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CHARACTERIZATION PROFILE OF PLANT MEDIATED BIOGENIC SILVER NANOPARTICLES: AN OVERVIEW

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Abstract

Nano-biotechnology is at leading edge of research development, making an impact in all spheres of human life. The size of nanoparticles is comparable to that of most of biological molecules (e.g., proteins, DNA) and structures (e.g., viruses and bacteria) therefore; nanoparticles can be developed for diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles. This review illustrates possibilities of development of reliable experimental protocols for the bio synthesis of nanomaterial's using different plant extracts by performing analytical comparisons of characterization techniques like Ultra Violet visible spectroscopy, Scanning Electron Microscope, Transmission Electron Microscope and X-Ray Diffraction. Biological methods of synthesis have paved way for the "greener synthesis" of nanoparticles and these have proven to be better methods due to slower kinetics, being environmentally friendly, less expensive. Also they offer better manipulation and control over stabilization of nanoparticles.

INTRODUCTION:

The term "nanotechnology" was first defined by Norio Taniguchi, Tokyo Science University in 1974 [1] as follows “Nanotechnology mainly consists of the processing, separation, consolidation, and deformation of materials by one atom or one molecule”. In nature also living cells are the good examples of machines in which basic function of all kind of metabolism operate at the Nano dimension and perform like generation of energy, extraction of targeted materials, etc. at very high efficiency. Most of subcellular components are also of nano dimension for example ribosome, enzymes, lysosome, the Golgi apparatus, the interior structure of the mitochondrion, the photosynthetic reaction center [2].

In recent year nanotechnology becomes great importance to human being because of wide range of application where classical means even can’t think. The development of new resistant strains of bacteria to current antibiotics [3], has become a serious problem in public health because of smaller size nanoparticle may provide an alternative to conventicle bactericides. Due to size dependence properties of nanoparticles it has a potential application in Nano-biotechnology. It is an emerging field which made its contribution to most of spheres of human life such as application of nano-scale drug system or Nano-medicine for diagnosis and cure of diseases and disease causing means. The potential benefits of Nano-materials in biomedical and industrial applications for human health and environment are now accepted in the literature [4, 5].

Metal nanoparticles have received considerable attention in recent years because of their unique properties and potential applications in catalysis [6], plasmonics [7], optoelectronics [8], biological sensor [9, 10] and pharmaceutical applications [11]. Nano-particles show entirely different properties comparative to bulk material because of their nanometer size they have a higher surface to volume ratio. The specific surface area of nanoparticles is directly proportional to their biological effectiveness due to the increase in surface energy [12].

Silver with atomic no. 47 and symbol ‘Ag’ is a white and brilliant metal. Pure silver is

ductile, malleable and has high electrical and thermal conductivity as well as the low contact resistance [13]. Silver has known to be a metal that came into use even before Neolithic revolution. Even the Greeks used it for cooking and to keep water safe [14, 15]. Silver is a health additive in traditional Chinese and Indian Ayurvedic medicine from long time period. The first recorded medicinal use of silver was reported during 8th century [16]. Silver has long recognized as inhibitory effect on microbes present in medical and industrial process [17] and have antimicrobial properties with low toxicity [18].

Silver compounds (silver sulfadiazine cream) have also been used in the medical field to treat burns and a variety of infections [19]. Amenitop (A silica gel microspheres containing silver-thiosulfate complex) is mixed into plastics for lasting antibacterial protection [20]. The urinary tract related bacterial pathogens are found to be susceptible to oligo-dynamic silver [21, 22]. Silver nanoparticle have been studied as a mean for antibiotic delivery [23], to synthesize composites which can be used as disinfecting filters [24] and coating materials [25].

Synthesis and characterization of nanoparticles is benchmark in research because size and shape of nanoparticles controls its physical and chemical properties [26, 27]. The current review throws light on different characterization techniques like visual observation of color change, UV-Vis spectroscopy, Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM) and X-Ray Diffraction (XRD) to analysis the biosynthesized silver nanoparticles. Analytical study of these techniques for different plants extract helps to sort the better condition for synthesis of good quality silver nanoparticles. In nature also nano-dimension molecules are synthesized by organism for example DNA, RNA, protein, many of signaling molecules and much more. Interestingly metallic nanoparticles synthesis by microorganism also observed. Some well-known examples of microorganisms synthesizing inorganic materials include magneto tactic bacteria synthesizing magnetite nanoparticles [28-30], diatoms synthesizing siliceous materials [31-33], and S-layer bacteria producing gypsum and calcium carbonate layers [34].

Silver nanoparticles be synthesized through array of methods like reduction in solutions [35], chemical and photochemical reactions in reverse micelles [36], thermal de-composition of silver compounds [37], radiation assisted [38], electrochemical [39], sono-chemical [40], microwave assisted process [41] and recently via green chemistry route i.e. biological synthesis [42]. In chemical synthesis method many of the reactants, substrate and by products may be toxic and Hazardous w.r.t to biological applications [43]. Chemical methods of nanoparticle synthesis may leads to nano-pollution (Nano-pollution is a generic name for all waste generated by nano-devices or during the nano-materials manufacturing process). Because of size in nanometer easily penetrate animal and plant cells causing unknown effects [44].

Most human-made nanoparticles do not appear in nature, so living organisms may not have appropriate means to deal with nano-waste, so there is a growing need to develop alternative to deal with this. Now a day's green synthesis means using biological molecules to reduce silver at the nano-scale level is used by researchers to overcome problems of chemical methods. Bio synthesis proves better methods because of slower kinetics [45], eco-friendliness, no use of toxic substrates, and compatibility for pharmaceutical and other biomedical applications. Green synthesis is also cost effective, can be easily scaled up for large scale synthesis and no need to use high pressure, energy, temperature as in case of chemical and physical methods [46]. Biological materials like plant leaf extract [47], bacteria [48], fungi [49] and enzymes [50] are used for the green synthesis of silver nanoparticles. It has been reported that the rate of reduction of metal ions using plants has been found to be much faster as compared to micro-organisms and stable formation of metal nanoparticles [51] and also there is no need of maintaining cell culture.

Different researchers Group synthesized silver nanoparticles using various plant extracts like, *Carica papaya* [52], *Allium cepa* [53], *Azadirachtaindica* [54], *Capsicum annum* [55], *Cassia auriculata* [18], *Citrulluscolocynthis* [56], *Elaeagnuslatifolia* [46], *Eucalyptus hybrid* [57], *Euphorbia hirta* [58], *Lactuca sativa* [59], *Neriumindicum* [58], *Ocimum sanctum* [60], *Padinatetrastromatica* [61],

Partheniumhysterophorous [62], *Phyllostachys*[63], Pomegranate seeds, [51], *Ricinuscommunis* [64], *Rosmarinusofficinalis* [65], *Saururuschinensis* [66], *Solanumtorvum* [67], *Spinaciaoleracea* [59], Syzygiumcumini[68], *Zingiberofficinale* [69].

SILVER NANOPARTICLE'S SYNTHESIS

Table 1 and 2 contains list of different plants whose extracts has being used to synthesis silver nanoparticle via green route synthesis. The biosynthesis of nanoparticles as an emerging field of the intersection between nanotechnology and biotechnology, received increasing attention due to a growing need to develop environmentally friendly technologies in material synthesis [70].

Chemical Reduction v/s Green Synthesis

Before emergence of green synthesis Chemical reduction is the most frequently used method for the synthesis of silver nanoparticles [Silver nanoparticles] as colloidal dispersions in water or organic solvents [71. 72]. The reduction of silver ions (Ag+0 in aqueous solution generally yields colloidal silver with particle diameters of several nanometers [72], but the scene was not easy as mentioned. In the chemical method reduction of various chemical complexes with Ag (+) ions lead to the formation of silver atoms Ag (0), which is followed by agglomeration into oligomer clusters. These clusters eventually lead to the formation of colloidal Ag particles [73].So there is a need of a strong reducing agent to produce small Ag particles.

In Different studies the enlargement of particles in the secondary step from about 20–45 nm to 120–170 nm was reported [74-76] probably due to the aggregation of two or more nanoparticles together. Therefore Chemical reduction method need a stabilizer to prevent unwanted agglomeration of the colloids, Also the initial solution was not reproducible and specialized equipment was needed [77]. The biosynthesis of silver nanoparticles thus proved a better method than the chemical methods due to slower kinetics [45], cost effective, and also there is no special experimental requirement. Slower kinetics helps better manipulation of nanoparticle synthesis and their stabilization.

Followed Protocol For Nanoparticle Synthesis

Most of the researchers used following pattern for bio-synthesizing silver nanoparticles. Extract of plant parts (mostly leaves) were obtained by washing of leaves by tap and distill water and then allows leaves to dry. Dried power was either directly mixed to the 1mM (Aqueous) silver nitrate ($AgNO_3$) solution or extracts of plant part by using Sox let apparatus and then filters by using whattman filter paper. Amount of extract and silver nitrate solution can be varied but concentration of $AgNO_3$ is kept 1mM in almost all references and also the quantity of silver nitrate solution is 70-90 % v/v to that of plant extract. Mixing of extract and AgNO3 solution was done at room temperature approx. synthesis of nanoparticles was observed visually by changes in color of solution. After some hours of incubation the solution was centrifuged and nanoparticles were separated out. Details of synthesis protocol used by researchers can be seen at the references.

CHARACTERIZATION

The effects of Silver nanoparticles on size dependent toxicity with various concentrations already explained earlier [78] suggest that a size controlled synthesis is verymuch necessary when it comes to cellular interactions and analytical study of characterization techniques helps to sort out better synthesizing conditions for good quality of Silver nanoparticles. Characterization of synthesized silver nanoparticles also provides information about correctness and efficiency of methods used. Synthesized nanoparticles can be characterize by visual observation of color change, UV-Vis spectroscopy, Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), X-Ray Diffraction (XRD), Fourier Transform irradiation microscopy (FTIR), Energy-dispersive X-ray (EDX), Atomic Force Microscope(AFM), etc.In this current review we were focusing light on analytical study of results of visual observation, UV-Vis spectroscopy, SEM, TEM, and XRD for the synthesized silver nanoparticles.

Visual Observation

On mixing the plant extract with $AgNO_3$ solution, the color of the solution changes. This color change is may be due to excitation of surface Plasmon vibrations in the silver metal nanoparticles [79].

Conflictions are there in color variation but uniquely final color of solution was found to be brown it may be dark or yellowish or reddish in combination, so we can say that appearance of brown color in solution provide preliminary support for synthesis of silver nanoparticles. Details of color change are mentioned in Table 1.

UV-Vis Spectroscopy

Reduction of Ag+ ions during mixing of the extract of plant part and aqueous silver nitrate solution was easily followed by UV-Vis spectroscopy using a standard spectrophotometer with a resolution of ±1nm between 200-800nm. It is generally recognized that UV–Vis spectroscopy could be used to examine size and shape controlled nanoparticles in aqueous suspensions [80]. High Dilution of final solution after mixing is must to reduce the possible error due to high density of solution. UV-VIS absorption spectrophotometer is used to investigate the LSPR phenomenon. Silver nanoparticles exhibits interesting optical properties directly related to Localized Surface Plasmon Resonance (LSPR) [66].

The frequency and width of the surface Plasmon absorption depends on the size and shape of the metal nanoparticles as well as on the dielectric constant of the metal itself and the surrounding medium [81-82]. The surface Plasmon resonance plays a major role in the determination of optical absorption spectra of metal nanoparticles, which shifts to a longer wavelength with increase in particle size [83]. According to Mie's theory, only a single SPR band is expected in the absorption spectra of spherical nanoparticles, whereas anisotropic particles could give rise to two or more SPR bands depending on the shape of the particles. The number of SPR peaks increases asthe symmetry of the nanoparticle decreases [84].

In Absorption spectra of the reaction media following outcome are possible:-

1. Single and strong peak between 410-465 nm: Solution only contains the silver nanoparticle that is isotropic in shape and uniform in size. This band is called the surface plasmon resonance [64].

2. Single but widen peak between 410-465 nm: Solution containing the silver nanoparticles arranged in poly dispersed manner [61], but of similar size.

3. More than one peaks between 410-465 nm: Solution containing the silver nanoparticles ofdifferent size.

4. Sometime peaks near 210nm, 280nm, other than mentioned range observed, this indicates the presence of impurities which may be protein, amino acid or other biomolecules of plant extract or may be due to unknown by products and compounds [64].

SEM and TEM Characterization

UV-Vis spectroscopy provides only preliminary information, it does not stats about Nanoparticle's morphology and Distribution, so structural analysis was done by using either Scanning Electron Microscope (SEM) or Transmission Electron Microscope (TEM). Thin films of the sample were prepared on a carbon coated copper grid by just dropping a very small amount of the sample on the grid, extra solution was removed using a blotting paper and then the film on the SEM/TEM grid were allowed to dry by putting it under a mercury lamp for 5-10 minutes [66]. Operating conditions may subject to vary according to the model of machine used for analytical study.

As listed in Table 1, Silver nanoparticles exhibit a broad size distribution mainly of spherical shape, although other shapes were also found. It is known that the shape of metal nanoparticles considerably change their optical and electronic properties [85]. SEM and TEM analysis explore spherical shaped silver nanoparticles of size ranged between 03-140 nm. due to the aggregation of two or more nanoparticles together larger particles size was observed which in turn Because of the presence of excess amounts of reducing moieties and the interactions between stabilizing molecules bound to the surface of particles and secondary reduction process on the surface of the preformed nuclei [86]. Smaller the size of nanoparticle larger its surface area to volume ratio thus with decrease in size interaction of nanoparticles with pathogen increases and become a potent antimicrobial agent. There is a possibility that a smaller nanoparticle shows uniform distribution, without aggregation i.e. mono-dispersed. Distribution of nanoparticles was

either mono-dispersed or poly-dispersed depending upon the types of nanoparticles formed. In the references where XRD also done addition to SEM/TEM size of Silver nanoparticles obtained by both means was comparative. It was noticeable that the edges of the particles were lighter than the centers, suggesting that some bioorganic compounds such as proteins capped the silver NPs [87] contributing to reduction of Ag+ ions to Ag. However, it is not yet clear which protein or compound is responsible for bio reduction of silver.

X-Ray Diffraction

Characterization technique like UV-Vis, SEM, TEM are compatible with the impurities present in Solution containing Silver nanoparticles and plant extract (obtained by help of soxhlet apparatus), because they only stats about qualitative detection of silver nanoparticles not quantitative. Further demonstration and quantitative analysis of biosynthesized Silver nanoparticles was done by X-Ray Diffraction (XRD). X-ray powder diffraction is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions [65].

For quantitative study of sample should be in pure form, so biosynthesized silver nanoparticles were subjected to centrifuged at 8000-12000 rotation per minute (rpm) for 15- 30 minutes in most of the references. Obtained silver nanoparticles were subjected to the re-dispersion into small amount of deionized water and allow freezing. After freeze drying of the purified silver particles, the structure and composition were analyzed by XRD [46], using X-ray diffract photometer operated at a voltage of 40kV and a current of 30mA with Cu Kα radiation in a θ- 2 θ configuration and range of 20°- 80° [64].

The crystallite domain size was calculated from the width of the XRD peaks, assuming that they are free from non-uniform strains, using the Debye-Scherer's formula:

$$D = 0.94 \lambda / \beta \cos \theta$$

where D is the average crystallite domain size perpendicular to the reflecting planes, λ is the X-ray wavelength, β is the full width at half maximum (FWHM), and θ is the diffraction angle [61]. To eliminate additional instrumental broadening the

FWHM was corrected, using the FWHM from a large grained Si sample:

β corrected = $(FWHM^2$ sample- $FWHM^2si)^{1/2}$

This modified formula is valid only when the crystallite size is smaller than 100 nm [88]. As listed in Table 2 XRD results shows 3 characteristics peaks between 20°-80°respectively to the different plane like [111], [200], [220], [112], [311], etc. Comparative observation of peaks results shows that most of the time 1st peak was observed approximately at 38° (range of 28.09°- 38.18°) in the plane [111], other peaks like [220] and [101] were also observed. Similarly 2nd peak was observed approximately at 44° (range of 32.46°-64.52°) in the plane [200], other peaks were also observed like [111] and [122] and 3rd peak was observed approximately at 64° (range of 44°- 67.52°) in the plane [220], other peaks were also observed like [112], [311] and [400].

Analysis of peak indicated that the structure of biosynthesized silver nanoparticles is face-centered cubic (fcc) and have crystalline geometry in all the mentioned references. Also in most of the case peak was of sharp nature, this sharpening of the peaks shows that the biosynthesized particles are of the nano-scale dimension [57]. Sometimes peaks other than above mentioned also obtained, probably due to human error or may be due to presence of impurities in minute quantity or may be the all silver ions not reduced but forms agglomerates.

CONCLUSION AND FUTURE PROSPECTS

This review illustrates possibilities of development of reliable experimental protocols for the synthesis of nano-materials by performing analytical comparison of characterization techniques like visual observation, UV-Vis spectroscopy, Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM) and X-Ray Diffraction (XRD). Appearance of brown color in solution of silver nitrate and plant extract provide preliminary support for synthesis of silver nanoparticles. This appearance of color directly related to Localized Surface Plasmon Resonance [LSPR] [66]. Based on LSPR the UV-visible optical absorption properties are analyzed and found the absorbance peak between 410-465 nm. In some cases shift of SPR wavelengths was

also observed indicating formation of smaller silver nanoparticles but UV-Vis tells a little about dispersion and morphology of nanoparticles, so characterization by SEM or TEM is required.

SEM or TEM images reveled that in almost all references silver nanoparticles were of spherical in shape and they are found either in mono-dispersed or poly-dispersed arrangement. Biosynthesized nanoparticles size ranged between 03-140 nm depending upon the capping efficiency of unknown compounds of plant extract. For further structural characterization XRD results were analyzed and interestingly they revealed that silver nanoparticles shows 3 characteristics peaks between 20°- 80°. In most of cases 1^{st}, 2^{nd} and 3^{rd} peaks were observed at 38, 44 °and 64 ° respectively. Studying plane [111], [200], [220] confirmed the crystalline nature of silver nanoparticles with face centered geometry and this crystallographic surface structure with their large surface to volume ratio may increase chemical activity of nanoparticles.

Analytical study of the characterization techniques helps to sort the better condition for synthesis of good quality silver nanoparticles. The presented method in the table's references can be economic, environment friendly and effective alternative for the large scale synthesis of silver nanoparticles in nanotechnology processing industries. However the elucidation of exact mechanism of nanoparticles production using living organisms needs much more experimentations. Reduction of silver nanoparticle accomplished mainly because of phytochemicals like polyphenols, ascorbic acid capsaicinoids which might have played the important role in fabrication of Ag NPs [55]. The flavonoid and terpenoid constituents which present in Eucalyptus hybridaleaf extract are the surface active molecules stabilizing the nanoparticles [57]. Further experiments are needed in order to determine the atoms in the functional groups that are involved in the binding and stability of Silver nanoparticles. Issues such as monodispersity and shape selectivity for obtaining phase pure monodisperse nanoparticles are yet to be addressed and focused on.

A very promising application of nanoparticles is its use in targeted drug

delivery or also in "multi-targeting", which is essential in the case of several diseases [89]. Although it requires an understanding of the mechanisms of nanoparticles entering and leaving the cells [90]. Silver nanoparticle can be effectively applied in biomedical application by the use of biologically synthesized nanoparticles, comparative to chemical synthesis protocol which may produce toxic nano-waste, requires highly specified protocols and even the synthesized nanoparticle were not stable also. The biosynthesized silver nanoparticles can be used as potential free radical scavengers and also against the various damages caused by free radicals [68]. The potential benefits of nano-materials in biomedical applications for human health is because particle size scale is similar to that of biological molecules (e.g., proteins, DNA) and structures e.g., viruses and bacteria). Nanoparticles can be developed for diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles.

Table 1: Plants listed for Bio-synthesis of silver nanoparticles and their characterization results.

S. N.	Plantae extract used	Charterization Techniques	Color of Solution		λmax (nm)	Size of AgNPs (nm)		Refe-rnce
			Initial	Final	UV-VIS	X-RD	SEM/TEM	
1	***Allium cepa***	UV-VIS,TEM, DLS	light yellow	dark brown	413	NA	31-48	[53]
2	***Azadirachtaindica***	UV-VIS, TEM, FTIR, X-RD	NA	yellowish brown	450	NA	5-35	[54]
3	***Capsicum annum***	UV-VIS,TEM, X-RD,SAED	yellowish green	reddish brown	441	NA	02-06	[55]
4	***Carica papaya***	UV-VIS, SEM, X-RD, FTIR	watery	yellowish brown	450	15	25-50	[52]

5	***Cassia auriculata***	UV-VIS, SEM, FTIR, X-RD	yellow	yellowish brown	450	21	30-70	[18]
6	***Citrulluscolocynthis***	AFM, FTIR	yellowish green	reddish brown	NA	NA	75	[56]
7	***Elaeagnuslatifolia***	UV-VIS,TEM, X-RD	pale yellow	dark brown	450	NA	30-50	[46]
8	***Eucalyptus hybrida***	UV-VIS, SEM, EDX, X-RD	pale yellow	reddish brown	412	NA	50-150	[57]
9	***Euphorbia hirta***	UV-VIS, SEM, FTIR, X-RD	light yellow	reddish brown	380	31	13-61	[58]
10	***Lactuca sativa***	UV-VIS, SEM,TEM, FTIR,X-RD	yellowish green	golden brown	445	NA	40-50	[59]
11	***Nerium indicum***	UV-VIS, SEM, FTIR, X-RD	light yellow	reddish brown	380	29	13-61	[58]
12	***Ocimum sanctum***	UV-VIS, TEM, FTIR, X-RD	watery	reddish yellow	436	6.2	3-20	[60]
13	***Padina tetrastro-matica***	UV-VIS, SEM,TEM, FTIR, X-RD	pale yellow	golden brown	426	NA	20	[61]
14	***Partheniumhysteroph-orous***	UV-VIS, SEM, X-RD,PL	NA	NA	462	NA	40-140	[62]
15	***Phyllostachys***	UV-VIS,TEM, X-RD	colorless	yellowish brown	425	NA	25-35	[63]
16	***pomegranate seeds***	UV-VIS,TEM, X-RD	watery	yellowish brown	430	NA	30	[51]
17	***Ricinuscommunis***	UV-VIS, SEM, FTIR, X-RD	watery	dark brown	420	29	NA	[64]
18	***Rosmarinusofficinalis***	UV-VIS, X-RD	yellowish	dark brown	460	60	NA	[65]
19	***Saururuschinensis***	UV-VIS, SEM, FTIR, EDX, X-RD	yellow	reddish brown	415	NA	38	[66]
20	***Solanum torvum***	UV-VIS, TEM, FTIR, X-RD	colorless	yellowish brown	434	14	13	[67]

21	***Spinaciaoleracea***	UV-VIS, SEM,TEM, FTIR, X-RD	yellowish green	golden brown	440	NA	40-70	[59]
22	***Syzygium cumini***	UV-VIS, SEM, FTIR, X-RD,EDX	light brown	yellowish brown	450	3.5	93	[68]
23	***Zingiberofficinale***	UV-VIS, TEM, FTIR, X-RD	colorless	yellowish brown	430	NA	10-66	[69]

Table 2: Plants listed for Bio-synthesis of silver nanoparticles and their XRD, SEM or TEM results.

S. N.	Plantae extract used	Silver nanoparticles		Braggs reflections at 2θ in XRD for:						Reference
		Morpho-logy	Distribution	1st Peak	Resp. Plane	2nd Peak	Resp. Plane	3rd Peak	Resp. Plane	
1	***Allium cepa***	spherical	polydispersed	NA	NA	NA	NA	NA	NA	[53]
2	***Azadir-achta indica***	spherical	polydispersed	38	111	45	200	64	220	[54]
3	***Capsicum annum***	spherical	monodispersed	38	111	44	200	64	220	[55]
4	***Carica papaya***	cubic	polydispersed	38.11	111	64.52	110	67.52	112	[52]
5	***Cassia auriculata***	spherical	polydispersed	38.02	111	NA	NA	NA	NA	[18]
6	***Citrulluscolocynthis***	spherical	NA	NA	NA	NA	NA	NA	NA	[56]
7	***Elaeagnus latifolia***	spherical	NA	38.06	111	44.64	200	64.58	220	[46]
8	***Eucalyptus hybrida***	cubic	monodispersed	30.8	111	38	NA	44	NA	[57]
9	***Euphorbia hirta***	spherical	monodispersed	38.11	111	44.46	200	65.24	220	[58]
10	***Lactuca sativa***	spherical	polydispersed	38.18	111	44.37	200	64.48	220	[59]

11	***Nerium indicum***	spherical	monodispersed	38.11	111	44.46	200	64.48	220	[58]
12	***Ocimum sanctum***	spherical	polydispersed	37.6	111	44.7	200	76.3	311	[60]
13	***Padinatetrastr-omatica***	spherical	monodispersed	28.09	220	32.46	122	42.18	400	[61]
14	***Partheniumhysteroph-orous***	spherical	polydispersed	38.1	111	44.6	200	64.8	220	[62]
15	***Phyllost-achys***	spherical	polydispersed	38	111	44	200	64	220	[63]
16	***Pomegr-anate seeds***	spherical	NA	NA	NA	NA	NA	NA	NA	[51]
17	***Ricinus communis***	NA	monodispersed	38.11	111	44.27	200	64.42	220	[64]
18	***Rosma-rinusofficinalis***	NA	NA	32.37	111	38.4	111	44.85	200	[65]
19	***Saururus chinensis***	spherical	polydispersed	32.22	NA	32.96	NA	38.08	111	[66]
20	***Solanum torvum***	spherical	monodispersed	38	111	44	200	64	220	[67]
21	***Spinacia oleracea***	spherical	polydispersed	38.18	111	44.37	200	46.18	200	[59]
22	***Syzygium Cumini***	spherical	monodispersed	32.4	101	38.2	111	44.4	200	[68]
23	***Zingiber officinale***	spherical	polydispersed	38	111	45	200	64	220	[69]

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