

Surfactant Mediated Synthesis of Noble Metal Nanoparticles and Their Cytotoxic Effects on Breast Cancer Cells

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Kaur *et al.*: Noble Nanoparticles Cytotoxicity on Cancer Cells

The biomedical applications of the noble metal nanoparticles have been the field of interest, especially in cancer therapy. In this paper, the synthesis of spherical silver and gold nanoparticles and their apoptotic activity against breast cancer cells is reported. The chemicals reduction method is used to synthesize nanoparticles. Two different types of surfactants i.e., citrate and polyvinylpyrrolidone were used as a reducing and capping agent. The synthesized nanoparticles have been characterized using X-ray diffraction, ultraviolet-visible absorption spectroscopy, dynamic light scattering, zeta potential and transmission electron microscopy. The synthesized nanoparticles have crystalline phase with average size in the range of 25-30 nm and possess negative surface charge. *In vitro* studies of nanoparticles against breast cancer cells (MCF-7), were performed. The results show the significant cytotoxicity of nanoparticles against the cancer cell line and found to be mediated by deoxyribonucleic acid damage.

Key words: Breast cancer cell line (MCF-7), deoxyribonucleic acid damage, metal nanoparticles, poly vinyl pyrrolidone, silver nanoparticles, trisodium citrate

Cancer is the largest cause of death worldwide, posing economic and quality-of-life challenges at all levels of society and medical treatment. Chemotherapy is preferable than radiotherapy and surgery in the treatment of cancer because it assures that anticancer medications such as vinblastine, doxorubicin, taxol and cisplatin, among others, reach all disease sites, including micrometastatic lesions^[1,2]. Currently, there are two primary issues with the systematic delivery of cytotoxic drugs during chemotherapy. Firstly, the patient's intrinsic or acquired multidrug resistance and secondly, the dose-limiting toxicity against healthy tissues. In this regard, nanomaterials has become more widely recognized as potentially useful diagnostic and therapeutic tools^[3-5]. Recent advances in synthesis and the potential to rationally modify silver and gold nanoparticle features such as physico-chemical and biological qualities have opened up new avenues for nano-medicine applications^[6,7]. The experimental conditions such as reactants, pH, temperature, order of mixing of reactants, presence of nucleophilic and

electrophilic reagents, nature of stabilizers and even the pace of addition of reducing agents are crucial parameters^[8-10]. These variables influence the advanced nanomaterials size, morphology, stability, colour and physicochemical properties of nanoparticles^[11]. To prevent aggregation in the synthesis and manufacture of metal nanoparticles, natural and synthetic ligands or polymers are commonly utilized as protective/capping agents^[12,13]. The choice of a suitable reducing agent is also critical, since the size, shape and particle size distribution are all influenced by the reducing agent's nature. The introduction of a reducing agent causes the metal precursor to be reduced^[14].

Metal nanoparticles of noble metals, such as silver, gold are particularly well investigated due to their

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applications in surface enhanced raman scattering and their outstanding properties such as high conductivity, catalytic and antibacterial effect and applications in electronics, catalysis, bio-labeling and other fields^[15-18]. The resonant oscillation of their free electrons in the presence of light causes noble nanomaterials to have substantial optical field enhancements. Noble metal nanoparticles are widely used in optics, imaging, sensing, cosmetics, cancer therapy and medication administration because of their unique features^[19-21]. Metal nanoparticles can be synthesised under simple and moderate conditions. Typical reducing agents including sodium borohydride, hydrazine, sodium citrate, thiols, amino acids and polyols are utilized in the presence of a stabilising layer like Cetyltrimethylammonium Bromide (CTAB), Polyvinyl Alcohol (PVA), cyclodextrin, poly (methylhydrosiloxane) or Polyvinylpyrrolidone (PVP)^[13,14,22-26]. PVP is a type of polymer that is both environmentally friendly and hydrophilic. The use of polymers such as PVP to cap nanoparticles has been recognized as a promising strategy for creating nanoparticles with customizable morphologies and optical properties.

In this study we attempt to synthesize silver and gold nanoparticles using trisodium citrate and PVP as capping agents. The comparative study has been investigated to study the effect of different surfactant capped nanoparticles against the breast cancer cells.

MATERIALS AND METHODS

Materials:

Silver Nitrate (AgNO_3), trisodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$), PVP, Sodium Borohydride (NaBH_4), Hydrochloroauric acid ($\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$) were obtained from Sigma Aldrich Chemicals.

Methods:

Tri-sodium citrate capped-silver nanoparticles and gold nanoparticles: For the synthesis of citrate capped silver nanoparticles (AgNPs_c), AgNO_3 (1 mM, 50 ml) was heated and stirred on a hot plate of magnetic stirrer. Then, 1 % tri sodium citrate solution was added drop wise to boiling solution with constant stirring. The absorbance of dark yellow colour indicates, that the formation of AgNPs_c . The tri-sodium citrate act as reducing as well as capping agent^[27].

For synthesis of citrate capped gold nanoparticles (AuNPs_c) in deionized water, a solution of Hydrochloroauric acid ($\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$) (1 mM, 50 ml) was prepared. Then, 50 ml $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ solution was heated and stirred continuously. When the solution started to boil, aqueous solution of tri-sodium citrate ($\text{C}_6\text{H}_5\text{Na}_3\text{O}_7$) (1 % w/w, 5 ml) was dropped into the boiling solution drop by drop. The solution turned red wine-colored, indicating the formation of AuNPs_c . The tri-sodium citrate acts as reducing and stabilization agent^[27,28]. Fig. 1 depicts a flow chart for the synthesis of AgNPs_c and AuNPs_c .

PVP capped-silver nanoparticles and gold nanoparticles: PVP capped silver nanoparticles ($\text{AgNPs}_{\text{PVP}}$) were synthesized by using NaBH_4 (2 mM, 30 ml) and PVP (0.3 %, 100 μl) which act as reducing and stabilizing agent respectively. An aqueous solution of AgNO_3 was added to ice cold NaBH_4 solution. As soon as the colour of solution changes PVP solution was added. Fig. 1 depicts a flow chart for the synthesis of $\text{AgNPs}_{\text{PVP}}$.

To synthesize $\text{AuNPs}_{\text{PVP}}$, aqueous $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ (1 mM, 50 ml) solution was used as starting solution. The solution was heated at 100° for 30 min to get Au^{3+} ions. These Au^{3+} ions were reduced by adding NaBH_4 (2 mM). To protect the solution against agglomeration, add 100 μl of 1 % PVP at the end of the reaction. Fig. 1 depicts a flow chart for the synthesis of $\text{AuNPs}_{\text{PVP}}$.

Characterization:

Ultraviolet (UV)-Visible absorption spectroscopy: To study optical absorption spectra the samples were scanned in the range of 300-700 nm using LABINDIA UV-3000⁺ spectrometer. The presence of plasmon resonance (SPR) peaked at 420 nm and 520 nm shows the formation of AgNPs and AuNPs respectively.

X-Ray Diffraction: X-Ray diffraction pattern AgNPs and AuNPs were recorded on X' Pert PRO X-Ray diffractometer using $\text{Cu K}\alpha$ (0.15406 nm) radiation. The film was deposited on clean glass slides by drop casting. The scanning speed set at $5^\circ/\text{min}$ and range was selected to $2\theta=35^\circ$ to 80° .

Transmission Electron Microscopy (TEM): The particle shape and size were analyzed by TEM. TEM (Hitachi H-7500, Japan) operating at voltage of 120 kV and equipped with charge-coupled

device camera is used for the ultra-structural determination of synthesized nanoparticles. This instrument has the high resolution of 0.36 nm with 40-120 kV operating voltage and can magnify object up to 600 000 times in high resolution mode. The particle shape and size were analyzed by TEM.

Dynamic light scattering and zeta potential:

The size distribution and zeta potential of AgNPs and AuNPs were studied using Malvern zetasizer (ZEN3600). Dynamic Light Scattering (DLS) was used to examine the particle size distribution of AgNPs_C, AgNPs_{PVP}, AuNPs_C and AgNPs_{PVP}. DLS is used to measure a wide variety of hydrodynamic sizes, ranges from nanometers to a few micrometres.

Cytotoxicity studies:

Cell culture: Breast cancer MCF-7 cells were maintained in continuous culture of Eagles MEM and maintained at 37°, in a humidified atmosphere of 5 % CO₂ supplemented with 10 % FBS. After every 48 h, media was replaced with fresh medium.

Confluent monolayer of MCF-7 cells were detached using trypsin (0.25 %)-ethylenediaminetetraacetic acid (0.02 % in PBS) by spinning at 200 ×g for 2 min followed by washing with serum free medium. Washed pellet were resuspended in 5 ml of complete media Eagle's MEM in T25 flask and incubated at 37° in 5 % CO₂ for further processing.

Cytotoxicity:

After the regular culturing of the cells, approximately 10 000 cells per well were plated into 96-well plate and cultured overnight in CO₂ incubator under humidified conditions. After 24 h cells were treated with various concentrations of AgNPs, AuNPs and standard chemotherapeutic drug palbociclib for different time intervals. After the respective treatment time intervals, cells were treated with 3-[4,5-dimethylthiazol-2-yl]-2,5 diphenyl tetrazolium bromide (MTT) and incubated for 4 h in the CO₂ incubator. Later Dimethyl Sulfoxide (DMSO) was added to dissolve the formazan crystals and absorbance was read at 532 nm in a plate reader for cytotoxicity assessment.

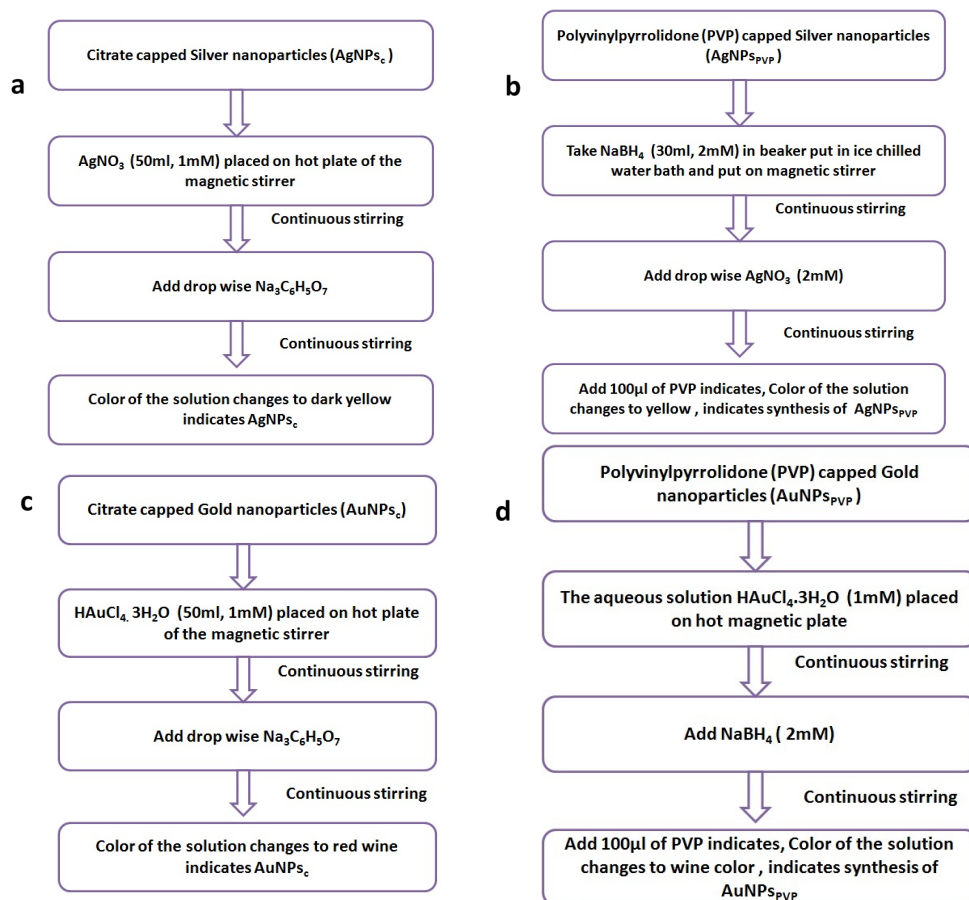


Fig. 1: Flowchart for synthesis of (a) AgNPs_C; (b) AgNPs_{PVP}; (c) AuNPs_C and (d) AuNPs_{PVP}

Structural changes by microscopy:

For studying the metallic nanoparticles-induced structural changes, the treated cells with various concentrations and for different time intervals, the cells were visualized for their morphology under the phase contrast microscope.

Apoptotic activity:

Fluorescence microscopy was performed to assess the AgNPs, AuNPs and palbociclib induced apoptotic activity. To perform these studies, treated the cells with metallic nanoparticles, further were treated with ethidium bromide and acridine orange to evaluate the extent of DNA damage and micronuclei formation.

RESULTS AND DISCUSSION

Fig. 2 shows the UV-visible absorption spectra of silver and gold nanoparticles. The typical SPR peak for spherical AgNPs occurs in the range of 400 nm to 450 nm and for AuNPs range 500-550 nm in the visible part of the electromagnetic spectrum. The absorption spectra shows the SPR peak of AgNPs_C, AuNPs_C, AgNPs_{PVP} and AuNPs_{PVP} at 420 nm, 525 nm, 431 nm and 520 nm respectively. It

can be observed from fig. 2 that SPR peaks of both AgNPs and AuNPs have different points for PVP and citrate capping agents. This is due to different interaction mechanism behaviour of surfactant and nanoparticles. The PVP cationic while citrate is anionic in nature. In the typical chemical reduction method, the tri-sodium citrate act as reducing as well as capping agents for AgNPs_C and AuNPs_C nanoparticles. The atoms are reduced throughout the reaction and subsequently nucleate in tiny clusters, which develop into particles. The precursor to reducing agent ratio, which ultimately governs the amount of atoms obtainable for the reaction, may be changed to control the size and structure of the nanoparticles^[27]. Through an electrostatic stabilization process, the anionic portion of citrate interacts with AgNPs/AuNPs and stabilizes them. PVP is a water-soluble polymer that is broadly utilized in the production of stable silver and gold nanoparticles *via* a steric stabilizing mechanism. PVP contains two extremely active sites for reacting with other molecules, one through the N atom and the other through the -CO atom^[29,30]. PVP functions as a stabilizing agent by interacting with the silver and gold surfaces through the N atom.

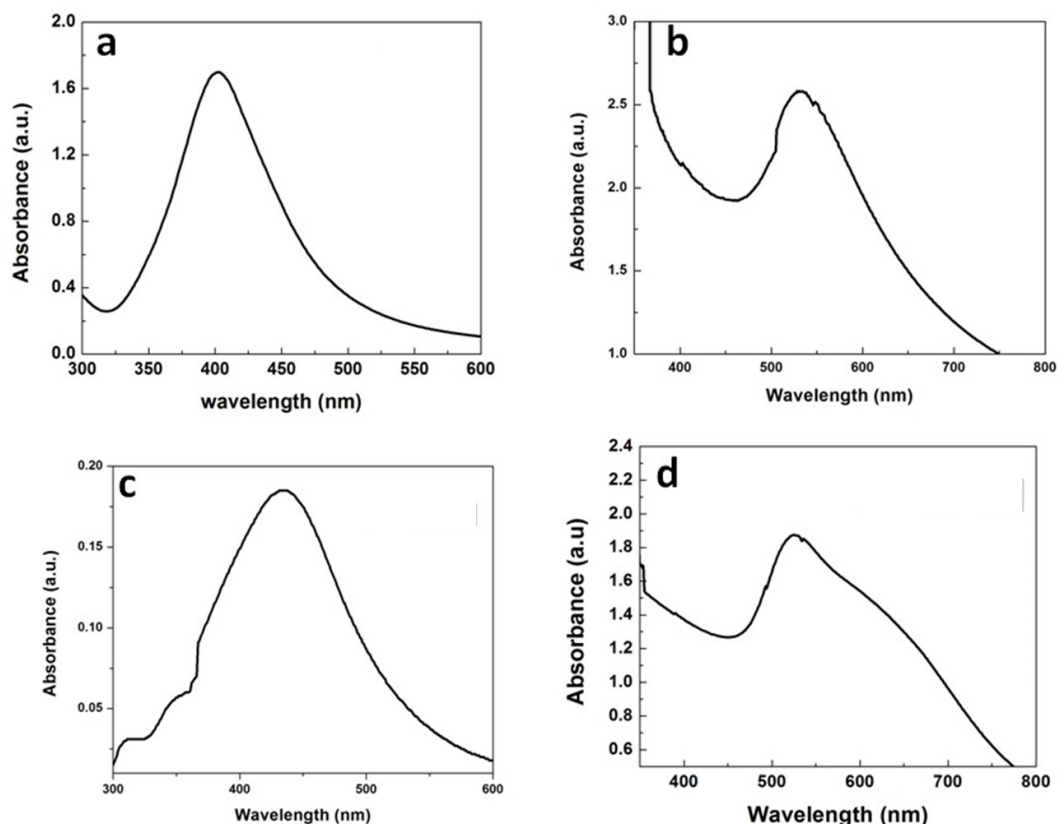


Fig. 2: The UV-Visible absorption spectra of (a) AgNPs_C; (b) AuNPs_C; (c) AgNPs_{PVP} and (d) AuNPs_{PVP} nanoparticles

XRD measurements were used to analyse the crystalline structure of produced AgNPs_C , AgNPs_{PVP} , AuNPs_C and AuNPs_{PVP} . The thin film of sample was prepared by dropcasting on a glass substrate and then diffraction pattern was taken. Fig. 3 shows the XRD pattern of AgNPs_C , AgNPs_{PVP} , AuNPs_C and AuNPs_{PVP} , respectively. The major peaks for AgNPs_C , AgNPs_{PVP} , AuNPs_C and AuNPs_{PVP} were found at 2θ values of 38° , 44.2° , 64.3° , 77.3° , 38.03° , 45.1° , 63.9° , 77.4° ; 37.9° , 44.4° , 64.3° , 77.4° and 38.1° , 45.2° , 64.4° , 77.2° respectively correspond to the (111), (200), (220) and (311) crystal planes of face centred cubic structure. These results are similar with standard values of JCPDS file no. 04-0783, 87-0717^[31,32]. The average crystalline size were calculated from Debye Scherer's formula.

$$D = k\lambda / (\beta \cos\theta)$$

Where k Debye Schere's constant, β full width half maxima (FWHM), θ diffraction angle and λ wavelength. The reflection line portion and average crystalline size values are given in Table 1.

Fig. 4 shows the size distribution of AgNPs_C ,

AgNPs_{PVP} , AuNPs_C and AuNPs_{PVP} . According to DLS data, synthesized AgNPs and AuNPs with various surfactants were poly-disperse in nature. The Polydispersity Index (PdI) is a measure of the aqueous sample's size distribution or degree of aggregation. Its value in zetasizer software varies from 0 to 1. The samples with a higher PdI value are more polydisperse in nature than those with a lower PdI value, while the samples with a lower PdI value are notably monodisperse. The hydrodynamic average size evaluated for AgNPs_C , AuNPs_C , AgNPs_{PVP} and AuNPs_{PVP} were 38 nm, 40 nm, 44 nm and 43 nm, respectively. It calculates the hydrodynamic radius of Brownian motion particles in aqueous solution by treating them as hard sphere.

Zeta potential gives the charge on the particles, hence Zeta-potential measurements were performed for AgNPs_C , AuNPs_C , AgNPs_{PVP} and AuNPs_{PVP} and shown in fig. 5. The zeta potential for AgNPs_C , AuNPs_C , AgNPs_{PVP} and AuNPs_{PVP} is -20.1 mV, -19.2 mV, -16.9 mV and -12.3 mV, respectively. The negative zeta potential values for the AgNPs_C , AgNPs_{PVP} , AuNPs_C and AuNPs_{PVP} dispersions indicate that the synthesized particles were quite stable for a long period of time.

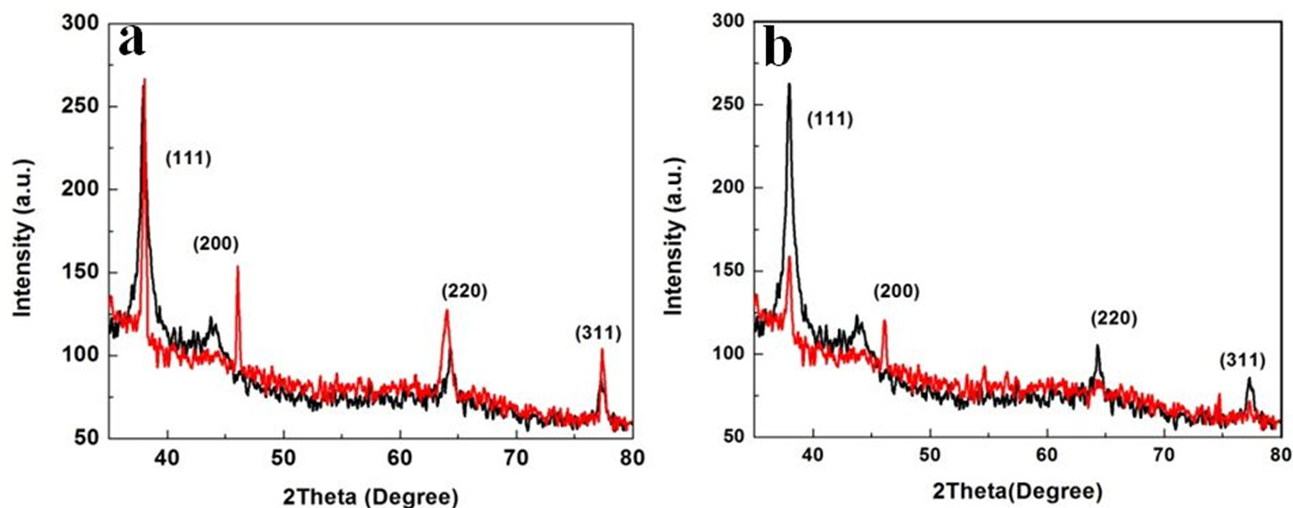


Fig. 3: XRD pattern of (a) AgNPs_C and AgNPs_{PVP} and (b) AuNPs_C and AuNPs_{PVP} recorded

TABLE 1: THE STRUCTURAL AND HYDRODYNAMICS PARAMETERS OF SYNTHESIZED NANOPARTICLES

Plane/ material	(111)	(200)	(220)	(311)	Average crystalline size	DLS	PdI	Zeta potential	TEM
AgNPs_{PVP}	38.03°	45.1°	63.9°	77.4°	~ 20 nm	44 nm	0.39	-16.9 mV	30 nm
AgNPs_C	38°	44.2°	64.3°	77.3°	~10 nm	38 nm	0.64	-20.1 mV	25 nm
AuNPs_C	37.9°	44.4°	64.3°	77.4°	~9 nm	40 nm	0.32	-19.2 mV	25 nm
AuNPs_{PVP}	38.1°	45.2°	64.4°	77.2°	~21 nm	43 nm	0.958	-12.3 mV	31 nm

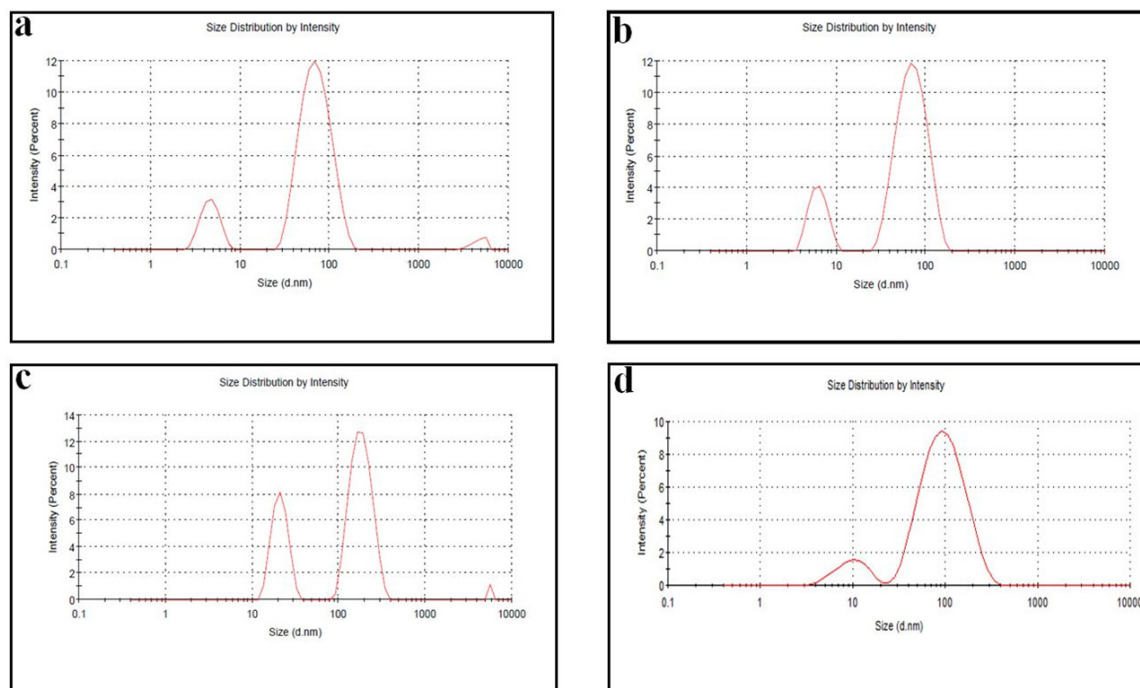


Fig. 4: The size distribution intensity for (a) AgNPs_C, (b) AgNPs_{PVP}, (c) AuNPs_C and (d) AuNPs_{PVP}

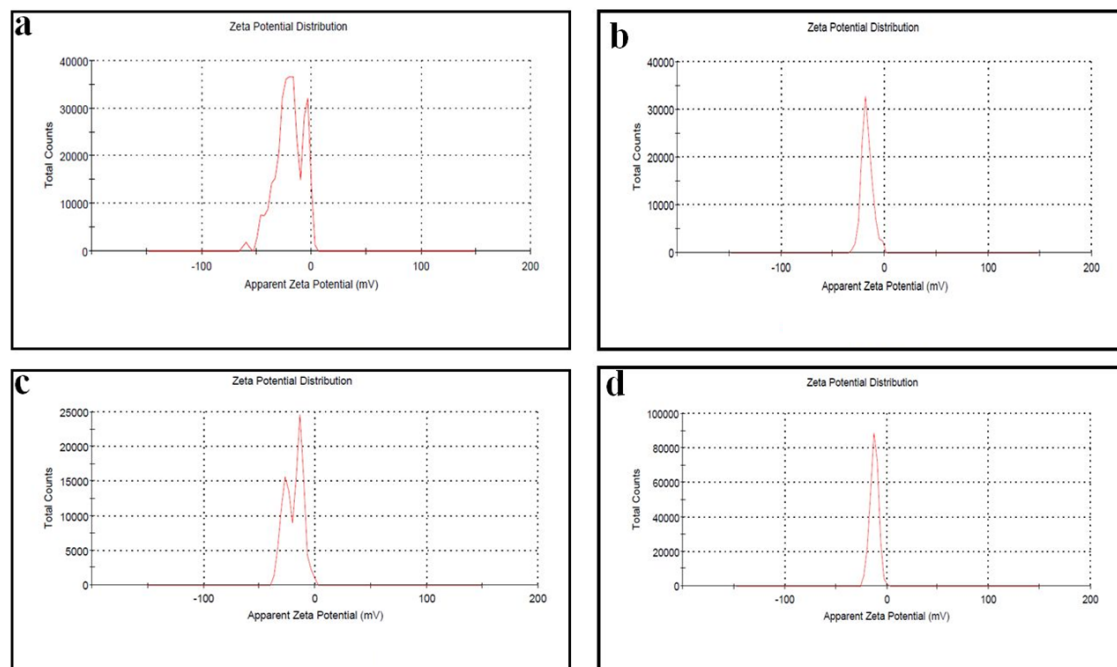


Fig. 5: Zeta potential of (a) AgNPs_C; (b) AgNPs_{PVP}; (c) AuNPs_C and (d) AuNPs_{PVP}

Fig. 6 shows the TEM image of AgNPs_C, AgNPs_{PVP}, AuNPs_C and AuNPs_{PVP}. TEM reveals that the particles were spherical in shape and found to be in the range of 20-35 nm. The average particles size of AgNPs_C, AgNPs_{PVP}, AuNPs_C and AuNPs_{PVP} were 25 nm, 30 nm, 25 nm and 31 nm respectively. The resulting particles are well-distributed and non-agglomerated. The size measured by TEM was

smaller than that obtained by DLS for the identical AgNPs_C, AgNPs_{PVP}, AuNPs_C and AuNPs_{PVP}. The DLS displays the wet and expanded hydrodynamic diameter of AgNPs_C, AgNPs_{PVP}, AuNPs_C and AuNPs_{PVP} suspension, but TEM reveals the dry and shrunk configuration of AgNPs_C, AgNPs_{PVP}, AuNPs_C and AuNPs_{PVP} [33].

The optical microscopy of the various nanoparticles treated for 48 h was performed and it shows that the treatment with AgNPs_C, AgNPs_{PVP}, AuNPs_C, AuNPs_{PVP} is uniform but over longer duration of 48 h the nanoparticles have formed aggregations. The non-aggregated finer respective nanoparticles also shows that these are uniformly spread and being uptaken by the MCF-7 cells. The cells which have uptaken the nanoparticles have shown the structural changes as compared to the normal/control cells where there is no treatment. This can also be seen as in the standard chemotherapeutic drug palbociclib where the cellular structural alterations are significant as compared to the normal cell morphology. To further evaluate the effect of these various nanoparticles on the cell viability MTT assay was performed. Fig. 7 shows the cell viability analysis using MTT assay of breast cancer cells upon treatment with various concentrations of the AgNPs_C, AgNPs_{PVP}, AuNPs_C, AuNPs_{PVP} and standard chemotherapeutic drug at 24 h and 48 h. MTT results shows that there was no significant effect on the cell viability at lower doses as compared to doses at or beyond 20 µl/well (fig. 7a and fig. 7b). However, the cells viability significantly reduced between the ranges 22 %-33 % respectively for the above nanoparticles (fig. 7a). The cells viability further reduced significantly in the dose range 20-40 µl/well with increasing duration (fig. 7b). The cellular viability reduction due to these nanoparticles is comparable to the standard chemotherapeutic drug up to the doses of 20 µl/well but at higher doses the drug palbociclib has significantly reduced further the cell viability as compared to the nanoparticles treated groups. It is also clear from the fig. 7a and fig. 7b that among both the silver nanoparticles, citrate has greater cytotoxic effects as compared to the PVP coated nanoparticles of either metallic nanoparticles. From the optical microscopy and MTT assay we could observe that the nanoparticles had cytotoxic effect on the breast cancer cells and comparable to the standard chemotherapeutic drug up to particular doses. It was also further evaluated to understand the effect of DNA damage, hence, the acridine orange and ethidium bromide studies were undertaken using fluorescence microscopy. It is known that the acridine orange has the ability to bind to the viable cells and ethidium binds to the DNA after damage to the cells. Fig. 8 shows

the fluorescence microscopic images of the DNA damage with various nanoparticles and palbociclib drug treatment. It is seen from these images that the nanoparticles and chemotherapeutic drug treated cells have bright red ethidium bromide staining as compared to the normal cells suggesting that these agents have DNA damaging effect in their cytotoxic behavior (fig. 8). Therefore, it is seen that the silver and gold nanoparticles synthesized from the chemical method using various agents results in the spherical nanoparticles with sizes in the range of 20-35 nm as seen from the TEM and DLS analysis shows strong cytotoxic effect through DNA damage as also seen in and comparable with the chemotherapeutic drug treatment. The nanoparticles in this size range are effectively and easily uptaken by various cell types as seen in many studies^[34]. These nanoparticles having citrate and PVP coatings on their surface have differential aggregation abilities once uptaken by the cells and hence reflect different cytotoxic properties as also seen in this study and compared with the standard chemotherapeutic drug. Therefore, it can be assumed that the gold and silver nanoparticles show potential as nanotherapeutic agents in cancer treatment.

In this study, colloidal silver and gold nanoparticles were synthesized and stabilized with PVP and trisodium citrate. The presence of SPR peaks confirms the formation of spherical nanoparticles in UV-visible absorption spectra. The DLS, TEM, XRD and Zeta potential reveals that the different surfactant nanoparticles morphology were spherical in shape, crystalline in nature, face centered cubic structure and highly stable due to negative zeta potential value. The effect of nanoparticles on the cellular morphology and cytotoxicity studies shows that these nanoparticles are uptaken by the cells and results in the cytotoxic effect and are comparable to the standard chemotherapeutic drug palbociclib. At higher dose of nanoparticles AgNPs_{PVP} show the higher cytotoxicity as compared to AgNPs_C, AuNPs_C, and AuNPs_{PVP}. Further, the cytotoxicity of these nanoparticles also leads to the DNA damage of the breast cancer cells which are also comparable to the chemotherapeutic drug thereby showing the potential as nanotherapeutic agents in cancer treatment.

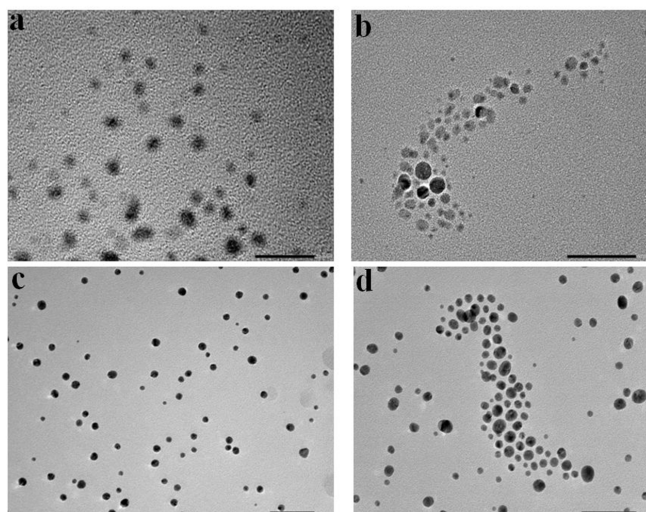


Fig. 6: The TEM micrographs of (a) AgNPs_C; (b) AgNPs_{PVP}; (c) AuNPs_C and (d) AuNPs_{PVP}

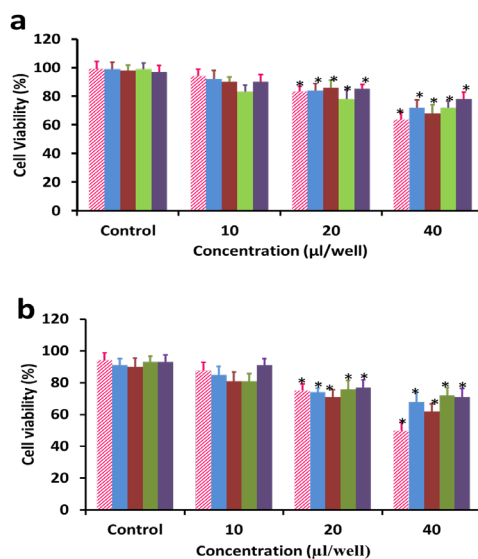


Fig. 7: Cell viability bar graph for MTT assay studies of different surfactant coated silver and gold nanoparticles on breast cancer cells (MCF-7) for 24 h (a) and 48 h (b); On the x-axis the concentration 10, 20 and 40 for palbociclib should be read as 10, 20 and 40 μM respectively

Note: (hatched bar): Palbociclib; (blue bar): AgNPs_C; (red bar): AgNPs_{PVP}; (green bar): AuNPs_C and (purple bar): AuNPs_{PVP}

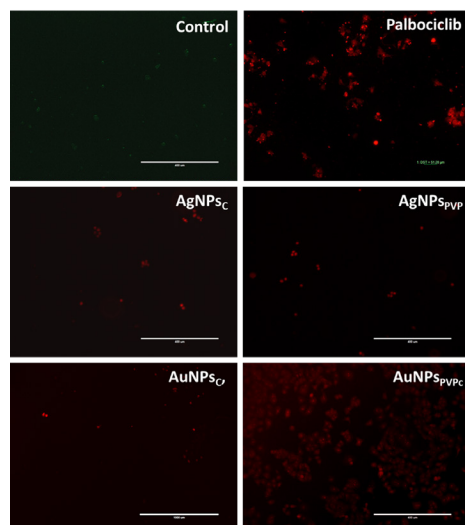


Fig. 8: DNA damage of the Breast cancer (MCF-7) cells changes using fluorescence microscopy (stained with ethidium bromide) at 48 h duration

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Author's contributions:

R. Kaur did the experimentation, data analysis and manuscript writing, A. Saini did data analysis and manuscript editing, data, experimentation, analysis and manuscript writing done by J. Singh. P. K. Avti did conceptualization, analysis and manuscript editing. Vivek Kumar did data analysis and manuscript editing. Rajesh Kumar did idea, conceptualization, analysis and manuscript editing.

Conflict of interests:

The authors declared no conflict of interests.

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