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GREEN SYNTHESIS OF METAL-BASED NANOPARTICLES USING MEDICINAL PLANTS: APPLICATIONS IN BIOMEDICINE AND ENVIRONMENTAL REMEDIATION

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Abstract
Nanotechnology has emerged as a prominent multidisciplinary field with wide-ranging applications across scientific and industrial sectors. While several nanoparticle synthesis methods—such as laser ablation, mechanical milling, spinning, and chemical deposition—are well established, they often face limitations due to high costs, the use of hazardous chemicals, and challenges in continuous production. This has led to a growing interest in sustainable, cost-effective, and environmentally friendly synthesis approaches. Green synthesis has gained considerable attention as a reliable and eco-conscious alternative for producing various nanoparticles. In this approach, plant-derived secondary metabolites—such as polyphenols, flavonoids, and terpenoids—serve as natural reducing and stabilizing agents during nanoparticle formation. Although many studies have demonstrated the biological activities of biosynthesized nanoparticles, including antimicrobial, antioxidant, cytotoxic, and catalytic properties, few have systematically compared them with chemically synthesized counterparts. This review focuses on the biosynthesis mechanisms of metal nanoparticles using Morus alba and Ficus benghalensis extracts, along with their characterization using advanced analytical techniques. Additionally, the potential applications of these nanoparticles in therapeutics, industrial catalysis, and environmental remediation are explored.

1. INTRODUCTION

One amongst the rapidly emerging ideas in recent years is nanotechnology in science and technology.[1-2] Nanotechnology is the branch of knowledge that is concerned with the material fabrication and handling at nanoscale. Nanoparticles are extremely small substances that have a structural measurement of fewer than 100 nm.[3-4] The nanomaterial that comprises distinguishing physicochemical parameters has the power to grow novel systems, structures, procedures, and nano platforms with imminent bids in wide range of disciplines. They include definite features like as big surface area and quantum confinement that are regarded to be an important condition of material.[3, 5]

Usually metal nanoparticles fabrication processes are categorized as top-down and other one is bottom- up methods.[6] The synthetic routes include sol-gel formation,[7-8] chemical vapor deposition, hydrothermal, lyophilization, sonochemical,[9] thermal decomposition, wet polymerization, solvothermal, precipitation, microwave assisted,[10] micro-emulsion and laser ablation.[11] However, these methods have a lot of disadvantages owing to the obscurity of scale up the procedure of fabrication, separation and refinement of nanoparticles from the co-surfactants, surfactants, toxic materials and organic solvents.[12] Above these usual synthesis techniques, the green synthetic route employing natural plant extracts is one of the new broadly accepted routine owing to its numerous advantages, such as need of no supplementary chemicals, easy, environmentally pleasant, cheap and reliable method.[13-14] In green technology, the enzymes act as the reducing and capping medium for the immense fabrication of nanoparticles.15 Numerous phytochemicals found in the leaf or other part's extract, apart from enzymes also work as stabilizing, reducing and capping power in the course of nanoparticles production.16 White mulberry belonging to the Morus genus is a fast-growing and tiny lived tree, that is broadly cultured in a subtropical, temperate, tropical countries and particularly in Asia.17-19 Morus alba also has an impact as anti-oxidant, anti-diabetic, antibacterial, neuroprotective, anti-inflammatory properties,20-21 hepatoprotective and anti-cancerous activities. Mulberry leaves, stems, and root are widely consumed as tea in many parts of the world due to their strong medicinal value.22-24 In herbal remedies, root bark has also been used as an antichloristic, diuretic, hepatoprotection, cough suppressant, analgesic, and hypotensive involving triterpenes, proteins, amino acids, carbohydrates, and vitamins C are all abundant in roots.25

Ficus benghalensis L. belongs to Moraceae family is usually famous as "banyan", that is an Indian local tree and has been widely probed for controlling stress, endocrine (diabetes), respiratory and gastrointestinal disarray.[26-27] Ficus is a big genus of flowering flora with widespread division in the semi-tropical temperate and tropical zones. Plants in this genus have engaged a lot of biological niches, and can be evergreen or deciduous trees, climbers, creepers, shrubs and herbs.[28-29] From a long time, the medical properties of the Ficus have been widely investigated, including studies into the antioxidant, anti-inflammatory,[30] antimicrobial,[31] anticancer, and antidiabetic activities of these plants.[28, 32] The leaves are fine for ulcers, seedlings and fruits are cooling, and the aerial roots can help with gonorrhea. A water extract of plant bark has been revealed to have a hypoglycemic effect.[33] This review concise the fabrication of various metallic nanoparticles using Morus alba and F. benghalensis plant extracts, which are recent developments in the green synthesis, with a focus on the applications of these nanoparticles in the field of biomedical and environmental remediation.

2. Fabrication of Nanoparticles

Nanoparticles are synthesized by utilizing various chemical and physical approaches including electrochemical, photochemical, laser ablation, hydrothermal and microwave irradiation.[34-36] Physical methods make the use of physical approach that uses various methodologies including laser ablation and condensation/evaporation. The chemical technique is a method of reducing metal ions in solution under conditions that favor the production of tiny metal clusters or aggregates.[37-38] These methods are classified into two types. In the bottom-up method, reaction parameters or controlled deposition are used to gather atoms and molecules into nanoparticles of the desired shape and size. Sol-gel, the formation of integrated circuits in electronic industry are examples of this approach. In top-down approach, suitable nanoparticles are formed by the removal of atoms and molecules from the bulk material by employing the reverse mechanism.[38]

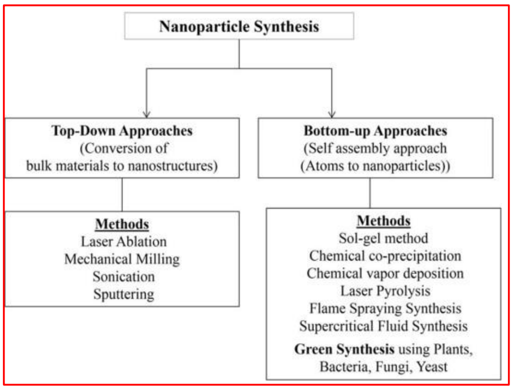

Figure 1: Different methods of nanoparticle synthesis

3. Green synthesis of nanoparticles

Biogenic fabrication of nanoparticles is an approach of green chemistry which interlinks nanotechnology and biotechnology.[39-40] Green fabrication of metallic nanoparticles has been adopted to contain a variety of natural materials (i.e., bacteria, algae, plant and fungi). In comparison to fungi and bacteria conciliated synthesis, consumption extracts of plants is a comparatively trouble-free and straightforward approach for fabricating metal or metal oxide nanomaterials on a big level.[16] Green synthesis of nanoparticles is a kind of bottom-up technique where the main effect is oxidation or reduction. These yields are identified communally as biosynthetic nanoparticles. The microbial enzyme and phytochemicals of the plant with antioxidant or reducing properties are regularly liable for producing particular nanoparticles by reduction of metal compounds.[41-42] The benefit of using flora for the production of nanoparticles is that they are simply accessible, secure to handle and have a large variability of metabolites that may assist in reduction.[41] Green synthesis of nanoparticles avoids various of the risky parameters by permitting the nanoparticles production at easygoing pH, pressure, and temperature at a notably minor price.[43-44] For nanoparticles green synthesis provides ecofriendly and non-toxic reagents. So biogenic production of nanoparticles is a bio-reduction technique of single step and use less power to manufacture eco-friendly nanoparticles.[45] When compared to alternative green sources, using plant material for the biosynthesis of nanomaterial with particular sizes, shapes, and functions is the best method.[46-47]

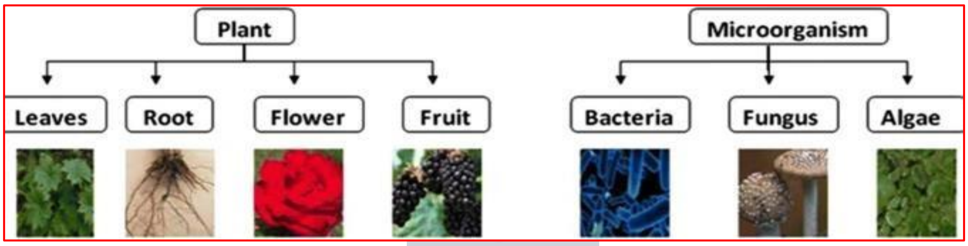

Figure 2. Sources to synthesize nanoparticles by green chemistry.

3.1. Why green synthesis?

This uprising is owing to the reliance of citizens in favor of herbal based items as majority of the people now conscious of side effects of a chemically derivative or antimicrobial synthetic substances, which have undesirable effects on human health. People are turning to herbal-based medicines, which are effective, environmentally safe, and relatively free of surface composition, in order to avoid such severe and life-threatening side effects.[48]

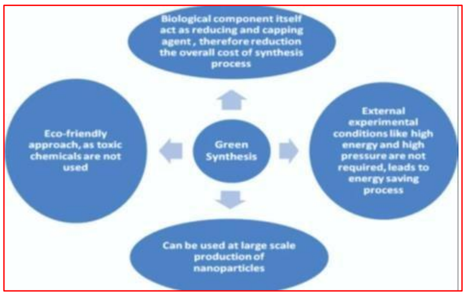

Figure 3: Key merits of green synthesis

4. Mechanism of Green Synthesis of nanoparticles by Plants

Many microorganisms and extracts of various plants have been employed in the green synthesis of metallic and metal oxide nanomaterial, such as Ag NPs, ZnO NPs, Au NPs, FeO NPs, Cu NPs, and other metal and metallic oxide nanoparticles in recent years. Phytochemicals like phenols, saponins, alkaloids, terpenoids, flavonoids, carbohydrates, tannins, and others are required for nanoparticle phytosynthesis and mechanism.[49] There are three processes to the bio-reduction of metallic NPs utilizing extracts of plants. The first is the stimulation stage, which involves metal ion reduction and aggregation. Second, the small nearby NPs merge to form larger particles, which is go along with an elevation in the nanoparticle's thermodynamic strength, which is referred to as the growth period. Lastly, the terminal phase determines the geometry of the nanoparticles.[50-51] Furthermore, several plants are recognized for accumulating heavy metals and their capacity to detoxify them. Metal resistance in plants is mediated by a variety of mechanisms, notably cell wall binding, metal ions active transport into the vacuole and metal chelation.[52] As a result, when botanical extract polyphenolics APOH combine with a metallic halogen initiator, the process for the production of nM^0 as zero-valent metallic atoms is as follows:

$$nAPOH + nM^{n+} \rightarrow nAPX + nM^0$$

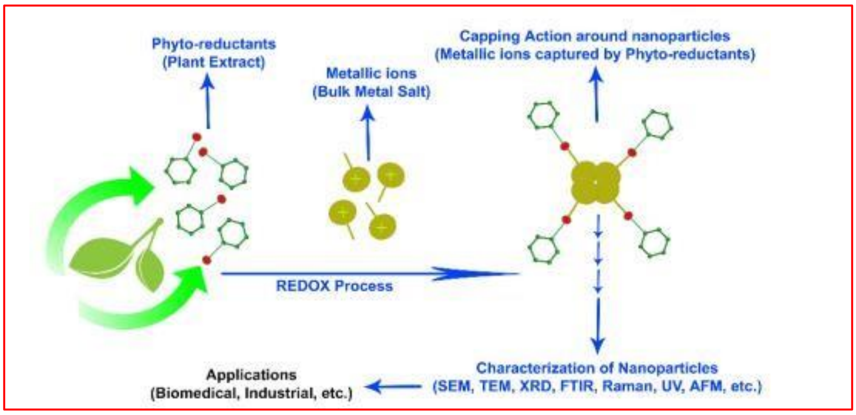

Figure 4. Schematic mechanism of metallic nanoparticles by plant extract.

5. Literature reported for synthesis of metal nanoparticles

5.1. Plant extract preparation

i. Ficus Benghalensis

Shinde, H., et al., reported the plant extract preparation of ficus benghalensis. The fresh leaves of F.B. were washed firstly with tap water for numerous times before being washed with deionized water to eradicate trash, other waste material and then shade dried to get rid of remaining humidity. Then, 5 g of grinded material was mixed with 50 mL of double distilled water and held on a hot plate with magnetic stirrer (at 40°C for an hour). This extract was filtered using Whatman filter paper and then successively used in the biological synthesis.[56]

ii. Morus alba. L

Liem, L.N. and D. Nguyen reported that mulberry leaves were collected from inhabited garden in good condition. After that clean leaves were then washed with fresh water and laid out uniformly to air dry.[57] Approximately 10 grams of foliage were lightly cut and cooked with 100 ml of distilled water for 60 minutes. To remove hanging contaminants, the aqueous extract was filtered through Whatman No. 1 paper and centrifuged for 5 minutes at 2000 rpm. The supernatant was employed for biogenic silver nanoparticle production.[22]

5.2. Green synthesis of metallic nanoparticles

5.2.1. Morus alba plant extract

R. Razavi et al., reported the synthesis of metallic nanoparticles using mulberry plant extract. An identified molarity of the metal salt solution (2 milli molar) and extracts of plants in volume-to-leaf extract ratio allowed for the green production of NPs (5:1).[17] The solution was allowed to cool to room temperature while being continuously stirred at 200 rpm. Auxiliary experiments were undertaken to determine the influence of concentration of cation by taking into account the color changes seen for Pd and Cu NPs at 3.3 hours, respectively.

Abbes, N., et al., investigated the fabrication of of ZnO nanoparticles. To make ZnO nanoparticles, 100 mL of fruit extracts was combined with 0.5 M of zinc acetate and rapidly agitated for 3 hours at 90°C. The material was permitted to stay for 24 hours before being isolated from the reaction mixture using centrifugation at 7000 revolutions per minutes for ten minutes and rinsed with distilled water several times to get rid of contaminants. Finally, the product was dried up at 80 degrees Celsius in an oven. The pulverized substance was then calcined for 2 hours at 600°C in a muffle furnace to produce a light white residue. The clear yellowish powder of ZnO nanoparticles with fruit extract of mulberry was kept in the freezer until this was needed for characterization tests.[58] Arshad, M., et al., reported that the silver nanoparticles were synthesized, according to the study. 8 mL of plant extract was gradually combined with 20 mL of silver nitrate solution (0.1M). The color of the combination gradually transformed from green to brownish precipitates as the silver nitrate solution was stirred with plant extract. To obtain pure silver nanoparticles manufactured from M. alba, this powdered sample was sintered in a furnace at 700°C.[59] Adavallan, K. and N. Krishnakumar, reported method to synthesize gold nanoparticles. The plant extract (0.2, 0.4, 0.6, 0.8, and 1 milli liters) was mixed to a briskly agitated 10 milli liter of 2×10^{-4} M $HAuCl_4 \cdot 3H_2O$ held at room temperature for the biogenesis of Au-NPs, yielding the suspended particles gm1-gm5. The lowering of gm1 was sluggish and took 36 hours to complete. The rate of decrease is observed to rise as the amount of leaf extract is increased. Quick reduction happened for gm5, as evidenced by the violet-pink color of the solution and the kinetics was finished in less than 4 hours. The gold nanoparticles that results is shown to be stable for more than two months.[60] Poguberović, S.S., et al., investigated production of iron nanoparticles. Weighing 4 g of leaf and transferring it to 300 mL Volumetric flask with 100 mL of water. After that it was put in a shaker at 80 degrees Celsius for 60 minutes for flasks with mulberry leaves. Through Buchner filtration the solution was filtered following shaking, and the filtrate was utilized to make "green" zero valent iron nanoparticles. In a 3:1 volume ratio, leaf extract was combined with 0.1 M Iron (III) solution.[61] Das, D., M.S. Haydar, and P. Mandal reported that silver nanoparticles were synthesized by mulberry leaves extract and 0.001 M solution silver nitrate. For phytosynthesis, 5 ml screened mulberry leaf extract was mixed dropwise to 45 ml of 0.001 M solution of silver nitrate with constant stirring (Remi equipment) for 5–10 min after vaporizing 10 g lightly diced leaves in 100ml deionized water for 60 minutes at 100°C. The reducing and encapsulating agents included in extract of leaves reduced translucent silver nitrate to a brown color, signifying the creation of silver nanoparticles.[62]

Table 1. Synthesis of nanoparticles from Morus Alba.

Sr. No.	NPs	Chemical used	Plant part	Extract/chemical amount	Heating	References
1.	Cu	$Cu(NO_3)_2 \cdot 3H_2O$	Leaf	20/100 mL (2mM)	25°C.	17
2.	Pd	$PdCl_2$	Leaf	20/100 mL (2mM)	25°C.	17
3.	ZnO	Zinc acetate	Fruit	100/100mL (0.5M)	90°C.	58
4.	Ag	$AgNO_3$	Leaf	8/20 mL (0.1M)	60°C.	59
5.	Au	$HAuCl_4$	Leaf	1/10 mL (0.0004M)	25°C.	60
6.	Ag	$AgNO_3$	Leaf	5/45 mL	100°C.	62
7.	Fe	$FeCl_3 \cdot 6H_2O$	Leaf	25/100 mL(0.1 M)	25°C.	61

5.2.2. Ficus Benghalensis plant extract

Lagashetty, A., et al., used 20 milliliter of leaf extract was put dropped into 20 mL of (0.1 Molar) dilute Zirconyl chloride octahydrate solution and continuously stirred using magnetic stirrer for biogenesis of ZrO_2 NPs. In microwave oven for 15 minutes at 900 W, the resulting solution was evaporated to dryness. To make a fine powder, the substance was pounded for 15 minutes with a mortar and pestle. The powder was then calcined for 3 hours at 500°C in a temperature-controlled muffle furnace.[63] Sudhakar, T., et al., investigated the synthesis of silver nanoparticles. In test and control test tubes, 1 mL of extract is mixed with 9ml milli 'Q' water. Weigh 0.5 grams of silver nitrate crystals and dissolve them in 5 milliliters of milli 'Q' water; the control sample is stored in a dark room uninterrupted. To the sample for testing A milli molar solution of silver nitrate is added to the test sample and left in the dark for 12 hours. The color change in the test sample may be seen after 12 hours.[64] Lagashetty, A., et al., reported fabrication of CeO_2 and Fe_3O_4 nanoparticles. In a 250 mL washed conical flask, 50 milliliter of $Ce(NO_3)_3 \cdot 6H_2O$ solution of 0.01 molarity was drained and put on a magnetic stirrer. 50 mL of freshly made Ficus benghalensis leaf extract was mixed for this reason, and the solution was agitated

for 30 minutes using a magnetic stirrer to ensure good mixing. This solution was then heated for 15 minutes in a household oven at rate of 2.45 Giga Hz and power of 800 W. Cooling the cerium oxide nanomaterials solution to room temperature and set aside for 30 minutes. The precipitate was collected by centrifugation at 500 rpm from a brown colour solution, that was then heated at 600ºC for 1 hour. After that, smooth crystals of CeO_2 particles were procured and rinsed in acetone before drying. Using F. benghalensis leaf extract, a same process was used to synthesis Fe_3O_4 from its corresponding salt solution.[63]
Esmael, H.H., E.J. Saheb, and S.A. Hasoon, investigated that the magnesium oxide NPs prepared from the Ficus benghalensis leaf extract as followed. 10 mL of the leaf extract was combined with 50 mL of the freshly prepared 0.1M Magnesium nitrate hexahydrate. 1M NaOH was mixed drop wise, and the mixture was stirred constantly for four hours at 800°C. A dramatic change in color from pale green to yellow was seen after adding Magnesium nitrate solution, indicating the creation of $Mg(OH)_2$ nanoparticles. The acquired object was centrifuged for 30 minutes at 4000 rpm, then washed many times with deionized water to remove the pollutants before being dried in the oven for five hours at 500 degrees. Subsequently, it was calcined at 450ºC for three hours in the Muffle heater yielding pale white colored MgO nanoparticles for powder production.[65]
Tripathi, R.M., et al., dissolved selenium metal grind powder (0.6 M) and sodium sulfide (3.87 M) in 10 mL distilled water and heated gently at for 1 hour with constant stirring at 90°C. The color shift from colorless to ruddy brown denotes the production of selenium sulfite. Then 0.5 mM of it was added to 100 mL distilled water and shaken for 10 min at room temperature then adding 5mL dropwise of leaf extract. The transform in color of the solution to reddish orange denoted the presence of selenium nanoparticles.[66] Ismail, H.H., et al., reported the synthesis of silver oxide nanoparticles. To make silver oxide NPs (Ag_2O NPs), 10 mL of F. benghalensis root extract was mixed with 90 mL of 0.458 g of $AgNO_3$ solution in 250 mL volumetric flasks, and the reaction was carried out at 80ºC on a magnetic thermal stirrer. The color of the reaction mixture changes from pale yellowish to dark brown after four hours, indicating the synthesis of silver nanoparticles.[67]
Achudhan, D., et al., synthesized TiO_2 nanoparticles. In a nutshell, 0.50 M Titanium tetrachloride (80 mL) was mixed with the fresh leaf extract (80 mL) and constantly stirred. The reduction of Ti^{4+} caused the color to transform from clear to pale white after 60 minutes, showing the production of NPs. The filtrates were then rinsed with ethanol, dried, calcined for 3 hours at 300°C, and crushed to yield a fine powder.[68]
Francis, G., et al., used various amounts of Ficus benghalensis plant extract added to ten mL of 10 mM Auric chloride ($HAuCl_4$) to achieve concentrations of 1:1, 1:2, 1:4, 1:8, and 1:8 nanomaterials. At 30 degrees Celsius, the reaction mixture was incubated for 5-7 minutes. The change in color of gold chloride to pinkish confirms the formation of nanoparticles.[69]

Table 2. Synthesis of nanoparticles from Ficus Benghalensis.

Sr.No.	Metallic nanoparticles	Chemical used	Plant part	Extract/ chemical amount	Heating	Ref.
1.	ZrO_2	$ZrOCl_2.8H_2O$	Leaf	20/20 mL (0.1M)	900 W	63
2.	Ag	$AgNO_3$	Leaf	1/50 mL	25°C	64
3.	CeO_2	$Ce(NO_3)_3.6H_2O$	Leaf	50/50 mL (0.01M)	800 W	63
4.	MgO	$Mg(NO_3)_2$	Leaf	10/50 mL (0.1M)	800°C	65
5.	Ag_2O	$AgNO_3$	Root	10/90 mL	80°C	67
6.	TiO_2	$TiCl_4$	Leaf	80/80 mL (0.5M)	25°C	68
7.	Au	$HAuCl_4$	Leaf	10/10 mL	30°C	69
8.	Fe_3O_4	$Fe(NO_3)_3.9H_2O$	Leaf	50/50 mL (0.01M)	800W	63

9.	Se	Selenium sulphite	Leaf	5/100 mL	25°C	66
10.	S	Na2S2O3.5H2O	Leaf	20/50 mL (0.078M)	-	70

6. Characterization Techniques

Characterization of synthesized nanoparticles becomes crucial because the applications of nanoparticles are mainly dependent on properties. The important techniques which are used for characterization of nanoparticles synthesized from extract of Ficus Benghalensis and Morus Alba are scanning electron microscopy, Fourier transform infrared spectroscopy, transmission electron microscopy, UV-Visible spectroscopy and X-ray diffraction technique.

Ultraviolet visible spectroscopy is a type of absorption spectroscopy which uses Beer Lambert law in its operation. The overall oscillations of electrons of conduction band together with electromagnetic waves and surface plasmon resonance are computed by using this approach.[71] UV-visible spectrophotometer consists of a wideband radiation source, dispersion element such as grating or prism, slits and detector. Incoming light is incident on dispersing element by means of narrow slit, whose aim is to separate the spectral lines component. These component lines are directed to pass through sample before being collected at detector. UV-vis spectroscopy is utilized in various applications including sensing, bio-medical, beverage, food and water assay etc.[72] M. Kavitha et al., carried UV-visible spectroscopy to characterize the silver nanoparticles prepared by using Ficus Benghalensis bark extract. The surface plasmon resonance band was observed at 436.47 nm.[37] Infrared spectroscopy deals with the interaction of infrared radiations with functional groups present in chemical substances, causing certain vibrations that serve as fingerprint of biological or chemical compounds in sample.[73] To determine distinct functional group present in nanoparticles, Fourier transform infrared spectrophotometer operates at long wavelengths. FTIR indicates the functional groups associated with extract having nanoparticles.[71] The biomolecules causing the stabilization of nanoparticles of gold produced by Morus alba leaf extract were indicated by FTIR.[60] The detail of various peaks is given in table. XRD is a tool to identify a material's crystalline and atomic structure; it allows for the evaluation of sample's crystal structure but provides no chemical information.[74-76] XRD tests revealed the crystalline nature of Au-Nps synthesized by mulberry leaf extract. The sharp diffraction peak was detected at 38.3° which was associated with the face centered cubic planes (111). The as prepared Au- Nps were of high purity which was indicated by the absence of peak flattening and crystallographic defects.[60] The information concerning about size, morphology, structure and shape of nanoparticles is determined by means of transmission electron microscopy (TEM) and scanning electron microscopy (SEM).

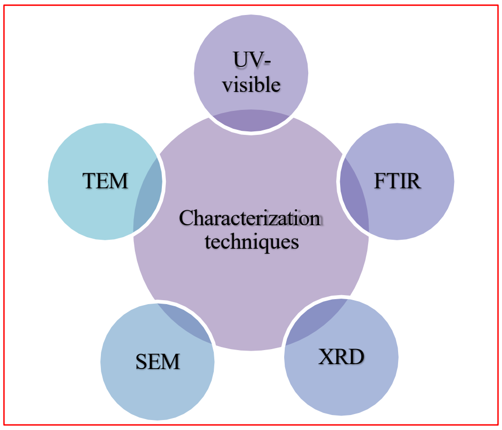

Figure 5: Characterization techniques of nanoparticles.

Table 3. Characterization techniques of Ficus Benghalensis mediated nanoparticles.

Sr. No.	NPs	Functional group analysis		SPR peak (nm)	Shape	Size (nm)	Ref.
		cm^{-1}	Groups				
1.	Ag	3410 1637 1211	-OH Aromatic rings Plant ascribed to multiplet C=O	436	Spherical	20	37
2.	ZrO_2	3274 1594 784	O-H C=O Zr-O-Zr	240-350	Spherical	15	34
3.	Ag	3370 2850 1590 1411	O-H C-H C=O	410	Spherical	14	77
		1390	Aromatic vibrations				
4.	Ag-ZrO_2	2930 1100-1500 1735 605-1048	O-H C=O O-H Zr-O-Zr	-	Spherical	15	77
5.	MgO	3700.33 3428.63 2459.27 1646.61 1450.83 1378.91 859.489 435.96	N-H O-H C-N C=C C=C C-O C-H Mg-O	-	Needle like	5.7	65, 78
6.	Sulfur	2357 3737 1396 3606 667.9 1056 880.6 1539	O=C=O -OH CO O N-H S8 S8 S8 S8	274	Random	~25-~120	76

7.	Ag_2O	3360 2922 1611 1383 1058	O-H/N-H C-H C=O N-C=O C-N	430	Spherical	42.7	79-80
8.	Fe_3O_4 CeO_2 ZnO	3300-3500 1500-1550 420-650	O-H C-H M-O	350, 360, 400	Spherical, irregular & needle like	-	63, 81-83
9.	Ag_2O	3441.07 2927.21 2359.27 1632.05 1034.06 460.1	O-H C-H C-N C=C C=O Ag-O	430	Spherical	16	84-87
10.	Se	-	-	268	Spherical	45-95	66
11.	Gold	1150 600 3500 1300	C-H C-C O-H C-N	530	Spherical	-	69

The TEM technique is preferred over SEM due to higher magnification and resolution as compared to SEM and TEM images provide exact data related to nanoparticle's size, composition and shape. TEM has the ability to distinguish between amorphous and crystalline objects by using selected area electron diffraction approach which is regarded as another advantage of TEM images.[88-89] The morphology of Selenium nanoparticles synthesized by using Ficus Benghalenis leaf is determined by R. M. Tripathi et al. The shape of Selenium nanoparticles was obtained to be spherical. The average particle size was determined to be approximately in the range of 45-95 nm.[66]

Table 4. Characterization techniques of Morus Alba mediated nanoparticles.

Sr. No.	Synthesized NPs	Functional group analysis		SPR Peak	Shape	Size	Ref.
		cm^{-1}	Groups			(nm)	
1.	Silver	-	-	400-450	Irregular	97	90
2.	Silver	3440 1680 1390 1490 1632	O-H H-O-H -C-O, -C-O-C =N-H -N-H	-	Spherical	50	59
3.	Silver	-	-	440	Spherical	15-25	91

5.	Silver	3257 2925 2855 1742 1633 1051	O-H N-H C-O O-H C-O N-O	410	Spherical	10-50	92
6.	Silver	3430.9 2919.8 2854.2 1627.7 1386.6 1033.7 796.4	N-H -CH2 -CH3 N-H C-N C-O N-H	423-450	Spherical	12-39	22
7.	Silver	3292.53 1627.27 1353.62	O-H C=O C-N	480	Spherical	11.8	93
8.	Copper	1704,16 27,1718 622	C=O Cu-O	780	Spherical	101.2	17
9.	Palladium	1704,16 27,1718 925, 850	C=O Pd-O	No peak	Non-regular	76.4	17
10.	Iron	-	-	-	Spherical	10-30	61
11.	Zinc	460.1 962.24 1045.99 1551.34	Zn-O C-H C-O C-C	350	Spherical	25.2	58
12.	Gold	3402 2920 1636 1385 1078	N-H, O-H C-H C=O C-N C-OH	538	Spherical	50	60

7. Biomedical applications of metal nanoparticles

7.1. Antimicrobial, Antibacterial and Antifungal activities

The biologic synthesis of metal nanoparticles is conventional approach and utilization of plant extract has gained popularity as a control method against diseases, besides being secure and having no potentially toxic impacts.[94] Kavitha et al., synthesized the silver nanoparticles to investigate the antimicrobial efficacy which was found to be mild in C. albicans and S. aureus as compared to E. coli. The differences in antimicrobial activity was ascribed to the peptidoglycan layer that is unique characteristic of membrane.[37]

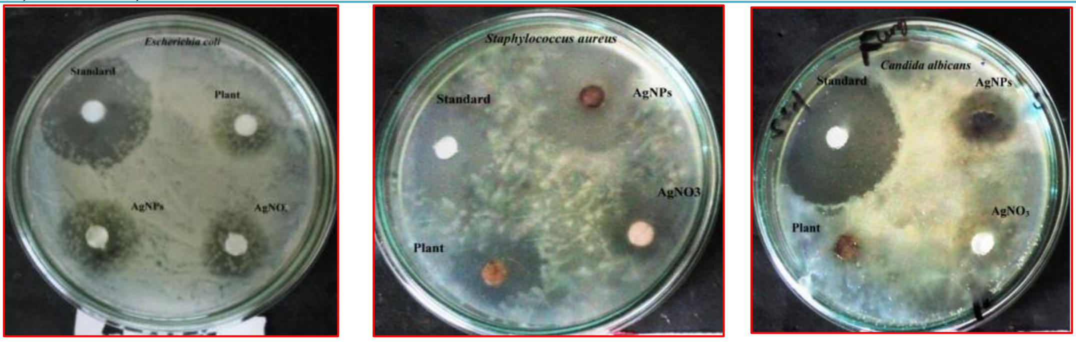

Figure 6. Antimicrobial activity of Ag nanoparticles Ficus Benghalensis against E. coli, S. aureus and C. albicans.

Kushare, V. N. et al., compared the antibacterial efficacy of silver nanoparticles synthesized by leaf extracts of various Ficus species. The highest activity was found in the Ag nanoparticles synthesized by F. Tribola while least activity was given by Ag nanoparticles prepared by F. Citrifiolia leaf extract against Mycobacterium. While in case of bacillus, the maximum inhibition was shown by Ag nanoparticles synthesized by using Ficus hispida while least activity was given by Ag nanoparticles of Ficus Benghalensis. F. citrifiolia mediated silver nanoparticles showed lowest antibacterial activity against citrifiolia.[95] Antibacterial and antifungal efficacy of silver nanoparticles synthesized by Morus Alba root extract was tested through disk diffusion technique by G.F Minhas et al. Silver nanoparticles synthesized by methanolic extract of M. Alba was found to possess high antibacterial (MIC=5), antifungal (MIC=5), antitumor (IC_{50}=59.03 µg/mL), antioxidant (IC_{50}=158.68 µg/mL) and cytotoxic activity (IC_{50}=24.83 µg/mL).[90] Antibacterial efficacy of silver nanoparticles synthesized by ficus benghalensis prop root extract (FBPRE) was reported by V. Manikandan et al., against L. acidophilus and S. mutans. The combination of FBPRE Ag_2O nanoparticles gave maximum inhibitory zones of 18 and 15 mm.[84] D. Achudhan et al., investigated TiO_2 nanoparticles for antibiofilm, mosquitocidal, antibacterial and antifogging activities against Candida albicans, Citrobacter freundi, Streptococcus mutans and Zika virus vector Aedes aegypti. The inhibition of both fungal and bacterial biofilms was observed at 100 µg/mL. The death of A. aegypti was found to be 98 % at 75 µg mL^{-1} of TiO_2 nanoparticles.[68]

C. Wang et al., and Tipaporn Kumkoon et al., evaluated the antioxidant, antimicrobial and anticancer potential of nanoparticles of Silver synthesized by green chemistry and chemical approaches. The largest inhibition zones were shown by Morus alba mediated Ag nanoparticles against E. coli and A. aureus by restricting the bacterial growth indicating the high antimicrobial activity of green synthesized silver nanoparticles.[96] S. Some et al., studied the green synthesized Ag nanoparticles for removal of silkworm bacteria. The inhibition in growth of ASM & ASE bacteria isolated from silkworm were noticed. MBC and MIC for ASM strain were determined to be 60 ppm and 30 ppm while MBC and MIC for ASH strain were found to be 80 ppm and 40 ppm respectively when these bacteria came in contact with silver nanoparticles.[93] The antibacterial efficacy of copper, silver and palladium nanoparticles has been evaluated by Razavi R. et al., against Listeria monocytogenes and Escherichia coli. The authors found out that copper nanoparticles exhibit high antibacterial potential as compared to silver and palladium nanoparticles.[17] The antioxidant activity of Zinc oxide nanoparticles made with mulberry leaf extract was tested using 2,2- Diphenyl-1-Picryl-Hydrazyl by N. Abbes et al. The antioxidant potential was found to enhance with the increase in zinc oxide nanoparticle's concentration.[58] K Adavallan et al., studied the antibacterial efficacy of gold nanoparticles made with Morus Alba leaf extract which was determined to be higher against Vibrio chlolera than Staphylococcus aureus.[60] The nanoparticles of gold were tested for antibacterial activity against gram positive and gram -ve bacteria by G. Francis et al. Against the test species, the gold nanoparticles were found to exhibit maximum inhibition zone for gram positive bacteria.[69]

7.2. Anti-Leishmaniasis activity

Leishmaniasis is a parasite disease spread by the bites of sand flies that affects humans, rodents and animals. There are several drugs that are being used for the treatment of leishmaniasis. Pentavalent antimonial and sodium stibogluconate are among the compounds that are most commonly used for its treatment. But this treatment imposes certain restrictions, including high cost, toxicity and resistance requirement. Nanoparticles are effective for the removal of parasites because of their inhibitory and destructive nature.[97-101] Ismail et al., synthesized Ag2O nanoparticles in order to check its anti- leishmaniasis activity against L. donavani parasite. The growth rate of parasite was decreased on treatment with Ag2O nanoparticles as compared to with pentostam drug.[67] Anti-leishmaniasis efficacy of Magnesium oxide nanoparticles were compared with Pentostam against L. donavani by H. H. Ismail et al. The growth of L. donovani was found to be lower on treatment with MgO nanoparticles in comparison to its growth on treatment with pentostam drug.[65]

7.3. Anti-Cancer activity

Osteosarcoma is the commonly found cancerous bone tumor, indicated by the development of juvenile bone or osteoid tissue by proliferating spindle cells. It has high carcinogenic tumor rate in teenagers, as well as high recurrence rate and a low survival rate.[102-106] Silver nanoparticles have gained the interest of many researchers due to its intriguing features, including high thermal and electrical conductivity, chemical inertness, high catalytic and microbial activities and surface intensified Raman scattering. These distinctive features of nanoparticles of silver are particularly beneficial for cancer therapies, since they resulted in increased chemotherapeutic activity with minimal toxic side effects.[107] D. Nayak et al., used MG-63 Osteosarcoma cell to investigate the antiproliferative response of silver nanoparticles. The IC50 value for F. Benghalensis mediated silver nanoparticles was found to be 75.5 ± 2.4 µg/mL.[108-109]

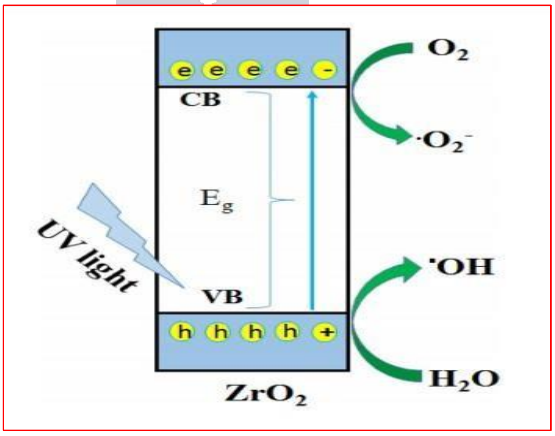

Figure 7: Mechanism for the Photocatalytic degradation of dyes using ZrO2.

Healing activity

Ag nanoparticles produced by M. Alba leaf extract were used as curative agents in vitro tests on hepatic carcinoma (HepG2) cells for cytotoxic activity and in vivo tests in model of rat for hepatoprotective impact by A. Singh et al. The IC50 values for leaf extract of Morus Alba and Ag NPs were determined to be 80 µg/mL and 20 µg/mL respectively against HepG2 cell after incubation period of 24 hours. The restoration of serum enzymes was observed when rats were exposed to Ag NPs fabricated N-nitrosodiethylamine.[92]

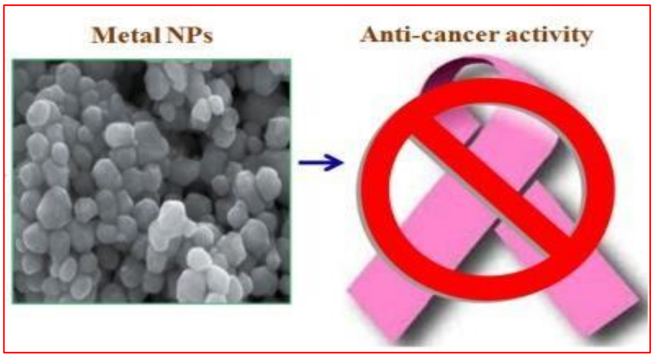

Figure 8: Anticancer activity of silver nanoparticles

Environmental remediation

7.4. Photocatalytic activity

Photocatalysis is a non-toxic and environmentally friendly water detoxification approach. In photocatalysis, light energy is converted into the redox reaction that degrades the pollutants present in water by the formation of free radical. Water detoxification through photocatalysis is a fascinating and commonly adopted because of its ease of use, low cost and durability.[110-111] H. M. Shinde et al., investigated the photocatalytic activity of ZrO2 which was found to be 3.73 and 7.36 % respectively for methyl orange and methylene blue dyes in the absence of ZrO2 while the degradation of methyl orange and methylene blue was found to be 69 and 91 % in the presence of ZrO2 under UV irradiation.[34]

H. M. Shinde at al., compared the photocatalytic activity of Ficus Benghalensis leaf extract mediated ZrO2 nanoparticles with Ag-ZrO2 nanocomposite towards methyl orange and methylene blue dyes using high pressure mercury lamp as a source of ultraviolet light. The photodegradation of methyl orange and methylene blue dyes were determined to be 99 and 91 % respectively.[112] The photocatalytic efficiency of selenium nanoparticles prepared by extract of Ficus Benghalensis leaf was evaluated against methylene blue dye in water under Ultraviolet light by R. M. Tripathi et al. Photocatalytic degradation of methylene blue dye was found to be 57.63 % in time period of 40 minutes and followed first order kinetics having rate constant of 0.02162 s^{-1}.[66]

7.5. Treatment of heavy metals

The heavy metal accumulation has been found to have negative health consequences in humans. Iron, aluminum, mercury, lead, cadmium and arsenic are some of the heavy metals that have adverse health effects. Internal body disorders are caused by repeated exposure to heavy metals, as they tend to build up in the body and the body begins to use them as a substitute of necessary minerals i.e., zinc is replaced by cadmium.[113-115] In their studies, the World Health Organization[97] indicated that the Cr (VI) content in drinking water should not exceed 0.05 mgl^{-1}. Cr (III) is 500 times less hazardous to living creatures than Cr (VI). So, reduction of Cr (VI) to Cr (III) becomes significant.[70, 116-117]

R. M. Tripathi et al., synthesized spherical shaped sulfur nanoparticles to determine their catalytic activity for the conversion of Cr (VI) to Cr (III) in the presence of formic acid. The decrease in amount of Cr (VI) was observed with increase in time. The conversion was found to follow first order kinetics.[70] Poguberovic S. S et al., synthesized zero valent iron nanoparticles to remove Cr (VI) and As (III) from water. Mulberry leaf mediated iron nanoparticles were determined to have high capacity for As (III) removal.[61] A. Lagashetty et al., studied the adsorption of mercury and lead ions through iron oxide, zinc oxide and cerium oxide nanoparticles. Among all of these nanoparticles, the maximum adsorption was shown by iron oxide nanoparticles.[63]

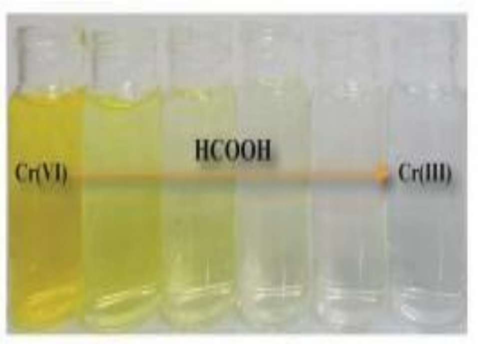

Figure 9. Reaction mixtures at various time intervals of Cr (VI) conversion to Cr (III).

8. CONCLUSION

This review article has elaborated the advancements in the synthesis of nanoparticles by the utilization of various parts of Ficus Benghalensis and Morus Alba. The biological components act as capping and reducing agent in nanoparticle's synthesis. It also highlights the mechanism of synthesis of nanoparticles by green approach. Green synthesis of nanoparticles has certain advantages than other techniques as it is efficient, ecofriendly and safe to use. Ficus Benghalensis and Morus Alba mediated nanoparticles show characterization results including UV-Vis, SEM, TEM, XRD and FTIR. The applications of these nanoparticles are explored with a specific focus in the field of biomedical and environmental remediation due to their high surface area and quantum confinement effect. These applications have provided a new insight into the fact that these nanoparticles act as novel therapeutic agent against various diseases.

9. REFERENCES

Kalpana, V.; Devi Rajeswari, V., A review on green synthesis, biomedical applications, and toxicity studies of ZnO NPs. Bioinorganic chemistry and applications **2018,** 2018 (1), 3569758.

Arruda, S. C. C.; Silva, A. L. D.; Galazzi, R. M.; Azevedo, R. A.; Arruda, M. A. Z., Nanoparticles applied to plant science: a review. Talanta **2015,** 131, 693-705.

Sadhasivam, S.; Shanmugam, M.; Umamaheswaran, P. D.; Venkattappan, A.; Shanmugam, A., Zinc oxide nanoparticles: green synthesis and biomedical applications. Journal of cluster Science **2021,** 32 (6), 1441-1455.

Iravani, S., Green synthesis of metal nanoparticles using plants. Green chemistry **2011,** 13 (10), 2638-2650.

Jeevanandam, J.; Barhoum, A.; Chan, Y. S.; Dufresne, A.; Danquah, M. K., Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations. Beilstein journal of nanotechnology **2018,** 9 (1), 1050-1074.

Thirumalai Arasu, V.; Prabhu, D.; Soniya, M., Stable silver nanoparticle synthesizing methods and its applications. J. Bio. Sci. Res **2010,** 1, 259-270.

El Ghoul, J.; Barthou, C.; El Mir, L., Synthesis by sol–gel process, structural and optical properties of nanoparticles of zinc oxide doped vanadium. Superlattices and Microstructures **2012,** 51 (6), 942-951.

Dobrucka, R.; Długaszewska, J., Biosynthesis and antibacterial activity of ZnO nanoparticles using Trifolium pratense flower extract. Saudi journal of biological sciences **2016,** 23 (4), 517-523.

Zak, A. K.; Abd Majid, W.; Wang, H.; Yousefi, R.; Golsheikh, A. M.; Ren, Z., Sonochemical synthesis of hierarchical ZnO nanostructures. Ultrasonics sonochemistry **2013,** 20 (1), 395-400.

Senthilkumar, N.; Vivek, E.; Shankar, M.; Meena, M.; Vimalan, M.; Potheher, I. V., Synthesis of ZnO nanorods by one step microwave-assisted hydrothermal route for electronic device applications. Journal of Materials Science: Materials in Electronics **2018,** 29, 2927-2938.

Sadrolhosseini, A. R.; Mahdi, M. A.; Alizadeh, F.; Rashid, S. A., Laser ablation technique for synthesis of metal nanoparticle in liquid. Laser Technology and its Applications **2019**, 63-83.

Awwad, A. M.; Albiss, B.; Ahmad, A. L., Green synthesis, characterization and optical properties of zinc oxide nanosheets using Olea europea leaf extract. Adv. Mater. Lett **2014,** 5 (9), 520- 524.

Matinise, N.; Fuku, X.; Kaviyarasu, K.; Mayedwa, N.; Maaza, M., ZnO nanoparticles via Moringa oleifera green synthesis: Physical properties & mechanism of formation. Applied Surface Science **2017,** 406, 339-347.

Bandeira, M.; Giovanela, M.; Roesch-Ely, M.; Devine, D. M.; da Silva Crespo, J., Green synthesis of zinc oxide nanoparticles: A review of the synthesis methodology and mechanism of formation. Sustainable Chemistry and Pharmacy **2020,** 15, 100223.

Sanket, S.; Das, S. K., Role of enzymes in synthesis of nanoparticles. Bioprospecting of Enzymes in Industry, Healthcare and Sustainable Environment **2021**, 139-153.

Singh, J.; Dutta, T.; Kim, K.-H.; Rawat, M.; Samddar, P.; Kumar, P., 'Green'synthesis of metals and their oxide nanoparticles: applications for environmental remediation. Journal of nanobiotechnology **2018,** 16, 1-24.

Razavi, R.; Molaei, R.; Moradi, M.; Tajik, H.; Ezati, P.; Shafipour Yordshahi, A., Biosynthesis of metallic nanoparticles using mulberry fruit (Morus alba L.) extract for the preparation of antimicrobial nanocellulose film. Applied Nanoscience **2020,** 10, 465-476.

Micić, R. J.; Dimitrijević, D. S.; Kostić, D. A.; Stojanović, G. S.; Mitić, S. S.; Mitić, M. N.; Pavlović, A. N.; Ranđelović, S. S., Content of heavy metals in mulberry fruits and their extracts- correlation analysis. American Journal of Analytical Chemistry **2013,** 4 (11), 674-682.

Özgen, M.; Serçe, S.; Kaya, C., Phytochemical and antioxidant properties of anthocyanin-rich Morus nigra and Morus rubra fruits. Scientia horticulturae **2009,** 119 (3), 275-279.

Salimi, F.; Moradi, M.; Tajik, H.; Molaei, R., Optimization and characterization of eco-friendly antimicrobial nanocellulose sheet prepared using carbon dots of white mulberry (Morus alba L.). Journal of the Science of Food and Agriculture **2021,** 101 (8), 3439-3447.

Thakur, K.; Zhang, Y.-Y.; Mocan, A.; Zhang, F.; Zhang, J.-G.; Wei, Z.-J., 1-Deoxynojirimycin, its potential for management of non-communicable metabolic diseases. Trends in Food Science & Technology **2019,** 89, 88-99.

Das, D.; Ghosh, R.; Mandal, P., Biogenic synthesis of silver nanoparticles using S1 genotype of Morus alba leaf extract: characterization, antimicrobial and antioxidant potential assessment. SN Applied Sciences **2019,** 1, 1-16.

Thaipitakwong, T.; Numhom, S.; Aramwit, P., Mulberry leaves and their potential effects against cardiometabolic risks: A review of chemical compositions, biological properties and clinical efficacy. Pharmaceutical biology **2018,** 56 (1), 109-118.

Wilson, R. D.; Islam, M. S., Effects of white mulberry (Morus alba) leaf tea investigated in a type 2 diabetes model of rats. Acta Pol Pharm **2015,** 72 (1), 153-160.

Hussain, F.; Rana, Z.; Shafique, H.; Malik, A.; Hussain, Z., Phytopharmacological potential of different species of Morus alba and their bioactive phytochemicals: A review. Asian Pacific journal of tropical biomedicine **2017,** 7 (10), 950-956.

Khanal, P.; Patil, B. M., In vitro and in silico anti-oxidant, cytotoxicity and biological activities of Ficus benghalensis and Duranta repens. Chinese Herbal Medicines **2020,** 12 (4), 406-413.

Singh, R. K.; Mehta, S.; Jaiswal, D.; Rai, P. K.; Watal, G., Antidiabetic effect of Ficus bengalensis aerial roots in experimental animals. Journal of ethnopharmacology **2009,** 123 (1), 110-114.

Shi, Y.; Mon, A. M.; Fu, Y.; Zhang, Y.; Wang, C.; Yang, X.; Wang, Y., The genus Ficus (Moraceae) used in diet: Its plant diversity, distribution, traditional uses and ethnopharmacological importance. Journal of ethnopharmacology **2018,** 226, 185-196.

Herre, E. A.; Jandér, K. C.; Machado, C. A., Evolutionary ecology of figs and their associates: recent progress and outstanding puzzles. Annual Review of Ecology, Evolution, and Systematics **2008,** 39 (1), 439-458.

Lansky, E. P.; Paavilainen, H. M.; Pawlus, A. D.; Newman, R. A., Ficus spp.(fig): Ethnobotany and potential as anticancer and anti-inflammatory agents. Journal of Ethnopharmacology **2008,** 119 (2), 195-213.

Salem, M. Z.; Salem, A.; Camacho, L.; Ali, H. M., Antimicrobial activities and phytochemical composition of extracts of Ficus species: An over view. Afr. J. Microbiol. Res **2013,** 7 (33), 4207-4219.

Khan, K. Y.; Khan, M. A.; Ahmad, M.; Mazari, P.; Hussain, I.; Ali, B.; Fazal, H.; Khan, I. Z., Ethno-medicinal species of genus Ficus L. used to treat diabetes in Pakistan. Journal of Applied Pharmaceutical Science **2011,** (Issue), 209-211.

Shukla, R.; Gupta, S.; Gambhir, J.; Prabhu, K.; Murthy, P., Antioxidant effect of aqueous extract of the bark of Ficus bengalensis in hypercholesterolaemic rabbits. Journal of ethnopharmacology **2004,** 92 (1), 47-51.

Shinde, H.; Bhosale, T.; Gavade, N.; Babar, S.; Kamble, R.; Shirke, B.; Garadkar, K., Biosynthesis of ZrO 2 nanoparticles from Ficus benghalensis leaf extract for photocatalytic activity. Journal of Materials Science: Materials in Electronics **2018,** 29, 14055-14064.

Park, J.; Kang, E.; Son, S. U.; Park, H. M.; Lee, M. K.; Kim, J.; Kim, K. W.; Noh, H.-J.; Park,

J.-H.; Bae, C. J., Monodisperse nanoparticles of Ni and NiO: synthesis, characterization, self-assembled superlattices, and catalytic applications in the Suzuki coupling reaction. Advanced Materials **2005,** 17 (4), 429-434.

Liang, W.; Church, T. L.; Harris, A. T., Biogenic synthesis of photocatalytically active Ag/TiO 2 and Au/TiO 2 composites. Green chemistry **2012,** 14 (4), 968-975.

Kavitha, M.; Thirumurugan, V., Synthesis of nanoparticles from Ficus benghalensis bark and evaluation of its antimicrobal and antioxidant activity. Asian J Innov Res **2017,** 2 (1), 38-48.

Khomutov, G.; Gubin, S., Interfacial synthesis of noble metal nanoparticles. Materials Science and Engineering: C **2002,** 22 (2), 141-146.

Rane, A. V.; Kanny, K.; Abitha, V. K.; Thomas, S., Chapter 5 - Methods for Synthesis of Nanoparticles and Fabrication of Nanocomposites. In Synthesis of Inorganic Nanomaterials, Mohan Bhagyaraj, S.; Oluwafemi, O. S.; Kalarikkal, N.; Thomas, S., Eds. Woodhead Publishing: 2018; pp 121- 139.