Review Paper:

Phyto-fabrication of metal nanoparticles using Thar desert plants

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Abstract

Nanoparticles possess characteristic properties that make them potential candidates for various applications in diversified fields. Developing novel strategies for the synthesis of nanoparticles is crucial to optimize their properties and expand their potential uses. The biological route of nanoparticle synthesis, also known as green method, has been portrayed as an efficient, cost effective and environmentally friendly technique. Biological materials like plants, bacteria, yeast, fungi and algae have indeed been reported to possess high bioreduction and stabilization abilities, enabling them to synthesize metallic nanoparticles of various sizes and shapes.

Among these biomaterials, this review mainly focuses on Thar desert plant-mediated biosynthesis of metallic nanoparticles. The phytochemicals in desert plants such as polyphenols, alkaloids, steroids, saponins and pregnane glycosides play a crucial role in reduction, capping and stabilization of metal nanoparticles. A systematic study of literature, based on effect of various desert plant materials and experimental conditions on properties of metal nanoparticles is also provided. This review also highlights the applications of nanoparticles stabilized by desert plants in various fields such as agriculture, food industry and medicine.

Keywords: Nanoparticles, Thar desert plants, Green synthesis, Phyto fabrication.

Introduction

Nanotechnology has emerged as the leading development in science comprising an interdisciplinary area which includes invention, designing and utilization of materials of size below 100 nm. Nowadays, there is an increasing number of research articles dedicated to nanoparticles due to their distinctive properties like tremendously small size, large surface to volume ratio, interface effect and quantum effect leading to both chemical and physical modifications in their characteristics in comparison with the bulk material[47]. Nanotechnology is playing a crucial role in many significant fields including biomedical science, mechanics, energy science, drug-gene delivery, optics, electronics, optoelectronic devices, nonlinear optical devices, chemical industry, catalysis and photoelectrochemicals[18]. NPs can be engineered to incorporate specific properties to carry drugs, to enhance contrast in imaging techniques like MRI and CT scans, to improve the efficiency of solar cells, to enhance battery performance, to serve as catalysts in energy-efficient reactions[7,9,22,40].

The general approaches for synthesis of nanoparticles include chemical and physical methods[28]. Chemical methods for the formation of nanoparticles requires the use of hazardous chemical reagents and solvents which can pose health risks to researchers and workers. Sodium borohydride, an expensive and toxic reducing agent, as well as other organic stabilisers and solvents are always extensively used in the case of chemical methods[38]. Additionally, the waste generated during these processes can be detrimental to both humans and the environment. Physical methods for nanoparticles preparation including ultraviolet, aerosol and thermal decomposition need consumption of high amount of energy, high temperatures and pressures which can lead to potential safety hazards[22]. For example, in aerosol method, a solution of metal ion precursor is atomized into aerosol droplets at temperature of about 2400 K to produce nanoparticulate metals[19].

Therefore, it is essential to follow proper safety protocols and disposal methods to minimize the risks related to metal nanoparticle. To solve the issue of toxicity associated with physical and chemical methods, green chemistry and nanotechnology agglutinate to design environment friendly nanoparticles via plants, micro-organisms, yeast, fungi etc[25]. In green nanotechnology, the amount of energy consumption is much lower than in other technologies; almost no toxic chemicals are used and no hazardous waste is produced during synthesis which makes this methodology environmentally compatible.

Biogenic synthesis of nanoparticles is beneficial not only because of its non hazardous impact on environment, but also because of relatively low cost, large scale production of biocompatible nanoparticles with well defined size and shape without any contamination[53]. Using extracts of diverse plant species to create NPs is found to be more advantageous than the use of microorganism which requires more complicated procedure for microbial culture maintenance[54].

Phytochemicals present in plant tissues act as reducing, capping, chelating and stabilizing matrix for nanoparticles synthesis. The characteristics of nanoparticles are greatly affected by the concentration and combination of natural products present in the extract of plant source.

Among several plant species, desert plants or xerophytes are on prime focus as they are specifically adapted to thrive in arid environment where water is scarce. Desert plants offer a valuable source of secondary metabolites such as polyphenols (phenolic acids, coumarins and flavonoids), alkaloids, saponins (furostanol saponins, spirostanol saponins and open chain steroidal saponins), steroids and pregnane glycosides which have been recognized and utilized by humans for several centuries[6]. Such phytochemicals derived from desert plants have medicinal values for human health including anti diabetic, antioxidants, anticancer, anti- inflammatory, antibacterial, molluscicide and hepatoprotective.

Plants native to hot desert, like *Leptadenia pyrotechnica* produce majority of phytochemicals including saponins, alkaloids, flavonoids and tannins for various purposes such as defense against herbivores, pathogens and harsh weather conditions[41]. Despite the promising benefits desert plants offer, the utilization of desert plants for synthesis and stabilization of metal nanoparticles is still underexplored. This review provides a brief overview of few desert plants utilized for synthesis of metal nanoparticles and their applications in diversified areas. With this update, extensive research could be directed towards the use of desert plants to synthesize metal nanoparticles with unique characteristics which can be explored for various applications in the area of cosmetics, construction, food, medicines, pharmaceuticals, agriculture and many others.

Importance of green method for nanoparticle synthesis

For nanoparticle synthesis, various physicochemical and biological pathways come under two distinct classes: a top-down and bottom-up approach[29] (fig. 1). The top-down approach for synthesis of nanoparticles involves reducing larger materials into smaller particles of nanometre size domain through mechanical or physical methods. This typically includes techniques like milling, grinding, lithography, or laser ablation. In these methods, the starting material is broken down into smaller particles through mechanical forces, high-energy collisions, or controlled etching processes. This method is often used when precision in size and shape control is crucial, but it might have limitations in terms of scalability and uniformity as compared to other methods[39]. The method introduces imperfection in the structure of nanoparticle surface and this is a major limitation of the method because the surface chemistry and physical properties of nanomaterials are significantly affected by surface structure. The bottom-up approach includes the formation of nanoparticles by joining smaller units into larger ones, like self assembly of atoms, molecules and smaller particles growing into larger particles possessing nanoscopic dimensions. This bottom-up approach includes chemical methods as well as biological methods for nanoparticle formation. Due to the use of hazardous reagents in chemical method, biosynthesis of nanomaterials is more advantageous.

Green synthesis of nanoparticles offers an eco-friendlier approach compared to traditional chemical methods[28]. Green methods typically use natural sources, like plant extracts or microorganisms which have less toxicity, generate less waste and byproducts and synthesize biocompatible and sustainable nanoparticles. Green synthesis encourages environmental sustainability and minimizes harm to the ecosystem.

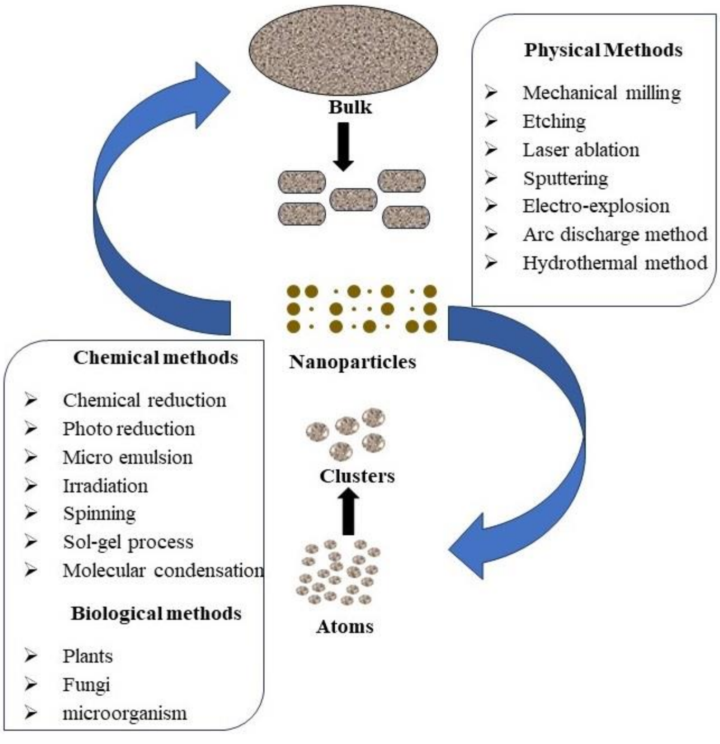

Fig. 1: Methods for synthesis of nanoparticles

Nanoparticles formed by green methods have been observed to have better characteristics and properties that can have a large-scale application in different fields. Plants are considered to be the most important biological entities for nanoparticle synthesis, as their universal abundance, biocompatibility and lack of pathogenicity make them superior over other biological sources. The use of extracts containing biomolecules of plants for designing nanoparticles is relatively easy, environment-friendly, cost-effective and less time consuming.

Phytochemicals in Thar desert plants as source for nanoparticles synthesis

Among plants species, Thar desert plants are extensively being explored to synthesize nanoparticles, due to the presence of numerous phytochemicals that can act as effective reducing, capping and stabilizing matrix for nanoparticles[27]. This methodology drew attention of scientists due to the easy availability, extensive distribution, survival in adverse climate condition of desert plants, as well as the fact that it is safe to utilize desert plants as a source of numerous metabolites of medicinal value. Desert plants, which are from arid region, produce secondary metabolites for example polyphenols (i.e. phenolic acids, flavonoids and coumarins) alkaloids, saponins (i.e. spirostanolsaponins, furastanolsaponins and open-chain steroidal saponins), steroids and pregnane glycosides. Such phytochemicals have many advantageous effects on human health including anti-cancer, anti-diabetic, anti-inflammatory, antioxidants, antibacterial and hepatoprotective.

Despite of having various secondary metabolites, very few reports highlight the use of desert plant extracts as reducing and stabilizing agents in the green synthesis of metal nanoparticles. Few reports on use of desert plants for the synthesis of MNPs have been discussed (table 1). General method for desert plants mediated synthesis of metal nanoparticles has been presented in fig. 2. The synthesis of metal nanoparticles is induced by inclusion of extracts obtained from different parts of desert plants like roots, flowers, seeds, stems, leaves, bark and fruits into the aqueous solution of metal ions.

The phytochemicals present in plant extract such as alkaloids, enzyme, proteins, amino acids, heterocyclic and vitamins are implicated in the bio reduction of metal ions. and stabilize the synthesized NPs. The mechanism and the specific plant components involved in synthesis of nanoparticles are indeed relatively intricate. The process of reduction is very crucial for synthesis of NPs as it supplies the required electrons to convert metal ion into zero valent state. Subsequently, the metal atoms undergo nucleation after the bioreduction process.

As the metal atoms assemble to form particles of size in nanometer range, a color change is observed due to their unique optical properties. As bio reduction and nucleation process continue, a growth phase is achieved where small size particles mechanically associate to form thermodynamically more stable larger particles. At the termination stage, bioactive compounds such as phenols, flavonoids, enzymes and terpenoids present in the plant extracts exert their stability potential and finally define the shape and morphology of NPs. During this phase, the growth of nanoparticles ceases as the bioactive compounds stabilize the formed nanoparticles. It is well reported in the literature that the mechanism involved in the process of synthesis of NPs from different desert plants differs due to variation in their bioactive compounds, composition and concentration[6].

Chemical, physical and biological activities of NPs are greatly affected by the concentration of the extract obtained from plant part, pH, temperature and reaction time[12]. It is reported that NPs have superior bioactivity as compared to plant extract[60]. NPs can be engineered as nanoplatforms for molecular diagnosis, targeted and effective drug delivery and to overcome the drawbacks associated with traditional medicines[61].

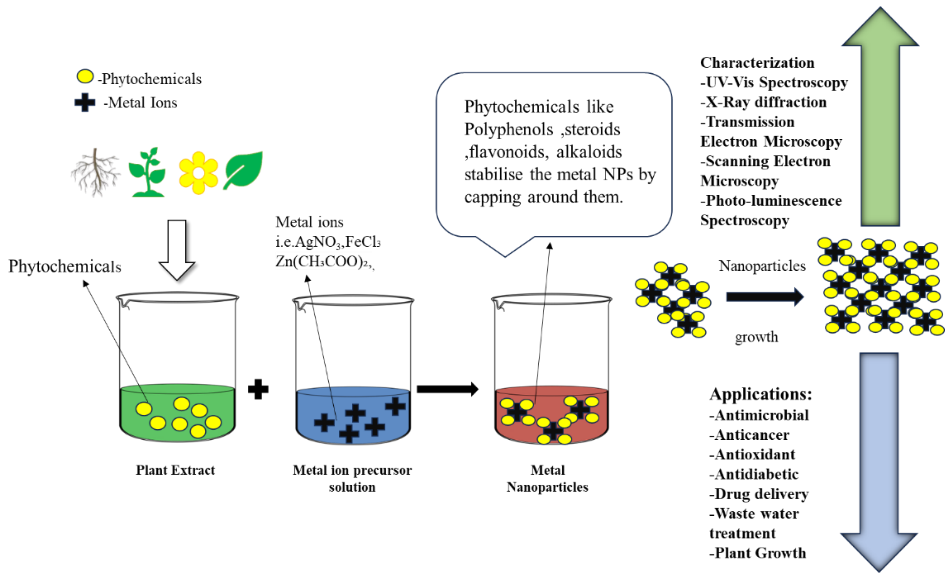

Fig. 2: Green Synthesis of nanoparticles by using desert plant

Several nanoparticles have been synthesized by green method till now and characterized by ultraviolet–visible spectroscopy, photoluminescence analysis (PL), transmission electron microscopy (TEM), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), energy dispersion analysis of X-ray (EDAX), atomic force microscopy (AFM), Raman spectroscopy, field emission scanning electron microscopy (FE-SEM), X-ray diffraction (XRD X-ray photoelectron microscopy (XPS), attenuated total reflection (ATR), thermal-gravimetric differential thermal analysis (TG-DTA), UV–visible diffuse reflectance spectroscopy (UV-DRS) and dynamic light scattering (DLS).

MNPs synthesized by using Thar desert plants

Silver Nanoparticles (Ag NPs): Silver nanoparticles have high reactivity and good conductivity which make them of high importance and increase their applications as well[14]. Silver metal nanoparticles prepared from various desert plants adopt different properties like antibacterial, antimicrobial, anticancer or antiproliferative activity, excellent catalytic properties for selective oxidation, photocatalytic degradation of dyes, synthesis of epoxide, enhancement of plant seedling growth, burn wound healing and drug delivery vehicles[23]. The typical green method for synthesis of silver nanoparticles (Ag NPs) includes the reduction of silver metal ion by reducing agents present in plant extract. The extracts are usually prepared by soaking the parts of desert plants such as leaves, fruits, seeds, stem, bark and flowers in suitable solvent (water, ethanol) under suitable environmental conditions (fig. 2).

The extracts are then mixed with solution of silver ion, a colour change in the solution is indicative of the formation of silver nanoparticles. There are numerous factors such as plant extract, pH, light and temperature which affect the green synthesis of Ag NPs (Table 1). Chaudhuri et al[11] have reported the synthesis of Ag NPs by using silver nitrate with aqueous leaf extract as well as flower extract of *Tecomella undulata* a desert plant called Rohira. The experiment was performed at 60 °C in orbital shaking incubator. Biomolecules present in the plant extract stabilized Ag NP. Polydispersity Index (PDI) of synthesized Ag NPs was found to be 0.378 indicating the longer shelf life of NPs. An enhancement in seedling growth was noticed in the presence of these Ag NPs. Spherical Ag NPs of approximately 20-52 nm size were synthesized by using fruit extract of *Tamarindus indica*[31]. FTIR results suggested that presence of carboxyl, amine, alcohol and amide groups present in biomolecules extracted from fruit shell may involve in the reduction of silver ions to silver nanoparticles.

Hashmi et al[23] have reported the synthesis of biocompatible Ag NPs by using antioxidant-rich plant extract of *Aerva javanica*. FTIR analysis confirmed that phenol acts as a capping agent for Ag NPs. *Cassia angustifolia* leaf extract was used for green synthesis of Ag NPs[4]. It was reported that sennosides present in leaf extract serve as reducing and capping agents. It was observed that the nanoparticles were poly- dispersed, spherical in shape with size in the range of 9-31 nm. Phytosynthesis of silver nanoparticles (Ag NPs) using *Acacia leucophloea* bark extract was reported[42]. FTIR results have shown that Ag NPs were capped by primary amines, aldehyde/ ketone, azo, aromatic and nitro compounds present in natural extract. The TEM images showed polydisperse spherical Ag NPs of size 17-19 nm. A size controlled synthesis of Ag NPs was demonstrated by using fruit extract of *Zizyphus mauritiana*[56]. The size distribution of Ag NPs was found to be affected by the concentration of fruit extract as well as concentration of silver nitrate and reaction time. The size of Ag NPs was found to decrease from 300 nm to 70 nm with increasing concentration of fruit extract.

Gold Nanoparticles (Au NPs)*:* Gold nanoparticles have been explored extensively and have effective ability to interact with light. Au NPs are well known for their selective termination of cancer cells, biocompatibility, low toxicity, tunable surface plasmon resonance, facile synthetic procedure and easy surface functionalization[52]. Various biomolecules like flavonoids, proteins, phenols etc. present in natural extract act as reducing as well as stabilizing agents in the preparation of Au NPs[48]. Kumari et al[34] utilized aqueous latex extract of *Calotropis procera* to synthesize gold nanoparticles. The effect of temperature on the rate of synthesis of AuNPs and their optical properties was studied in detail. It was observed that rate of synthesis of AuNPs was enhanced with increase in reaction temperature, however, surface plasmon resonance (SPR) peaks for all AuNPs solutions obtained at different temperatures exhibited only a shift of 1-5 nm. Polyphenolic compounds present in leaf extract of *Acacia nilotica* were successfully utilized for the synthesis of Au NPs[36]. It was observed that size of AuNPs reduces upon increasing concentration of leaf extract.

Zinc oxide Nanoparticles (ZnO NPs): Zinc oxide nanoparticles are considered as a significant inorganic nanomaterial with a wide range of applications in the fields of biomedicals as well as optics and electronics[37]. ZnO NPs have been used as a trace element in the metabolic process due to low toxicity at optimal concentrations.

Alharthi et al[3] have reported the synthesis of ZnO nanorods and nanoparticles by using *Salvadora persica* leaf extract via sol gel method. It was observed that synthetic pathway chosen affects the morphology of ZnO NPs significantly. Root extract of *Salvadora persica* was also found to be efficient for synthesis of ZnO nanorods and nanoparticles[57]. Leaf extract of *Ocimum tenuiflorum* was used as reducing as well as capping agent for ZnO NPs of size 50-63 nm[8].

Rasha et al[49] reported the biosynthesis of ZnO NPs using fruit extract of *Acacia nilotica*. FTIR studies revealed that O-H and C-H functional groups present in secondary metabolites of fruit extract of *Acacia nilotica* were responsible for synthesis of ZnO NPs.

Table 1
Nanoparticles synthesized from Thar desert plants

Nanoparticle	Common Name	Scientific name	Plant extract part	Properties
Ag	Rohira /luar/desert teak	*Tecomella undulata*	leaf extract	Enhance seedling effect in crop plants[10]
Ag	gum arabic tree/babul	*Acacia nilotica*	leaf extract	Antibacterial, antifungal[61]
Ag	Imli /tamarind	*Tamarindus indica*	fruit extract	Highlystable-microwave assisted[31]
Ag	Bui /desert cotton	*Aerva javanica*	aqueous extract	Antioxidant, burn wound healing[23]
Ag	*Amla*	*Phyllanthus emblica*	fruit extracts	Effective reducing agent[14]
Ag	Indian clove	*Syzygium aromaticum*	leaf extracts	Antimicrobial, anti-diabetic[2]
Au	Aakado/giant mikweed	*Calotropis procera*	aqueous latex extract	Antimicrobial for treating skin wound infection[13]
Au	*Gokhru*	*Tribulus terrestris*	leaf, stem, root extracts	Anti-infective[45]
Pd	*Assyrian plum*	*Cordia myxa*	gum extract	Antibacterial, antimicrobial[44]
Pd	Boswellia Tree	*Indian frankincense*	gum extract	Antioxidant, Degradation[33]
Pd	Choti-dhudhi	*Euphorbia thymifolia*	leaf extract	Catalytic efficacy[46]
Fe	*Khejri*	*Prosopis cineraria*	leaf extracts	Dye-removal efficiency 59%[34]
Fe	*Bada Peelu*	*Salvadora oleoides*	leaf extracts	Dye-removal efficiency 40%[34]
Fe_2O_3 and Fe_3O_4	Indian Almond	*Terminalia catappa*	leaf extracts	Anti microbial and Anti cancer[16]
Fe_3O_4	Imli /tamarind	*Tamarindus indica*	leaf extract	Peroxidase and dye removal activity[1]
CuO	Bui /desert cotton	*Aerva javanica*	leaf extract	Antimicrobial[5]
CuO	Aakado/giant mikweed	*Calotropis procera*	aqueous latex extract	Adsorptive removal of Cr(4) from aqous solution[15]
CuO	kair/kareel	*Capparis decidua*	leaf extract	Antibacterial[29]
CuO	Imli /tamarind	*Tamarindus indica*	fruit and leave extract	Photocatalytic and antibacterial activity[60]
ZnO	Gum arabic tree/babul	*Acacia nilotica*	aqueous fruit extract	Antibacterial activity against carbapenem-resistant Klebsiella pneumoniae[49]
ZnO	Jaal /peelu/mustardtree	*Salvadora persica*	leaf extracted	Photocatalytic Degradation[3]
ZnO/Ag	Imli /tamarind	*Tamarindus indica*	leaf extract	Facile, eco-friendly, cauliflower like NPs[17]
ZnO	Aakado/giant mikweed	*Calotropis procera*	leaf extract	Photodegradation of methyl orange[20]
ZnO	Tulsi /holy basil	*Ocimum tenuiflorum*	leaf extract	photocatalytic and antimicrobial[55]
TiO_2	Sweet lime	*Citrus limetta*	leaf extracts	Photocataltic[43]
TiO_2	*Giloy*	*Tinospora cordifolia*	stem extracts	Photocatalytic degradation[51]
TiO_2	Imli /tamarind	*Tamarindus indica*	leaf extract	Photocatalytic degradation[24]
TiO_2	Sargado /bitter drumstick	*Moringa concanesis*	aqueous solution of leaf extract	Antibacterial against PDR *E.coli*[59]

The effect of concentration of leaf extract of *Cordia myxa* on morphology of ZnO NPs was studied[50]. It was observed that Wurtzite shaped ZnO NPs were obtained at 25% extract concentration while spherical shaped particles possessing layer-by-layer discs like structures were observed at 10% extract concentration. ZnO NPs of cauliflower like structure were obtained in the presence of leaf extract of *Tamarindus indica*[17].

Copper Oxide Nanoparticles (CuO NPs): Copper oxide NPs possess various properties and have numerous applications in the field of biomedicine, textile industry, catalysis, high temperature super conductors, environmental remediation etc[58]. Very few desert plants have been utilized for phytosynthesis of CuO NPs till now. The phytochemicals react with copper ion leading to the reduction followed by stabilization of CuO NPs[60]. The fruit and leaf extract of *Tamarindus indica* have been used for reduction and stabilization of CuO NPs[60].

It was observed that the source of extract significantly affects the growth and properties of CuO NPs. Quantum dots of CuO NPs of size 5-10 nm were obtained with fruit extract while leaf extract mediated the synthesis of polydisperse spherical nanoparticles of size 50-100 nm. The use of leaf extract of *Capparis decidua* has led to the formation of six petals flower shaped structure of CuO NPs with catalytically active large surface area[29].

Other metal oxide Nanoparticles: Various oxides of iron, titanium, cerium, magnesium etc. are found to have numerous applications (Table 1) in environmental remediation, catalysis, textile industry, biomedical electronics and energy nanogenerators[37].

Hussain et al[26] have reported the synthesis of NiO NPs in extract of *Acacia nilotica* prepared in water and ethanol. A prominent effect of solvent on size of nanoparticles was observed. Their study concluded that the sizes of spherical shaped NiONPs were found around 16 nm and 28 nm in aqueous and ethanolic solutions respectively. Effective green synthesis of spherical anatase phase TiO_2 nanoparticles of size range 20-40 nm was achieved by using leaf extract of *Tamarindus indica*[24].

FTIR studies revealed that bioreduction and stabilization of TiO_2 NPs are governed by phytochemicals such as secondary amines, carboxylic acids, quinones, alcohols, amides, aromatic compounds and polysulphides. A green and facile method was performed to synthesize magnesium oxide nanoparticles (MgO NPs) by using *Camellia-sinensis* leaves extract[32]. MgO NPs exhibited highly porous crystalline nanostructure of 22-25 nm. Akanda et al[1] studied the optimized condition for the phytosynthesis of iron oxide (Fe_3O_4) NPs by using extract of leaves of *Tamarindus indica*. The parameters such as solvents system, concentration of leaf extract, pH, buffer and time were optimized for synthesis of Fe_3O_4 NPs. SEM analysis confirmed the formation of cubic morphology and particle size of 80 ± 3 nm.

Applications

Due to unique properties, nanoparticles are extensively utilized in various fields such as agriculture, medicine, electronics, drug delivery, catalysis and waste water treatment (Table 1). The metal-based nanoparticles synthesized by Thar desert plants of medicinal value are much preferred in biomedical applications. The use of nanoparticles for cancer treatment has been dragging attention in recent years. Zubair et al[61] have synthesized Ag NPs by using leaves extract of *Acacia nilotica* which exhibited significant anticancer, antioxidant and antidiabetic potential. Ag NPs were found efficient therapeutic agents against liver cancer cells in humans, scavenging agent for free radicals that drive oxidative stress and strong inhibitor for α-glucosidase enzyme activity. The antimicrobial activity of nanoparticles makes it a potential candidate in the field of food preservation as well as sanitizing agents for sterilizing equipment in food industry[7].

Ag NPs synthesized from leaf extract of *Datura stramonium* exhibited pronounced antibacterial activity against *E. coli*[21]. Nanoparticles have been extensively explored as plant growth promoters in the field of agriculture. ZnO NPs synthesized from leaf extract of *Calotropis* showed significant enhancement in growth of *Azadirachta indica*, *Pongamia pinnata* and *Alstonia scholaris*[20]. The nanosized metal nanoparticles are extensively being used as catalyst for waste water treatment due to high surface area to volume ratio[7]. The photocatalytic activity of heterogeneous TiO_2 NPs synthesized by leaf extract of *Tamarindus indica* was tested on photodegradation of Titan yellow dye by semiconductor photocatalysis mechanism[31]. The photo degradation process followed the pseudo first order kinetics.

Conclusion

Extracts of Thar desert plants can indeed be efficiently used in the synthesis of metal nanoparticles, providing a greener and more sustainable approach. Biosynthesis of nanoparticles using desert plants is recognized for its simplicity, availability of vast medicinal value based secondary metabolites present in desert plants, cost effectiveness, environment friendliness and safety. This process is typically a one-step method, leveraging the natural reducing and stabilizing agents found in plant extracts. While the potential of plant-mediated nanoparticle synthesis is well-recognized, the exact mechanisms remain elusive.

By employing a combination of advanced experimental techniques, researchers can gain deeper insights into the roles of specific phytochemicals and functional groups in the synthesis process. Understanding these mechanisms will not only enhance the efficiency and control of biosynthesis but will also pave the way for the development of new applications and innovations in nanotechnology. More systematic and interdisciplinary research efforts are needed to fully elucidate the green synthesis pathways offered by diverse plant species.

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