Review Paper

Green synthesis of metallic nanoparticles using leaf extract of Calotropis spp and their applications: A Review.

Abstract

Biosynthesis of metallic nanomaterials has become an important field of research. The synthesis of metallic nanomaterials using plant extracts is a single-step, simple, rapid, bottom-up green synthesis (Eco-friendly). The reducing agents involved include the various water-soluble secondary metabolites (Alkaloids, phenolic compounds, terpenoids, carbohydrates etc.) of the plant extracts. Diverse salts of metals of the transition metal series such as Gold (Au), Silver (Ag), Iron (Fe), Zinc (Zn) and Copper (Cu) etc, have been used in the synthesis. This review focused on the use of extracts of *Calotropis spp* in the synthesis of metallic nanoparticles. The methods of characterization and various applications of the synthesized nanoparticles are also discussed.

Keywords: Metallic nanoparticles, biosynthesis, green synthesis.

10 Introduction

This review focused on synthesis of metallic nanomaterials using plant extracts of *Calotropis spp*. The methods used in characterizing the nanomaterials are also considered. The emerging or potential applications of these nanomaterials in clinical diagnostics, therapy (Azzazy *et al*., 2012;

Chen *et al*., 2012; Daria *et al*., 2012; Fortina *et al*., 2007; Lagunho and Baptista, 2012; Sahoo *et al*., 2007; Salata *et al*., 2004; Seil and Webster, 2012;Wagner *et al*., 2006; Youns *et al*., 2011; zhang *et al*., 2008), photovoltaics (Yoon *et al*., 2010), food storage (Costa *et al*., 2011), textiles (Perelshtein *et al*., 2008) as well as in environmental technology (Li *et al*., 2008) is highlighted.

Nanomaterials could be synthesized using various physical and chemical methods (CaO, 2004; Sepeur, 2008) but, biosynthesis is more preferred because of its non-toxicity and environment-friendly, and could be used to produce large quantities of nanoparticles that are free of contamination with well defined size and morphology (Hutchinson, 2008).Plant extracts ability to reduce metal ions has been known since 1900' but, the nature of the reducing agents involved was not well understood (Mittal *et al*., 2013). Within the last 30 years, phytosynthesis of nanoparticles has attracted considerable attention (Ankanwar, 2010; Armendariz *et al*., 2004; Beattie and Haverkamp, 2011; Gran and Li, 2012; Gardea-Torresdey *et al*., 2003; Gericke and Pinches, 2006; Haverkamp and Marshall, 2009; Iravani, 2011; Kandasamy *et al*., 2012; Kumar and Yadav, 2009; Marshall *et al*., 2007; Park *et al*., 2011; Parsons *et al*., 2007).

When compared to whole plant, the use of plant extracts for synthesis of nanoparticles is simpler (Mittal *et al*., 2013). Plant extract-mediated synthesis is becoming a focus a attention (Ali *et al*., 2011; Ankamwar, 2010; Babu abd Prabu, 2011; Benerjee, 2011; Bankar *et al*., 2010; Bar *et al*., 2009; Baskaralingam *et al*., 2012; Castro *et al*., 2011; Chandran *et al*., 2006; Daisy and Sapriye, 2012; Dubey *et al*., 2009; Kaler *et al*., 2011; Kesharwani *et al*., 2009; Lee *et al*., 2011; Singh *et al*., 2010;Song *et al*., 2009). The synthesis processes using plant extracts are readily scalable and may be less expensive (Iravani, 2011) compared to microbial processes of synthesis (Dhillon *et al*., 2012; Li *et al*., 2011; Wangpipat *et al*., 2011; Sastry *et al*., 2003) and whole plants (Armrndariz *et al*., 2004; Beattie and Haverkamp, 2011; Haverkamp and Marshall, 2009; Kumar and Yadav, 2009; Marshall *et al*., 2007).

Plant extracts may act as reducing or stabilizing agent or both, in the synthesis of nanoparticles (Kumar and Yadav, 2009). The source of the plant extract is known to influence the characteristics of the nanoparticles synthesized (Kumar and Yadav, 2009). Plant extract-mediated synthesis of nanoparticles is a single-step process involving mixing of the aqueous extract of the plant with an aqueous solution of the metal salt of interest (Mittal *et al*., 2013). The reaction occurs at room temperature and is completed in a matter of minutes. Since there are various components of the extract involved in the bioreduction, the process tends to be relatively complex (Mittal *et al*., 2013).

Metallic nanoparticles are the most flexible of the nanoparticles due to the synthetic control of their shape, size, composition, structure, assembly and encapsulation, as well as tunability of their optical properties. Metallic nanoparticles have been used in vivo and in vitro in diagnostics (Vio Vet., 2017; Baptista *et al*., 2011; Azzazy and Mansoor, 2009; Radwan and Azzazy, 2009) and drug delivery (Ahmad *et al*., 2010; Adeyemi and Sulaiman, 2015). The wide application of metallic nanoparticles is due to their large surface area per unit mass, unique thermal, optical and electrical properties.

There are only two species of Calotropis (family: Asclepiadaceae) plant widely distributed across Africa, Asia and South America (Mascolo *et al*., 1988). The plant is erect, tall, large, branched and perennial with milky latex throughout. The different parts of the plant are used in traditional medicine for the treatment of painful muscular spasm, dysentery, fever, rheumatism, asthma and as an expectorant and purgative. A large quantity of latex can be easily collected from its green parts (Irvine, 1961). Local people use it successfully to combat some cutaneous fungal infections. The abundance of latex (containing alkaloids) in the green parts of the plant reinforces the idea that it produced and accumulated latex as a defence strategy against organisms such as virus, fungi and insects (Lahrsini *et al*., 1997). The presence of plant defence related proteins such as hevein, an alpha-amylase inhibitor has been described to occur in the latex secretion of other plants (Wititsuwannakul *et al*., 1998).

2.0 Characterization of nanoparticles of Calotropis spp

Nanoparticles are generally characterized by their size, shape, surface area and dispersity (Jiang *et al*., 2009). The characterization techniques employed for the metallic nanoparticles synthesized via the extracts of Calotropis ssp include ; Scanning electron microscopy (SEM), transmission electron microscopy (TEM), ultraviolet-visible (UV-Visible) spectroscopy, X-ray diffraction(XRD), Fourier transform infra-red spectroscopy (FTIR), dynamic light scattering (DLS) and SAED (Ratil kumar Das *et al*., 2012; Alkammash, 2017; Prevani and Gayathramma, 2015; Nipane *et al*., 2016).

UV-visible spectroscopy is a technique commonly used (Pal *et al*., 2007) where light of wavelength 300-800nm are used to characterize metallic nanoparticles of size 2-100nm (Feildheim and Foss, 2002). Absorption measurements in the wavelength ranges 400-450 (Hang and Yang, 2004) and 500-530nm (Shankar *et al*., 2004) have been used in characterizing silver and gold nanoparticles respectively.

The dynamic light scattering (DLS) have been used in characterizing the surface charge and size distribution of the particles suspended in a liquid (Jiang *et al*., 2009).

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are used for characterizing the morphology of nanoparticles (Shaffer *et al*., 2009). TEM has higher resolution (1000-fold) than SEM (Eppler *et al*., 2000). FTIR spectroscopy is used for characterizing the surface chemistry of nanoparticles (Chitrani *et al*., 2006) where functional groups like carbonyl, hydroxyl and other chemical residues are attached to the surface.

XRD is used for characterizing crystal structures of the nanoparticles and also for phase identification (Sun *et al*., 2000). The diffraction pattern generated when X-rays penetrate the nanoparticles is used to obtain structural information when compared with standards. Energy dispersion spectroscopy (EDS) is used to establish the composition of the synthesized metallic nanoparticles (Strasser *et al*., 2010).

3.0 Synthetic methods of nanoparticles

There are two major pathways for synthesizing nanoparticles. These are the “Top-down” and “Bottom-up” approach (Sepeur, 2008).

In “Top-down” synthesis, nanoparticles are produced by size reduction from a suitable starting material (Meyers *et al*., 2006). The size reduction is achieved by various physical and chemical treatments (Fig.1) (Mittal *et al*., 2006). Top-down synthesis introduce imperfections in the surface structure of the product, which is a setback since the surface chemistry and other physical properties of nanoparticles are dependent on the surface structure (Thakkar *et al*., 2010)

Bottom-up synthesis involves building the nanoparticles from smaller entities by joining atoms, molecules or particles (Mukherjee *et al*., 2001). The building blocks of the nanoparticles are formed first and assembled to produce the final particles (Thakkar *et al*., 2009) (Fig.2) (Mittal *et* *al*., 2013). Bottom-up approach relies on chemical and biological methods of production. The biological method of synthesis based on micro-organisms have been widely reported (Dhillon *et al*., 2012;Gericke and Pinches, 2006; Kaler *et al*., 2011; Korbekandi *et al*., 2009; Li *et al*., 2011; Mohanpuria *et al*., 2008). Even though microbial synthesis is readily scalable, environment-friendly and compatible with the use of product for medical applications but, the production of the micro-organisms is often more expensive than the production of plant extracts. Plant extract-mediated synthesis have been widely reported (Gardea-Torresdey *et al*., 2003; Park *et al*., 2011; Haleemkhan *et al*., 2015).

4.0 The use of extracts of *Calotropis spp* in metallic nanoparticles synthesis

In the production of metallic nanoparticles using plant extracts, the extract is simply mixed with a solution of the metal salt at room temperature and the reaction is complete within minutes (Mittal *et al*., 2013).

Nanoparticles of silver, gold and many other metals have been synthesized this way (Li *et al*., 2011). The nature of the extract, its concentration, the concentration of the metal salt, the pH, the temperature and contact time are known to affect the rate of production of nanoparticles, their quantity and other characteristics (Dwivedi and Gopal, 2010).

Babu and Prabu (2011) synthesized 35nm silver nanoparticles (AgNPs) using flower extract of *C. procera*. Baskaralingham *et al*. (2012) used a leaf extract of C. gigantean to produce AgNPs that showed antibacterial activity against *vibrio alginolyticus* (Baskaralingham *et al*., 2012).

Alkammash (2017) reported the synthesis of AgNPs using leaf extract of *C. procera*. The nanoparticles were spherical and mostly aggregated with size ranges of 8-20nm. In a study reported by Pavani and Gayathramma (2015), they used flower extract of *C. gigantean* to synthesize AgNPs within 60 minutes. The AgNPs were polydispersed, crystalline and yeast-like with size ranges of 10-50nm. XRD confirmed the face-centred cubic structure of the AgNPs.

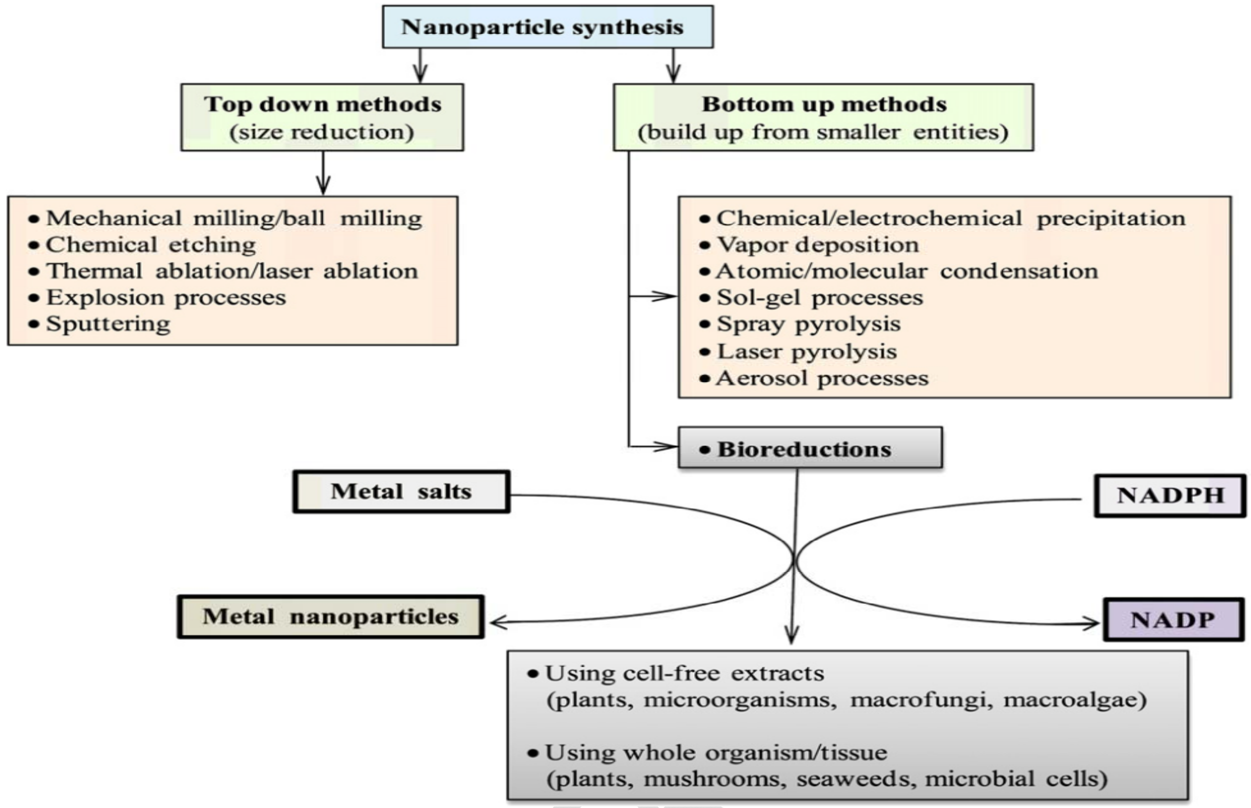

Fig. 1.Various approaches for making nanoparticles and cofactor dependent bioreduction (Mittal *et al*, 2013).

The summary of the various reports of synthesis of metallic nanoparticles using the extracts of the two species of Calotropis (*C. procera* and *C. gigantean*) is given in (Table 1).

Nipane *et al*. (2016) synthesized AgNPs using flower extract of *C. procera*. The particles were spherical, with size ranges of 20-35nm, and their surface showed selective adsorption of Fe2+ ions in aqueous medium which could be used in quantitative estimation of Fe2+ ions in environmental samples.

Chandrasekar (2014) reported that AgNPs, synthesized from leaf extract of *C. gigantean*, showed mosquito larvicidal property against *A. aegypti* and *A. stephensis*.

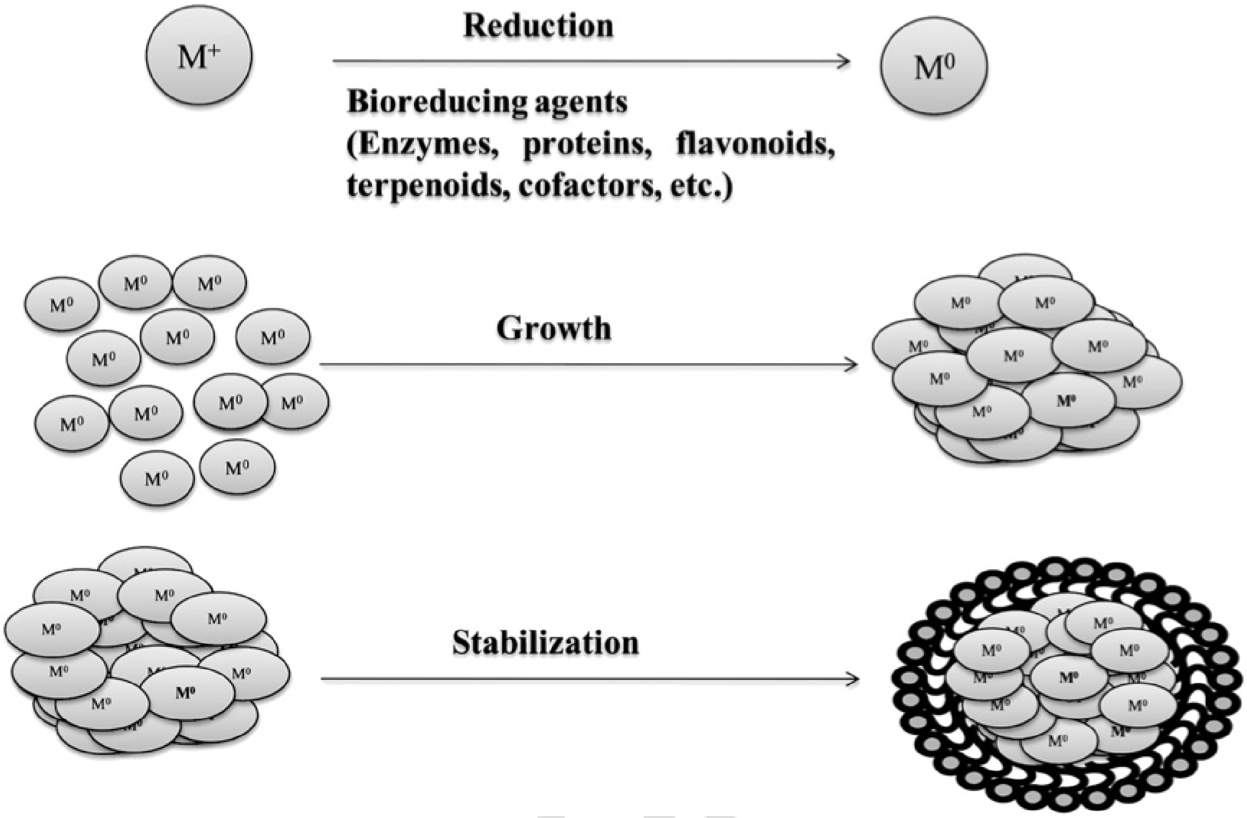

Fig.2. Schematic of biosynthesis of nanoparticles

In a study by Sivakumar *et al*. (2011), AgNPs of various sizes were synthesized using leaves extract of C. gigantean. Spherical AgNPs (Nipane *et al*., 2016) with average size of 55nm were synthesized from leaf extract of *C. procera* (Vinothkumar and Udayasoorian, 2015).

Gold nanoparticles with average size of 45nm have been synthesized using aqueous leaf extract of *C. procera*. FTIR indicated that phenolic phytochemicals were responsible for the reduction process as reported by Tamar and Gary (2013). The AuNPs showed inhibitory effect on the growth of MCF-cell line with increase in concentration. In a microwave-mediated synthesis, Ratil Kumar Das *et al*. (2012) used latex of *C. procera* to produce crystalline and spherical, gold nanoparticles (AuNPs), stable at room temperature for a long period (6 months) with size ranges of 5-13nm. The surface of the AuNPs was coated by organic materials.

Table1. Summary of synthesis of metallic nanoparticles from *Calotropis spp*

Plant/Part	Nanoparticles	size/Application	Reference
C. procera flower	AgNPs	35nm	Babu & Prabu, 2011.
C. *gigantean* leaf	AgNPs	antibacterial activity.	Baskaralingham *et al.*, 2012; Priyanka *et al.*, 2015.
C. procera latex	AgNPs	Antibacterial activity.	Nadia Hussein Mohamed, 2014.
C. procera leaf	AgNPs	8-20nm	Alkammash, 2017.
C. *gigantean* flower	AgNPs	10-50/Environmental decontamination.	Pavani & Gayathramma, 2015.
C. procera flower	AgNPs	20-35nm	Nipane *et al*., 2016.
C. *gigantean* leaf	AgNPs	antilavicidal activity	Chandrasekar *et al*., 2014.
C. *gigantean* latex	AgNPs	antibacterial activity	Chandrasekar, 2015.
C. *gigantean* leaf	AgNPs		Sivakumar *et al.*, 2011.
C. *procera* leaf	AgNPs	55nm	Nipane *et al.*, 2016; Vinothkumar & Udayasoorian, 2015.
C. *procera* leaf	AuNPs	45nm/Inhibitory effect on cancer cells.	Tamar & Gary, 2013.
C. *procera* latex	AuNPs	5-13nm	Patil Kumar das *et al.*, 2012.
C. *procera* leaf	ZnONPs	15-25nm/Environmental decontamination.	Gawade *et al.*, 2017.
C. *procera* leaf	ZnONPs	30-35nm/antibacterial activity.	Vidya *et al*., 2013; Poovizhi & Krishnaveni,2015.
C. *gigantean* leaf	ZnONPs	Growth enhancement.	Sadhankumar & Lalit, 2017.
C. *gigantean* latex	ZnONPs	Cytotoxic effect.	Panda *et al*., 2017.
C. procera leaf, root, Flower & latex	ZnONPs	Antibacterial effect.	Salem & Schild, 2015.
C. *gigantean* leaf	TiONPs	antiparasitic activity.	Marimathu *et al*., 2013.
C. *procera* leaf	CuONPs	environmental Decontamination.	Dubey & Sherma, 2017.

C. *gigantean* leaf	CuONPs	Counter electrode in DSSCs.	Sherma *et al*., 2015.
C. *gigantean* flower	CuONPs	Cytotoxic effect.	Kumari *et al*., 2017.
C. *gigantean* flower	ZVIN	Environmental decontamination.	Srivanthi *et al*., 2018.
C. *gigantean* leaf	FeONPs	3-6nm	Davendra *et al*., 2013.

Gawade *et al*. (2017) used leaves of *C. procera* to produce spherical ZnO nanoparticles which associate to hexagonal wurtzite structure with sizes ranging from 15-25nm. The nanoparticles were utilized for the degradation of methyl orange. Vidya *et al* (2013) were able to produce ZnO nanoparticles with sizes of between 30-35nm. Poovizhi and Krishnaveni (2015) reported that ZnO nanoparticles exhibited high bactericidal efficacy against some bacterial strains (*E. coli, P.aeruginosa, K. pneumonia* and *S. aureus*). Antibacterial activity against similar strains was demonstrated using AgNPs synthesized from latex of *C. gigantean* (Chandrasekaran *et al*., 2015).

Activity against Gram Positive bacterial strains (*S. subtilis* and *Streptococcus sp*.) were reported (Priyanka *et al*., 2015) for AgNPs synthesized from leaf extract of *C. gigantean*. Nadia Hussein Mohamed *et al*. (2014) reported antifungal activity (against *T. rubrum, C. albicans* and *A. terreus*) of AgNPs synthesized from latex of *C. procera*.

ZnONPs synthesized from leaf extract of *C. gigantean* were shown to significantly enhance growth of seedlings of Neem and Milkwood-pine trees when sprayed at nursery stage (Sadhankumar and Lalit, 2017). In a study by Panda *et al* (2017), ZnONPs synthesized from latex extract of *C. gigantean* showed cytotoxic effect by inducing oxidative stress and DNA damage in the root assay system of *L. sativus*. Biosynthesized AgNPs and ZnONPs from extract of *C. procera* showed potential inhibitory effect on two bacterial strains (*V. cholera* and *E. coli*) irrespective of the type of extract (leaf, flower, or fruit) used (Salem and Schild, 2015).

The first reported TiO nanoparticles synthesis with excellent antiparasitic activity was by Marimathu *et al*. (2013), who tested the TiONPs against the larvae of *R. micropulus* and *H. bispinosa*.

CuO nanoparticles (CuONPs) have been synthesized, using leaf extract of *C. procera*, and showed high absorptive capacity for Cr(IV) and hence could serve as good alternative for Cr (IV) removal from aqueous solutions (Dubey and Sherma, 2017). In a similar synthesis using leaf extract of *C. gigantean*, Sherma *et al*. (2015) used the produced CuONPs as counter electrode in dye-sensitized solar cells (DSSCs) and found moderately high solar to electrical energy conversion efficiency 0f 3.4% with high current density of 8.13mA/cm^2, open circuit voltage of 0.67V and fill factor (FF) of 0.62. Flower extract of *C. gigantean* was used to synthesize CuONPs in an in-vivo cytotoxic comparative study of the impact of synthesized AgNPs in comparison to commercially available ones on fish embryo (Kumari *et al*., 2017). They inferred that the biosynthesized AgNPs showed less toxicity than the commercial ones at optimum usage. Zero-valent iron nanoparticles (ZVFeNPs or ZVIN) were synthesized from flower extract of *C. gigantean* and showed high adsorptive capacity for aniline and methylene blue, hence have potential for use in treatment of contaminated water (Sravanthi *et al*., 2018). Iron oxide nanoparticles (FeONPs) of sizes 3-6nm were synthesized using aqueous leaf extract of *C. gigantean* as reported by Devendra *et al* (2013).

5.0 Applications of nanoparticles

Nanoparticles synthesized from the two species of Calotropis have been widely applied for various uses. They have found use in water treatment (Sravanthi *et al*., 2018), in dye-sentisized solar cells (Sherma *et al*., 2015). TiO nanoparticles have shown excellent antiparasitic activity (Marimathu *et al*., 2013).

Nanoparticles of silver, gold and ZnO have exhibited wide spectrum antibacterial activities (Salem and Schild, 2015; Priyanka *et al*., 2015; Poovizhi and Krishnaveni, 2015; Chandrasekaran *et al*., 2015; Baskaralingham *et al*., 2012) against some bacterial strains (*E. coli*, *P.aeruginosa, K. pneumonia, S. aureus, S. subtilis, Streptococcus sp*., *V. cholera* and *E. coli)*

Antiparasitic (Sivakumar *et al*., 2011) and antifungal (Nadia Hussein Mohamed *et al*., 2014) activities against *T. rubrum, C. albicans* and *A. terreus* was shown by AgNPs.

ZnONPs have shown growth enhancement of seedlings (Sadhankumar and Lalit, 2017) and cytotoxic effect in the root system of some plants (Panda *et al*., 2017).

CuO have shown potential for use as heavy metals environmental decontaminant (Dubey and Sherma). ZVIN have potential use in treatment of contaminated water because of their high adsorptive for some organics (Sravanthi *et al.*, 2018).

CONCLUSION

Plant extracts are used for synthesis of metallic nanoparticles. The synthesis is simple, rapid easily scaled up and the nanoparticles are environmental friendly. Metallic nanoparticles are used widely for various applications ranging from antimicrobial agents in water treatment; in targeted drug delivery; in clinical diagnostics; in solar cells; in environmental decontamination etc.

REFERENCES

Adeyemi, O.S., Sulaiman, F.A (2015). Evaluation of metal nanoparticles for drug delivery systems. *J Biomed Res*; 29(2):145-9.

Ahmad, M.Z., Akhter, S., Jain, G.K., Rahman, M., Pathan, S.A., Ahmad, F.J., Kher, R.K (2010). Metallic nanoparticles: technology overview and drug delivery application in oncology. *Expert Open Drug Deliv*; 7(8):927-42.

Ali, D.M., Thajuddin, N., Jeganathan, K., Gunasekaran, M (2011). Plant extract mediated synthesis of silver and gold nanoparticles and its antibacterial activity against clinically isolated pathogens. *Colloids Surf B Biointerfaces*.; 85:360–5.

Alkammash, N.M ((2017). Synthesis of silver nanoparticles from *Artemisia sieberi* and *Calotropis procera* medical plant extracts and their characterization using SEM analysis. Biosci Biotech Res Asia; 14(2): 34-6

and reducing implications of nanotechnology. *ACS Nano*.; 2:395–402.

Ankamwar, B (2010). Biosynthesis of gold nanoparticles (green-gold) using leaf extract of *Terminalia catappa*. *Eur J Chem.*; 7: 1334–9.

Ankamwar, B., Damle, C., Ahmad, A., Sastry, M (2005). Biosynthesis of gold and silver nanoparticles using *Emblica officinalis* fruit extract, their phase transfer and trans-metallation in an organic solution. *J Nanosci Nanotechnol*; 5: 1665–71.

Armendariz, V., Herrera, I., Peralta-Videa, J.R., Jose-Yacaman, M., Troiani, H., Santiago, P (2004). Size controlled gold nanoparticle formation by *Avena sativa* biomass: use of plants in nanobiotechnology. *J Nanopart Res.*; 6:377–82.

Azzazy, H.M., Mansoor, M.M (2009). In vitro diagnostic prospects of nanopaeticles. *Clin Chim Acta*; 403(1-2):1-8.

Azzazy, H.M.E., Mansour, M.M.H., Samir, T.M., Franco, R (2012). Gold nanoparticles in the clinical laboratory: principles of preparation and applications. Clin Chem Lab Med.; 50:193–209.

Babu, S.A., Prabu, H.G (2011). Synthesis of AgNPs using the extract of *Calotropis procera* flower at room temperature. *Mater Lett.;* 65:1675–7.

Banerjee, J., Narendhirakannan, R (2011). Biosynthesis of silver nanoparticles from *Syzygium cumini* (L.) seed extract and evaluation of their in vitro antioxidant activities. *Dig J Nanomater Biostruct.*;6: 961–8.

Bankar, A., Joshi, B., Kumar, A.R., Zinjarde, S (2010). Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids Surf A.*; 368: 58–63.

Baptista, P.V., Doria, G., Quaresma, P., Cavadeas, M., Neves, C.S., Gomes, I., Eaton, P., Pereira, E., Franco, R (2011). Nanoparticles in molecular diagnostics. *Prog Mol Biol Transl Sci*; 104:427-88.

Baskaralingam, V., Sargunar, C.G., Lin, Y.C., Chen, J.C (2012). Green synthesis of silver nanoparticles through *Calotropis gigantea* leaf extracts and evaluation of antibacterial activity against *Vibrio alginolyticus*. *Nanotechnol Dev.*; 2:3. http://dx.doi.org/10.4081/nd.2012.e3.

Beattie, I.R., Haverkamp, R.G (2011). Silver and gold nanoparticles in plants: sites for the reduction to metal. *Metallomics*. 3:628–32.

Cao, G (2004). Nanostructures and nanomaterials: synthesis, properties and applications. Imperial College Press, London, UK.

Castro, L., Blázquez, M.L., Muñoz, J.A., González, F., García-Balboa, C., Ballester, A (2011). Biosynthesis of gold nanowires using sugar beet pulp. *Process Biochem.*; 46:1076–82.

Chandran, S.P., Chaudhary, M., Pasricha, R., Ahmad, A., Sastry, M (2006). Synthesis of gold nanotriangles and silver nanoparticles using *Aloe vera* plant extract. *Biotechnol Prog*. ; 22:577–83.

Chandrasekar, R (2014). Green synthesis of siver nanoparticles using Calotropis gigantean and their potential mosquito larvicidal property. *Intl J of Pure and App Zoology;* 2:128-137.

Chandrasekaran, R., Kannaiah, S., Satishkumar, G., Sivaramakhrishnan, S (2015). Antimicrobial & cytotoxic potential of AgNPs synthesized using latex of *C. gigantean* L. *Spec Acta Part A: Mol & Biomol Spec*;136:924-930.

Chen, X.J., Sanchez-Gaytan, B.L., Qian, Z.X., Park, S.J (2012). Noble metal nanoparticles in DNA detection and delivery. Wiley Interdiscip Rev *Nanomed Nanobiotechnol*.; 4: 273–90.

Chithrani, B.D., Ghazani, A.A., Chan, W.C.W (2006). Determining the size and shape dependence of gold nanoparticle uptake into mammalian cells. *Nano Lett*.; 6:662–8.

Devendra, J., Kaldeep Singh, R., Rohit, J., Himmat, S., Sumita, K., Kothari, S.L (2013). Adv Sci Foc;1(4):318-321.

Dhillon, G.S., Brar, S.K., Kaur, S., Verma, M (2012). Green approach for nanoparticles biosynthesis by fungi: current trends and applications. *Crit Rev Biotechnol*.; 32:49–73. *Diopyros kaki* leaf extract. *Bioprocess Biosyst Engr* ; 33:159–64.

Doria, G., Conde, J., Veigas, B., Giestas, L., Almeida, C., Assunção, M (2012). Nobel metal nanoparticles for biosensing applications. *Sensors* (Basel).; 12:1657–87.

Dubey, S., Sharma, C (2017). *C. procera* mediated one-pot green synthesis of cupric oxide nanoparticles for adsorptive removal of Cr(IV) from aqueous solution. *App Organometallic Chem.;*3(12:39–41.

Duran, N., Seabra, A.B (2012). Metallic oxide nanoparticles: state of the art in biogenic syntheses and their mechanisms. *Appl Microbiol Biotechnol*.; 95:275–88.

Dwivedi, A.D., Gopal, K (2011). Plant-mediated biosynthesis of silver and gold nanoparticles. *J Biomed Nanotechnol*.; 7:163–4.

Eppler, A.S., Rupprechter, G., Anderson, E.A., Somorjai, G.A (2000). Thermal and chemical stability and adhesion strength of Pt nanoparticle arrays supported on silica studied by transmission electron microscopy and atomic force microscopy. *J Phys Chem B*.; 104:7286–92.

Feldheim, D.L., Foss, C.A (2002). Metal nanoparticles: synthesis, characterization, and applications. CRC Press, Boca Raton, Fl, USA.

Fortina, P., Kricka, L.J., Graves, D.J., Park, J., Hyslop, T., Tam, F (2007). Applications of nanoparticles to diagnostics and therapeutics in colorectal cancer. *Trends Biotechnol*.; 25:145–52.

Gan, P.P., Li, S.F.Y (2012). Potential of plant as a biological factory to synthesize gold and silver nanoparticles and their applications. *Rev Environ Sci Biotechnol*.; 11:169–206.

Gardea-Torresdey, J.L., Gomez, E., Peralta-Videa, J.R., Parsons, J.G., Troiani, H., Jose-Yacaman, M (2003). Alfalfa sprouts: a natural source for the synthesis of silver nanoparticles. *Langmuir*.; 19:1357–61.

Gawade, V.V., Gavade, N.L., Shinde, H.M., Babar, S.B., Kadam, A.N., Garadkar, K.M (2017). Green synthesis of ZnO nanoparticles by using *C. procera* leaves for the photodegradation of methyl orange. *J of Mat Sci. Mat in Electr;* 28(18):14033-14039.

Gericke, M., Pinches, A (2006). Biological synthesis of metal nanoparticles. *Hydrometallurgy*.; 83:132–40.

Haleemkhan, A.A., Naseem, B.,Vardhini, V (2015). Synthesis of nanoparticles from plant extracts. *Intl J Modern Chem & App Sci*; 2(3):195-203.

Haverkamp, R.G., Marshall, A.T (2009). The mechanism of metal nanoparticle formation in plants: limits on accumulation. *J Nanopart Res*.; 11:1453–63.

Hutchison, J.E (2008). Greener nanoscience: a proactive approach to advancing applications

Iravani, S (2011).. Green synthesis of metal nanoparticles using plants. *Green Chem*.; 13: 2638–50.

Irvine, F.R (1961). Woody plants of Ghana. Oxford University Press, London, UK: 48-50.

Jain, D., Daima, H.K., Kachhwaha, S., Kothari, S (2009). Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluation of their antimicrobial activities. *Dig J Nanomater Biostruct*.; 4:557–63.

Jiang, J., Oberdörster, G., Biswas, P (2009). Characterization of size, surface charge, and agglomeration state of nanoparticle dispersions for toxicological studies. *J Nanopart Res* ;11:77–89.

Kaler, A., Nankar, R., Bhattacharyya, M.S., Banerjee, U.C (2011). Extracellular biosynthesis of silver nanoparticles using aqueous extract of *Candida viswanathii*. *J Bionanosci*.; 5:53–8.

Kandasamy, K., Alikunhi, N.M., Manickaswami, G., Nabikhan, A., Ayyavu, G (2012). Synthesis of silver nanoparticles by coastal plant *Prosopis chilensis* (L.) and their efficacy in controlling vibriosis in shrimp *Penaeus monodon*. *Appl Nanosci*.; 12: 44-64

Kesharwani, J., Yoon, K.Y., Hwang, J., Rai, M (2009). Phytofabrication of silver nanoparticles by leaf extract of *Datura metel*: hypothetical mechanism involved in synthesis. *J Bionanosci*.; 3:39–44.

Korbekandi, H., Iravani, S., Abbasi, S (2009). Production of nanoparticles using organisms. *Crit*

Kouvaris, P., Delimitis, A., Zaspalis, V., Papadopoulos, D., Tsipas, S., Michailidis, N (2012). Green synthesis and characterization of silver nanoparticles produced using *Arbiutusunedo* leaf extract. *Mater Lett*.; 76:18–20.

Kumar, V., Yadav, S.C., Yadav, S.K (2010). *Syzygium cumini* leaf and seed extract mediated biosynthesis of silver nanoparticles and their characterization. *J Chem Technol Biotechnol*.; 85:1301–9.

Kumar, V., Yadav, S.K (2009). Plant-mediated synthesis of silver and gold nanoparticles and their applications. *J Chem Technol Biotechnol*.; 84:151–7.

Kumari, P., Panda, P.K., Jha, E., Kumari, K., Nisha, K., Mallick, M.A., Verma, K.V (2015). Mechanistic insight to ROS and apoptosis regulated cytotoxicity inferred by green synthesized CuONPs from *C. gigantean* to embryonic zebra-fish. *Sci Rep*;7(16):33-40.

Lahrsini M, Bousad M, Lazrek HB, Jana M, Amarouch H (1997) Evaluation of antifungal and molluscicidal properties of extracts of Calotropis procera. Fitoterapia 68: 371-373.

Larguinho, M., Baptista, P.V (2012). Gold and silver nanoparticles for clinical diagnostics — from genomics to proteomics. *J Proteomics*.; 75:2811–23.

Lee, H.J., Lee, G., Jang, N.R., Yun, J.H., Song, J.Y., Kim, B.S (2011). Biological synthesis of copper nanoparticles using plant extract. *Nanotechnology*.; 1:371–4.

Li S, Shen Y, Xie A, Yu X, Zhang X, Yang L. Rapid, room-temperature synthesis of amorphous selenium/protein composites using *Capsicum annuum* L extract. *Nanotechnology*; 18: 405.

Li, S., Shen, Y., Xie, A., Yu, X., Qui, L., Zhang, L (2007a). Green synthesis of silver nanoparticles using *Capsicum annum* L. extract. *Green Chem*.; 9:852–8.

Li, W.R., Xie, X.B., Shi, Q.S., Zeng, H.Y., Ou-Yang, Y.S., Chen, Y.B (2010). Antibacterial activity and mechanism of silver nanoparticles on *Escherichia coli*. *Appl Microbiol Biotechnol*.; 85:1115–22.

Liu, Q., Liu, H., Yuan, Z., Wei, D., Ye, Y (2012). Evaluation of antioxidant activity of *chrysanthemum* extracts and tea beverages by gold nanoparticles-based assay. *Colloids Surf B Biointerfaces*.; 92:348–52.

Luangpipat, T., Beattie, I.R., Chisti, Y., Haverkamp, R.G (2011). Gold nanoparticles produced in a microalga. *J Nanopart Res*.; 13:6439–45.

Marimuthu, S., Rahuman, A.A., Jayasaleen, C., Kirthi, A.V., Santoshkumar, T., Velayuthan, K., Bagarav, A., Kamaraj, C., Elango, G., Iyappa, M., Siva, C., Karthik, L., RaO, K.V (2013). Acaricidal activity of synthesized TiO nanoparticles using *C. gigantean* against *R. microplus* and *H. bisipinosa.* Asian Pac J Trop Med; 6(9):682-8.

Marshall, A.T., Haverkamp, R.G., Davies, C.E., Parsons, J.G, Gardea-Torresdey, J.L., van Agterveld, D (2007). Accumulation of gold nanoparticles in *Brassic juncea*. *Int J Phytoremediation*.; 9:197–206.

Mittal, A.K., Chisti, Y., Banerjee, U.C (2013). Synthesis of silver nanoparticles plant extracts. *Biotech Adv*.; 31:346-356..

Mittal, A.K., Kaler, A., Banerjee, U.C (2012). Free radical scavenging and antioxidant activity of

Mohanpuria, P., Rana, N.K., Yadav, S.K (2008). Biosynthesis of nanoparticles: technological concepts and future applications. *J Nanopart Res*.; 10:507–17.

Mukherjee, P., Ahmad, A., Mandal, D., Senapati, S., Sainkar, S.R., Khan, M.I (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelia matrix: a novel biological approach to nanoparticle synthesis. *Nano Lett*.; 1:515–9.

Nadia, H.M., Isamil, M.A., Abdel-Mageed, W.M., Shoreit, A.a.M (2014). Antimicrobial activity of latex silver nanoparticles using *C. procera*. Asia Pac J Trop Med; 4(1):876-883.

Nipane, S.V., Prasad, G.M., Gokavi, G.S (2016). Green synthesis of silver nanoparticles in *Calotropis procera* flower extract and its application for Fe^{2+} sensing in aqueous solution. *Intl J of Recent & Innov Trends in Comp and Commun*; 4(10):98-107.

Pal, S., Tak, Y.K., Song, J.M (2007). Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the Gram-negative bacterium *Escherichia coli*. *Appl Environ Microbiol*.; 73:1712–20.

Panda, K.A., Golari, D., Venugopal, A., Achary, V.M.M, Phaomei, G., Parinandi, L.L., Sahu, H.K., Panda, B.B (2017). Green synthesized ZnO nanoparticles induce oxidative stress and DNA damage in Lathyrus sativus L. root bioassay system. Antioxidants; 6(2):35-45..

Park, Y., Hong, Y.N., Weyers, A., Kim, Y.S., Linhardt, R.J (2011). Polysaccharides and phytochemicals: a natural reservoir for the green synthesis of gold and silver nanoparticles. *IET Nanobiotechnol;* 5:69–78.

Parsons, J., Peralta-Videa, J., Gardea-Torresdey, J (2007). Use of plants in biotechnology: synthesis of metal nanoparticles by inactivated plant tissues, plant extracts, and living plants. *Dev Environ Sci*.; 5:463–85.

Pavani, K.V., Gayathramma, K (2015). Synthesis of silver nanoparticles using extracts of Calotropis gigantean flowers. Intl J Pharm Res Nanosci; 4(4):236-240.

Poovizhi, J., Krishnaveni, B (2015). Synthesis, characterization and antimicrobial activity of ZnO nanoparticles synthesized from *C. procera*. *Intl J of Pharm Sci and Drug Res*; 7(5):425-431.

Priyanka, S.J., Ramesh, G., Pakiyan, J.E., Shobha, K.J (2017). Green synthesis and evaluation of AgNPs using leaf extract from *C. gigantean. Intl J Curr Biotech;* 5(3):1-5.

Radwan, S.H., Azzazy, H.M (2009). Gold nanoparticles for molecular diagnostics. Expert Rev Mol Diagn; 9(5):511-24.

Ratul Kumar Das, Punuri, J.B., Gogoi, N., Sharma, P., Bora, U (2012). Microwave mediated rapid synthesis of gold nanoparticles using Calotropis procera latex and study of optical properties. Nanomaterials; 2012:610-616.

Raveendran, P., Fu, J., Wallen, S.L (2003). Completely "green" synthesis and stabilization of metal nanoparticles. *J Am Chem Soc*.; 125:13940–1.

Rev Biotechnol.; 29:279–306.

Sadhan Kumar, C., Lalit, M (2015). Biosynthesis of ZnO nanoparticles using leaf extract of *C. gigantean*: Characterization and its evaluation on tree seedling growth in nursery stage. *App Nano*;7(8):501-512.

Sahoo, S., Parveen, S., Panda, J (2007). The present and future of nanotechnology in human health care. *Nanomed Nanotechnol Biol Med*.; 3:20–31.

Salata, O (2004). Applications of nanoparticles in biology and medicine. *J Nanobiotechnol.*; 10:2-3.

Salem, W., Schild, S (2015). Detection of plant synthesized nanoparticles and their antibacterial capacity. Intl J Med Microbiol;305:85-95.

Santhoshkumar, T., Rahuman, A.A., Rajakumar, G., Marimuthu, S., Bagavan, A., Jayaseelan, C (2011). Synthesis of silver nanoparticles using *Nelumbo nucifera* leaf extract and its larvicidal activity against malaria and filariasis vectors. *Parasitol Res*.; 108:693–702.

Sastry, M., Ahmad, A., Islam Khan, M., Kumar, R (2003). Biosynthesis of metal nanoparticles using fungi and actinomycete. *Curr Sci*.; 85:162–70.

Sathishkumar, M., Sneha, K., Kwak, I.S., Mao, J., Tripathy, S., Yun, Y.S (2009a). Phyto-crystallization of palladium through reduction process using *Cinnamom zeylanicum* bark extract. *J Hazard Mater*.; 171:400–4.

Sathishkumar, M., Sneha, K., Won, S., Cho, C.W., Kim, S., Yun, Y.S (2009b). *Cinnamon zeylanicum* bark extract and powder mediated green synthesis of nano-crystalline silver particles and its bactericidal activity. *Colloids Surf B Biointerfaces*.; 73:332–8.

Sathishkumar, M., Sneha, K., Yun, Y.S (2010). Immobilization of silver nanoparticles synthesized using *Curcuma longa* tuber powder and extract on cotton cloth for bactericidal activity. *Biores Technol*.; 101:7958–65.

Schaffer, B., Hohenester, U., Trugler, A., Hofer, F (2009). High-resolution surface plasmon imaging of gold nanoparticles by energy-filtered transmission electron microscopy. Phys Rev B; 79:401.

Seil, J.T., Webster, T.J (2012). Antimicrobial applications of nanotechnology: methods and literature. *Int J Nanomed*. ; 7:2767–81.

Sepeur, S (2008). Nanotechnology: technical basics and applications. Vincentz Publishers; Hannover, Germany.

Shankar, S.S., Ahmad, A., Sastry, M (2003). *Geranium* leaf assisted biosynthesis of silver nanoparticles. *Biotech Prog;* 19:1627-31.

Sharma, J.K., Akhar, M.S., Ameen, S., Srivastava, P., Singh, G (2015). Green synthesis of CuONPs with leaf extract of *C. gigantean* and its dye-sensitized solar cells application. *J of Alloys and Compounds;* 632:321-325.

silver nanoparticles synthesized from flower extract of *Rhododendron dauricum*. *Nano BioMed Eng*.; 4:118–24.

Sivakumar, J., Premkumar, C., Santhane, P., Saraswathi, N (2011). Biosynthesis of nanoparticles using C. gigantean leaf extract. *J of Basic and App Sci*; 3(6):265-290.

Song, J.Y., Jang, H.K., Kim, B.S (2009). Biological synthesis of gold nanoparticles using *Magnolia kobus* and *Diopyros kaki* leaf extracts. *Process Biochem*; 44:1133–8.

Song, J.Y., Kwon, E.Y., Kim, B.S (2010). Biological synthesis of platinum nanoparticles using

Sravanthi, K., Ayodhya, D., Swamy, Y (2018). Green synthesis and characterization of biomaterial supported zero-valent iron nanoparticles for contaminated water treatment. J of Anal Sci and Tech; 9(3):134-9.

Strasser, P., Koh, S., Anniyev, T., Greeley, J., More, K., Yu, C (2010). Lattice-strain control of the activity in dealloyed core–shell fuel cell catalysts. *Nat Chem*; 2:454–60.

Sun, S., Murray, C., Weller, D., Folks, L., Moser, A (2000). Monodisperse FePt nanoparticles and ferromagnetic FePt nanocrystal superlattices. *Science*; 287:1989–92.

Thakkar, K.N., Mhatre, S.S., Parikh, R.Y (2010). Biological synthesis of metallic nanoparticles. *Nanomed Nanotechnol Biol Med*; 6:257–62.

Vidya, C., Shilpa, H., Chandraprabha, M.N., Lourdu, A.M.A., Gopal, I.V., Jam, A., Bansal, K (2013). Green synthesis oof ZnO nanoparticles by C. gigantean. *Intl J Curr Engr and Tech* (*SE*); 118-120.

Vinothkumar, K., Udayasoorian, C (2015). Biobase synthesis of AgNPs using leaf extract of *C. procera*. *J Inno Agri;* 2(1):34-38.

Vio Vel (2017). Metal nanoparticles for the treatment and diagnosis of neurodegenerative brain diseases. *Curr Pharm Des*; 23(13):1916-1926.

Virkutyte, J., Varma, R.S (2011). Green synthesis of metal nanoparticles: biodegradable polymers and enzymes in stabilization and surface functionalization. *Chem Sci*; 2: 837–46.

Vivek, M., Kumar, P.S., Steffi, S., Sudha, S (2011). Biogenic silver nanoparticles by *Gelidiella acerosa* extract and their antifungal effects. *Avicenna J Med Biotechnol*; 3:143–8.

Wagner, V., Dullaart, A., Bock, A.K., Zweck, A (2006). The emerging nanomedicine landscape. *Nat Biotechnol*; 24:1211–8.

Wititsuwannakul, R., Wititsuwannakul, D., Sakulborirug, C (1998). A lectin from the bark of the rubber tree (*Hevea brasilliensis*). *Phytochem*; 47: 183-187.

Yang, X., Li, Q., Wang, H., Huang, J., Lin, L., Wang, W (2010). Green synthesis of palladium nanoparticles using broth of *Cinnamomum camphora* leaf. *J Nanopart Res*; 12:1589–98.

Youns, M., Hoheisel, J.D., Efferth, T (2011). Therapeutic and diagnostic applications of nanoparticles. *Curr Drug Targets*; 12:357–65.

Zhang, L., Gu, F.X., Chan, J.M.,Wang, A.Z., Langer, R.S., Farokhzad, O.C (2008). Nanoparticles in medicine: therapeutic applications and developments. *Clin Pharmacol Ther*; 83:761–9.