World Journal of Pharmaceutical Sciences
ISSN (Print): 2321-3310; ISSN (Online): 2321-3086
Published by Atom and Cell Publishers
Available online at: http://www.wjpsonline.org/
Review Article

Nanotechnology as a novel tool for aquaculture industry: A review

Bharathi Selvaraj[1], Kumaran Subramanian[1], Suresh Gopal[1] and Pugazhvendan Sampath Renuga[2]

[1]Department of Microbiology, Sri Sankara Arts and Science College, (Affiliated to University of Madras), Enathur, Kanchipuram, Tamil Nadu, India
[2]Department of Zoology Wing-DDE, Annamalai University, Annamalaignagar, Tamil Nadu, India

Received: 31-07-2014 / Revised: 14-08-2014 / Accepted: 25-08-2014

ABSTRACT

The properties of silver nanoparticles are attractive and beneficial to the aquaculture industry. The major methods used for silver nanoparticle synthesis are the physical and chemical methods. The problem with the chemical and physical methods is that the synthesis is expensive and can also have toxic substances absorbed onto them. To overcome this, the biological method provides a feasible alternative. The major biological systems involved in this are bacteria, fungi, and plant extracts. The major applications of silver nanoparticles in the aquaculture include diagnostic applications and therapeutic applications. In most immunostimulator and antimicrobial property of silver nanoparticles that is being majorly explored. In addition to this silver nanaoparticles may be explored for fish packaging, in prevention of biofouling, DNA nano vaccines and DNA biosensor. This review provides a comprehensive view on the production, applications of silver nanoparticles in the aquaculture industry.

Key words: silver nanoparticles; aquaculture; biofouling; immunostimulation.

INTRODUCTION

Nanoparticle having one or more dimensions of the order of 100nm or less- have attracted considerable attraction due to their unusual and fascinating properties, with various applications, over their bulk counterparts (Daniel *et al.*, 2004, Kato, 2011). Nanoparticles are seen as solutions to many technological and environmental challenges. Various metals have been used for the synthesis of stable dispersions of nanoparticles, which are useful in the areas of photography, catalysis, biological labeling, photonics, optoelectronics and surface enhanced Raman scattering (SERS) detection (Dahl *et al.*, 2007). The term Nanotechnology was coined by Professor Norio Taniguchi of Tokyo Science University in the year 1974. Nanoparticles can be broadly grouped into two, namely, organic nanoparticles which include carbon nanoparticles (fullerness) while, some of the inorganic nanoparticles include magnetic nanoparticles, noble metal nanoparticles (like gold and silver) and semi-conductor nanoparticles (like titanium oxide and zinc oxide). There is a growing interest in inorganic biomass i.e of noble metal nanoparticles (Gold and silver) as they provide superior material properties and functional versatility. Metallic nanoparticles are most promising and remarkable biomedical agents. The most effectively studied nanoparticles today are those made from noble metals in particular Ag, Pt, Au and Pd. Among the above four, silver nanoparticles play a significant role in the field of biology and medicine.

SILVER NANOPARTICLES

Silver (Ag) Nanoparticles are mostly used in application research in nanotechnology. The medical properties of silver have been known for over 2,000 years. Since the nineteenth century, silver-based compounds have been used in many antimicrobial applications. It is a well-known fact that silver ions and silver-based compounds are

***Corresponding Author Address: Bharathi Selvaraj,** *Department of Microbiology, Sri Sankara Arts and Science College, (Affiliated to University of Madras), Enathur, Kanchipuram, Tamil Nadu, India; E-mail: sbharathimicro@gmail.com and pugazhvendan@gmail.com*

highly toxic to microorganisms which include 16 major species of bacteria (Zhao *et al.,* 1998, Sondi *et al.,* 2004). This aspect of silver makes it an excellent choice for multiple roles in the medical field. Silver ions are used in the formulation of dental resin composites; in coatings of medical devices; as a bactericidal coating in water filters; as an antimicrobial agent in air sanitizer sprays, pillows, respirators, socks, wet wipes, detergents, soaps, shampoos, toothpastes, washing machines, and many other consumer products; as bone cement; and in many wound dressings to name a few.

Properties of silver nanoparticles: Silver nanoparticles have diverse properties like catalysis, magnetic and optical polarizability, electrical conductivity, and microbial activity and enhanced Raman scattering. Silver NPs have unique optical properties because they support surface plasmons. At specific wavelengths of light the surface plasmons are driven into resonance and the AgNPs have a distinct color that is a function of their size, shape and environment (Noguez 2007). The plasmons resonance of AgNPs is responsible for yellow color in solution. Any visible change to the NPs in solution typically indicates that the aggregation of the nanoparticles has changed (Pietrobon and Kitaev, 2008). The wavelength of silver nanoparticles is 430nm and is an evidence for the formation of silver nanoparticles (Foldbjerg *et al.,* 2009). Silver nanoparticles are extraordinarily efficient at absorbing and scattering light and, many dyes and pigments, have a colour that depends upon the size and shape of the particle. A unique property of spherical silver nanoparticles is that this SPR peak wavelength can be tuned from 400nm [violet length] to 530nm [green light] by changing the particle size and the local refractive index near the particle Surface (Ma *et al.,* 2004). When silver nanoparticles are in solution molecules associate with the nanoparticle surface to establish a double layer of charge that stabilizes the particles and prevents aggregation, and silver nanoparticles in catalysis, magnetic, and optical polarizability, electrical conductivity, antimicrobial activity (Shipway *et al.,* 2000).

Synthesis of silver nanoparticles: Previously nanoparticles were produced only by physical and chemical methods with various techniques. Some of the commonly used physical and chemical methods are Chemical reduction, Solvothermal synthesis, Sol gel technique, Laser ablation (Rosarin and Mirunalini, 2011). The problem with most of the chemical and physical methods of nanosilver production is that they are extremely expensive and also involve the use of toxic, hazardous chemicals, which may pose potential environmental and biological risks. It is an unavoidable fact that the silver nanoparticles synthesized have to be handled by humans and must be available at cheaper rates for their effective utilization; thus, there is a need for an environmentally and economically feasible way to synthesize these nanoparticles. The quest for such a method has led to the need for biomimetic production of silver nanoparticles whereby biological methods are used to synthesize the silver nanoparticles. The growing need to develop environmentally friendly and economically feasible technologies for material synthesis led to the search for biomimetic methods of synthesis (Kalishwaralal *et al.,* 2008). In biosynthesis method bacterium, fungi and plant parts were used; this biosynthesis method is eco friendly comparing to physical and chemical methods. Basically there are two approaches for nanoparticles synthesis. They are bottom up approach and the top down approach. In the top down approach scientist try to formulate nanoparticles using larger ones to direct their assembly (Acosta *et al.,* 2009). But in the bottom up approach is a process that builds towards larger and more complex systems by starting at the molecular level maintaining precise control of molecular structure. The bottom up approach promises a better change to obtain nanostructures with less defects. The nanoparticle will have more homogenous chemical composition and better short and long range ordering, because this approach is mainly driven by the reduction of Gibb's free energy (Lee, 2007). Biosynthesis of nanoparticles is a kind of bottom up approach where the main reaction occurring is reduction/ oxidation. Micro organisms and plant extracts are used in general. Here, we summarize some of the organisms used in the biosynthesis of nanomaterials and describe the properties that should be inherent for the production of nanoparticles of desired characteristics.

Synthesis of Silver nanoparticles by bacteria: The biological synthesis of nanoparticles germinated from the experiments on biosorption of metals with Gram negative and Gram positive bacteria. The synthesized molecules were not identified as nanoparticles but as aggregates (Mullen *et al.,* 1989). The first evidence of synthesizing silver nanoparticles was established in 1984 using the microorganism *Pseudomonas stutzeri* AG259, a bacterial strain that was originally isolated from silver mine (Haefeli *et al.,* 1984). Some bacteria which have been used for the production of nanoparticles are summarized in Table 1.

Synthesis of silver nanoparticles by fungi: When in comparison with bacteria, fungi can produce larger amounts of nanoparticles because they can secrete larger amounts of proteins which directly translate to higher productivity of nanoparticles (Mohanpuria *et al.,* 2008). It was found that fungi score more advantages over other biological systems because of their high tolerance towards the heavy metals. Fungi producing the silver nanoparticles were summarized in table 2.

Synthesis of silver nanoparticles by plants: The major advantage of using plant extracts for silver nanoparticle synthesis is that they are easily available, safe, and nontoxic in most cases, have a broad variety of metabolites that can aid in the reduction of silver ions, and are quicker than microbes in the synthesis (Prabhu and Poulose *et al.,* 2012). Indeed, the time required for completion of the reaction using bacteria and fungi ranged from 24 to 124 hours; in contrast, more than 90% of the reaction using extract of plants is complete within 9 hours. Some plants which have been used for the production of nanoparticles are summarized in Table 3.

Applications of silver nanoparticles

The fisheries and aquaculture industry can be revolutionized by using nanotechnology with new tools like rapid disease detection, enhancing the ability of fish to absorb drugs like hormones, vaccines and nutrients etc. rapidly. As per National Science Foundation (USA), current prediction estimates the emergence of value of the global nanotechnology industry at USD one trillion by 2015. This could be possible due to vast potential of nanotechnology not only in electronic and materials science but also in humans, animal food and agriculture sectors involving aquaculture and its application in biomedical and biological sciences for analysis of biomolecules, cancer therapy, development of non-viral vectors for gene therapy, as transport vehicle for DNA, protein or cells; targeting drug delivery, clinical diagnosis and therapeutics etc. Although much of development research is needed to enhance the potential use of nanotechnology in aquaculture, at present, there are numerous glimpses of the future application of this technology in fish health management, water treatment in aquaculture, animal breeding, harvest and postharvest technology (Can et al., 2011)[82].

Antimicrobial activity of AgNPs: Fish disease is one of the major threats to the sustainable development of aquaculture causing loss of millions of dollars annually. The ubiquitous nature of the bacterium in aquatic environments provides significant opportunity for animals, mainly fish and amphibians to contact and ingest organisms. The use of antimicrobial drugs in aquatic medicine can cause a serious problem in the environment because of the rapid spread of antibiotics through water. The use of metallic silver as an antimicrobial agent has been recognized for a long time (Lansdown 2002) and several types of silver compounds are used today, including silver dressings, silver nitrate, silver zeolite and silver nanoparticles, for a variety of antimicrobial purposes (Kim., 2007). Due to the increase in the outbreak of bacterial diseases in the aquaculture industry and the development of bacterial resistance, new antibacterial agents are required One possibility is to use nanoparticles as antimicrobial drugs. Silver nanoparticles have proved to be one of the most effective metallic nanoparticles as they have a good antimicrobial efficacy against some bacteria, viruses and other eukaryotic microorganisms (Gong 2007). Sarkar et *al.*, 2012 studied the antimicrobial efficacy of silver nanoparticles from *Cedrus deodar* leaf extracts against the major fish pathogen *Aeromonas hydrophila* for improvement of better fish health management. Kandasamy *et al.,* 2013 investigated the effect of leaf extract from coastal plant *Prosopis chilensis* on synthesis of silver nanoparticles using $AgNO_3$ as a substrate and to find their antibacterial potential on pathogenic *Vibrio species* in the shrimp, *Penaeus monodon*. The silver nanoparticles were found to inhibit *Vibrio* pathogens viz., *Vibrio cholerae, V. harveyi,* and *V. parahaemolyticus* and this antibacterial effect was better than that of leaf extract, as proved by disc diffusion assay. The shrimps *Penaeus monodon* fed with silver nanoparticles exhibited higher survival, associated with immunomodulation in terms of higher haemocyte counts, phenoloxidase and antibacterial activities of haemolymph of *P. monodon* which is on par with that of control.

Fish packaging: The perishable nature of fresh fish is a long-standing concern, and any packaging that may increase the shelf life of fresh fish would be advantageous. There are several ways by which this can be achieved. First, nanopolymers and coatings are available for strengthening packaging and this could reduce the incidence of bruising or mechanical damage to packed fish fillets. Nanopackaging can be made from natural nanoscale polymers, such as cellulose and starch, or chitosan particles (De Azeredo, 2009), and are therefore likely to be biodegradable, unlike some conventional plastics (Thompson *et al*., 2004). Strong and light nanopackaging has also been suggested for the meat industry (Lee, 2010).

Prevention of biofouling: Water quality is, of course, a critical factor in fish health. There is also a concern about pathogens. Indeed, fish disease is arguably one of the main threats to intensive aquaculture systems (Toranzo *et al*., 2005). The antimicrobial properties of nano silver can be exploited to reduce the build-up of bacteria in the aquaculture system (Muhling *et al*., 2009). In addition to adding nanoparticles to food, this could include antibacterial coatings on the sides of fish tanks and pipe work to prevent biofouling. Similar to polymers and films used for food packaging, these nanoparticles can be fixed to the surfaces so that the threat to the sensitive biofiltration systems used in re-circulating aquaria is negligible.

Nano – biosensors: Nanotechnology based biosensors can be used in the aquaculture industry for microbe control. Researchers at the National Aeronautics and Space Administration have developed a sensitized carbon nanotubes-based biosensor that is capable of detecting minute amount of microbes including bacteria, viruses and parasites and also heavy metals from water and food sources. Nano colloidal sliver is one of the most beneficial products of nanotechnology that acts as a catalyst. It works on a wide spectrum of bacteria, fungi, parasites and viruses by rendering an enzyme which is used for their metabolism, inoperative. Unlike antibiotic resistant strains of bacteria, no such strains are known to develop by using colloidal sliver. Sliver nanoparticles are even able to kill methicilin resistant *Staphylococcus aureus* (Sung hoon *et al.* 2004). Tracking nanosensors such as "Smart fish" are being developed which may be fitted with sensors and locators that relay data about fish health and geographical location to a central computer. Such technology may be used to control cognitive cage systems or individual fish (ETC Group Report, 2003).

DNA Nano-Vaccines: A number of approaches have been made in attempts to solve disease problem in aquaculture, one among these is vaccination. The use of oil emulsion as adjuvant in this effort may cause major drawbacks as some fishes and shellfishes show unacceptable levels of side effects. In this context, use of nanoparticle carriers like chitosan and poly-lactide-co-glycolide acid (PLGA) (Rajeshkumar *et al.* 2009) of vaccine antigens together with mild inflammatory inducers may give a high level of protection to fishes and shellfishes not only against bacterial diseases, but also from certain viral diseases with vaccine-induced side effect. Further, the mass vaccination of fish can be done using nanocapsules containing nano-particles. These will be resistant to digestion and degradation. These nanocapsules contain short strand DNA which when applied to water containing fishes are absorbed into fish cells. The ultrasound mechanism is used to break the capsules which in turn release the DNA thus elicting an immune response.

CONCLUSION

Nanotechnology is one of them and it can be used in many different industries such as pharmaceutics, food technology, engineering, medicine etc. Major nanotechnological applications used in aquaculture and seafood industries are nanoparticles, nanofiltration and food packaging. Nanoparticles can be used in feed production technology, also nano filtration can be used filtration of treatment water which is used seafood processing. Nanotechnology undoubtedly presents a major opportunity for the economy and sustainable development of aquatic resources in many countries. Although the application of nanotechnology is still at a very early stage in aquaculture, it may have the potential to solve most of the problems in aquaculture and fisheries with better technical innovation at different levels.

Acknowledgement

The authors sincerely thank Prof. K. R. Venkatesan, Principal, Sri Sankara Arts & Science College for his encouragement and also thank Management authorities for providing the research facilities.

Table 1: Silver nanoparticles synthesis by bacteria

S. No	Organism	Size (nm)	Author (year)
1.	*Pseudomonas stutzeri AG259*	200	Tanja *et al.*, 1999
2.	*Bacillus megaterium*	46.9	*Fu et al.*, 1999
3.	*Lactobacillus Strains*	500	Nair and Pradeep 2002
4.	*Corynebacterium sp.*	10–15	Zhang *et al.*, 2005
5.	*Klebsiella pneumonia (culture supernatant)*	50	Ahmad *et al.*, 2007
6.	*Bacillus licheniformis*	50	Kalimuthu *et al.*, 2008
7.	*Bacillus licheniformis* (culture supernatant)	50	Kalishwaralal *et al.*, 2008
8.	*Geobacter sulfurreducens*	200	Law *et al.*, 2008
9.	*Morganella sp*	205	Parikh *et al.*, 2008
10.	*Bacillus subtilis*	5–60	Saifuddin *et al.*, 2009
11.	*Escherichia coli*	1–100	Gurunathan *et al.*, 2009a,b
12.	*Proteus mirabilis*	10–20	Samadi *et al.*, 2009

13.	*Bacillus sp.*	. 5–15	Pugazhenthiran *et al.*, 2009
14.	*Bacillus cereus*	4 and 5	Ganesh Babu and Gunasekaran 2009
15.	*Staphylococcus aureus*	1–100	Nanda and Saravanan 2009
16.	*Lactic acid bacteria*	11.2	Sintubin *et al.*, 2009
17.	*Brevibacterium casei*	50	Kalishwaralal *et al.*, 2010
18.	*Bacillus Cereus*	10 - 30	Prakash *et al.*, 2011
19.	*Bacillus sp*	65 to 70	Malarkodi *et al.*, 2013
20.	*B. amyloliquefaciens*	10 to 100	Behera *et al.*, 2013

Table 2: Silver nanoparticles synthesis by fungi

S. No	Organism	Size (nm)	Author (year)
1.	*Verticillium sp*	25 12	Mukherjee *et al.*, 2001
2.	*Fusarium oxysporum*	5–50	Ahmad *et al.*, 2003
3.	*Aspergillus fumigatus*	5–25	Bhainsa and D'Souza 2006
4.	*Phanerochaete chrysosporium*	100	Vigneshwaran *et al.*, 2006
5.	*Aspergillus flavus*	8.92+/- 1.61	Vigneshwaran *et al.*, 2007
6.	*Aspergillus niger*	20	Gade *et al.*, 2008
7.	*Fusarium semitectum*	10–60	Basavaraja *et al.*, 2008
8.	*Trichoderma asperellum*	13–18	Mukherjee *et al.*, 2008a, b
9.	*Fusarium acuminatum*	5–40	Ingle *et al.*, 2008
10.	*Cladosporium cladosporioides*	10–100	Balaji *et al.*, 2009
11.	*Penicillium fellutanum*	1–100	Kathiresan *et al.*, 2009
12.	*Penicillium brevicompactum WA 2315*	23–105	Shaligram *et al.*, 2009
13.	*Fusarium solani*	5–35	Gade *et al.*, 2009
14.	*Trichoderma viride*	5–40	Fayaz *et al.*, 2010
15.	*Aspergillus clavatus*	10–25	Verma *et al.*, 2010
16.	*Trichoderma Harzianum*	30 - 50	Singh *et al.*, 2011
17.	*Trichoderma Reesei*	5-50	Vahabi *et al.*, 2011
18.	*Aspergillus flavus*	7	Moharre *et al.*, 2012
19.	*Aspergillus terreus*	1 to 20	Li *et al.*, 2012
20.	*Fusarium oxysporum*	10 to 40	Birla *et al.*, 2013

Table 3: Silver nanoparticles synthesis by plants

S. No	Organism	Size	Author (year)
1	*Azadirachta indica*	50	Shankar *et al.*, 2004
2	*Cinnamomum camphora leaf*	55–80	Huang *et al.*, 2007
5	*Cinnamomum camphora* Leaf	5–40	Huang *et al.*, 2008
3	*Glycine max (soybean)* leaf extract	25–100	Vivekanandhan *et al.*, 2009
4	*Jatropha curcas*	10–20	Bar *et al.*, 2009
6	*Phyllanthus amarus*	18–38	Kasthuri *et al.*, 2009
7	*Carica papaya*	60–80	Mude *et al.*, 2009
8	*Gliricidia sepium*	10–50	Raut *et al.*, 2009
15	*Sesuvium portulacastrum* leaves	5 to 20	Nabikha *et al.*, 2009
9	*Coriandrum sativum* leaf extract	26	Sathyavathi *et al.*, 2010
10	*Acalypha indica* leaf extracts	20–30	Krishnaraj *et al.*, 2010
11	*Chenopodium album* leaf	10-30	Dwivedi *et al.*, 2010
12	*Rosa rugosa*	12	Dubey *et al.*, 2010
13	*Trianthema decandra* roots	15	Geethalakshmi *et al.*, 2010
14	*Ocimum sanctum* stems and roots	10+/-2 and 5+/-1.5, respectively	Ahmad *et al.*, 2010
16	*Macrotyloma uniflorum* seeds	12	Vidhu *et al.*, 2011
17	*Andrographis paniculata*	28	Sulochana *et al.*, 2012
18	*Brassica Oleracea L.var. Italica*	40-50	Caroling *et al.*, 2013
19	*Ocimum sanctum*	18	Ramteke *et al.*, 2013
20	*Curcuma Longa*	5-10	Elumalai *et al.*, 2014
21	*Achyranthus aspera*	105-600	Kalidasan *et al.*, 2014

REFERENCES

1. Daniel MC, Astruc D. Gold nanoparticles: assembly, supramolecular chemistry, quantum-size-related properties, and applications toward biology, catalysis, and nanotechnology. Chem Rev 2004; 104:293–346**.**
2. Kato H. In vitro assays: tracking nanoparticles inside cells, Nat. Nanotechnol 2011; 6:139–140**.**
3. Dahl JA et al. Toward Greener Nanosynthesis. Chemical Reviews 2007; 107: 2228–2269.
4. Zhao GJ, Stevens SE. Multiple parameters for the comprehensive evaluation of the susceptibility of *Escherichia coli* to the silver ion. Biometals 1998; 11**:** 27–32.
5. Sondi I Salopek-Sondi B. Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. J Colloid Interface Sci 2004; 275**:** 177–182.
6. Noguez C. Surface plasmons on metal nanoparticles: The influence of shape and physical environment. J Phys Chem C 2007; 111: 3806–3819.
7. Pietrobon B, Kitaev V. Photochemical synthesis of monodisperse size controlled silver decahedral nanoparticles and their remarkable optical properties. Chem. Mater 2008; 20: 5186-5190.
8. Foldbjerg R et al. PVP coated silver nanoparticles and silver ions induce reactive oxygen species, apoptosis and necrosis in THP-1 monocytes. Toxicol Lett 2009; 190: 156-162.
9. Ma H et al. Spontaneous Organization of Individual Silver Nanoparticles into One-Dimensionally Ordered Nanostructures. Chem Phys Chem 2004; 5: 713–716.
10. Shipway AN et al. Nanoparticle arrays on surfaces for electronic, optical, and sensor applications. Chem Phys Chem 2000; 1: 18-52.
11. Rosarin FS, Mirunalini S. Nobel Metallic Nanoparticles with Novel Biomedical Properties. J Bioanal Biomed 2011; 3(4): 085-091.
12. Kalishwaralal K et al. Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis.* Mater Lett 2008; 62: 4411–4413.
13. Acosta E. Bioavailability of nanoparticles in nutrient and nutraceutical delivery. Curr Opinion Colloid Interface Sci 2009; 14: 3-15.
14. Lee SW et al. "Bottom-up" approach for implementing nano/microstructure using biological and chemical interactions. Biotechnol and Bioproc Eng 2007; 12: 185-199.
15. Mullen MD et al. Bacterial sorption of heavy metals. Appl Environ Microbiol 1989; 55:3143–3149.
16. Haefeli C et al. Plasmid-determined silver resistance in Pseudomonas stutzeri isolated from silver mine. J Bacteriol 1984; 158:389–392.
17. Tanja K et al. Silver-based crystalline nanoparticles, microbially fabricated. Proc Natl Acad Sci 1999; 96:13611–13614.
18. Fu JK et al. Characterization of adsorption and reduction of noble metal ions by bacteria. Chin J Chem Univ 1999; 20:1452–1454.
19. Nair B, Pradeep T. Coalescence of nanoclusters and formation of submicron crystallites assisted by *Lactobacillus strains*. Cryst Growth Des 2002; 2:293–298.
20. Zhang H et al. Biosorption and bioreduction of diamine silver complex by Corynebacterium. J Chem Technol Biotechnol 2005; 80:285–290.
21. Ahmad RS et al. Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: a novel biological approach. Process Biochem 2007; 42:919–923.
22. Kalimuthu K et al. Biosynthesis of silver nanocrystals by *Bacillus licheniformis*. Colloids Surf B 2008; 65:150–153.
23. Kalishwaralal, K et al. Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. Mater Lett 2008; 62:4411–3.
24. Law N et al. The formation of nano-scale elemental silver particles via enzymatic reduction by *Geobacter sulfurreducens.* Appl Environ Microbiol 2008; 74:7090–7093.
25. Parikh RY et al. Extracellular synthesis of crystalline silver nanoparticles and molecular evidence of silver resistance from *Morganella. sp*.: towards understanding biochemical synthesis mechanism. Chembiochem 2008; 9:1415–1422.
26. Saifuddin N et al. Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. Eur J Chem; 2009; 6:61–70.
27. Gurunathan S et al. Antiangiogenic properties of silver nanoparticles. Biomaterials 2009a; 30:6341–6350.
28. Gurunathan S et al. Biosynthesis, purification and characterization of silver nano particles using *Escherichia coli.* Colloids Surf B 2009b; 74(1):328–335.
29. Samadi N et al. Intra/ Extra cellular biosynthesis of silver nanoparticles by an autochthonous strain of Proteus mirabilis isolated from photographic waste. J Biomed Nanotechnol; 2009; 5(3):247–253.
30. Pugazhenthiran N et al. Microbial synthesis of silver nanoparticles by Bacillus sp. J Nanopart Res; 2009; 11(7):1811–1815.
31. Ganesh Babu MM, Gunasekaran P. Production and structural characterization of crystalline silver nanoparticles from *Bacillus cereusisolate*. Colloids Surf B 2009; 74(1):191–195.
32. Nanda A, Saravanan M. Biosynthesis of silver nanoparticles from Staphylococcus aureus and its antimicrobial activity against MRSA and MRSE. Nanomedicine 2009; 5(4):452–456.
33. Sintubin L et al. Lactic acid bacteria as reducing and capping agent for the fast and efficient production of silver nanoparticles. Appl Microbiol Biotechnol 2009; 84(4):741–749.
34. Kalishwaralal K et al. Biosynthesis of silver and gold nanoparticles using *Brevibacterium casei*. Colloids Surf B 2010; 77(2):257–262.
35. Prakash A et al. Synthesis of Agnps By *Bacillus Cereus* bacteria and their antimicrobial potential. Journal of Biomaterials and Nanobiotechnology 2011; 2:156 -162.
36. Malarkodi C et al. Eco-friendly synthesis and characterization of gold nanoparticles using *Klebsiella pneumonia.* Journal of Nanostructure in Chemistry 2013; 3:30.
37. Behera SS et al. Synthesis of Silver Nanoparticles from microbial source-a green synthesis approach, and evaluation of its antimicrobial activity against *Escherichia coli* . International Journal of Engineering Research and Applications 2013; 3(2): 058-062.
38. Mohanpuria P et al. Biosynthesis of nanoparticles: technological concepts and future applications. J. Nanopart. Res 2008; 10: 507–517.

39. Mukherjee P et al. Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticles synthesis. Nano Lett 2001; 1:515–519.
40. Ahmad A et al. Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Colloids Surf B 2003; 28:313–318.
41. Bhainsa KC, D'Souza SF. Extracellular biosynthesis of silver nanoparticles using the fungus *Aspergillus fumigatus*. Colloids Surf B 2006; 47:160–164.
42. Vigneshwaran N et al. Biomimetics of silver nanoparticles by white rot fungus, *Phaenerochaete chrysosporium*. Colloid Surf B 2006; 53:55–59.
43. Vigneshwaran N et al. Biological synthesis of silver nanoparticles using the fungus *Aspergillus flavus*. Mater Lett 2007; 66:1413–1418.
44. Gade AK et al. Exploitation of *Aspergillus niger* for synthesis of silver nanoparticles. J Biobased Mater Bioenergy 2008; 3:123–129.
45. Basavaraja S et al. Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium semitectum*. Mater Res Bull; 2008; 43(5):1164–1170.
46. Mukherjee P et al. Green synthesis of highly stabilized nanocrystalline silver particles by a non-pathogenic and agriculturally important fungus *T. asperellum*. Nanotechnology; 2008a; 19:075103.1 075103.7.
47. Mukherjee P et al. Green synthesis of highly stabilized nanocrystalline silver particles by a non-pathogenic and agriculturally important fungus *T. asperellum*. Nanotechnology 2008b; 19:7.
48. Ingle AP et al. Mycosynthesis of silver nanoparticles using the fungus Fusarium acuminatum and its activity against some human pathogenic bacteria. Curr Nanosci 2008; 4:141–144.
49. Balaji DS et al. Extracellular biosynthesis of functionalized silver nanoparticles by strains of *Cladosporium cladosporioides*. Colloids Surf B2009; 68:88–92.
50. Kathiresan K et al. Studies on silver nanoparticles synthesized by a marine fungus, *Penicillium fellutanum* isolated from coastal mangrove sediment. Colloids Surf B 2009; 71(1):133–137.
51. Shaligram NS et al. Biosynthesis of silver nanoparticles using aqueous extract from the compactin producing fungal strain. Process Biochem 2009; 44(8):939–943.
52. Gade A et al. Fusarium solani: a novel biological agent for the extracellular synthesis of silver nanoparticles. J Nanopart Res; 2009; 11:2079–2085
53. Fayaz M et al. Blue orange light emission from biogenic synthesized silver nanoparticles using *Trichoderma viride*. Colloids Surf B; 2010; 75(1):175–178.
54. Verma VC et al. Biosynthesis of antimicrobial silver nanoparticles by the endophytic fungus *Aspergillus clavatus*. Nanomedicine; 2010; 5(1):33–40.
55. Singh P, Raja RB. Biological Synthesis and Characterization of Silver Nanoparticles Using the Fungus *Trichoderma Harzianum.* Asian J Exp Biol Sci; 2011; 2(4):600-605.
56. Vahabi K et al. Biosynthesis of Silver Nanoparticles by Fungus *Trichoderma Reesei* (A Route for Large-Scale Production of AgNPs). Insciences J 2011; 1(1): 65-79.
57. Moharrer S et al. Biological Synthesis of Silver Nanoparticles by *Aspergillus flavus,* Isolated from Soil of Ahar Copper Mine. Indian Journal of science and technology 2012; 5(3):2443-2444.
58. Li G et al. Fungus mediated green synthesis of silver nanoparticles using *Aspergillus terreus.* International journal of molecular sciences 2012; 13(1): 466–476.
59. Birla SS et al. Rapid synthesis of silver nanoparticles from *Fusarium oxysporum* by optimizing physicocultural conditions. The Scientific World Journal 2013; Article ID 796018, 12 pages
60. Prabhu S, Poulose E. Silver nanoparticles: mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. International Nano Letters 2012; 2:32.
61. Shankar SS et al. Rapid synthesis of Au, Ag and bimetallic Au core–Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. J Colloid Interface Sci; 2004; 275:496–502.
62. Huang J et al. Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnamomum camphora* leaf. Nanotechnology; 2007; 18:105104.1–105104.11.
63. Huang J et al. Continuous-flow biosynthesis of silver nanoparticles by lixivium of Sundried *Cinnamomum camphora* leaf in tubular microreactors. Ind Eng Chem Res; 2008; 47(16):6081–6090.
64. Vivekanandan S et al. Biological synthesis of silver nanoparticles using Glycine max (soybean) leaf extract: an investigation on different varieties. J nanoscience & Nanotechnol 2009; 9(12): 6828-6833.
65. Bar H et al. Green synthesis of silver nanoparticles using seed extract of *Jatropha curcas*. Colloids Surf A Physico Chem Eng Asp 2009; 348:212–216.
66. Kasthuri J et al. Phyllanthin-assisted biosynthesis of silver and gold nanoparticles: a novel biological approach. J Nanopart Res 2009; 11(5):1075–1085.
67. Mude N et al. Synthesis of silver nanoparticles using callus extract of *Carica papaya* – a first report. J Plant Biochem Biotechnol 2009; 18(1):83–86.
68. Raut R et al. Photosynthesis of silver nanoparticles using *Gliricidia sepium* (Jacq.). Curr Nanosci 2009; 5(1):117–122.
69. Nabikha K et al. Synthesis of antimicrobial silver nanoparticles by callus and leaf extract from salt marsh plants, *Sesuvium portulacastrum* L. Colliods and Surface:Biointerfaces 2009; 79: 488- 493.
70. Sathyavathi R et al. Biosynthesis of silver nanoparticles using *Coriandrum sativum* leaf extract and their application in nonlinear optics. Adv Sci Lett 2010; 3(2):138–143.
71. Krishnaraj C et al. Synthesis of silver nanoparticles using *Acalypha indica* leaf extracts and its antimicrobial activity against water borne pathogens. Colloids Surf B Biointerfaces 2010; 76: 50-56.
72. Dwivedi AD, Gopal K. Biosynthesis of silver and gold nanoparticles using *Chenopodium album* leaf extract, Colloid Surf A Physicochem Eng Aspect 2010; 369: 27-33.
73. Dubey SP et al. Green synthesis and characterization of silver and gold nanoparticles using leaf extract of Rosarugosa. Colloid Surf A Physicochem Eng. Aspect 2010; 364: 34-41.
74. Geethalakshmi R, Sarada DVL. Synthesis of plant-mediated silver nanoparticles using *Trianthema decandra* extract and evaluation of their anti microbial activities. International Journal of Engineering Science and Technology 2010; 2(5): 970-975.
75. Ahmad N et al. Rapid synthesis of silver nanoparticles using dried medicinal plant of basil. Colloids and Surfaces B 2010; 81(1): 81–86.

76. Vidhu VK et al. Green synthesis of silver nanoparticles using Macrotyloma antibacterial activity. Spectrochim Acta A Mol Biomol Spectros 2011; 83: 392-397.
77. Sulochana S et al. Synthesis of silver nanoparticles using leaf extracts of *Andrographis paniculata.* Journal of pharmacology and toxicology 2012; 7(5): 251-258.
78. Caroling G et al. Biosynthesis of silver nanoparticles using aqueous broccoli extract- characterization and study of antimicrobial, cytotoxic effects. Asian J Pharm Clin Res; 2013; 6(4):165-172.
79. Ramteke C et al. Synthesis of silver nanoparticles from the aqueous extract of leaves of *Ocimum sanctum* for enhanced antibacterial activity. Journal of Chemistry 2013; Article ID 278925, 7 pages.
80. Elumalai S, Devika R. Biosynthesis of silver nanoparticles using *Curcuma Longa* and their antibacterial activity. Int J Pharm Res Sci 2014; 02(1): 98-103.
81. Kalidasan M, Yogamoorthi A. Biosynthesis of silver nanoparticles using *Achyranthus aspera* and its characterization. International Journal of Nanomaterials and Biostructures 2014; 4(1): 5-11.
82. Can E et al. Nanotechnological applications in aquaculture-seafood industries and adverse effects of nanoparticles on environment. Journal of Materials Science and Engineering 2011; 5:605-609.
83. Lansdown AB. Silver. 1. Its antibacterial properties and mechanism of action. J Wound Care 2002; 11:125–130.
84. Kim JS et al. Antimicrobial effects of silver nanoparticles. Nanomedicine 2007; 3: 95–101.
85. Gong P et al. Preparation and antibacterial activity of Ag nanoparticles. Nanotechnology 2007; 18: 604-611.
86. Sarkar B et al. Inhibitory role of silver nanoparticles against important fish pathogen, *Aeromonas hydrophila*. International Journal of Nanomaterials and Biostructures 2012; 2(4): 70-74.
87. Kandasamy K et al. Synthesis of silver nanoparticles by coastal plant *Prosopis chilensis* (L.) and their efficacy in controlling vibriosis in shrimp *Penaeus monodon.* Appl Nanosci 2013; 3:65–73.
88. De Azeredo, HMC. Nanocomposites for food packaging applications. Food Res Int 2009; 42:1240–1253.
89. Thompson RC et al. Lost at sea: where is all the plastic? Science 2004; 204:838.
90. Lee KT. Quality and safety aspects of meat products as affected by various physical manipulations of packaging materials. Meat Sci 2010; 86:138–150.
91. Toranzo AE et al. A review of the main bacterial fish diseases in mariculture systems. Aquaculture 2005; 246: 37–61.
92. Muhling M et al. An investigation into the effects of silver nanoparticles on antibiotic resistance of naturally occurring bacteria in estuarine sediment. Mar Environ Res 2009 68: 278–283.
93. Sung hoon J et al. Antibacterial properties of padded PP/PE non wovens incorporating nanosized silver colloids. Journal of Material Science 2005; 40:5413- 5418.
94. ETC (Action Group on Erosion, Technology and Concentration), Down on the Farm: The Impact of Nanoscale Technologies on Food and Agriculture. 2003; [http://www.etcgroup.org/en/materials/publications.html?pub_id=80].

Rajeshkumar S et al. Oral delivery of DNA constructs using chitosan nanoparticles to protect the shrimp from white spot syndrome virus (WSSV). Fish & Shellfish Immunology 2009; 26:429-437.