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Green synthesis of nanoparticles by different microorganisms

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Abstract

Green synthesis of nanoparticles as a simple, low-cost and eco-friendly method compared to the Physical and chemical methods and its materials have become more widely used. In the green synthesis of plants, algae and microorganisms and their components are used as reducing agents for the production of nanoparticles. In the meantime, biosynthesis Nanoparticles by microorganisms due to high environmental compatibility reduced energy consumption and cost taken into attention. Various microorganisms to carry out their vital processes from organic sources and minerals feed on the environment, these organisms are highly resistant to metals and when exposed to metal ions, they produce nanoparticles by different mechanisms. Metallic nanoparticles can be used for various fields such as optics due to their unique physical and chemical properties, catalysts, antimicrobials, medicine and food packaging. This paper describes how microorganisms can synthesize metal nanoparticles as well as their function and application in biomedicine.

Keywords: Green synthesis; Nanoparticles; Microorganisms; Eco-friendly

1. Introduction

Nanoparticles are microscopic particles that are less than nanometers in size in at least one dimension [1]. Nano production Particles with different shapes, sizes and chemical levels cause different optical, electrical, thermal and mechanical properties. [2]. Certain properties of nanoparticles such as high surface to volume ratio, improved solubility, multiple performance [3] Ability to pass through arteries and target organs [1] and nanoparticle size, application, DNA Ability to bind to single strands Makes them possible in biomedicine. [3] Microorganisms such as bacteria, fungi and yeasts play an essential role In the recovery of minerals in the environment and for the manufacture of metal nanoparticles, semiconductors and quantum dots of size and Different forms are used, so the use of microorganisms to protect the environment Appropriate [4].

Table 1 shows the number of microorganisms and nanoparticles synthesized by them [5] today's studies focus on the synthesis of metal nanoparticles by prokaryotes due to their abundance in the environment. Biology, their ability to adapt to hard conditions, high growth rate [6]. Marine microorganisms as well they are a rich source of bioactive compounds that play an important role in the synthesis of Nano drugs, so in pharmacy And the development of industrial products and biotechnology are used. Because marine microbes live deep in the sea and have regenerated large amounts of deep-sea minerals over the past millions of years, so they can have the potential to synthesize nanoparticles. In addition nanoparticles synthesized by microorganisms tend they are stabilized by peptides, which prevent their accumulation. These peptides are formed in response to the stress of heavy metals and as a mechanism for the separation of metal ions in Bacteria and fungi have been used [7]. Many microorganisms produce nanoparticles inside or outside the cell But the mechanism of intracellular and extracellular synthesis of nanoparticles is different with different biological factors. Nitrate enzyme which plays an essential role in the conversion of metal ions into nanoparticles. In the intracellular synthesis of NADH reductase-dependent load positive metal ions interact

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electrostatically with the negative charge of the cell wall and the enzymes in the cell wall. They are cells that regenerate ions into nanoparticles, so that these nanoparticles penetrate through the cell wall [8].

A review of the biosynthesis of metal nanoparticles by bacteria, fungi, yeasts and microorganisms is presented here, along with a discussion of their biomedical applications.

Table 1 Biosynthesis of different metal nanoparticles by different microbial sources

Microorganism	Nanoparticle type	Size (nm)	Morphology	Reference
Aspergillus deflectus and *Penicillium pinophilum*	Ag/CS	15–40 nm –	cubic	Osman et al. (22)
Aspergillus foetidus Fungus	Au	30–50 nm	Spherical	Roy et al. (23)
Bacillus cereus Bacterium	TiO2	69–140 nm	Spherical	Sunkar et al. (24)
Beauveria bassiana Fungus	Ag	20.44 – 34.16 nm	Spherical	Kanakalakshmi et al. (25)
Fusarium oxysporum Fungus	Au	10–40 nm	Spherical	Ahmad Siddiqui and colleagues (26)
Penicillium brevicompactum Fungus	Au	10–120 nm	Spherical, triangular	Mishra and colleagues (27)
Streptomyces naganishii Actinobacteria	Ag	5–50 nm	Spherical	Shanmugasundaram et al. (28)

2. Production of nanoparticles by bacteria

Bacteria are known as efficient organisms because of their ability to produce large amounts of enzymes, amino acids, they contain polysaccharides and vitamins that act as reducing agents of metal ions [9]. In addition to cells Bacteria have the ability to chemically detoxify so they can grow in high concentrations of toxic metals [10]. For the first time explain the different mechanisms of metal nanoparticle formation in different bacteria their results showed that they made a *Delftia acidovorans*. The group synthesizes pure gold nanoparticles by Responsible for the production of gold nanoparticles. This peptide triggers the mechanism of bacterial resistance, a small non-ribosomal peptide. When microorganisms are stressed by metal salts, Enzymes, proteins, and their biologically active molecules bind to metal ions, thus ions. They regenerate metal and form nanoparticles. In another study conducted by [11]The culture medium during incubation leads to the production of nanoparticles of different shapes and sizes, with the pH changing Nanoparticles form the pH of silver nanoparticles with a size of about 55 to 5. Nm and increase with decreasing pH. Reported at room temperature. *Lactobacillus casei* sub sp. Biosynthesis of green using silver nanoparticles 0. Nanometers (or aggregates) ~ 555 nanometers (were. Decomposition and - silver nanoparticles produced almost spherical, individually Electron microscopy analysis showed that silver nanoparticles on the surface of the cell membrane, inside the cytoplasm and outside Cells were formed, probably due to the reduction of metal ions by enzymes in the cytoplasm and fluid is cytoplasmic [12]. The best method of industrial scale production of silver nanoparticles instead of adding metal ions to a live culture medium, the cultures were centrifuged to produce metal nanoparticles. In general, extracellular formation of nanoparticles is more favorable not only because of simple purification but also Production ratio increases [13] Intracellular synthesis requires additional steps such as ultrasound and reaction with detergents Showed that this is *Streptomyces griseus* for the separation of nanoparticles [14]. Results of studies on the synthesis of nanoparticles by bacteria capable of producing extracellular spheres of gold nanoparticles with an average nanoparticle size of 51 nm in time hydrophilic are 48 hours [15]. The first report of bacterial biosynthesis of zinc oxide nanoparticles by bacteria it is presented to be environmentally friendly and the morphology of medium-sized spherical or elliptical nanoparticles of *Aeromonas* 57 nm. Previous studies privileged enzymatic synthesis of manganese oxide with a size of less than 511 nm by bacteria which was isolated from the Persian Gulf water, reported a steady phase of growth. Sandaram et al. From *Actinobacter* sp Used [13]. When Fe3O for extracellular synthesis of spherical nanoparticles *Bacillus subtilis* species Incubate *Rhodopseudomonas palustris in* cadmium sulfate solution at 31 ° C for 72 hours Cadmium sulfide nanoparticles were formed and it was determined that cysteine de-sulfatase, which is located in the cytoplasm can make palladium oxide nanoparticles with the help of *E. coli* Is responsible for the formation of cadmium sulfide nanocrystals[16] Synthesize dehydrogenase in bacteria and accumulate in the cell wall.

3. Production of nanoparticles by fungi

Nowadays, fungi are resistant to toxins, high storage capacity, economical, simple synthesis method, operation Simple extraction, ease of biomass management [14], convenient manipulation [8] and convenient large-scale operation, for Bioproduction of nanoparticles are used [6]. Fungi have a high capacity to secrete a wide range of metabolites which maintains homeostasis, so can in harsh environmental conditions with low nutrients and in the presence of substances Are because they survive a toxic *Actinomycetes* [9]. The most common group of fungi for the biosynthesis of gold nanoparticles from They are intermediates between prokaryotes and fungi [17]. Ahmed et al. For the first time succeeded in producing gold nanoparticles in in size *Thermomonospora* and thermophilic *Actinomycetes Rhodococcus*). for the first time in a very short time gold nanoparticles by fungi In addition to the catalytic and antimicrobial activity of non-pathogenic *Hypocrea lixii* and *Trichoderma viride* Used to produce many *Fusarium oxysporum* nanoparticles, these nanoparticles have been successfully demonstrated [26]. Mushrooms Especially for the production of silver nanoparticles, the synthesized silver nanoparticles were in the size range of 5 to 15 nm. The production of Pt nanoparticles by this fungus has also been reported, in which case nanoparticles were formed inside and outside the cell. However, the amount of synthesized intracellular nanoparticles is small and with the change of temperature, the amount of platinum production changes and even Has more benefits *Trichoderma reesei* inhibits the production of Pt nanoparticles, but the use of pH changes slightly Compared to other fungi for the production of metal nanoparticles, it can be easily genetically engineered to 111 produce aids in the synthesis of nanoparticles. A study on the synthesis of silver nanoparticles. These fungi have the ability to synthesize nanoparticles inside and outside the cell, so the production process [20] Is not fixed and can change depending on environmental conditions[18] Production of nanoparticles by yeasts are eukaryotic microorganisms that grow under conditions due to their high tolerance to toxic metals [4]. Simple laboratory, simple nutrient utilization and fast growth can be used for mass production of metal nanoparticles [19]. One of the advantages of using yeast cells as nanoparticles carriers is the simple encapsulation process Yeast cells carrying nanoparticles can easily activate the phagocytic process thus in the fields They can be used for internal production of *Candida glabrata* and *Saccharomyces* [15]. Yeasts cellular nanoparticles of cadmium sulfide, silver, selenium, titanium and gold are used. Production of nanoparticles by yeasts PH sensitization can be expressed by the presence of oxides and reductases and cyanotic membrane quinines. Oxidoreductases to in the intracellular environment, they activate reductases and act as pH and act alternatively, increasing at the same time, metal ions are reduced, resulting in the formation of metal nanoparticles. Also, the presence of metals in the environment can it causes a stress response and thus initiates a metabolic cascade that produces enzyme synthase and glutathione [29]. Enzymes responsible for removing intracellular stress [28]. Among eukaryotes, yeasts play an important role in the production of semiconductor nanoparticles. For example against cadmium ions causes the production of intracellular cadmium sulfide [5] *Candida glabrata* and *Saccharomyces cerevisiae* has been thoroughly studied for the synthesis of silver and gold nanoparticles. Most recently *Saccharomyces cerevisiae* is used to synthesize cadmium telluride quantum dots, which are biologically they are compatible with the body and therefore can be useful for bio-imaging and labeling [4]. Cells Bread yeast can be positioned as carriers for the production of nanoparticles through metal ion reduction methods to be used. Silver and palladium nanoparticles at different positions of bread yeast cells in the wall covering Synthesized in the cell or inside the yeast cell, glucans act as reducing agents in the cell wall. By TEM nanoparticle sizes were shown to be about 8 nm and spherical in shape. SEM electron microscope imaging it was found that the distribution of silver nanoparticles was more around the cell and a small amount inside the cell. Structure of silver nanoparticles it was shown in 3 crystalline forms. It was reported that palladium nanoparticles with a size of about 55 XRD by spectrum Nanometers were formed by hydrazine hydrate reduction in and around bread yeast cells [30]. Plus the supernatant Incubated with gold ions Ability to rapidly synthesize gold nanoparticles in various forms of cell-free *Magnusiomyces ingens* they were spherical, triangular and hexagonal. It was suggested that the carboxyl and amide groups of proteins could be synthesized engage gold nanoparticles. Different cell concentrations as well as gold ion concentrations, size and shape of gold nanoparticles Controls[31].Production of nanoparticles by marine microorganisms Marine microorganisms such as bacteria, cyanobacteria, *actinobacteria*, yeasts, fungi and algae organisms are prokaryotes and tiny eukaryotes that live in marine ecosystems. These microorganisms are the best Sources produce metabolites, accounting for 98% of ocean biomass, which is highly industrialized they have been noticed. These microorganisms are present everywhere in the marine environment, meaning the ability to grow in the spectrum they have a wide range of extreme conditions such as acidic, alkaline, high temperature and salinity. In recent years, a lot of studies Focuses on the potential of using marine microorganisms as "nanoparticles factories" to produce metal nanoparticles has been. It is safer to use these microorganisms to synthesize nanoparticles because they are not pathogenic to humans [32]. Now limited reports are available on the biosynthesis of metal nanoparticles by marine microorganisms [18] Produces large amounts of bioactive molecules for the synthesis of green nanoparticles of *Streptomyces* sp. genus Used. For the first time the synthesis of silver nanoparticles with a size of about 33 nanometers by it has been widely reported for the synthesis of *Chlorella* sp. nanoparticles in the periplasmic space. Seaweed AG259 various coastal sediments of *Penicillium fellutanum* including palladium, gold and silver have been used. Mushrooms Mangroves were isolated and used to synthesize silver nanoparticles. Extracellular silver nanoparticles with a size of about For *Rhodosporidium diobovatum* 5 nm free cells were formed in the supernatant [5.]. Marine yeast Intracellular synthesis of lead sulfide nanoparticles has been used[21] Biomedical application of metal nanoparticles in various medical fields including diagnosis, treatment, drug delivery, coating of medical devices, dressings Wounds, medical textiles, contraceptives, anti-fungal and anti-inflammatory, etc. are used [33]. Currently Oxide metal nanoparticles such as zinc oxide and titanium dioxide in cosmetics, sunscreens, toothpaste and drugs are used [22]. Also iron and iron oxide nanoparticles for cell marking, tissue regeneration and imaging have been reported [23]. Gold nanoparticles due to their compatibility with the immune system and non-toxic (MRI) magnetic resonance are suitable for preparing drug delivery scaffolding. Studies have shown that silver nanoparticles through the production of radical's free oxygen can activate apoptotic pathways within the cell and inhibit cell proliferation, thus. Titles of anti-tumor and anti-angiogenic agents have been considered for the diagnosis and treatment of human cancer, Combined gold nanoparticles with cyanine antibody complex and Targeted breast cancer that leads to the production of single oxygen and thus the killing of breast cancer cells By combining with chemical agents, they became Fe3O [24]. Some studies have also suggested that magnetite nanoparticle Therapies such as methotrexate and toxin are used to treat cancer [33]. Researchers reported they are used as wound healing agents, *Aspergillus niger* synthesized by Ag (Ag), silver nanoparticles That is, they inhibit the activity of pathogenic bacteria as well as modulate the cytokines involved in wound healing, which Its benefits are the reduction in the time required for fibroblasts and To detect *Candida albicas* synthesized by (Au) resulting in faster wound healing [25]. Gold nanoparticles Liver cancer cells were studied, and were able to explicitly separate normal cells from cancer cells Human chorionic also as an essential tool for the detection of the hormone (Au). Used in urine samples of pregnant women. gonadotropin (HCG) as a biosensor, they are highly sensitive to determine adrenaline [26]. Antibacterial activity of Pt nanoparticles (Pt) Different is not the same, meaning that each nanoparticle kills a specific range of bacteria. From years of anti-activity known. The small size of nanoparticles makes them suitable for microbial Zn, Ti, Au, Cu, and Ag Suitable for antimicrobial purposes and fight against intracellular bacteria [27]. Silver nanoparticles due to anti-inflammatory activity their microbes are widely used in medical textiles [28]. These nanoparticles alter the permeability of the membrane [29] .They become cells, thus causing improper transfer of substances through the cell membrane of bacteria and their death.

4. Conclusion

The ultimate reliability of green nanomaterials for the treatment and diagnosis of cancer is yet to be determined in clinical trials, although they are currently in the research phase. A number of new possibilities have come into account in relation to the use of green nanomaterials, owing to their biocompatibility and effectiveness. Furthermore, green nanomaterials may someday cure many types of cancer that are currently incurable.

Future prospects

Overall Microorganisms including bacteria, yeasts and fungi can synthesize nanoparticles for intracellular and extracellular to be used. The use of microorganisms due to the cheapness of their cultivation, easy control of growth conditions such as and incubation time is one of the best different biological methods of producing metal nanoparticles. Shape and pH, temperature, oxygen PH, size of nanoparticles synthesized by microorganisms by changing parameters such as temperature, incubation time, oxygenation Substrate concentration, growth phase of microorganism, type of microorganism and cell manipulation change at genome and proteomic level Slowly Emergence of antibiotic-resistant strains leads to an increase in infectious diseases associated with these microorganisms And complex mechanisms for antibiotic resistance have been developed, such as metabolic pathway conversion, etc. Therefore, there is a need for alternative antibiotics with strong antibacterial and growth inhibitory activity. Nanoparticles Microbes have strong antibacterial activity. Nanotechnology-based drug delivery systems in the treatment of disease Humans such as cancer, diabetes, microbial infections and gene therapy are used. Nanoparticles as Drug delivery systems are able to enhance several important properties of drugs such as solubility, stability in living organisms, Pharmacokinetics, biological distribution and increase their efficiency. Extensive research on improving synthesis efficiency Nanoparticles and the application of these nanoparticles in the field of biomedicine has been done. It is hoped that these methods will be used Benefit from the development of large-scale production, commercial medical and healthcare programs in the coming years Let's go.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no competing interest.

References

[1] Das SK. Nanoparticles advanced characterization techniques: a view point. Journal of atoms and molecules. 2017 Jul 1;7(4):1091.

[2] Thakkar KN, Mhatre SS, Parikh RY. Biological synthesis of metallic nanoparticles. Nanomedicine: nanotechnology, biology and medicine. 2010 Apr 1;6(2):257-62.

[3] Barabadi H, Honary S, Ebrahimi P, Mohammadi MA, Alizadeh A, Naghibi F. Microbial mediated preparation, characterization and optimization of gold nanoparticles. Brazilian Journal of Microbiology. 2014;45:1493-501.

[4] Saratale RG, Karuppusamy I, Saratale GD, Pugazhendhi A, Kumar G, Park Y, Ghodake GS, Bharagava RN, Banu JR, Shin HS. A comprehensive review on green nanomaterials using biological systems: Recent perception and their future applications. Colloids and Surfaces B: Biointerfaces. 2018 Oct 1;170:20-35.

[5] Fariq A, Khan T, Yasmin A. Microbial synthesis of nanoparticles and their potential applications in biomedicine. Journal of Applied Biomedicine. 2017 Nov 1;15(4):241-8.

[6] Pantidos N, Horsfall LE. Biological synthesis of metallic nanoparticles by bacteria, fungi and plants. Journal of Nanomedicine & Nanotechnology. 2014 Sep 1;5(5):1.

[7] Singh CR, Kathiresan K, Anandhan S. A review on marine based nanoparticles and their potential applications. African Journal of Biotechnology. 2015 Jun 4;14(18):1525-32.

[8] Hulkoti NI, Taranath TC. Biosynthesis of nanoparticles using microbes—a review. Colloids and surfaces B: Biointerfaces. 2014 Sep 1;121:474-83.

[9] Mohammadlou M, Maghsoudi H, Jafarizadeh-Malmiri HJ. A review on green silver nanoparticles based on plants: Synthesis, potential applications and eco-friendly approach. International Food Research Journal. 2016 Mar 1;23(2):446.

[10] Iravani S. Bacteria in nanoparticle synthesis: current status and future prospects. International scholarly research notices. 2014;2014.

[11] Rahaiee RM. An overview of the importance of metallicl nanoparticles synthesized by microorganisms and their medicinal applications.

[12] Das RK, Pachapur VL, Lonappan L, Naghdi M, Pulicharla R, Maiti S, Cledon M, Dalila LM, Sarma SJ, Brar SK. Biological synthesis of metallic nanoparticles: plants, animals and microbial aspects. Nanotechnology for Environmental Engineering. 2017 Dec;2(1):1-21.

[13] Ghashghaei S, Emtiazi G. The methods of nanoparticle synthesis using bacteria as biological nanofactories, their mechanisms and major applications. Current Bionanotechnology (Discontinued). 2015 May 1;1(1):3-17.

[14] Ingale AG, Chaudhari AN. Biogenic synthesis of nanoparticles and potential applications: an eco-friendly approach. J Nanomed Nanotechol. 2013;4(165):1-7.

[15] Sehgal N, Soni K, Gupta N, Kohli K. Microorganism assisted synthesis of gold nanoparticles: a review. Asian J. Biomed. Pharm. Sci. 2018;8(64):22-9.

[16] Salunke BK, Sawant SS, Lee SI, Kim BS. Comparative study of MnO2 nanoparticle synthesis by marine bacterium Saccharophagus degradans and yeast Saccharomyces cerevisiae. Applied microbiology and biotechnology. 2015 Jul;99(13):5419-27.

[17] Thakkar KN, Mhatre SS, Parikh RY. Biological synthesis of metallic nanoparticles. Nanomedicine: nanotechnology, biology and medicine. 2010 Apr 1;6(2):257-62.

[18] Chokriwal A, Sharma MM, Singh A. Biological synthesis of nanoparticles using bacteria and their applications. American Journal of PharmTech Research. 2014;4(6):38-61.

[19] Thakkar KN, Mhatre SS, Parikh RY. Biological synthesis of metallic nanoparticles. Nanomedicine: nanotechnology, biology and medicine. 2010 Apr 1;6(2):257-62.

[20] Fariq A, Khan T, Yasmin A. Microbial synthesis of nanoparticles and their potential applications in biomedicine. Journal of Applied Biomedicine. 2017 Nov 1;15(4):241-8.

[21] Pantidos N, Horsfall LE. Biological synthesis of metallic nanoparticles by bacteria, fungi and plants. Journal of Nanomedicine & Nanotechnology. 2014 Sep 1;5(5):1.

[22] Singh CR, Kathiresan K, Anandhan S. A review on marine based nanoparticles and their potential applications. African Journal of Biotechnology. 2015 Jun 4;14(18):1525-32.

[23] Hulkoti NI, Taranath TC. Biosynthesis of nanoparticles using microbes—a review. Colloids and surfaces B: Biointerfaces. 2014 Sep 1;121:474-83.

[24] Enshasy HA, Marzugi NA, Elsayed EA, Ling OM, Malek RA, Kepli AN, Othman NZ, Ramli S. Medical and cosmetic applications of fungal nanotechnology: production, characterization, and bioactivity. InFungal nanobionics: Principles and applications 2018 (pp. 21-59). Springer, Singapore.

[25] Iravani S. Bacteria in nanoparticle synthesis: current status and future prospects. International scholarly research notices. 2014;2014.

[26] Mazina O, Allikalt A, Tapanainen JS, Salumets A, Rinken A. Determination of biological activity of gonadotropins hCG and FSH by Förster resonance energy transfer based biosensors. Scientific reports. 2017 Feb 9;7(1):1-7.

[27] Das RK, Pachapur VL, Lonappan L, Naghdi M, Pulicharla R, Maiti S, Cledon M, Dalila LM, Sarma SJ, Brar SK. Biological synthesis of metallic nanoparticles: plants, animals and microbial aspects. Nanotechnology for Environmental Engineering. 2017 Dec;2(1):1-21.

[28] Hebeish A, El-Rafie MH, El-Sheikh MA, Seleem AA, El-Naggar ME. Antimicrobial wound dressing and anti-inflammatory efficacy of silver nanoparticles. International journal of biological macromolecules. 2014 Apr 1;65:509-15.

[29] Roy S, Das TK, Maiti GP, Basu U. Microbial biosynthesis of nontoxic gold nanoparticles. Materials Science and Engineering: B. 2016 Jan 1;203:41-51.

[30] Sunkar S, Nachiyar CV, Lerensha R, Renugadevi K. Biogenesis of TiO2 nanoparticles using endophytic Bacillus cereus. Journal of nanoparticle research. 2014 Nov;16(11):1-1.

[31] Pourali P, Yahyaei B. Biological production of silver nanoparticles by soil isolated bacteria and preliminary study of their cytotoxicity and cutaneous wound healing efficiency in rat. Journal of Trace Elements in Medicine and Biology. 2016 Mar 1;34:22-31.

[32] Velusamy P, Kumar GV, Jeyanthi V, Das J, Pachaiappan R. Bio-inspired green nanoparticles: synthesis, mechanism, and antibacterial application. Toxicological research. 2016 Apr;32(2):95-102.

[33] Mishra A, Tripathy SK, Wahab R, Jeong SH, Hwang I, Yang YB, Kim YS, Shin HS, Yun SI. Microbial synthesis of gold nanoparticles using the fungus Penicillium brevicompactum and their cytotoxic effects against mouse mayo blast cancer C2C12 cells. Applied microbiology and biotechnology. 2011 Nov;92(3):617-30.

[34] Shanmugasundaram T, Radhakrishnan M, Gopikrishnan V, Pazhanimurugan R, Balagurunathan R. A study of the bactericidal, anti-biofouling, cytotoxic and antioxidant properties of actinobacterially synthesised silver nanoparticles. Colloids and Surfaces B: Biointerfaces. 2013 Nov 1;111:680-7.