Pharmaceutical Breakthroughs
Volume 1, Issue 1, 24-36
DOI: 10.59762/pb724290251120231110131451

Investigation of Biological Activities Catalytic Activity Antioxidant Activity of Silver Nanoparticles Synthesized By Using Mulberry (Morus) Leaf Extract

Shabir Ahmad wani[1] Bibi Ahmadi Khatoon[2]* Farhath Khanum[3]
[1]*Department of Chemistry, Yuvaraja's College, University of Mysore, India.*
[2]**Department of Chemistry, Yuvaraja's College, University of Mysore, India.*
[3]*Department of Nutrition, biochemistry and Toxicology, Defense Food Research Laboratory, Sidharthanagar Mysore, India.*

Abstract
Few decades ago, almost no one understood the importance of remarks "There is plenty of room at the bottom" expressed by Robert Feynman until its reality appeared in the form of technology called nanotechnology, which has left its footprints in almost every field of science and technology. Nanotechnology is based on two approaches i.e. Top-Down Approach and Bottom-up Approach. These two approaches include different physical, chemical and biological methods for the production of materials at Nano scale. Biological method especially use of plant parts (green method) is strongly recommended nowadays due its unique features i.e. simplicity, biocompatibility, cost-effectiveness and eco-friendliness. In the present study, we have synthesized silver nanoparticles through green method by using Mulberry leaves. The green synthesized silver nanoparticles were characterized by techniques such as Uv-visible spectrophotometry, Scanning Electron Microscopy, Dynamic light scattering, Fourier transformer-infrared, X-ray Diffraction. The nanoparticles were studied for their different activities i.e. antimicrobial activity, antidiabetic activity, antioxidant activity, catalytic activity and cytotoxic activity.

Key Words: - Silver nanoparticles, antidiabetic activity, antioxidant activity, catalytic activity and cytotoxic activity.

Introduction
Nanotechnology involves the generation of nanoparticles which are in size range 1 to 100 nm. Nanoparticles possess different shapes which give them unique chemical 1.Singh, J. et al 2018, physical 2. Yilmaz, A. & Yilmaz et al 2020 and optical properties 3.Scholes, G. D and 4.Susarrey-Arce, A. et al 2011. Intensive research is being done on silver nanoparticles (AgNPs) owing to their wide range of applications in medical devices 5.He Y, et al 2013, pharmaceuticals 6.Kumar V.G, et al 2011, clothing 7.Vigneshwaran N, et al 2007,water purification 8. L i n S, et al 2013 and also in adsorption of metals and pesticides 9.Asthana A, and 10.Das SK, et al 2012 etc. NPs can be synthesized with physical, chemical and biological methods 11. Chen, H et al 2008. These methods have unique advantages and disadvantages depending on their application 12.Smetana, A and 16. Kholoud,M et al 2010. These methods can be time-consuming and are restricted to particular requirements like high temperature or pressure, which might result in wastage and damage to equipment and associated cost 17.Toisawa, K and 18.Iravani, S et al 2010. The critical environmental issues had led the scientific community towards green produc-

Bibi Ahmadi Khatoon
Department of Chemistry, Yuvaraja's College, University of Mysore, India.
bakhatoon@rediffmail.com

tion of nanoparticles using living systems such as plants, fungi, and bacteria 19.Krishnaraj C et al 2010. These green synthesized nanoparticles are much better than nanoparticles synthesized from chemical procedure 20.Baker. S et al 2013. The green synthesized nanoparticles have fast, environmental-friendly, and low-cost production strategies, and are biocompatible. Phytochemicals of Plants like carbohydrates, fats, enzymes, polyphenols, alkaloids, flavonoids and terpenoids act as stabilizing , reducing and capping agents in the reaction 21.Makarov VV et al 2014. Silver nanoparticles have been synthesized using parts of plants i.e. leaf 22. Prakash P, et al 2013 , bark 23.Sathishkumar M, et al 2009, seeds 24.Bar H, et al 2009, roots 25. S u - man T, et al 2013, fruit extract of Emblica officinalis 26.Ankamwar, Be et al 2005, leaves extract of Citrus limon 27.Vankar, P. S., and Shukla, D et al 2012, green tea (Camellia sinensis) 28.Nakhjavani, M et al 2017, Coffea Arabica 29.Dhand, V et al 2015, neem (Azadirachta indica) 30.Ahmed, S et al 2016, Acalypha indica 31.Krishnaraj, C et al 2012, Aloe vera plant extract 32.Tippayawat, P et al 2016, latex of Jatropha gossypifolia 33.Borase, H et al 2014, Phoenix dactylifera 34.Oves, M et al 2018, inflorescence extract of Mangifera indica 35.Qayyum, S et al 2017 etc. In the present work, we synthesised the silver nanoparticles using Mulberry leaf extract through green method and also studied some of their applications.

Materials and Methods

Materials required

Leaves of Mulberry plant, glass beaker, filter paper, test tubes, magnetic stirrer, funnel, burette, burette stand, syringe

Chemicals required

Silver nitrate, 1,1-Diphenyl-2-picryl hydroxyl (Dpph), α-amylase, sodium borohydrate, ortho-nitrophenol, para-nitrophenol, congo red, methylene blue.

Methodology

Preparation of leaf extract

Mulberry leaves were collected from department of sericulture university of mysore (Mysuru) india. Leaves were oven dried and pounded to powder. The powder was collected and stored. 10gm of leaf powder was taken in a glass beaker and 100ml of water was added. The mixture was boiled for 30 minutes at 70°c and then filtered. The filtrate was kept in a beaker with a label of Mulberry leaf extract and then kept at 4°c in refrigerator.

Synthesis of silver nanoparticles

Mulberry leaves extract (5ml) was taken in 250ml beaker and kept on magnetic stirrer which was adjusted at 700rmp and 70°c. 50ml of 0.001M AgNO3 were added drop-wise by burette to the beaker containing leaf extract. The mixture was kept at same rmp value and temperature until the colour change was observed i.e. light yellow to greyish brown which is first indication of formation of silver nanoparticles.

Characterisation

The spectrophotometric techniques used for characterisation are: (i) Uv-visible spectrophotometer (nano spectrostar (BMG LAB TECH) (ii) scanning electron microscope (SEM) equipped with an energy-dispersive X-ray (EDX) (JFC1600 instrument (JEOL, Ltd., Tokyo, Japan) (iii) Dynamic Light Scaterring (Malvern Zeta sizer) and (iv) Fourier transform infrared spectroscopy (FTIR) analysis using a Spectrum One FTIR spectrophotometer (PerkinElmer, Inc.) and X-ray diffractometry. The instruments were used to determine various parameters such as formation of nanoparticles, shape, size, zeta potential, stability, elemental composition, functional group and crystalline nature of synthesized AgNPs.

Encapsulation Efficiency

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

Amalgamation of materials of same or different structure to assist the fabrication of requisite characteristics is known as Encapsulation. Metal load efficiency in the mother solution of nanoparticle was determined by Inductive coupling plasma with optic emission spectrometry technic (ICP-OES). It was achieved with atomic emission spectrophotometer ICP-OES Varian 725-ES using argon as carrier gas. Sample ashing was carried out at 550°c in furnace. Collected ash of sample was then dissolved in 0.5M nitric acid. The solution was then filtered by Ashless filter paper. Finally, filtered solution (sample) was

made upto the volume of 50ml. Sample solution was then put into ICP-OES [36]. The results obtained are expressed as mg of copper per gram of leaf extract. The encapsulation efficiency percentage is calculated by following formula

$$\% EE = Ci \div C0$$

Where, Ci is the real concentration calculated by ICP. and C0 is theoretical concentration of product involved into the process.

Anti-diabetic (α-amylase assay)

The inhibition of α-amylase was carried out by the method [37] with slight modifications. 20 µl of alpha amylase (.5mg/ml) were taken in test tubes. Different concentrations i.e. 20µl, 40µl, 60µl of test samples (plant extract, silver nanoparticles) were taken in test tubes and 10µl of 0.02m phosphate buffer (ph 6.9) were added to each test tubes and the incubation of mixture was done for 10minutes. 1ml of 1%starch solution was added to the mixture and again incubated for 20minutes. Finally 400µl of DNS reagent was added to stop the reaction and then the reaction mixture was boiled for 5minutes. Control was prepared wherein amylase was not added. Absorbance was measured at 540nm.

Antimicrobial (Agar well diffusion)

The antibacterial assay was performed by agar well diffusion method on Escherichia coli (E.Coli), Staphylococcus, Bacillus cereus which were obtained from Food Microbiology, Defence Food Laboratory Mysore. The bacterial culture medium used, was nutrient agar medium. The dissolved medium was autoclaved at 15 lbs pressure at 121 °C for 15 minutes. The autoclaved medium was mixed well and poured onto 100 mm petriplates (25-30ml/plate) while still molten [38]. After 30 minutes, the cultured medium was inoculated with the test organisms Petriplates containing 20 ml Muller Hinton medium were seeded with 24hrs culture of bacterial strains. Wells were cut and 100 µl of the silver nanoparticles were added along with the standard antibacterial agent were placed onto an agar plate. Silver salt solution was used as a standard antibacterial agent. The plates were then incubated at 37 °C for 24 hrs. The antibacterial activity was assayed by measuring the diameter of the zone of inhibition formed around the well. The inhibition cleared zone around the sample decides the efficiency of the antibacterial agent to inhibit the growth of bacteria.

In vitro cytotoxicity by MTT assay

Cell lines and culture medium

MCF-7 cancer cell line was purchased from the national centre for cell sciences (NCCS), Pune, India. Dulbecco's modified eagle's growth medium (DMEM)-high glucose (#AL111, himedia) with 10% fetal bovine serum (#RM10432, hi media) was used in order to culture the cancer cells and incubation was done at a temperature of 37±0.2 °C. MTT reagent (5mg/ml) #4060) was purchased from hi media. Cytotoxic activity of silver nanoparticles against MCF-7 was evaluated by MTT(3-(4,5-dimethyl-2-thiazolyl)-2,5-diphenyltetrazoliumbromide) colorimetric assay. Key aim of the assay is the reduction effect of the NAD (P)H dependent oxidoreductase enzymes of viable cells on yellow coloured water-soluble tetrazolium dye to give a formazan product with deep purple colour . The cytotoxicity assay was completed by seeding 100 µl cell suspension in a 96-well plate at required cell density (10,000 cells per well) and incubated for 24 h at 37 °C [39]. Different concentrations (15, 30, 50, 90 and 120 µg/ml) of test sample (silver nanoparticles) were taken and incubated for 24 h at 37 °C. Cancer cells without test compound were used as control. Exhausted media was taken out after the incubation period and MTT reagent was added to a final concentration of 0.25 mg/ml of total volume and incubated again. After incubation MTT reagent was removed and finally 50µl solubilized solution of dimethyl sulfoxide (DMSO) was added to get the purple formazan crystals for complete dissolution. The colorimetric assay is analysed and noted the absorbance at 570 nm using an spectrophotometer [40]. Cell viability and cytotoxicity percentage were calculated using the following equation [41, 42]:

$$\text{Cell Viability \%} = \text{Test OD} \div \text{Control OD} \times 100 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{Cytotoxicity \%} = 100 - \text{Viability \%} \quad \ldots\ldots\ldots\ldots (2)$$

Catalytic Activity

1ml of 0.2M freshly prepared sodium boro-hy-

dride was taken in a cuvette and 1.9ml of 0.2Mm of dye was added to the cuvette containing sodium boro-hydride. Cuvette was shaked and placed in the uv-visible spectrophotometer to record the absorbance[43].The cuvette was removed and 0.1ml of test sample was added and shaken vigorously and kept in Uv-visible spectrophotometer and absorbance was recorded.

Antioxidant (Dpph assay)

DPPH free radical scavenging of plant extract and silver nanoparticles was examined by following procedure described by [44] was followed with a little modification. A stock solution of dpph (7mg in 10ml of methanol) was prepared. To 1ml of stock solution 10ml of methanol was added and was labelled as working solution. Different concentrations of test samples (plant extract, silver nanoparticles) were taken in test tubes. To each sample 800µl of methanol and

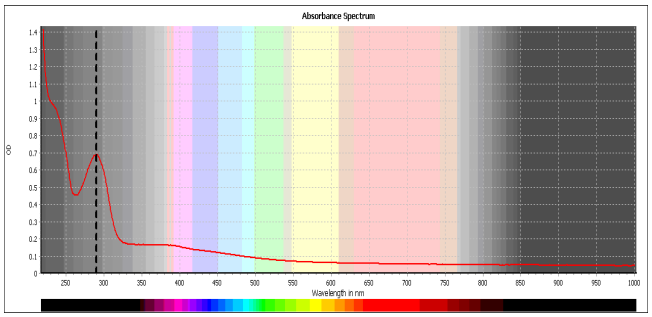

Figure. 1
Uv spectrum of silver nanoparticles

400µl of dpph was added. Dpph solution without test sample was used as control. All the samples were incubated for half an hour in dark and then absorbance was measured at 517nm [45].

Results and Discussions

Ultraviolet-Visible Spectroscopy

The absorption spectra of the green synthesized silver nanoparticles was taken by Uv –visible spectrophotometer (NANO STAR SPECTRA BMG Lab tech). Colour change indicates the formation of silver nanoparticles [46]. Phytochemicals like Flavones, amides, carboxylic acid, aldehydes, ketones, terpenoids, quinines, and anthraquinones play prominent part in the preparation of nanoparticles [47]. The wavelength set between 200nm and 800nm produce absorption band of silver nanoparticles [48]. An absorption peak (fig.1) was observed at 295nm which confirms the formation of silver nanoparticles. The results obtained are in accordance with previous reports.

Dynamic Light Scattering

Dynamic light scattering (DLS) was used to determine the particle size distribution and average particle size of all metal NPs at a scattering angle of 90°. The average particle size of silver nanoparticles was found 102nm. Poly-distribution index was found 0.231. Morphology i.e. shape and size of green synthesized silver nanoparticles was studied by Scanning Electron microscopy. The SEM image (fig.3) shows green synthesized AgNPs with different size i.e. 63nm, 64, 135nm, etc. The morphology of the silver nanoparticles made using Mulberry leaves were spherical in shape. Aggregations or impurities were also

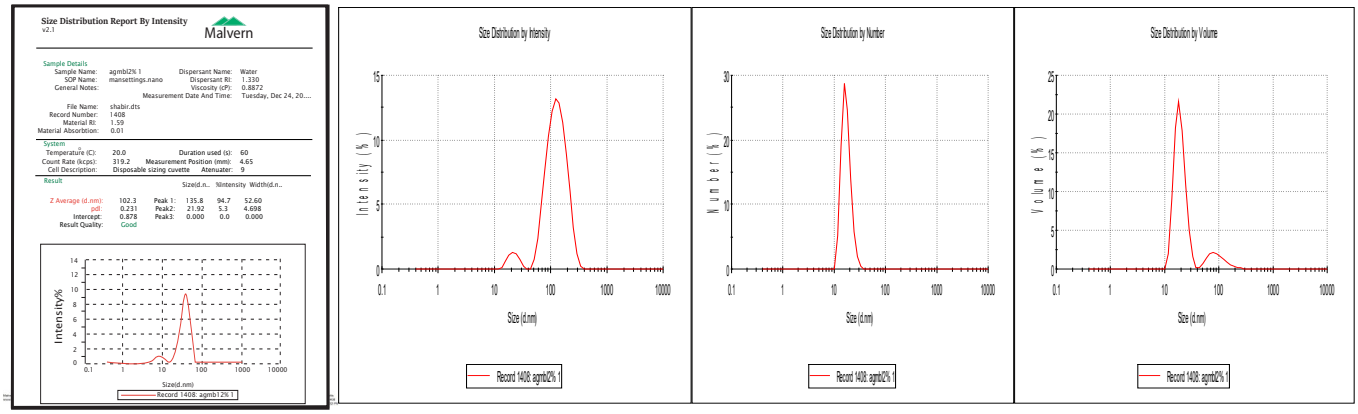

Figure.2
Scanning Electron Microscopy

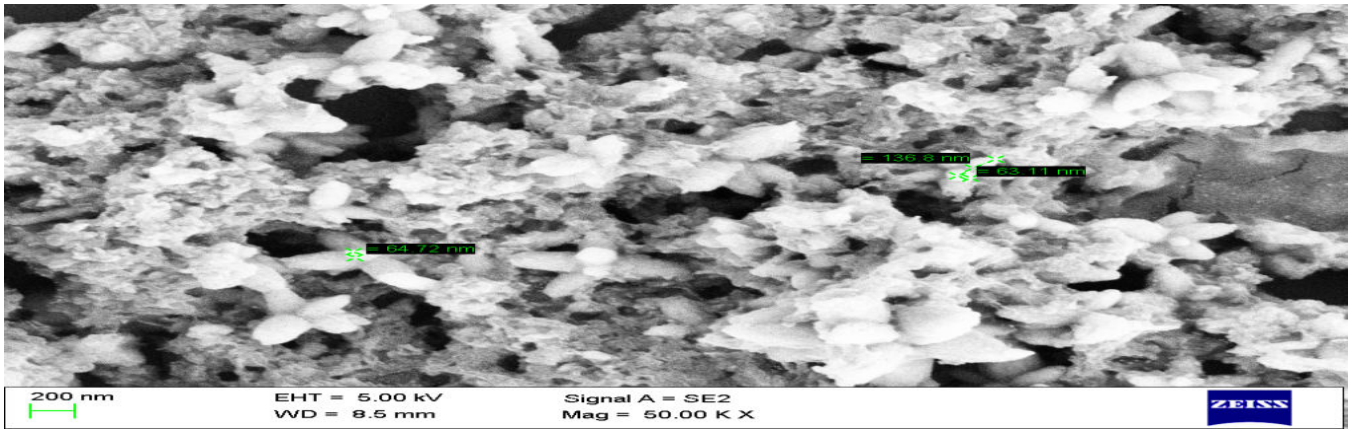

Figure. 3
SEM image of silver nanoparticles

observed. Particles could be seen well dispersed. These bigger particles are either waste plant material, or bigger particles formed due to agglomeration.

Fourier Transformer-Infrared

FTIR spectroscopic analysis was used to determine the functional groups present in the synthesized silver nanoparticles from Mulberry leaf extract. FT-IR spectrum of dry powder of synthesized AgNPs is shown in (Fig.4). The IR-spectrum of the silver nanoparticles synthesized from Mulberry leaves showed absorption bands at 622, 871,1039,1387,1653, 2932, 3417 and 3700 cm−1 which are due to presence of functional groups such as alkyl halides N–C=O amide, C–H stretch of aldehydes, C–H of alkanes, O–H of alcohol, N–H of amines, C=O of carboxylic acid/ aldehydes or ester, H–C=O:C≡N stretch of nitriles [49-50].

X-Ray Diffraction

The formation of AgNPs nanoparticles was detected by X-ray diffraction (XRD). The crystallinity, phase structure and purity of the silver nanoparticles nanoparticles were determined by its typical powder XRD diffraction patterns. All the diffraction peaks corresponds to the lattice planes of (110), (111), (200) and (211) in between 2θ values: 38.17º, 47.29º, 66.42º and 78.71º (Fig.4) is in good agreement with the Agnps which can be indexed on the basis of JCPDS card no. 65-2309. Sharp peaks in diffraction pattern show the crystalline nature of the particles.

Encapsulation Efficiency

The ICP-OES spectroscopy was used to determine the Ag ion concentration encapsulated by phytochemicals of plants ex

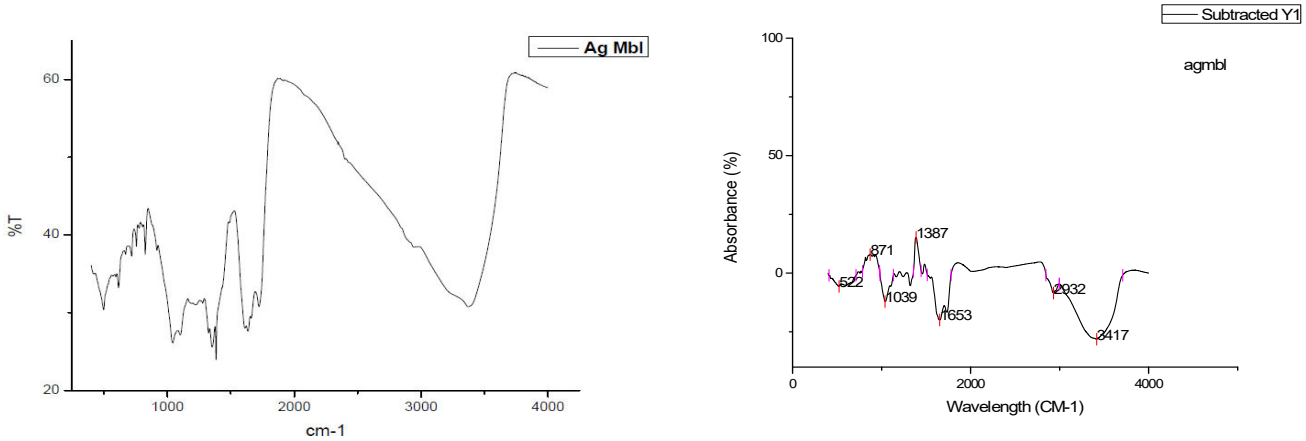

Figure. 4
FT-IR spectrum of silver nanoparticles

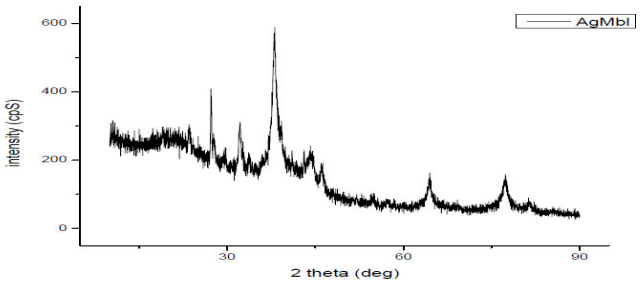

Figure. 5
XRD spectrum of Silver nanoparticles

xtract in the solution of AgNPs. Ag content in the solution was determined by ICP-OES equivalent to 1.45g which accounts for 72.5% of total amount of nanoparticles. Hence, it confirms the formation of high yield of silver nanoparticles.

Anti-diabetic Activity

Alpha-amylase is the main enzyme responsible for breakdown of starch and carbohydrates into sugars. The sugars enter into blood and increase the blood glucose level. This increase in blood glucose level is commonly known as diabetes. The inhibitory effect of this enzyme has strong effect on diabetes. The inhibitory effect on enzyme is produced by different agents. Here the inhibitory effect of Mulberry leaf extract, synthe

Concentration (µl)	Control %	Lagerstroemia leaf %	Silver nanoparticles %
20	0	56.18	77
40	0	63.14	81
60	0	68.01	87

Table. 1
Inhibition percentage (%) versus different concentration of test samples

sized silver nanoparticles was studied on enzyme. It was observed that silver nanoparticles showed strong inhibition i.e. the levels of enzymes are decreased, which are accountable for catalyzing the hydrolysis of complex carbohydrates and increased the utilisation rate of glucose than leaf extract. It was also observed that inhibition increased with increase in concentration until it reaches maximum. The percentage of inhibition of Mulberry leaf extract and silver nanoparticles is given (table. 1). The results obtained are in agreement with previous studies [51-53].

Antimicrobial Activity

Antimicrobial activity of Mulberry leaf extract, silver nanoparticles and silver nitrate (standard) was carried out against the pathogens such as Escherichia coli, Staphylococcus and Bacillus cereus. It was found that Silver nanoparticles show strong zone of inhibition against all pathogens

Samples	Zone of inhibition by well diffusion assay		
	E.coli ATCC 10536	Staphylococcus ATCC 11632	Bacillus cereus ATCC 14579
Silver standard	16mm	18mm	15mm
Mulberry Leaf extract	14mm	16mm	No inhibition
Silver nanoparticles	19mm	27mm	23mm

Table. 2
Zone of Inhibition versus different concentrations of test samples against pathogens

used during study than plant extract, silver nitrate standard. The zone of inhibition of all test samples is given in the (table. 2). AgNPs show high antibacterial activity against bacteria in previous studies [54-55]. The phytochemicals which act as capping agents and stabilizing agent for synthesis of AgNPs are selective for bacterial strains changes. Conformational changes in the membrane structure of bacterial cell wall are thought to be generated by the action of AgNPs which increases the chances of permeability of membrane, and hence lead to bacterial cell death [56].

In vitro anticancer activity

MTT Assay and Cell Morphology

In this experiment, the MTT assay was used to compute the anticancer capability of AgNPs on breast cancer cell line (MCF-7). From the study it was witnessed that the cytotoxicity against breast cancer cell line increases with increasing concentration of AgNPs. The IC50 of AgNPs was found at 92µg/ml against the MCF-7 cancer cell lines. It was revealed that 50% inhibition of cells was observed compared to untreated control. The proliferation of MCF-7 cancer cell line subjected to AgNPs was considerably inhibited in a dose-dependent manner as shown in (fig.5). The inspection of cytotoxic effect of synthesized AgNPs on cancer cells was done by checking

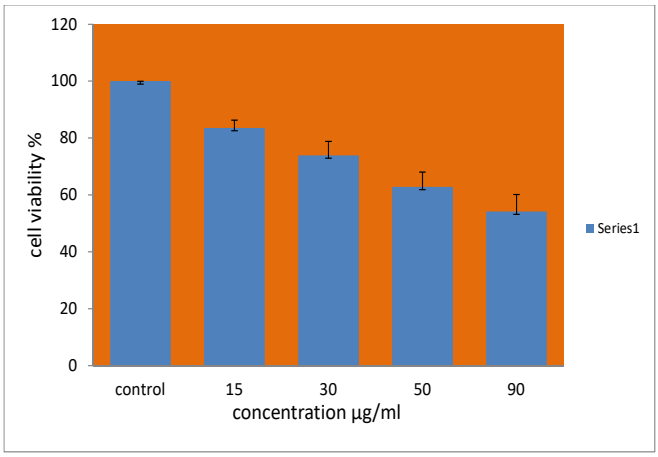

Figure.6
Cell Viability % versus concentration µg/ml of test sample

the morphology of all the cells under an optical microscope. It was established that the morphological evaluation of AgNPs treated cancer cells show apparent structural changes such as change in cells membrane surface, cell contraction and inhibition of cell growth. Therefore, validating that apoptosis has been induced in AgNPs treated MCF-7 cancer cells [57].

Catalytic Activity

The reduction of 4-nitrophenol (4- NP), 2-nitrophenol (2-NP) and dyes such as congo red, methylene blue was studied using NaBH4 in the presence of synthesized AgNPs using Mulberry (Morus) plant leaves at room temperature and monitored by UV-Visible spectroscopy [58-59]. The reduction of 4-NP, 2-nitrophenol, congo red, methylene blue using aqueous NaBH4 is thermodynamically favourable but due to large energy barrier feasibility of reaction decreases. To overcome the energy barrier metal nanoparticles were used which help fast transfer of electrons from the donor – to acceptor thus catalysing the reaction and hence act as catalysts. Absorption peaks have been observed for pure 4-NP, 2-nitrophenol, congo red, methylene blue at 317, 355nm, 500nm, 600nm. Upon addition of NABH4 change in colour and shift in absorption peaks to 400nm, 420nm 550nm, 650nm appeared which indicated the intermediate formation. No further change was observed until the addition silver nanoparticles. The addition of silver nanoparticles completely changed the colour i.e. coloured to colourless and

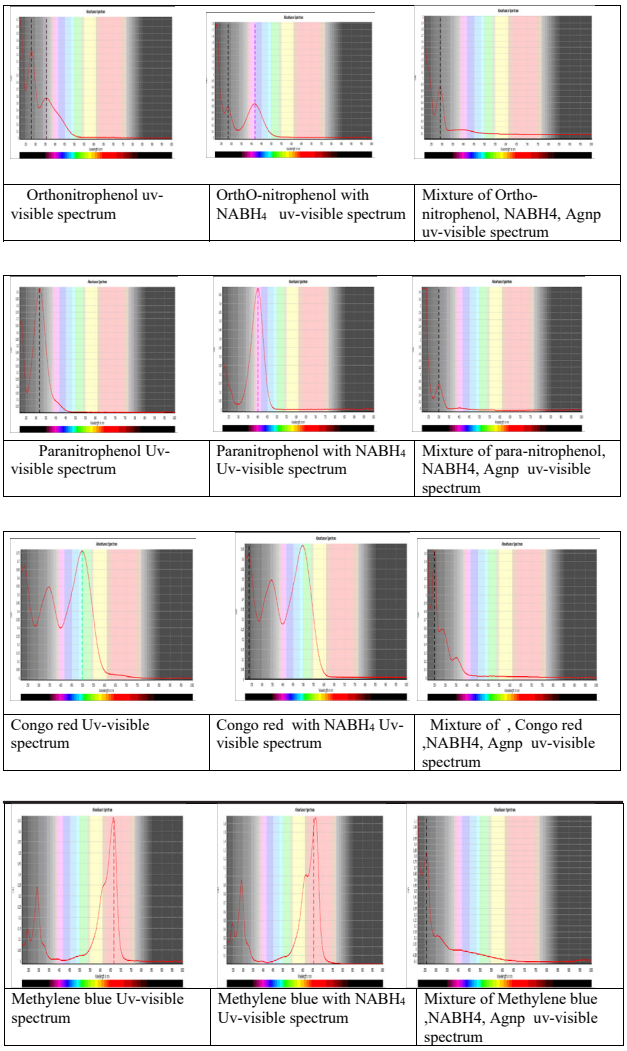

Figure .7

further shifted the absorption peaks to 292nm, 290nm, 250nm, 255nm respectively. Thus, it was concluded that silver nanoparticles act as catalysts. The results obtained are given below.

Antioxidant Activity

DPPH is a stable free radical scavenger and shows a characteristic absorption at 517 nm wavelength and after reduction colour changes from violet to yellow [60]. The antioxidants react with DPPH and convert it to 1,1- diphenyl-2-picryl hydrazine with decolourisation scavenging DPPH due to donation of hydrogen atom to stable the DPPH molecule [61-62]. The silver nanoparticles showed higher free radical scavenging power than plant extract. The free radical scavenging activity of AgNPs at higher concentration (60µl) was found higher

than plant extract (Table.3). This is due to the efficient oxidation of AgNPs. The AgNPs quenched the activity of DPPH by donating silver's electrons.

Concentration (µl)	Control %	Lagerstroemia leaf %	Silver nanoparticles %
20	0	53.80	75
40	0	61.95	80
60	0	70.10	85

Table. 3
Scavinging (%) versus different concentration of test samples

Conclusion

Metal nanoparticles are gaining importance in different fields of science and technology because of their peculiar properties. We have synthesized the silver nanoparticles through green synthetic method using Mulberry plant leaves because of its simplicity, cost-effectiveness and eco-friendliness. The synthesized silver nanoparticles were characterized by UV-VIS SPECTROPHOTOMETER, DLS, SEM, FT-IR, XRD etc. to determine the various parameters such as size, shape, stability, composition and nature of nanoparticles. The silver nanoparticles were studied for various activities like antimicrobial activity, antioxidant activity, antidiabetic activity, catalytic activity and cytotoxic activity by different assays and the results obtained showed strong activities.

Acknowledgement

We are thank to Director Defense, Food, Research, Laboratory, Sidhartha Nagar, Mysore, Karnataka, India for providing the lab facilities to carry out the work in the nano science project under the able guidance of DR. FARHATH KHANUM (HOD OF Nutrition , Biochemistry and Toxocology).

References

Abideen S, Sankar VM. In vitro screening of anti-diabetic and antimicrobial activity against green synthesized AgNO3 using seaweeds. Nanomed Nanotech 2015;S6. https://doi.org/10.4172/2157-7439.S6-001

Ahmed, S., Saifullah, Ahmad, M., Swami, B. L., and Ikram, S. (2016). Green synthesis of silver nanoparticles using Azadirachta indica aqueous leaf extract. J. Rad. Res. Appl. Sci. 9, 1-7. https://doi.org/10.1016/j.jrras.2015.06.006

Ankamwar, B., Damle, C., Ahmad, A., and Sastry, M. (2005). Biosynthesis of gold and silver nanoparticles using Emblica officinalis fruit extract, their phase transfer and transmetallation in an organic solution. J. Nanosci. Nanotechnol. 5, 1665-1671. https://doi.org/10.1166/jnn.2005.184 PMid:16245525

Anna, Z. et al. Preparation of silver nanoparticles with controlled particle size. Procedia Chem. 1, 1560-1566. (2009). https://doi.org/10.1016/j.proche.2009.11.004

Asthana A, et al. Silver Nanoparticle Entrapped Calcium-Alginate Beads for Fe (II) Removal via Adsorption. in Macromolecular Symposia: Wiley Online Library; 2016. https://doi.org/10.1002/masy.201650045

B. Kumar, K. Smita, et al., in: S. Ranjan, et al. (Eds.), Nanoscience in Food and Agriculture 2, Sustainable Agriculture Reviews, Volume 2, chapter 7 Springer International Publishing, Switzerland, 2016, pp. 235-252. chapter 7 https://doi.org/10.1007/978-3-319-39306-3_7

Baker. S, Rakshith D, Kavitha KS, Santosh P, Kavitha HU, Rao Y, et al. Plants: emerging as nanofactories towards facile route in synthesis. BioImpacts Nanopart. 2013;3(3):111-7.

Bar H, et al. Green synthesis of silver nanoparticles using seed extract of Jatropha

curcas. Colloids Surf A Physicochem Eng Asp. 2009;348(1-3):212-6. https://doi.org/10.1016/j.colsurfa.2009.07.021

Basavegowda N, Mishra K, Thombal RS, Kaliraj K, Lee YR. Sonochemical green synthesis of yttrium oxide (Y2O3) nanoparticles as a novel heterogeneous catalyst for the construction of biologically interesting 1, 3-thiazoli

Borase, H. P., Patil, C. D., Salunkhe, R. B., Suryawanshi, R. K., Salunke, B. K., and Patil, S. V. (2014). Transformation of aromatic dyes using green synthesized silver nanoparticles. Bioprocess Biosyst. Eng. 37, 1695-1705. https://doi.org/10.1007/s00449-014-1142-4 PMid:24525834

C. Dipankar, S. Murugan, Colloids Surf. B 98 (2012) 112-119. https://doi.org/10.1016/j.colsurfb.2012.04.006 PMid:22705935

Chen, H., Roco, M. C., Li, X. & Lin, Y. Trends in nanotechnology patents. Nat. Nanotechnol. 3, 123-125. (2008). https://doi.org/10.1038/nnano.2008.51 PMid:18654475

D. Jain, H. Kumar Daima, S. Kachhwaha, and S. L. Kothari, "Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluation of their anti microbial activities," Digest Journal of Nanomaterials and Biostructures, vol. 4, no. 3, pp. 557-563, 2009.

Das SK, et al. Silver-nano biohybride material: synthesis, characterization and application in water purification. Bioresour Technol. 2012;124:495-9. https://doi.org/10.1016/j.biortech.2012.08.071 PMid:23021961

Dhand, V., Soumya, L., Bharadwaj, S., Chakra, S., Bhatt, D., and Sreedhar, B. (2016). Green synthesis of silver nanoparticles using Coffea arabica seed extract and its antibacterial activity. Mater. Sci. Eng. C. Mater. Biol. Appl. 58, 36-43. https://doi.org/10.1016/j.msec.2015.08.018 PMid:26478284

Donda MR, Kudle KR, Alwala J, Miryala A, Sreedhar B, Rudra MP. Synthesis of silver nanoparticles using extracts of Securinegaleucopyrus and evaluation of its antibacterial activity. IJCST. 2013;7:1-8.

Ejaz K, Sadia H, Zia G, Nazir S, Raza A, Ali S, et al. Biofilm reduction, cell proliferation, anthelmintic and cytotoxicity effect of green synthesised silver nanoparticle using Artemisia vulgaris extract. IET Nanobiotechnol. 2017;12(1):71-7. https://doi.org/10.1049/iet-nbt.2017.0096 PMCid:PMC8676192

El-Naggar, N. E. A., Hussein, M. H., & El-Sawah, A. A. (2017). Bio-fabrication of silver nanoparticles by phycocyanin, characterization, in vitro anticancer activity against breast cancer cell line and in vivo cytotxicity. Scientific reports, 7(1), 1-20. https://doi.org/10.1038/s41598-017-11121-3 PMid:28883419 PMCid:PMC5589729

G. Babu, C. Arulvasu, D. Prabhu, R. Jegadeesh, R. Manikandan, Mater. Lett. 122 (2014) 98-102 https://doi.org/10.1016/j.matlet.2014.02.003

Gao, X., Yourick, J. J., Topping, V. D., Black, T., Olejnik, N., Keltner, Z., et al. (2014). Toxicogenomic study in rat thymus of F1 generation offspring following maternal exposure to silver ion. Toxicology Reports. http://dx.doi.org/10.1016/j.toxrep.2014.12.008

H. Y. Lin and C.-C. Chou, "Antioxidative activities of watersoluble disaccharide chitosan derivatives," Food Research International, vol. 37, no. 9, pp. 883-889, 2004. https://doi.org/10.1016/j.foodres.2004.04.007

He Y, et al. Green synthesis of silver nanoparticles by Chrysanthemum morifolium Ramat. extract and their application in clinical ultrasound gel. Int J Nanomedicine. 2013;8:1809. https://doi.org/10.2147/IJN.S43289 PMid:23687447 PMCid:PMC3653761

Iravani, S., Korbekandi, H., Mirmohammadi, S. V. & Zolfaghari, B. Synthesis of silver nanoparticles:chemical, physical and biological methods. Res. Pharm. Sci. 9, 385-406.

K. Kuroda, T. Ishida, and M. Haruta, "Reduction of 4-nitrophenol to 4-aminophenol over Au nanoparticles deposited on PMMA," Journal of Molecular Catalysis A: Chemical, vol. 298, no. 1-2, pp. 7-11, 2009. https://doi.org/10.1016/j.molcata.2008.09.009

Kanipandian N, Kannan S, Ramesh R, Subramanian P, Thirumurugan R. Characterization, antioxidant and cytotoxicity evaluation of green synthesized silver nanoparticles using Cleistanthus collinus extract as surface modifier. Mater Res Bull 2014;49:494-502 https://doi.org/10.1016/j.materresbull.2013.09.016

Kholoud, M. M. et al. Synthesis and applications of silver nanoparticles. Arab. J. Chem. 3, 135-140. (2010). https://doi.org/10.1016/j.arabjc.2010.04.008

Krishnaraj C, Jagan EG, Rajasekar S, Selvakumar P, Kalaichelvan PT, Mohan N. Synthesis of silver nanoparticles using Acalyphaindica leaf extracts and its antibacterial activity against water-borne pathogens. Colloids Surf B. 2010, 1;76(1):50-60. https://doi.org/10.1016/j.colsurfb.2009.10.008 PMid:19896347

Krishnaraj, C., Ramachandran, R., Mohan, K., and Kalaichelvan, P. T. (2012). Optimization for rapid synthesis of silver nanoparticles and its effect on phytopathogenic fungi. Spectrochim. Acta A Mol. Biomol. Spectrosc. 93, 95-99. https://doi.org/10.1016/j.saa.2012.03.002 PMid:22465774

Kumar V.G, et al. Facile green synthesis of gold nanoparticles using leaf extract of antidiabetic potent Cassia auriculata. Colloids Surf B: Biointerfaces. 2011; 87(1):159-63. https://doi.org/10.1016/j.colsurfb.2011.05.016 PMid:21640563

Lee, H., Chou, K. S. & Huang, K. C. Inkjet printing of nanosized silver colloids. Nanotechnology 16, 2436-2441 (2005). https://doi.org/10.1088/0957-4484/16/10/074 PMid:20818031

Lin S, et al. Silver nanoparticle-alginate composite beads for point-of-use drinking water disinfection. Water Res. 2013;47(12):3959-65. https://doi.org/10.1016/j.watres.2012.09.005 PMid:23036278

Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, Taliansky ME, et al. Green nanotechnologies: synthesis of metal nanoparticles using plants. Acta Nat. 2014;6:1-20. https://doi.org/10.32607/20758251-2014-6-1-35-44

Malik CP, Singh MB. A text manual plant enzymology and histoenzymology. New Delhi: NavinShandara; 1980. p. 66-71.

Molyneux P. The use of the stable free radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity. Songklanakarin J Sci Technol 2004;26 (2):211-9.

N. Pradhan, A. Pal, and T. Pal, "Silver nanoparticle catalyzed reduction of aromatic nitro compounds," Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 196, no. 2-3, pp. 247-257, 2002. https://doi.org/10.1016/S0927-7757(01)01040-8

Nakhjavani, M., Mohsen Sarafraz, M., Nikkhah, V., Shoja, S., and Sarafraz, M. (2017). Green synthesis of silver nanoparticles using green tea leaves: experimental study on the morphological, rheological and antibacterial behaviour. Heat Mass Transfer 53, 3201-3209. https://doi.org/10.1007/s00231-017-2065-9

Otunola GA, Afolayan AJ, Ajayi EO, Odeyemi SW. Characterization, antibacterial and antioxidant properties of silve nanoparticles synthesized from aqueous extracts of Allium sativum, Zingiber officinale, and Capsicum frutescens. Pharmacogn Mag. 2017;13(2):201. https://doi.org/10.4103/pm.pm_430_16 PMid:28808381 PMCid:P-MC5538155

Oves, M., Aslam, M., Rauf, M. A., Qayyum, S., Qari, H. A., Khan, M. S., et al. (2018). Antimicrobial and anticancer activities of silver nanoparticles synthesized from the root hair extract of Phoenix dactylifera. Mater. Sci. Eng. C Mater. Biol. Appl. 89, 429-443 https://doi.org/10.1016/j.msec.2018.03.035 PMid:29752116

P. Dibrov, J. Dzioba, K.K. Gosink, C.C. Hase, Antimicrob. Agents Chemother. 46 (2002) 2668-2670. https://doi.org/10.1128/AAC.46.8.2668-2670.2002 PMid:12121953 PMCid:P-MC127333

Patra JK, Baek K-H. Antibacterial activity and synergistic antibacterial potential of biosynthesized silver nanoparticles against foodborne pathogenic bacteria along with its anticandidal and antioxidant effects. Frontiers in microbiology. 2017; 8:167. https://doi.org/10.3389/fmicb.2017.00167 PMid:28261161 PMCid:P-MC5309230

Pohlit AM, Rezende AR, Baldin ELL, Lopes NP, de Andrade Neto VF. Plant extracts, isolated phytochemicals, and plant derived agents which are lethal to arthropod vectors of human tropical diseases - a review. Planta Med. 2011;77(6):618-30. https://doi.org/10.1055/s-0030-1270949 PMid:21432748

Prabhu N, Raj DT, Yamuna GK, Ayisha SS, Puspha J, Innocent D. DIG J NANOMATER BIOS (DJNB). 5 (2010).

Prakash P, et al. Green synthesis of silver nanoparticles from leaf extract of Mimusops elengi, Linn. for enhanced antibacterial activity against multi drug resistant clinical isolates. Colloids Surf B: Biointerfaces. 2013;108:255 -9. https://doi.org/10.1016/j.colsurfb.2013.03.017 PMid:23563291

Qayyum, S., Oves, M., and Khan, A. U. (2017). Obliteration of bacterial growth and biofilm through ROS generation by facilely synthesized green silver nanoparticles. PLoS One 12:e0181363. https://doi.org/10.1371/journal.pone.0181363 PMid:28771501 PMCid:PMC5542591

Rai, M. et al. Broad-spectrum bioactivities of silver nanoparticles: the emerging trends and future prospects. Appl. Microbiol. Biotechnol. 98, 1951-1961 (2014). https://doi.org/10.1007/s00253-013-5473-x PMid:24407450 PMCid:PMC7080016

Rajaram K, Aiswarya DC, Sureshkumar P. Green synthesis of silver nanoparticle using Tephrosia tinctoria and its anti-diabetic activity. Mater Lett 2015;138:251-4. https://doi.org/10.1016/j.matlet.2014.10.017

Sathishkumar M, et al. Cinnamon zeylanicum bark extract and powder mediated green synthesis of nano-crystalline silver particles and its bactericidal activity. Colloids Surf B: Biointerfaces. 2009;73(2):332 -8. https://doi.org/10.1016/j.colsurfb.2009.06.005 PMid:19576733

Scholes, G. D. Controlling the optical properties of inorganic nanoparticles. Adv. Funct. Mater. 18, 1157-1172.(2008). https://doi.org/10.1002/adfm.200800151

Sengottaiyan A, Aravinthan A, Sudhakar C, Selvam K, Srinivasan P, Govarthanan M, Manoharan K, Selvankumar T. Synthesis and characterization of Solanum nigrum mediated silver nanoparticles and its protective effect on alloxan-induced diabetic rats. J Nanostruct Chem 2016;6 (1):41-8. https://doi.org/10.1007/s40097-015-0178-6

Singh, J. et al. 'Green' synthesis of metals and their oxide nanoparticles: applications for environmental remediation. J. Nanobiotechnol. 16, 1-24. (2018). https://doi.org/10.1186/s12951-018-0408-4 PMid:30373622 PMCid:PMC6206834

Smetana, A. B., Klabunde, K. J. & Sorensen, C. M. Synthesis of spherical silver nanoparticles by digestive ripening, stabilization with various agents and their 3-D and 2-D superlattice formation. J. Colloid Interface Sci. 284, 521-526. (2005). https://doi.org/10.1016/j.jcis.2004.10.038 PMid:15780291

Suman T, et al. Biosynthesis, characterization and cytotoxic effect of plant mediated silver nanoparticles using Morinda citrifolia root extract. Colloids Surf B: Biointerfaces. 2013;106:74 -8. https://doi.org/10.1016/j.colsurfb.2013.01.037 PMid:23434694

Susarrey-Arce, A. et al. Inception and trapping of ZnO nanoparticles within desilicated mordenite and ZSM-5 zeolites.

Part. Part. Syst. Char. 27, 100-111. (2011). https://doi.org/10.1002/ppsc.201000027

Tippayawat, P., Phromviyo, N., Boueroy, P., and Chompoosor, A. (2016). Green synthesis of silver nanoparticles in Aloe vera plant extract prepared by a hydrothermal method and their synergistic antibacterial activity. PeerJ 4:e2589. https://doi.org/10.7717/peerj.2589 PMid:27781173 PMCid:PMC5075710

Toisawa, K., Hayashi, Y. & Takizawa, H. Synthesis of highly concentrated Ag nanoparticles in a heterogeneous solid-liquid system under ultrasonic irradiation. Mater. Trans. 51, 1764-1768. (2010). https://doi.org/10.2320/matertrans.MJ201005

Vankar, P. S., and Shukla, D. (2012). Biosynthesis of silver nanoparticles using lemon leaves extract and its application for antimicrobial finish on fabric. Appl. Nanosci. 2, 163-168. https://doi.org/10.1007/s13204-011-0051-y

Vigneshwaran N, et al. Functional finishing of cotton fabrics using silver nanoparticles. J Nanosci Nanotechnol. 2007a;7(6):1893 -7. https://doi.org/10.1166/jnn.2007.737 PMid:17654961

Wakuda, D., Kim, K. S. & Suganuma, K. Room temperature sintering of Ag nanoparticles by drying solvent. Scripta Mater. 59, 649-652. https://doi.org/10.1016/j.scriptamat.2008.05.028 (2008). 10 Vol:. (1234567890) Scientific Reports | (2020) 10:12805 | www.nature.com/scientificreports/ https://doi.org/10.1038/s41598-020-69606-7 PMid:32732959 PMCid:PMC7393152

Yayama, K., Konishi, K., Ohta, A., Takano, M., Ohtani, R., Itoh, N., & Okamoto, H. (1993). Elevation of plasma angiotensinogen in rats with experimentally induced nephrosis. Nephron, 63(1), 89-93.KS, U. S., Govindaraju, K., Prabhu, D., Arulvasu, C., Karthick, V., & Changmai, N. (2016). Anti-proliferative effect of biogenic gold nanoparticles against breast cancer cell lines (MDA-MB-231 & MCF-7). Applied Surface Science, 371, 415-424. https://doi.org/10.1159/000187148 PMid:8446257

Yilmaz, A. & Yilmaz, M. Bimetallic core-shell nanoparticles of gold and silver via bioinspired polydopamine layer as surfaceenhanced Raman spectroscopy (SERS) platform. Nanomaterials 10, 688. (2020). https://doi.org/10.3390/nano10040688 PMid:32260586 PMCid:PMC7221921

Zia G, Sadia H, Nazir S, Ejaz K, Ali S, Iqbal T, et al. In vitro studies on cytotoxic, DNA protecting, antibiofilm and antibacterial effects of Biogenic silver nanoparticles prepared with Bergenia ciliata rhizome extract. Curr Pharm Biotechnol. 2018;19(1):68-78. https://doi.org/10.2174/1389201019666180417160049 PMid:29667550