys Chem B 110(33):16248–16253

Pandian SRK, Deepak V, Kalishwaralal K, Muniyandi J, Rameshkumar N, Gurunathan S (2009) Synthesis of PHB nanoparticles from optimized medium utilizing dairy industrial waste using Brevibacterium casei SRKP2: a green chemistry approach. Colloids Surf B Biointerfaces 74(1):266–273

Parak WJ, Boudreau R, Le Gros M et al (2002) Cell motility and metastatic potential studies based on quantum dot imaging of phagokinetic tracks. Adv Mater 14(12):882–885

Paulkumar K, Gnanajobitha G, Vanaja M, Rajeshkumar S, Malarkodi C, Pandian K, Annadurai G (2014) Piper nigrum leaf and stem assisted green synthesis of silver nanoparticles and evaluation of its antibacterial activity against agricultural plant pathogens. Scientific World J. https://doi.org/10.1155/2014/829894

Perez-Gonzalez T, Jimenez-Lopez C, Neal AL et al (2010) Magnetite biomineralization induced by *Shewanella oneidensis*. Geochim Cosmochim Acta 74(3):967–979

Peteu SF, Oancea F, Sicuia OA, Constantinescu F, Dinu S (2010) Responsive polymers for crop protection. Polymers 2:229–251

Piao MJ, Kang KA, Lee IK et al (2011) Silver nanoparticles induce oxidative cell damage in human liver cells through inhibition of reduced glutathione and induction of mitochondria-involved apoptosis. Toxicol Lett 201(1):92–100

Ponmurugan P, Manjukarunambika K, Elango V, Gnanamangai BM (2016) Antifungal activity of biosynthesized copper nanoparticles evaluated against red root-rot disease in tea plants. J Exp Nanosci 11:1019–1031

Prasad R, Bhattacharyya A, Nguyen QD (2017a) Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. Front Microbiol 8:1014. https://doi.org/10.3389/fmicb.2017.01014

Prasad R, Gupta N, Kumar M, Kumar V, Wang S, Abd-Elsalam KA (2017b) Nanomaterials act as plant defense mechanism. In: Prasad R, Kumar V, Kumar M (eds) Nanotechnology. Springer, Singapore, pp 253–269

Ragaei M, Sabry KH (2014) Nanotechnology for insect pest control. Int J Sci Environ Technol 3(2):528–545

Rautaray D, Sanyal A, Adyanthaya SD, Ahmad A, Sastry M (2004) Biological synthesis of strontium carbonate crystals using the fungus *Fusarium oxysporum*. Langmuir 20(16):6827–6833

Reith F, Lengke MF, Falconer D, Craw D, Southam G (2007) The geomicrobiology of gold. ISME J 1(7):567–584

Sánchez-López E, Gomes D, Esteruelas G, Bonilla L et al (2020) Metal-based nanoparticles as antimicrobial agents: an overview. Nanomaterials 10(292):1–39. https://doi.org/10.3390/nano10020292

Sanghi R, Verma P (2009) A facile green extracellular biosynthesis of CDs nanoparticles by immobilized fungus. Chem Eng J 155(3):886–891

Sanyal A, Rautaray D, Bansal V, Ahmad A, Sastry M (2005) Heavy-metal remediation by a fungus as a means of production of lead and cadmium carbonate crystals. Langmuir 21(16):7220–7224

Sarsar V, Selwal MK, Selwal KK (2015) Biofabrication, characterization and antibacterial efficacy of extracellular silver nanoparticles using novel fungal strain of *Penicillium atramentosum* KMJ. Saudi Chem Soc 19:682

Sawle BD, Salimath B, Deshpande R, Bedre MD, Prabhakar BK, Venkataraman A (2008) Biosynthesis and stabilization of Au and Au-Ag alloy nanoparticles by fungus, *Fusarium semitectum*. Sci Technol Adv Mater 9(3):1–6. Article ID 035012

Saxena J, Sharma P, Singh A (2017) Biomimetic synthesis of silver nanoparticles from *Penicillium chrysogenum* strain FGCC/BLS1 by optimizing physico-cultural conditions and assessment of their antimicrobial potential. IET Nanobiotechnol 11:576

Senapati S, Ahmad A, Khan MI, Sastry M, Kumar R (2005) Extracellular biosynthesis of bimetallic Au-Ag alloy nanoparticles. Small 1(5):517–520

Shaligram NS, Bule M, Bhambure R, Singhal RS, Singh SK, Szakacs G, Pandey A (2009) Biosynthesis of silver nanoparticles using aqueous extract from the compactin producing fungal strain. Process Biochem 44:939–943

Sheet S, Sathishkumar Y, Sivakumar AS, Shim KS, Lee YS (2017) Low-shear-modeled microgravity-grown *Penicillium chrysogenum*-mediated biosynthesis of silver nanoparticles with enhanced antimicrobial activity and its anticancer effect in human liver cancer and fibroblast cells. Bioprocess Biosyst Eng 40:1529–1542

Singaravelu G, Arockiamary JS, Kumar VG, Govindaraju K (2007) A novel extracellular synthesis of monodisperse gold nanoparticles using marine alga, Sargassum wightii Greville. Colloids Surf B 57(1):97–101

Singh D, Rathod V, Ninganagouda S, Hiremath J, Singh AK, Mathew J (2014) Optimization and characterization of silver nanoparticle by endophytic fungi Penicillium sp. isolated from *Curcuma longa* (turmeric) and application studies against MDR *E. coli* and *S. aureus*. Bioinorg Chem Appl 2014:408021. https://doi.org/10.1155/2014/408021

Sinha A, Khare SK (2011) Mercury bioaccumulation and simultaneous nanoparticle synthesis by Enterobacter sp. cells. Bioresour Technol 102:4281–4284

Smith K, Evans DA, El-Hiti GA (2008) Role of modern chemistry in sustainable arable crop protection. Phil Trans R Soc B 363:623–637

Sneha K, Sathishkumar M, Mao J, Kwak IS, Yun YS (2010) *Corynebacterium glutamicum*-mediated crystallization of silver ions through sorption and reduction processes. Chem Eng J 162(3):989–996

Solanki BD, Ramani HR, Garaniya NH, Parmar DV (2016) Biosynthesis of silver nanoparticles using fungus Penicillium Brevicompactum and evaluation of their anti-bacterial activity against some human pathogens. Res J Biotechnol 11:44

Soni N, Prakash S (2011) Factors affecting the geometry of silver nanoparticles synthesis in *Chrysosporium tropicum* and *Fusarium oxysporum*. Am J Nanotechnol 2(1):112–121

Southam G, Beveridge TJ (1996) The occurrence of sulfur and phosphorus within bacterially derived crystalline and pseudocrystalline octahedral gold formed in vitro. Geochim Cosmochim Acta 60(22):4369–4376

Spring S, Schleifer KH (1995) Diversity of magnetotactic bacteria. Syst Appl Microbiol 18(2):147–153

Suresh AK, Pelletier DA, Wang W et al (2011) Biofabrication of discrete spherical gold nanoparticles using the metal reducing bacterium *Shewanella oneidensis*. Acta Biomater 7(5):2148–2152

Suriyaprabha R, Karunakaran G, Kavitha K, Yuvakkumar R, Rajendran V, Kannan N (2014) Application of silica nanoparticles in maize to enhance fungal resistance. IET Nanobiotechnol 8(3):133–137

Sweeney RY, Mao C, Gao X et al (2004) Bacterial biosynthesis of cadmium sulfide nanocrystals. Chem Biol 11(11):1553–1559

Tanase C, Berta L, Coman NA, Ros ca I, Man A, Toma F, Mocan A, Nicolescu A, Jakab-Farkas L, Biró D et al (2019) Antibacterial and antioxidant potential of silver nanoparticles biosynthesized using the spruce bark extract. Nanomaterials 9:11

Tang H, Yan M, Zhang H, Xia M, Yang D (2005) Preparation and characterization of water-soluble CdS nanocrystals by surface modification of ethylene diamine. Mater Lett 59(8–9):1024–1027

Thornhill RH, Burgess JG, Matsunaga T (1995) PCR for direct detection of indigenous uncultured magnetic cocci in sediment and phylogenetic analysis of amplified 16S ribosomal DNA. Appl Environ Microbiol 61(2):495–500

Tian F, Prina-Mello A, Estrada G et al (2008) A novel assay for the quantification of internalized nanoparticles in macrophages. Nanotoxicology 2(4):232–242

Vazquez-Muñoz R, Meza-Villezcas AP, Fournier GJ, Soria-Castro E et al (2019) Enhancement of antibiotics antimicrobial activity due to the silver nanoparticles impact on the cell membrane. PLoS One 14(11):e0224904. https://doi.org/10.1371/journal.pone.0224904

Verma S, Abirami S, Mahalakshmi V (2013) Anticancer and antibacterial activity of silver nanoparticles biosynthesized by Penicillium spp. and its synergistic effect with antibiotic. Microbiol Biotechnol Res 3:54

Vijayakumar PS, Abhilash OU, Khan BM, Prasad BLV (2010) Nanogold-loaded sharp-edged carbon bullets as plant-gene carriers. Adv Funct Mater 20:2416–2423

Watson JHP, Ellwood DC, Soper AK, Charnock J (1999) Nanosized strongly-magnetic bacterially-produced iron sulfide materials. J Magn Magn Mater 203(1–3):69–72

Yan S, He W, Sun C et al (2009) The biomimetic synthesis of zinc phosphate nanoparticles. Dyes Pigments 80(2):254–258

Yang H, Santra S, Holloway PH (2005) Syntheses and applications of Mn-doped II-VI semiconductor nanocrystals. J Nanosci Nanotechnol 5(9):1364–1375

Yao KS, Li SJ, Tzeng KC, Cheng TC, Chang CY, Chiu CY, Liao CY, Hsu JJ, Lin ZP (2009) Fluorescence silica nanoprobe as a biomarker for rapid detection of plant pathogens. Adv Mater Res 79:513–516

Yassin MA, El-Samawaty A, Dawoud TM, Abd-Elkader OH, Al Maary KS, Hatamleh AA, Elgorban AM (2017) Characterization and anti-*Aspergillus flavus* impact of nanoparticles synthesized by *Penicillium citrinum*. Saudi J Biol Sci 24:1243

Zhang X, Yan S, Tyagi RD, Surampalli RY (2011) Synthesis of nanoparticles by microorganisms and their application in enhancing microbiological reaction rates. Chemosphere 82(4):489–494

Zhang P, Zhang R, Fang X, Song T, Cai X, Liu H, Du S (2016) Toxic effects of graphene on the growth and nutritional levels of wheat (*Triticum aestivum* L.): short- and long-term exposure studies. J Hazard Mater 317:543–551

Zhou W, He W, Zhang X et al (2009a) Biosynthesis of iron phosphate nanopowders. Powder Technol 194(1–2):106–108

Zhou W, He W, Zhong S et al (2009b) Biosynthesis and magnetic properties of mesoporous Fe_3O_4 composites. J Magn Magn Mater 321(8):1025–1028

Zhu K, Pan H, Li J et al (2010) Isolation and characterization of a marine magnetotactic spirillum axenic culture QH-2 from an intertidal zone of the China Sea. Res Microbiol 161(4):276–283

Zheng D, Hu C, Gan T, Dang X, Hu, S (2010) Preparation and application of a novel vanillin sensor based on biosynthesis of Au-Ag alloy nanoparticles. Sensors and Actuators B: Chemical 148: 247–252

Zong X, Wang W, Wei H, Wang J, Chen X, Xu L, Zhu D, Tan Y, Liu Q (2014) Rapid detection of Prunus necrotic ringspot virus using magnetic nanoparticle-assisted reverse transcription loop-mediated isothermal amplification. J Virol Methods 208:85–89