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An Eco-friendly Approach for Nanosilver Synthesis and its Therapeutic Aspects

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ABSTRACT

Nanosciences along with the emergence of nanobiotechnolgy and nanomedicine in the last few decades provided a number of opportunities for exploring the bactericidal and fungicidal activities of metal nanoparticles. In the present scenario silver in the form of nanoparticles are playing a major role in the field of Nanotechnology and Nano medicine, their unique size dependent properties make them superior and indispensable. Silver nanoparticles are particles in the size ranging between 1 and 100 nm. Although nanoparticles can be synthesized through array of conventional methods, biological route of synthesizing are good competent over the physical and chemical techniques. Green principle route of synthesizing have emerged as alternative to overcome the limitation of conventional methods among which plant and microorganisms are majorly exploited. Employing plants towards synthesis of nanoparticles are emerging as advantageous compared to microbes with the presence of broad variability of bio-molecules in plants can act as capping and reducing agents and thus increases the rate of reduction and stabilization. In addition, the biological synthesis of metallic nanoparticles is inexpensive, single step and eco-friendly methods. Nanosilver has developed as a potent antibacterial, antifungal, anti-viral and anti-inflammatory agent and also in diagnostic and therapeutic applications. The aim of this review is to provide an overview of recent trends in synthesizing nanoparticles via biological entities and their potential applications.

Keywords: Silver nanoparticles, Nanosilver, Green synthesis, Application.

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INTRODUCTION

Nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 1-100nm. The biosynthesis of silver nanoparticles has been proposed as a cost-effective and environmentally friendly alternative to chemical and physical methods. Plant-mediated synthesis of nanoparticles is a green chemistry approach that connects nanotechnology with plants. Novel methods of ideally synthesizing NPs are thus thought that are formed at ambient temperatures, neutral pH, low costs and environmentally friendly fashion. Keeping these goals in view nanomaterials have been synthesized using various routes. Among the biological alternatives, plants and plant extracts seem to be the best option. Plants are nature's "chemical factories". They are cost efficient and require low maintenance .[1]

Plant extracts are used for the metal ions bioreduction to form nanoparticles. It has been demonstrated that plant metabolites like sugars, terpenoids, polyphenols, alkaloids, phenolic acids, and proteins play an important role in metal ions reduction into nanoparticles and in supporting their subsequent stability. Properties of the nanometric materials atoms are quite different from those of the bulk materials. Conventionally synthesizing nanoparticles by chemical method in which chemicals are used because of their general toxicity; engendering the serious concern to develop environment friendly processes. Thus, to solve the aim; biological approaches are coming up to fill the void; for instance green synthesis using biological as the molecules of extracts derived from plant sources exhibiting superiority over chemical and/or biological methods .[1]

HISTORY

Silver has a long history of its usage in different forms and for different purposes. For centuries, the antibacterial properties of silver have been used to fumigate potable water by storage in silver containers .[2] There is anecdotal evidence for the use of nanosilver in ancient Egypt and Rome.[3] The Macedonians used silver plates to improve wound healing and Hippocrates used silver in the treatment of ulcers. In 1520, Paracelsus used silver internally and also applied silver nitrate as a caustic for the treatment of wounds, a practice that continues today.[4]In 1614, Angelo

Sala administered silver nitrate internally as a counterirritant, as a purgative and for the treatment of brain infections.[4] C. S. F. Crede is credited with the first scientific publication to describe the medical use of silver in the late nineteenth century. Crede used eye drops containing 1% silver nitrate solution to treat eye infections in new-born. [3] In the United States, colloidal nanosilver, i.e. suspensions of silver particles in liquid, which was registered in 1954 as a biocidal material has been used in medications for nearly one hundred years.[3,5] Use of silver for antimicrobial properties is not a recent development. [5]

SYNTHESIS OF SILVER NANOPARTICLE

Silver nanoparticles are generally synthesized by two approaches, (i) "top to bottom" approach and (ii) bottom to top approach. In top to bottom approach, suitable bulk material is broken down into smaller fine particles by size reduction using various techniques like grinding, milling, sputtering, thermal/laser ablation, etc., thus the "top-down" method comprises of mechanical grinding of bulk metals with subsequent stabilization using colloidal protecting agents while in bottom to top approach, nanoparticles are synthesized using chemical and biological methods by self-assembly of atoms to new nuclei, which grow into nano size particles while the "bottom-up" methods include chemical reduction, electrochemical methods and sono-decomposition. [6, 7]

The biggest advantage of "bottom to top" approach method is the production of a large quantity of nanoparticles within a short span of time. The major advantage of chemical methods is high yield, contrary to physical methods, which have low yield. In case of "top to bottom" approach nanoparticles are generally synthesized by evaporation condensation technique with the help of a tube furnace at atmospheric pressure. In this method, the primary material placed centred at the furnace is vaporized into a carrier gas, within a boat. One of the biggest limitations of this method is the imperfections in the surface structure of the product and the other physical properties of nanoparticles are highly dependent on the surface structure in reference to surface chemistry. Hence, cost effective and environment friendly alternate synthetic route was inevitable that culminated into the green synthesis. [7]

CHEMICAL SYNTHESIS

Chemical method of synthesis is valuable as it takes tiny period of time for synthesis of large quantity of nanoparticles. Nevertheless, in this method, capping agents are necessary for size stabilization of the nanoparticles. Nanoparticles have been synthesized, most recurrently by three chemical techniques:

• Dispersion of preformed polymers

• Polymerization of monomers

• Ionic gelation or coacervation of hydrophilic polymers

- **Dispersion of preformed polymers:** A number of methods have been recommended to prepare nanoparticles from PLA (polylactic acid), PLG (poly-D-L-glycolide), PLGA (poly-D-L-lactidecoglycolide) and PCA (Poly-ε-caprolactone), by dispersing the preformed polymers .
- **Polymerization of monomers:** Nanoparticles can moreover be prepared by polymerization of monomers. Polymeric nanoparticles achieved from copolymers of methacrylic acid, acrylic esters or metacrylics, have been extensively been used.
- **Ionic gelation or coacervation of hydrophilic polymers:** During this method, ionic gelation of the material experienced transition from liquid to gel due to ionic interactions. Chitosan, gelatin and sodium alginate is utilized for preparation of hydrophilic nanoparticles by ionic gelation.

PHYSICAL SYNTHESIS

Metal nanoparticles are synthesized by evaporation–condensation, which might be carried out using a tube furnace at atmospheric pressure. The starting material inside a boat centered at the furnace is vaporized into a carrier gas.

BIOLOGICAL SYNTHESIS

Our key purpose is to highlight on the biological synthesis of nanoparticles, because of its easiness of rapid synthesis, controlled toxicity, controlling on size characteristics, reasonable, and ecofriendly approach. A sum of natural sources is there for nanoparticle synthesis, together with plants, fungi, yeast, bacteria, etc.

Nanoparticle synthesis by plant extracts: Make use of plants in the synthesis of nanoparticles has drawn more interest of workers because it provides single step biosynthesis process. Plants tender a superior option for synthesis of nanoparticle, as the protocols involving plant sources are free from toxicants; furthermore, natural capping agents are readily supplied by the plants. The green synthesis is preferred over physical and chemical

methods as the former is environment friendly, cost effective, easily scalable to large scale syntheses, no need to use high temperature, energy and toxic chemicals. The use of plant extracts is potentially beneficial over microorganisms due to the ease of improvement, the less biohazard and strenuous process of maintaining cell cultures as required in microorganism process .[8]

Preparation of Silver Nanoparticles using biological synthesis

The protocol for the nanoparticle syntheses involves: the collection of the part of plant of interest from the available sites then it's washing thoroughly with tap water to remove contamination followed by surface sterilization with double distilled water and air dried at room temperature. These clean and fresh sources are then powdered using domestic blender or cut it into very small pieces. And for the plant broth preparation, around 10-25g of the dried powder or finally chopped leaves were kept in a beaker and boiled with 100mL of deionised distilled water. The extract was filtered with Whatman filter paper No.1 further the filtrate was used as reducing source for the synthesis of silver nanoparticles.

Synthesis of silver nanoparticles was carried out by adding 10ml of leaf extract to 100ml of 1mM silver nitrate ($AgNO3$) solution with continuous stirring at room temperature. Reduction of $Ag+$ to $Ag0$ was confirmed by the colour change of solution from colourless to brown. Its formation was further confirmed by using UV-Visible spectroscopy .[9] (Figure 1)

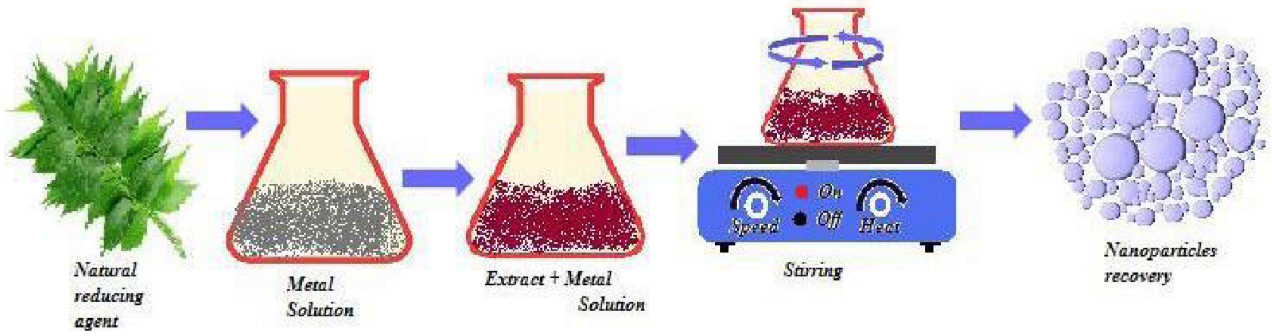

Fig 1: Synthesis process of green nanoparticles

Table1: *Use of different plant parts extract in the synthesis of silver nanoparticles as a precursor.*

Sr. No.	Latin name	Family	Part Extract	Size and Shape	References
1.	*Azadirachta indica*	*Meliaceae*	Leaves	spherical	[11]
2.	*Aloe vera*	Xanthorrhoeaceae	Leaves	12.5,spherical	[13]
3.	Nyctanthes arbor-tristis	Nyctanthes	Seeds	50 and 80 nm, spherical	[10]
4.	Emblica officinalis	Euphorbiaceae	Fruit	10-20 nm	[12]
5.	Cinnamon zeylanicum	Lauraceae	Bark/Stem powder	31-40nm, spherical	[14]
6.	Zingiber offcinale	Zingiberaceae	Tuber/root/rizome	6-20nm, spherical	[15]
7.	Hibiscus sabdariffa	Malvaceae	Flower		[15]

MECHANISM OF ACTION OF SILVER NANOPARTICLES

The exact mechanism which silver nanoparticles employ to cause antimicrobial effect is not clearly known and is a debated topic. There are however various theories on the action of silver nanoparticles on microbes to cause the microbicidal effect. Silver nanoparticles have the ability to anchor to the bacterial cell wall and subsequently penetrate it, thereby causing structural changes in the cell membrane like the permeability of the cell membrane and death of the cell. There is formation of pits on the cell surface, and there is accumulation of the nanoparticles on the cell surface. The formation of free radicals by the silver nanoparticles may be considered to be another mechanism by which the cells die. There have been electron spin resonance spectroscopy studies that suggested that there is formation of free radicals by the silver nanoparticles when in contact with the bacteria, and these free radicals have the ability to damage the cell membrane and make it porous which can ultimately lead to cell death . It has also been proposed that there can be release of silver ions by the nanoparticles , and these ions can interact with the thiol groups of many vital enzymes and inactivate them. The bacterial cells in contact with silver take in silver ions, which inhibit several functions in the cell and damage the cells. Then, there is the generation of reactive oxygen species, which are produced possibly through the inhibition of a respiratory enzyme by silver ions and attack the cell itself. Silver is a soft acid, and there is a natural tendency of an acid to react with a base, in this case, a soft acid to react with a soft base . The cells are majorly made up of sulfur and phosphorus which are soft bases. The action of these nanoparticles on the cell can cause the reaction to take place and subsequently lead to cell death. Another fact is that the DNA has sulfur and phosphorus as its major components; the nanoparticles can act on these soft bases and destroy the DNA which would definitely lead to cell death. The interaction of the silver nanoparticles with the sulfur and phosphorus of the DNA can lead to problems in the DNA replication of the bacteria and thus terminate the microbes. It has also been found that the nanoparticles can modulate the signal transduction in bacteria. It is a well established fact that phosphorylation of protein substrates in bacteria influences bacterial signal transduction. Dephosphorylation is noted only in the tyrosine residues of gram-negative bacteria. The phosphotyrosine profile of bacterial peptides is altered by the nanoparticles. It was found that the nanoparticles dephosphorylate the peptide substrates on tyrosine residues, which leads to signal transduction inhibition and thus the stoppage of growth .[16] (Figure 2)

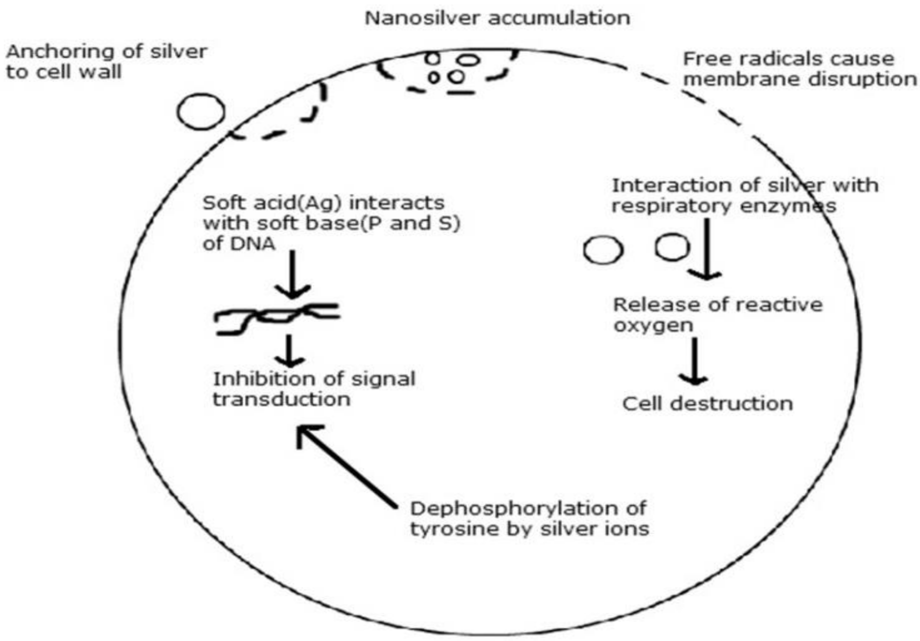

Fig. 2: Various modes of action of silver nanoparticles on bacteria.

CHARACTERIZATION

Characterization of nanoparticles is significant to appreciate and control nanoparticles synthesis and applications. Nanoparticles characterization is executed using a range of diverse techniques like scanning and transmission electron microscopy (SEM,TEM), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), dynamic light scattering (DLS), powder X-ray diffractometry (XRD), and UV– Vis spectroscopy. These techniques are helpful to resolve diverse parameters such as particle size, shape, crystallinity, fractal dimensions, pore size and surface area. Additionally, orientation, intercalation and dispersion of nanoparticles and nanotubes in nanocomposite materials could be decided by these techniques. The morphology and particle size possibly will be determined by TEM, SEM and AFM. The improvement of AFM over conventional microscopes such as SEM and TEM is

that AFM technique measures 3D images, so that particle height and volume can be intended. Moreover, dynamic light scattering is applied for determination of particles size distribution. Furthermore, X-ray diffraction is exercise for the determination of crystallinity, while UV– Vis spectroscopy is utilized to confirm sample formation by exhibiting the Plasmon resonance. [17]

PHARMACEUTICAL ASPECTS OF SILVER NANOPARTICLES

Different formulations

- Patil and Kumbhar synthesized silver nanoparticle via green synthesis using extract of Lantana camara L. leaves and found these NPs to exhibit dose dependent antioxidant potential comparable to that of standard ascorbic acid. AgNPs also showed significant antimicrobial activity against Gram positive Staphylococcus aureus than Gram negative Pseudomonas aeruginosa and E. coli comparable with standard, Ciprofloxacin.[18]

- Jha et al. synthesized AgNPs from Ocimum tenuiflorum extract followed by study of AgNP loaded multi-walled carbon nanotubes (MWCNT) with mammalian sperm to evaluate the increased targeting potential for the development of portable diagnostic tool for the infertility management. AFM demonstrated the loading of AgNP inside MWCNT as surface height of MWCNT increased from 22 to 32 nm, which in turn assured the encapsulation of 10nm size of AgNP inside the tube. [19]

- Kumar et al. reported green synthesis of AgNP by Jatropha curcas and Lannea grandis, which further demonstrated low MIC and low minimum biofilm eradication concentration against C. albicans biofilm. The formulation developed was stable and cytotoxic against goat blood RBC and it could be further used for treatment of C. albicans associated infection. [20]

- Bilal et al. synthesized AgNPs loaded chitosan-alginate construct from methanolic extract of E. helioscopia and antibacterial activities against six clinically pathogenic strains including S. aureus, P. aeruginosa, Klebsiella pneumoniae, Acinetobacter baumannii, Morganella morganii and Haemophilus influenza were investigated. All construct exhibited excellent biocompatibility for normal cell line, i.e. L929 and anti-cancer efficacy against HeLa cells. Thus, the newly engineered construct could be a useful candidate for biomedical applications. [21]

- Castangia et al. synthesized grape-silver nanoparticles stabilized by phospholipids vesicles, which inhibited proliferation of S. aureus and P. aeruginosa providing safeguard of keratinocytes and fibroblast against oxidative stress that could be used as topical formulation for skin damages. [22]

- Loo et al. investigated interaction of silver and curcumin NPs against Gram positive and Gram negative bacteria and their 100 mg/mL concentration distorted matured bacterial biofilms. This formulation could be used for its sustained antibacterial effects. [23]

- Ibrahim and Hassan developed silver nanoparticle functionalized cotton fabric using green synthesis, which displayed good qualitative and quantitative antibacterial activity against E. coli and S. aureus and support that this property could be further utilized in manufacturing antimicrobial finishing and textiles. [24]

- Jadhav et al. synthesized antibacterial silver nanoparticles using extract of Ammannia baccifera. AgNPs gel (0.025% w/w) when compared with marketed 0.2% w/w silver nitrate gel displayed equal zone of inhibition against all pathogenic bacteria responsible for infections in burns. The formulated AgNPs gel could be used as an efficient and better substitute in burns by promoting cellular growth and relieving pain .[25]
- Khan et al. described the method of synthesis of nanoparticle using Heliotropium crispum plant extract. The antibacterial action of AgNPs was found to be species independent and strictly strain dependent as both Gram negative P. aeruginosa (PA) and A. baumannii (AB) and Gram positive Multiple Drug Resistant S. aureus (MRSA) exhibited differential inhibition zones and decrease in bacterial viability. [26]
- Kajani et al. synthesized AgNP using extract of T. baccata plant, which showed better anticancer activity than the previously reported ones due to the synergistic role of Taxus compound in the nanoparticle cytotoxicity. It was concluded that the biogenic synthesis of AgNPs in combination with targeted therapy of tumours may give rise an alternative approach for efficient treatment of cancers with fewer side effects .[27]
- Sadat et al. developed high drug-loaded Imatinib-loaded silver nanoparticle for potent bioavailability and decreasing dose frequency which is important in antitumor drug delivery to breast cancer cells, which was incited by apoptosis rather than necrosis. They concluded that green synthesized silver nanoparticles are promising sustained release system to the Imatinib and will be potentially useful for controlled drug delivery.[28]
- Govindarajan et al. reported mosquitocidal silver nanoparticle using aqueous leaf extract of A. indica and suggested that the synthesis of nanoparticle using A. indica may be considered for the development of newer and safer mosquito larvicides .[29]
- Sahana et al. formulated antibacterial cold cream using biosynthesized silver nanoparticle from flower extract of Cassia auriculata as a reducing agent. The cold cream containing the flower extract alone showed a minimum inhibitory effect on the pathogens whereas the bactericidal cold cream containing the NPs synthesized from the flower extract showed an excellent antibacterial activity. [30]
- Goyal et al. synthesized AgNP using b-glucan replacing conventional reducing agents with biocompatible and structural compatible sugar molecules. An efficient nanoemulsions delivery method for AgNP was developed wherein DOX was encapsulated in nanoemulsions containing AgNP and displayed antibacterial effects together with antitumor efficacy, which is quite useful in treatment of cancer cells, while preventing microbial infection. The effective loading of drug was about 15–30%. [31]
- Wildt et al. introduced a novel technique, nanoparticle associated cytotoxicity microscopy analysis (NACMA), which integrates fluorescence microscopy detection using ethidium homodimer-1, a cell permeability marker that binds to DNA after a cell membrane is compromised (a classical dead-cell indicator dye), with live cell time-lapse microscopy and image analysis to concomitantly enquire silver nanoparticle accumulation and cytotoxicity in L-929 fibroblast cells. Studies conducted on 10, 50, 100 and

  200nm silver nanoparticles disclosed size dependent cytotoxicity with particularly high cytotoxicity from 10nm particles. In addition, NACMA results, when combined with transmission electron microscopy imaging, reveal direct affirmation of intracellular silver ion dissolution and possible nanoparticle reformation within cells for all silver nanoparticle sizes .[32]
- Verma et al. formulated wound dressing carbopol based hydro gel using sericin and chitosan capped AgNP, which displayed higher antibacterial activity and were found to be non-irritant, potential wound healer, biocompatible by in vivo studies .[33]
- Borrego et al. tested the antiviral activity of AgNP formulated as Argovit against Rift valley fever virus, which represents an important zoonotic pathogen and potential biological weapon. Silver nanoparticles combined with the virus will help to plan a more effective application of Argovit against viral infections both prophylactically and therapeutically. [34]

Table 2: *Commercially available medical products containing Nanosilver.*

Sr. no.	**Product**	**Company**	**Description**	**Clinical Uses**
1.	Acticoat™	Smith & Nephew	Nanocrystalline silver wound dressing	Dressing for a range of wounds including burns and ulcers; prevents bacterial infection and improves wound healing.
2.	Silverline®	Spiegelberg	Polyurethane ventricular catheter impregnated with NS	Neurosurgical drain of CSF for hydrocephalus. Also can be adapted for use as shunts. Antibacterial silver NP coating prevents catheter-associated infections.
3.	SilvaSorb®	Medline Industries and AcryMed	Antibacterial products: hand gels, wound dressings, cavity filler	Wound dressings and cavity filler prevent bacterial infection. Hand gels used to disinfect skin in clinical and personal hygiene purposes.
4.	ON-Q SilverSoaker™	I-Flow Corporation	Silver-NP-coated catheter for drug delivery	Delivery of medication (e.g. local anesthetics or analgesics) per-, peri- or post-operatively for pain management or for antibiotic treatment.

APPLICATIONS

Due to unique properties of silver nanoparticles, such as size and shape which depend on optical, electrical and magnetic properties, they are of immense interest and can be subsumed into antimicrobial applications, biosensor materials, composite fibres, cryogenic superconducting materials, cosmetic products and electronic components. Nanoparticles have numerous applications in different fields, such as medical imaging, nano-composites, filters, drug delivery and hyperthermia of tumours.[35]

(a) Antimicrobial activity of AgNPs

AgNPs have been used tremendously as anti-bacterial agents in the health industry, food storage, textile coatings, numerous environmental applications, as an antibacterial agent from fumigating medical devices and home appliances to water treatment cotton fibre.[36] Smaller AgNPs have a greater binding surface and show more bactericidal activity when compared to larger AgNPs. The reason for the sensitivity of Gram positive and Gram negative bacteria towards AgNP is because of variation in thickness and molecular composition of the membrane structures. Bactericidal activity is apparently due to alteration in the bacterial cell wall structure as a result of interactions with embedded AgNPs, leading to enhanced membrane permeability and finally death. AgNPs also react with sulphur and phosphorus-rich biomaterials, such as proteins or DNA, or membrane protein, which affect the respiration, division and ultimately survival of cells. Upon entering the bacterial cell wall, silver ions (as part of AgNPs) can enter into cells, leading to the aggregation of damaged DNA and exert effect on protein synthesis.[37]

(b) AgNPs in cancer control

Since AgNPs can disrupt the mitochondrial respiratory chain, they could be expanded to instigate the reactive oxygen species (ROS) production, ATP synthesis and finally DNA damage; they can perform well in cancer therapeutics. Sesbania grandiflora leaf extract mediated AgNPs exhibited cytotoxicity to MCF-7 cancer cells instigating ROS production resulting in oxidative stress and caspase-mediated synthesis with further changes in morphological attributes including hampering of membrane integrity, cell growth reduction, cytoplasmic condensation, etc. G. mangiferae extracts mediated AgNP synthesis are highly biocompatible with IC50 values of AgNPs were 63.37, 27.54 and 23.84 lg/mL against normal African monkey kidney (Vero), HeLa (cervical), and MCF-7 (breast) cells, respectively, should be probed or examined as promising candidates for a variety of biomedical/pharmaceutical and agricultural applications. The alcoholic flower extract of Nyctanthes arbor-tristis mediated AgNP can be used for molecular imaging and drug delivery and AgNP were slightly toxic to L929 cells even at highest concentration, i.e. 250 mg/mL. MCF-7 cells treated with either AgNPs or cisplatin demonstrated decreased Bcl-2 expression and increased Bax expression, pointing out the embroilment of mitochondria in the mechanism of death induced by AgNPs. Rosa indica mediated AgNP synthesis may be used in vast range of therapeutic anticancer application and act as radical scavenger and induce apoptosis in HCT-15 cells and the ROS generation.[37]

There are several secreted glycoproteins and among them VEGF-A are secreted by tumor cells. It is a tumor-secreted cytokine with critical importance in both normal and tumor-associated angiogenesis. VEGF-A exerts its biologic effect through interaction with cell surface receptors. Dimerization of receptors leads to their activation and subsequent autophosphorylation on certain tyrosine residues, which in turn triggers intracellular signaling cascade mediated by several effectors, which are able to recognize and dock at phosphorylated tyrosine residues of the activated receptors. The cancer cells can be targeted using silver nanoparticle conjugatedwith a tissue specific ligand that can activate any of the VEGF receptors and express its effect on any of the downstream molecules. The illustration explains that all the molecules that are represented could be a possible target and depending upon the targeting its impact on proliferation, migration and vascular permeability can be studied. The inhibition of some/all of the kinases in the downstream signaling could evolve silver nanoparticles as an antiangiogenic agent. However, more studies are required to augment such a prediction and also exploring such a pathway will serve as a benchmark not only in cancer but also other diseases involving similar signalling mechanisms.

The role of silver nanoparticles as an anti-cancer agent should open new doors in the field of medicine. The design of smart multifunctional nanosystems for intracellular imaging and targeted therapeutic applicationsn requires a thorough understanding of the mechanisms of nanoparticles entering and leaving the cells. For biological and clinical applications, the ability to control and manipulate the accumulation of nanoparticles for an extended period of time inside a cell can lead to improvements in diagnostic sensitivity and therapeutic efficiency. This when revealed completely would eliminate the use of expensive drugs for cancer treatment. In general, silver nanoparticles should serve as one of the best ways of treating diseases that involve cell proliferation and cell death .[38](Figure 3)

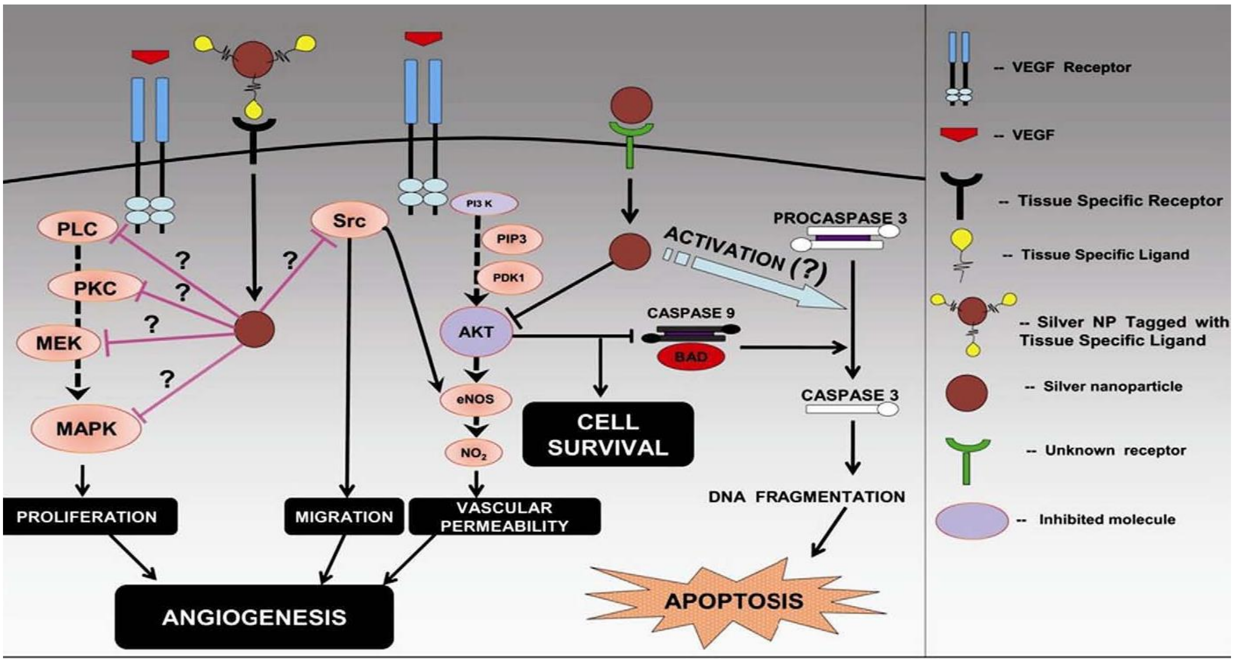

Fig.3: Possible signaling pathways induced by silver nanoparticles when bound to an unknown as well as VEGF receptor.

(c) Antidiabetic activity of AgNPs

Tephrosia tinctoria stem extracts mediated AgNP synthesis was evaluated for control of blood sugar levels. AgNPs scavenged free radicals, reduced the levels of enzymes that bring about the hydrolysis of complex carbohydrates (a-glucosidase and a-amylase), and as a result of which there is an increase in consumption rate of glucose.[35]

(d) Antioxidant activity of AgNPs

The highest recorded radical scavenging activity is 64.81% at a concentration of 500 mg/mL is by AgNP synthesized using leaf extracts of Leptadenia reticulate whose extract bolster dose dependent DPPH radical scavenging activity. The potential of antioxidants to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals is probably due to their capability to donate hydrogen and easily incorporate electrons; the latter is possible due to the presence of host lipophilic radicals. As compared to nanoparticles, the DPPH radical scavenging activity of HAuCl4 and AgNO3 was negligible, which may be due to salt conditions or weaker solubility of metal oxides.[37]

(e) Different field applications of AgNPs

Nanotechnology is rapidly developing nano products and nanoparticles (NPs) that can have peculiar and size-correlated physicochemical properties which are quite different from larger material. These unique characteristics of NPs have been utilized in several possible applications in medicine, cosmetics, biomedical and environmental remediation. [39]

The pharmaceutical industry seems to be one of the largest beneficiaries of AgNPs; employing these nano materials as antimicrobial and anti-fungal preparations. Silver has been used anciently for burns, wounds and bacterial infections; the utility of AgNP in these treatments is better appreciated in modern context due to growing overwhelming antibiotic resistance in bacteria. AgNPs have been shown to improve efficiency of cancer treatments by increasing effectiveness of drug delivery and producing anti-tumorogenic effects, which display great capability in cancer therapeutics. Studies concentrating on the therapeutic applications of AgNPs in the gastrointestinal tract have displayed that gastric cells can be sensitized to radiation by the use of AgNP and they may bypass the stomach and instead release the drug in small intestine. [37]

As antimicrobial agents silver nanoparticles have been used largely in the health industry, food storage, textile coatings and a number of environmental applications. Indigofera aspalathoides extract mediated silver nanoparticles were assessed in wound-healing applications following excision in animal model. Chrysanthemum morifolium extract mediated AgNPs were added to clinical ultrasound gels, which are used with an ultrasound probe, and were found to possess bactericidal activity, aiding to the sterility of the instrument. [40]

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