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Review

Biogenic fabrication of nanomaterials from flower-based chemical compounds, characterization and their various applications: A review

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ABSTRACT

Nanotechnology is evolving as a significant discipline of research with various applications. It includes the materials and their applications having one dimension in the range of 1–100 nm. Many chemical and physical protocol have been utilized for the nanoparticles (NPs) fabrication. These protocols are costly, hazardous and consumes high energy. Thus, researchers are inclined towards biological synthesis of NPs using plant and or herbal extract as these methods are simple, sustainable, ecofriendly and cost-effective. Flower is an important part of plants, and contained several phytochemicals such as flavonoids, terpenoids, coumarins, sterol and xanthones which acts as an important precursor for NPs synthesis. These compounds acted as reducing as well as stablishing agent during fabrication processes. They have been thoroughly characterized by various techniques. The fabricated NPs have shown potential antimicrobial activity against bacterial and fungal infections. They have been also used as potential therapeutic agent for human breast cancer, gastric adenocarcinoma cell, colorectal adenocarcinoma cell and pancreas ductal adenocarcinoma cells. Overall, the aim of this review article to facilitates the recent understanding of flower-mediated NPs fabrication (a sustainable and ecofriendly resource), their application in different disciplines and challenges.

Contents

1. Introduction

Nanotechnology is evolving as a significant discipline of science with its various applications such as in biomedicines, pharmaceutics, catalysis, sensors, cosmetics, agriculture, textile products,

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mechanics, optics, electronics, energy etc. (Boomi et al., 2019; Gour and Jain, 2019; Husen and Siddiqi, 2014; Bachheti et al., 2019; Husen, 2019; Husen, 2019a; Husen et al., 2019; Husen, 2020a; Husen, 2020b; Joshi et al., 2019; Mishra et al., 2019; Singh and Husen, 2019). It includes the particles and their applications having one dimension in the range of 1–100 nm; and are called nanomaterials (NMs). Various chemical/physical protocol have been utilized for the NMs synthesis. These conventional methods used for NMs synthesis are considered as expensive, time consuming and hazardous to environment due to involvement of unsafe and toxic chemicals. Thus, researchers are inclined towards the biological route of nanoparticles (NPs) synthesis from the various plant parts as these procedures are simple, sustainable, ecofriendly and cost-effective (Husen and Siddiqi, 2014; Siddiqi et al., 2018a, 2018b; Bachheti et al., 2020a; Husen, 2020c; Painuli et al., 2020). Among the various NMs, metal and metal-oxide NPs are considered as most effective as these particles have shown significant biomedical and other applications due to their increased surface area to volume ratio. In recent past, the utilization of various plant species and herbal extract (obtained from different plant parts) worked as reducing and capping agents in the synthesis of NPs has evolved as a novel field of nanoscience. Initially, the entire plant part extracts without isolation of pure compounds were used in the green synthesis of NPs. Further, the isolated pure plant-based compounds such as cellulose, glucose, starch or the whole plants, plant dry mass or extracts were utilized in the synthesis of NPs (Alle et al., 2020a, 2020b, 2020c; Chandran et al., 2006; Song et al., 2008; Kasthuri et al., 2009; Husen and Iqbal 2019). For example, leaf (Siddiqi et al. 2019; Khan et al., 2019), latex (Arsalani et al., 2018; Arsalani et al 2019), seeds (Radini et al., 2018, Hussein et al., 2018), gums (Alle et al., 2020a, 2020b, 2020c, 2019), flowers (Abdallah et al., 2019, Johnson et al., 2018; fruits (Lakshmanan et al., 2018), peel (Vinay et al., 2018), stem (Azad et al., 2014), bark (Rao and Rao 2016; Das and Smita 2018), pulp (Pushkar and Sevak 2018) and root (Shaikh et al., 2019; Bachheti et al., 2020b) were used NPs synthesis. Additionally, some researcher isolated cellulose nanocrystals and nanofibrils from various forest wood and non-wood products (Alle et al., 2020a, 2020b, 2020c).

It has been already understood that the most of the plant parts are rich in terms phytochemical, and floral extract is one them. Flowers are the important part of human life and used by people to mark important event in their lives such as for decoration in marriages, birthday, celebration and many other events. Many flowers are used for cooking, drinks, as salad and to prepare cake (Kelley et al., 2001, 2002). Flower are the source of vegetables (such as cauliflower, broccoli), spices (saffron-most expensive spices, cloves and capers) as flavoring agent for beer (Hops flowers), raw material for wine (dandelion and elder flower) and squash (*Rhododendron arboreum* flower). Flowers are easily available (a sustainable and ecofriendly resource), contain huge amount of phytochemical. They are rich in flavonoids (anthocyanins and catechins), coumarins, terpenoids, sterol and xanthones which can be used as precursor for NPs synthesis. Anthocyanins are plant pigments responsible for giving colour to different parts of plants especially flower in different species. It seems as red pigment in acidic condition, whereas blue in alkaline condition. It is responsible for imparting colour to most of flower for example, in red hibiscus, red rose, red pineapple sage, red clover, and pink blossom (Khoo et al., 2017). Anthocyanins have many biological activities for instance antioxidant, anticancer and anti-inflammatory features (Bowen-Forbes et al., 2010). Anthocyanins are water soluble (Wang et al., 2010) which make it suitable for NPs synthesis. Abbasi et al. (2019) fabricated, silver NPs (Ag-NPs) from anthocyanins extract of purple basil (*Ocimum basilicum*). Also, kaempferol (flavonoid) a phytochemical present in many flowers was used for gold NPs (Au-NPs) synthesis (Raghavan et al., 2015). Hussain et al. (2019) and Mashwani et al. (2016) have also examined the role of flavonoids and terpenoids in NPs synthesis and their various applications, respectively.

Another phytochemical coumarins present in different part of plant but in large concentration in flower and fruits (Miranda and Cuéllar 2001) and it is reported to use for NP synthesis (Karthik et al., 2017). Five new xanthones, garciniacowones along with 14 known xanthones, were isolated from fruits and fresh flowers of *Garcinia cowa* (Sriyatep et al., 2015). Some xanthones are also reported for NPs synthesis (Aisha et al., 2015). Recent published paper showed that terpenoids obtained from the flower bud extract of *Tussilago farfara* were also used for Ag-NPs and Au-NPs synthesis (Lee et al., 2019).

Till date, there has been no review available on the involvement of flower extract in the biological synthesis of metal/metal-oxide NPs. The present review article highlights and elucidates the mechanistic role of flower constituents as reducing as well as capping agent in the NPs synthesis. Additionally, the present review also focuses the applications of synthesized NPs in various discipline of science.

2. Important phytochemicals of some flowers

As already reported, like other parts of plants, flowers are also important source of phytochemical and known for large number of biological activities. For instance, *Punica granatum* is a shrub found in Iran, China and Afghanistan (Flora Respublicae Popularis Sinicae, Tomus, 1983; Wang et al., 2006). The flower of *Punica granatum* was observed as an, astringent and haemostatic. In Unani and Ayurvedic medicine systems its flower was reported to use in diabetes while in traditional Chinese medicine it is used for injuries treatment, hair fall and greying of hair. Medicinal use of pomegranate flowers was reported in Ayurvedic, Unani and Chinese medicine system (Sivarajan and Balachandran, 1994; Wang et al., 2006). Phytochemical present in pomegranate flowers are polyphenols, gallic acid (Huang et al., 2005a), ellagic acid and ethyl brevifolincarboxylate (Wang et al., 2006), triterpenes - oleanolic acid, ursolic acid (Huang et al., 2005b), maslinic acid and asiatic acids (Batta and Rangaswami, 1973).

Also, tea flowers chemical compositions were reported similar to its leaves and contain good quantities of total catechins. (Lin et al., 2003; Su et al., 2000). Moreover, the tea flower extracts reported for antioxidant activity (Lin et al., 2003). Eight catechins, five flavonol glycosides were isolated from ethyl acetate-soluble fraction (EEA) from the tea flowers which showed antioxidant activity (Yang et al., 2009). Structure of isolated compounds were elucidated by mass spectrometry and nuclear magnetic resonance. The isolated compounds were Myricetin 3-O-β-D-galactopyranoside, Quercetin 3-O- β -D-galactopyranoside, Kaempferol 3-O- β -D-galactopyranoside, Kaempferol 3-O- β-D-glucopyranoside, Kaempferol 3-O-[α-L-rhamnopyranosyl-(1–6)- β -D-glucopyranoside. Four anthocyanins (1) delphinidin 3,5-di-O-(6-O-malonyl-β-d-glucoside) (ii) delphinidin 3-O-(6-O-malonyl-b -d-glucoside)-5-O-β-D-glucoside (iii)delphinidin 3-O- β -D-glucoside-5-O-(6-O-malonyl- β-D-glucoside) (iv) delphinidin 3,5-di-O- β -D-glucoside were isolated from flowers of *Cichorium intybus* (Nørbæk, et al., 2002). These anthocyanins are responsible for imparting color to flowers. Delphinidin, pelargonidin, peonidinis and petunidin are example of such anthocyanins (Katsumoto et al., 2007; Bąkowska-Barczak, 2005; Tanaka et al., 1998; Yabuya et al., 1997). Four prenylated flavanones (1) 5,7,4′-trihydroxy-8-prenylflavanone, (2) 5,4′-dihydroxy-7-methoxy-8-prenyl flavanone (3) 5,7,4′-trihydroxy-3′,8-diprenylflavanone (4) and 5,7,4′-trihydroxy- 3′,5′-diprenylflavanone were isolated from the

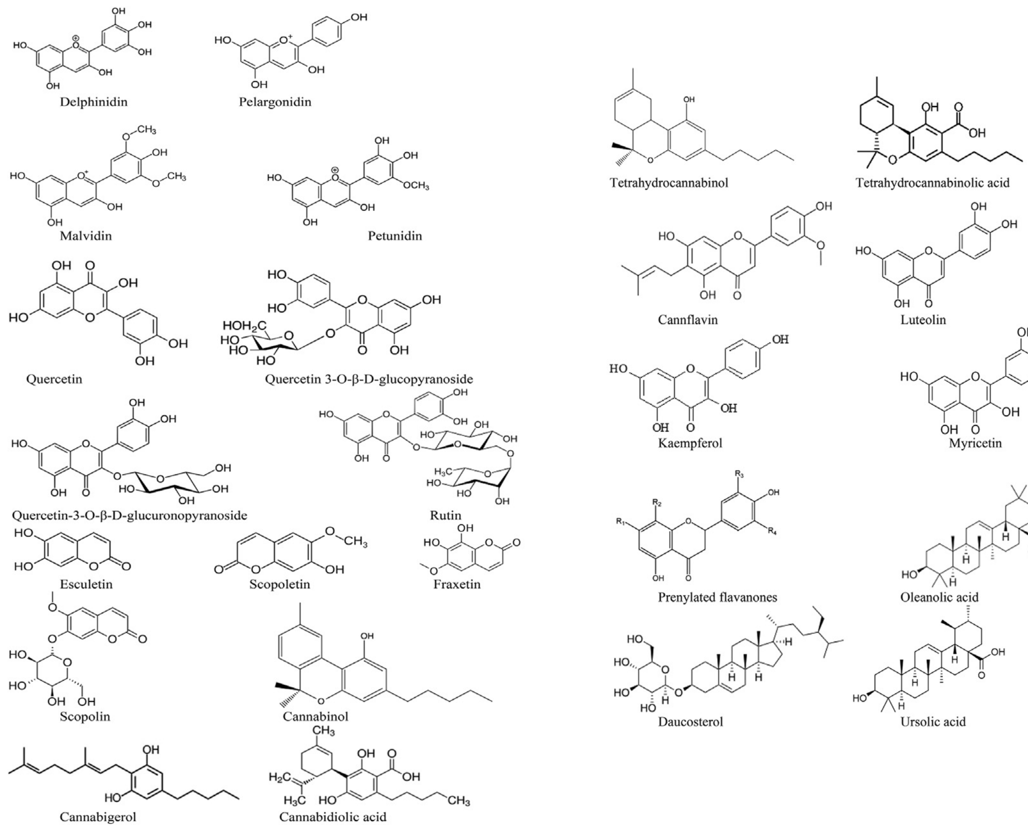

Fig. 1. Important phytochemical obtained from various flowers.

methanol extract of the flowers of *Azadirachta indica* (Nakahara et al., 2003). From the above information it is clear that flowers obtained from various plant species are rich source of different chemicals as presented in Fig. 1 and, thus these products or compounds can be used for reducing as well as stablishing agent in the process of green synthesis of NPs.

3. Flower-based NMs synthesis and their characterization

3.1. Metal NMs

Petals aqueous extract of *Rosa santana* (rose) was used for Ag-NPs fabrication. An absorption peak at 438 nm in UV–vis confirmed the formation of the Ag-NPs. Further, they were examined by Fourier transform infrared spectroscopy (FTIR). FTIR characterization of flower extract showed 3447 cm^{-1} due to –O–H bonded, intramolecular hydrogen bond, 2926 cm $^{-1}$ due –C–H saturated alkane (stretch), 1639 cm $^{-1}$ due to alkenyl stretching (monosubstituted), 10623 cm^{-1} due to sulfoxide, 968 cm^{-1} due to alkenyl stretching (disubstituted (trans), 799 cm^{-1} due to alkenyl stretching (trisubstituted), 660 cm $^{-1}$ due to halo compounds (C-X bond). These chemicals act as reducing as well as stablishing agent for Ag-NPs. The shape of NPs was observed to be spherical by TEM with size 6.52–25.24 nm with particle size of ~ 14.48 nm. The average zeta potential value was −26.50 mV for the Ag-NPs which shows long term stability of NPs (Jahan et al. 20019). Patil et al. (2019) reported Au-NPs synthesis from *Lonicera japonica* flower-extract. Change in color from light yellow to ruby red and absorbance ~530-580 nm in UV–vis spectroscopy confirmed the formation of Au-NPs. FTIR analysis of flower extract shows the presence of alcohols, phenols, 1° amines, aromatic amines, carboxylic acids, alkane and alkynes. Shape of most of synthesized Au-NPs were spherical, in addition, few were triangular, and hexagonal with size between 10 and 40 nm. Energy-dispersive X-ray (EDX) spectroscopy and X-ray diffraction (XRD) studies exhibited the crystalline nature of synthesized Au-NPs.

Alshehri et al. (2017) have investigated the fabrication of iron NPs (Fe-NPs) using aqueous flower extract of *Hibiscus sabdariffa*. TEM analysis exhibited the spherical shape of synthesized Fe-NPs with size 100 nm. FTIR study revealed the presence of anthocyanin compound in the extract of *H. sabdariffa*. Manjari et al. (2017) synthesized Ag-NPs and Au-NPs from flower extract o *Aglaia elaeagnoidea*. TEM studies exhibited spherical shape Ag-NPs and Au-NPs with size of 17 and 25 nm, respectively. It was claimed by FTIR that phenols, proteins, sugars, and other phytochemicals present in *A. elaeagnoidea* flower extract worked as reducing as well as stablishing agent. Mata et al. (2016) used flower extract of *Plumeria alba* for Au-NPs synthesis. TEM analysis showed that size of NPs varies between 28 ± 5.6 and 15.6 ± 3.4. Mata et al. (2015) also reported the Ag-NPs synthesis from same *P. alba* flower extract with size of 36.19 nm and spherical in shape. FTIR studies showed the presence of polyphenols in the flower extract. *Caesalpinia pulcherrima* flower extract was used by Nagaraj et al. (2012) for Au-NPs synthesis. TEM studies revealed that the synthesized NPs were spherical in shape and particles size were range from 10 to 50 nm.

Gnidia glauca plant extracts obtained from flower, leaf and stem were used for copper NPs (Cu-NPs) synthesis (Jamdade et al. 2019). Colour change from pale blue to yellow and finally to dark brown confirmed the formation of Cu-NPs. HR-TEM showed that 5 nm spherical nanoparticle were obtained when prepared from flower extract of *Gnidia glauca*. FTIR spectra showed sharp characteristic peak at ~3400–3420 cm^{-1} due to the presence hydroxyl group in alcoholic and phenolic compounds (Ogunyemi et al. 2019). Flower extract of *Albizia lebbeck* was used as reducing as well as capping agents for Ag-NPs synthesis (Gharpure et al. 2019). Obtained Ag-NPs, under HR-TEM investigation have shown the average particles size of 25 nm.

Fritillaria flower plant extract act as reducing and stabilizing agent for Ag-NPs synthesis (Hemmati et al., 2019). Absorption band at 430 nm in UV–Vis spectrum shows the formation of Ag-NPs. FTIR analysis of *Fritillaria* flower extract showed medium intense band at 1637 cm^{-1} was due to C = O stretching vibration, broad peak at 3421 cm^{-1} was due to presence of O-H stretching vibration. The two bands noted at 1387 cm^{-1} and 1087 cm^{-1} was assigned to the C-N stretching vibrations of aromatic and aliphatic amines. Both SEM/TEM studies revealed that Ag-NPs particles were spherical in shape with an average size of 10 nm. Further, Ag-NPs purity in the composite was noted to be 77.5 wt % by thermogravimetric analysis (TGA).

Ag-NPs were also prepared using an aqueous flower extract of *Scrophularia striata* (Mameneh et al. 2019). They were further examined by FE-SEM, XRD, UV–Vis and FTIR analysis. The peak at 440 nm in UV–Vis was corresponding to SPR band of Ag-NPs. Size of synthesized Ag-NPs was noted 8–12 nm. FTIR analysis of flower extract revealed the presence of hydroxyl, amine and carbonyl groups, which acts as reducing and stabilizing agents for Ag-NPs. Spherical shaped Ag-NPs were obtained from flower extract of *Bauhinia variegata*. The size of NPs was fond to be 5–15 nm when analyzed by TEM. FTIR analysis indicated the presence of phenols, flavonoids, benzophenones, nitro compounds, aromatics and aliphatic (Johnson et al., 2018). Mladenova et al. (2018) synthesized Ag-NPs from flower extract of *Tilia cordata*, *Matricaria chamomilla Calendula officinalis* and *Lavandula angustifolia* and investigated by UV–Vis, TEM and XRD. The shape of synthesized Ag-NPs was spherical and they were between 5 and 30 nm in size. XRD revealed the face-centered cubic (FCC) structure of Ag-NPs.

Ipomoea digitata flower extract was used for Ag-NPs synthesis (Varadavenkatesan et al. 2018). A peak of 412 nm in UV–Vis studies revealed the synthesis of Ag-NPs. SEM studies have shown the polydispersed nature of NP, and presence of elemental Ag in NPs which was confirmed by EDX. XRD studied showed face-centered cubic structure of NPs. The zeta potential was −25.1 mV which indicated the stability of the NPs. Au-NPs were prepared at room temperature from the aqueous flowers extract of *Melastoma malabathricum* (Krishnaprabha and Pattabi, 2019). Morphological, optical, and structural characterization of synthesized Au-NPs were performed by UV–Vis, FTIR spectroscopy, FESEM, TEM and XRD studies. UV–Vis investigation showed the fabrication of Au-NPs synthesis. FESEM and TEM studies showed spherical shape Au-NPs, and size ranged from 20 to 60 nm. Crystallinity of the synthesized Au-NP was examined by using XRD. FTIR studies of flower extract showed absorption band at 3331 cm^{-1}, due to the –OH stretching which shifted to 3308 cm^{-1} thus showed the presence of –OH group in the reduction of Au^{3+} to Au. Karthik et al. (2019) produced Ag-NPs from flower of *Calotropis gigantea* and further characterized by UV–Vis, FTIR, FESEM, and XRD analysis. XRD revealed the crystalline and face centered structure of Ag-NPs with average size 50 nm (Table 1).

Hajra et al. (2016) used petal extracts of marigold for synthesis of cadmium NPs (Cd-NPs). Most fabricated particles were roughly in shape. *Moringa oleifera* flower extract mediated palladium nanoparticles (Pd-NPs) was synthesized by Anand et al. (2016). Further they were examined using SEM, EDX, FTIR, DLS and TEM. GC–MS was used to determine the chemical composition of crude flower extract which showed that palmitic acid, docosane, tricosane, tetracosane, pentacosane, Bis(2-ethylhexyl) phthalate, octacosane and hexacosane were major constituent of flower extract. TEM images revealed that size of NPs range between 10 and 50 nm. EDX showed the presence of elemental Pd in NPs. Nayan et al. (2018) used flower extract of *Mangifera indica* for Au-NPs synthesis and characterized by UV–Vis, FTIR, TEM, HRTEM, EDX spectroscopy, and NP tracking analysis (NTA), DLS. These particles were spherical and size varied from 10 to 60 nm by TEM studies and a modal size of 32 nm by NTA (Nayan et al. 2018).

Ghosh et al. (2012) used flower extract of *Gnidia glauca* for Au-NPs synthesis; and optimized condition for chloroauric acid concentration was 0.7 mM and at temperature 50 °C. EDX was use to check the presence elemental gold in synthesized Au-NPs. Average size of NPs was ~ 10 nm and shape were spherical.

Flower extract of *Mangifera indica* was used for Ag-NPs fabrication (Ameen et al., 2019). TEM showed spherical shape of NPs with size range between 10 and 20 nm. EDX studies revealed the presence of Ag in synthesized NPs. FTIR indicated the presence of phytochemical alkaloids, flavonoids, amino acids and proteins which acted as reducing and stabilizing agents Further, details of various investigations are presented and summarized in Table 1.

3.2. Metal-oxide NMs

Abdallah et al. (2019) used aqueous flower extract of *Rosmarinus officinalis* for fabrication of magnesium oxide NPs (MgO-NPs). Reaction conditions used were continuous stirring at 70°C for 4 h to obtained MgO-NPs. These synthesized MgO-NPs were further analyzed by using UV–Vis, SEM, TEM, XRD and FTIR studies. UV–Vis shows the absorption peak at 250 nm, and exhibited the formation of MgO-NPs. Particles size were 8.8 nm. Elements present in synthesized NPs were confirmed by EDS which shows Mg 35.55% and O 64.45%.

Matricaria chamomilla (chamomile flower) flower extract of along with olive leave and tomato fruit were used for zinc oxide NPs (ZnO-NPs) synthesis. Further, UV–Vis, FTIR, XRD, SEM and TEM techniques were used for the characterization of synthesized ZnO-NPs (Mladenova et al. 2018). Average size of *M. chamomilla* flower extract synthesized ZnO-NPs was 51.2 ± 3.2 nm (Table 2).

Iron oxide NPs (FeO-NPs) were prepared using a flower extract of *Avicennia marina* (Karpagavinayagam and Vedhi 2019) and UV–Vis spectra of FeO-NPs showed absorption peak 295–301 nm. SEM image revealed that average size of synthesized NPs was in the range of 30–100 nm.

Kumar et al. (2014) fabricated titanium dioxide NPs (TiO_2-NPs) from the flower of *Hibiscus rosa-sinensis*. Average size of fabricated NPs was 7 nm based on XRD data. SEM showed that NPs were monodispersed spherical with no agglomeration. FTIR spectra showed that the phytochemicals present in flower extract acted as a capping as well as stabilizing agents. Marimuthu et al. (2013) used the aqueous extract of the flower of *Calotropis gigantean* for TiO_2-NPs synthesis. XRD revealed the average size of synthesized TiO_2-NPs was 10.52 nm. SEM showed an aggregated sphere structure with a size of 160–220 nm. In another study zinc nitrate and flower extract of *Aspalathus linearis* were used for ZnO-NPs synthesis. The synthesis was performed by heating the solution at 80 °C for 2 h to yield 1–8.5 nm amorphous ZnO-NPs; and then hardened the sample at 300 °C for 2 h to yield crystallized ZnO NPs without changing the size (Diallo et al 2015). ZnO-NPs was fabricated using flower extract of *Jacaranda mimosifolia.* GCMS of flower extract showed that oleic acid was present as major phytochemical and act as stabilizing agent. The size of synthesized ZnO-NPs was 2 to 4 nm (Sharma et al., 2016). Dobrucka and Długaszewska (2016) fabricated ZnO-NPs using *Trifolium pratense* flower extract. The synthesized particles shape was spherical and size ranged from 60 to 70 nm when calculated from XRD while SEM studies revealed 100–190 nm in size.

Flower extract of *Peltophorum pterocarpum* was used for the synthesis of zinc oxide NPs (ZnO-NPs). Characterization was performed using UV–Vis, FTIR, XRD, SEM, zeta potential analysis and TGA. SEM analysis revealed that shape of NPs was spherical and

Table 1
Flower-based metal NPs synthesis and their various applications.

Metal NPs	Plant name (Family)	Synthesis condition	Size (nm)	Shape	Characterization techniques	Responsible phytochemical	Applications	Key reference
Ag	*Osmanthus fragrans* (Oleaceae)	@ temp of (25 °C, 40 °C and 60 °C)	13.54-18.17	Spherical	UV–Vis, SEM, FTIR, XRD, TGA and Zetasizer	Carboxylic acid, hydroxyl and methylene group containing compound	Waste water treatment, bio-medicals, medical textiles, wound dressing and antimicrobial activities	Chinyerenwa et al., 2018
Ag	*Datura inoxia* (Solanaceae)	Reaction carried out at 37 °C	15–73	polygonal	UV–Vis, FTIR, EDX and XRD	Ketones, aromatics and aliphatic amines and alkyl halides	Cytotoxic activity	Gajendran et al., 2019
Ag	*Mangifera indica* (Anacardiaceae)	—	10–20	Spherical	UV–Vis, FTIR, EDX and TEM	Alkaloids, flavonoids, amino acids and proteins	Antibacterial activity	Ameen et al., 2019
Ag	*Catharanthus roseus* (Apocynaceae)	Incubated on a sand bath 60 ^{0}C for 10 min	6–25	Spherical	UV–Vis, FTIR and TEM	–	Antibacterial activity	Manisha et al., 2014
Ag	*Bauhinia variegate* (Fabaceae)	@ room temp	5–15	Spherical	UV–Vis, FTIR, XRD, EDX and Zetasizer	Phenols, flavonoids, benzophenones, nitro compounds, aromatics and aliphatic amines	Antioxidant activity	Johnson et al., 2018
Ag	*Bauhinia purpurea* (Fabaceae)	pH 7.0 and time 24 hrs	20	Spherical	UV–Vis, FTIR, TEM), SEM, EDS and XRD	Alcohols, phenolic Compounds, carbonyl group	Antibacterial activity	Chinnappan et al., 2018
Ag	*Fritillaria* (Liliaceae)	@ 30 ^{0}C	5–10	Spherical	TEM SEM, FTIR, XRD and EDX	Hydroxyl, amid and carbonyl groups	Antibacterial activity	Hemmati et al., 2019
Ag	*Ipomoea digitate* (Convolvulaceae)	Heated in a water bath (80 ^{0}C) for 10 min	100	Spherical	UV–Vis, SEM, EDX, XRD, DLS and FTIR	Aromatic amines, amides, carbonyl groups, polyphenols, alcohols and proteins	Catalytic and antibacterial activities	Varadavenkatesan et al., 2018
Ag	*Couroupita guianensis* (Lecythidaceae)	@ 70 ^{0}C for 15mins on water bath and incubated overnight	15–57	Spherical	TLC, UV–Vis, SEM, TEM, XRD and FTIR	Alcohol and phenol, amide linkages of the proteins	Antioxidant and antibacterial activities	Pandurangan et al., 2018
Ag	*Allamanda cathartica* (Apocynaceae)	@ 37 ^{0}C for 15 min	39	Spherical	UV–Vis, FTIR, EDS, TEM and XRD	(E,E)-geranyl linalool, n-pentacosane, 1,8-cineole and n-tricosane.	Antibacterial and antioxidant activities	Karunakaran et al., 2016
Ag	*Millettia pinnata* (Fabaceae)	Heated with magnetic stirrer at 60 ^{0}C for 30 min	16–38	Spherical	UV–Vis, XRD, SEM, TEM and FTIR	Nitriles. alkenes and aromatic groups	Antibacterial, and cytotoxicity activities	Rajakumar et al., 2017
Ag	*Scrophularia striata* (Scrophulariaceae)	Incubated for 24 h at 27 ^{0}C at 120 rpm	8–12	–	GC–MS, UV–Vis, FESEM, XRD and FTIR	Alcohols, phenols, alkanes, aromatic, aromatic amines, alcohols and carboxylic acids	Toxicity studies	Mameneh et al., 2019
Ag	*Caesalpinia Pulcherrima* (Fabaceae)	Boiling timing was 5 min for flower extract, 1 mM silver nitrate con., pH 8, and reaction time was 24 h	2–22	Spherical	FTIR, XRD, TEM and TGA	Alkanes group and the aldehyde group, primary amines and carbonyl group	Antimicrobial, antioxidant and cytotoxic activities	Moteriya and Chanda, 2017
Ag	*Spartium junceum* (Fabaceae)	Heated @ 80 ^{0}C and pH = 9 for 20 min	15–25	Nearly-spherical in shape	UV–Vis, FTIR, XRD, DLS and TEM	–	–	Nasseri et al., 2019
Ag	*Albizia lebbeck* (Fabaceae)	@ room temperature	25	Spherical	UV–Vis, TEM, FTIR, GC–MS and NMR	Alcohols, amines and alkyls	Antibacterial and anticancer activities	Gharpure et al., 2019
Ag	*Tagetes erecta* (Asteraceae)	@ room temperature	10–90	Spherical, hexagonal and irregular	UV–Vis, FTIR, SEM, TEM, SAED, EDX and zeta potential	Amide, aromatic monosubstituted benzene and vinyl disubstituted alkenes	Antibacterial activity	Padalia et al., 2015
Ag	*Hydrangea paniculata* (Hydrangeaceae)	@ 25 ^{0}C	36–75	Spherical	UV–Vis, SEM, TEM, FTIR, XRD, EDX and SAED	Terpenoids, steroid, saponins, alkaloids, quinone, glycosides and flavonoid	Antioxidant potential and antibacterial activities	Karunakaran et al., 2017
Ag	*Tilia cordata*, (Malvaceae) *Matricaria chamomilla*	@ 25 ^{0}C	5–30	Spherical	UV–Vis, TEM and XRD	–	–	Mladenova et al., 2018

(*continued on next page*)

Table 1 (*continued*)

Metal NPs	Plant name (Family)	Synthesis condition	Size (nm)	Shape	Characterization techniques	Responsible phytochemical	Applications	Key reference
	(Asteraceae) *Calendula officinalis* (Asteraceae) and *Lavandula angustifolia* (Lamiaceae)							
Ag	*Rosa santana* (rose) Petals ()	Heated at 80 ^{0}C for 60 min	6.5–25.2	Nearly spherical	UV–Vis, FTIR, XRD, TEM, and Zeta-size analyzer	Functional group containing –O–H, C-H, –C = C and –S = O	Antimicrobial activity, and cytotoxic effect	Jahan et al., 2019
Ag	*Tussilago farfara* (Asteraceae)	80 ^{0}C dry oven for 4 h or 24 h.	13.57 ± 3.26	Spherical	UV–Vis, HR-XRD, FE-TEM, AFM and zeta Potential	Sesquiterpenoids	Antibacterial and anticancer activities	Lee et al., 2019
Au	*Tussilago farfara* (Asteraceae))	80 ^{0}C dry oven for 4 h or 24 h.	18.20 ± 4.11	Spherical	UV–Vis, HR-XRD, FE-TEM, AFM and zeta Potential	Sesquiterpenoids	Antibacterial and anticancer activities	Lee et al., 2019
Au	*Gnidia glauca* (Thymelaeaceae.)	@ tem 50 ^{0}C, 20 min, with 0.7 mM of $AuCl_4$	~10	Spherical	UV–Vis, TEM, HR-TEM, XRD, EM and DLS	Hydroxyl group in alcoholic, phenolic and amine group	Catalytic	Ghosh et al., 2012
Au	*Alhagi maurorum* (Fabaceae)	@35 ^{0}C for 15 min	12–24	Spherical	UV–Vis, TEM and FTIR	methyl, methylene and methoxy groups	Antimicrobial	Preeti et al., 2017
Au	*Mangifera indica* (Anacardiaceae)	@ different temp (25, 30, 45, 60 ^{0}C)	10–60	Spherical, triangular, pentagons and hexagons	UV–Vis, HRTEM, EDS, SAED, XRD and FTIR	Polyphenols or flavonoids such as mangiferin, quercetin and gallic acid	Catalytic	Nayan et al., 2018
Au	*Mimosa pudica* (Fabaceae)	@100 ^{0}C and at 30 ^{0}C.	24	Spherical	UV–Vis, SEM, TEM, XRD, DLS, Zeta sizer and FTIR	Hydroxyl stretching group	Catalytic	Mapala and Pattabi, 2017
Au	*Lonicera Japonica* (Caprifoliaceae)	Incubated @ 60 ^{0}C	10–40	Spherical and hexagonal	UV–Vis, EDX and XRD, FTIR and GC–MS	Alkaloids, phenolic, polyphenols, amino acids and vitamins	Anticancer activity	Patil et al., 2019
Cd	Rose (Rosaceae) and marigold (Asteraceae)	Room temperature	–	Spherical	UV–Vis, SEM and FTIR	Tannins, flavonoids, alkaloids and carotenoids	Mosquito larvicidal activity	Hajra et al., 2016
Cu	*Coccinia grandis* (Cucurbitaceae)	Heated at 60 ^{0}C for 10 min after 6 h stirring mixture at room temp	18–20	Spherical	UV–Vis, FTIR, XRD, SEM, TEM, and SAED	Alcohols, ester/ether and amine group	Catalysis	Devi and Aharuzzaman, 2018
Mg	*Hydrangea paniculata* (Hydrangeaceae)	@ 25 ^{0}C	56–107	Spherical	UV–Vis, SEM, TEM, FTIR, XRD and EDX	Bis 3,5,5- tri methyl hexyl ether,1,2-diphenyl-1,2 dithiocyantolethane and phytol acetate	Antioxidant potential and antibacterial activities	Karunakaran et al., 2017
Pd	*Moringa oleifera* (Moringaceae)	1 mM Pd acetae, 20 min	10–50	Spherical	UV–Vis, SEM with EDX, FTIR, TEM & DLS, GC–MS coupled with FTIR and NMR	Bis-phthalate compounds	Catalytic and antimicrobial activities	Anand et al., 2016

Table 2
. Flower-based metal-oxide NPs synthesis and their various applications.

Metal-oxide NPs	Plant name (Family)	Synthesis condition	Size (nm)	Shape	Characterization techniques	Responsible phytochemical	Applications	Key reference
CdO	*Cassia auriculta* (Caesalpiniaceae)	Heated on magnetic stirrer at70 ^{0}C	–	–	–		Photocatalytic activity	Gurulakshmi et al., 2019
CdO	*Hibiscus Sabdariffa* (Malvaceae)	Room temp (25 °C)	16–41	Cuboid	HRSEM, HRTEM, EDX and XRD	Pectin and delphinidin	–	Thovhogi et al., 2016
CeO_2	*Hibiscus Sabdariffa* (Malvaceae)	Solution was mixed and then thermal annealing at 500 °C (2 h)	3.9	Face centered cubic	HRTEM, EDX, ATR-FTIR, X-rays and photoemission spectroscopy	Quercetin, pectin, hibiscetin, hossypectin and delphinidin	–	Thovhogi et al., 2015
Cr_2O_3	*Callistemon viminalis* (Myrtaceae)	Synthesis was performed room temp. and product obtained was dried at 250 °C and heated at 500 °C (2 h)	~92.2	Cubic-like platelet with sharp edges	HRTEM, XRD, ATR/FT-IR, X-Ray and Raman spectroscopy	Flavonoids, monoterpenoids, tannins and triterpenoids	Antimicrobial activity	Sone et al., 2016
FeO	*Avicennia marina* (Acanthaceae)	–	30–100		UV–Vis, SEM, FTIR, XRD and AFM	Aromatic and aliphatic C-H stretching	Electro catalytic	Karpagavinayagam and Vedhi, 2019
Fe_3O_4	*Polpala* (Amaranthaceae)	Heated @ 60 ^{0}C until reduced	38	Irregular spherical	UV–Vis, FTIR, XRD and SEM	Alcohol, aldehydes and amine	Nano-catalyst	Clarina et al., 2018
HgO	*Callistemon viminalis* (Myrtaceae)	Boiled for 10 min at 80 ^{0}C			UV–Vis and FTIR	Saponins, phenolic compounds and flavonoids	Antibacterial activity	Das et al., 2014
MgO	*Rosmarinus officinalis* L. (Lamiaceae)	Heated at 600 rpm (70 ^{0}C) for 4 h using magnetic stirrer	≤20	Flower - shaped	UV–Vis, XRD, SEM, TEM and FTIR	Amine and alcohol group	Antibacterial activity	Abdallah et al., 2019
ZnO	*Chamomile* (Asteraceae) Olive (Oleaceae) and Red tomato fruit (Solanaceae)	On water bath at 60–70 ^{0}C for 4 h	40.5–124.0	–	UV–Vis, FTIR, XRD, SEM, TEM, and EDS	Terpenes, saponins, alkaloids, flavonoids, tannins, glycosides and carbohydrates	Antibacterial activity	Ogunyemi et al., 2019
ZnO	*Peltophorum pterocarpum* (Fabaceae)	Heated @ 80 ^{0}C until deep yellow paste	50–100	Spherical and irregular	UV–Vis, FTIR, XRD, XRD, SEM and TEM	Phenolic compounds, flavonoids, saponins, steroids, etc	Antimicrobial and cytotoxic activities	Khara et al., 2018
ZnO	*Trifolium pretense* (Fabaceae)	Solution was stirred for 4 h (at 90 ^{0}C)	60–70	Spherical	UV–Vis, FTIR, XRD, XRD, SEM, TEM and total reflection X-ray fluorescence analysis	–	Antimicrobial activity	Dobrucka and Długaszewska (2016)
ZnO	*Nyctanthes arbor-tristis* (Oleaceae)	pH at 12 solution was stirred continuously for 2 h	12–32	–	UV–Vis, FTIR XRD, DLS and TEM	Amide, aromatic amine, aliphatic amine and alcohol group	Antifungal activity	Jamdagni et al., 2016
ZnO	*Bougainvillea* (Nyctaginaceae)	Under dark, stirring conditions at room temperature overnight	40	–	UV–Vis, FTIR, DLS, SEM and EDX	OH functional group	Antimicrobial and anticancer activities	Rauf et al., 2019

irregular with average size 69.45 nm. TGA curve of ZnO-NPs indicated that synthesized NPs were stable between 200 and 800 ^{0}C temperature range. Surface charge of ZnO-NPs was measured by zeta potential fond to be 0.73 mV (Khara et al., 2018). Recently, ZnO-NPs were fabricated by using *Bougainvillea* flower extracts by Rauf et al. (2019). These biosynthesized ZnO-NPs were examined by UV–Vis, SEM, FTIR, DLS and EDX which showed that size of NPs was 40 nm. Further, details of various investigations are presented and summarized in Table 2.

4. Applications

Overall, a summarized flower-based NMs fabrication and their various applications is presented in Fig. 2.

4.1. Antimicrobial activities

Flower-mediated metal and metal-oxides NPs were studied and have shown better antimicrobial activities. The antibacterial potential of NPs could be verified using well diffusion method. *Ipomoea digitata* flower extract mediated Ag-NPs showed effective antimicrobial activity against both pathogenic gram-positive as well as gram-negative bacteria (Varadavenkatesan et al., 2018). Abdallah et al. (2019) biosynthesized MgO-NPs using *Rosmarinus officinalis* flower extract and tested them against the bacteria causing blight disease in rice. Result showed that MgO-NPs remarkedly reduced bacterial growth, biofilm formation, and motility of *Xanthomonas oryzae* pv. *oryzae*. Authors have reported that the bacterial cell death was due to the damage of cell integrity, and which leads to the leakage of intracellular content.

The antibacterial activities of the fabricated Ag-NPs from *Rosa santana* (rose) petals were tested against *S. aureus* (ATCC 25923) and *E. coli* (TCC 25922). The zone of inhibition was 11.73 ± 0.25 mm for *S. aureus* and in case of *Escherichia coli* it was 10.20 ± 0.3 6 mm. The cytotoxic effect of synthesized Ag-NPs tested on a mouse fibroblast cell line (L929) which showed that NPs were non-toxic to normal cell line at various doses (Jahan et al. 20019). ZnO-NPs synthesized by *Matricaria chamomilla* showed antibacterial activity against cultured Xoo strain GZ 0003 bacteria responsible for leaf blight diseases of rice (Ogunyemi et al. (2019). Ag-NPs@Fritillaria showed greater antibacterial activity than Ag-NPs and Fritillaria extract. Antibacterial activity of fabricated Ag-NPs@Fritillaria was examined on bacteria growth; and inhibitory zone was ranging from 10.2 ± 0.83 mm for *P. mirabilis* and 59 ± 1 mm in case of *S. saprophyticus* (Hemmati et al. 2019). *Jacaranda mimosifolia* flower extract fabricated ZnO-NPs and was examined for antibacterial activity by treating bacterial culture with varying doses of NPs (10–100 μg mL^{-1}). The synthesized ZnO-NPs showed effective antibacterial activity against *E. coli* and *E. faecium* bacteria (Sharma et al., 2016). Karthik et al. (2019) fabricated the Ag-NPs using the flower extract of *Calotropis gigantea* which exhibited antibacterial activity in case of *E. coli*. Agar well diffusion method was used to examine the antimicrobial activity of fabricated ZnO-NPs from *Peltophorum pterocarpum* flower extract against four Gram positive bacteria *(Bacillus cereus*, *Bacillus subtilis* , *Staphylococcus aureus*, *Corynebacterium rubrum*) four Gram negative bacteria (*E. coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Salmonella typhimurium*) and three fungi (*Cryptococcus neoformans*, *Candida albicans*, *Candida glabrata).* Fabricated ZnO-NPs showed a remarkable antimicrobial activity in comparison to some antibiotics (Khara et al., 2018)

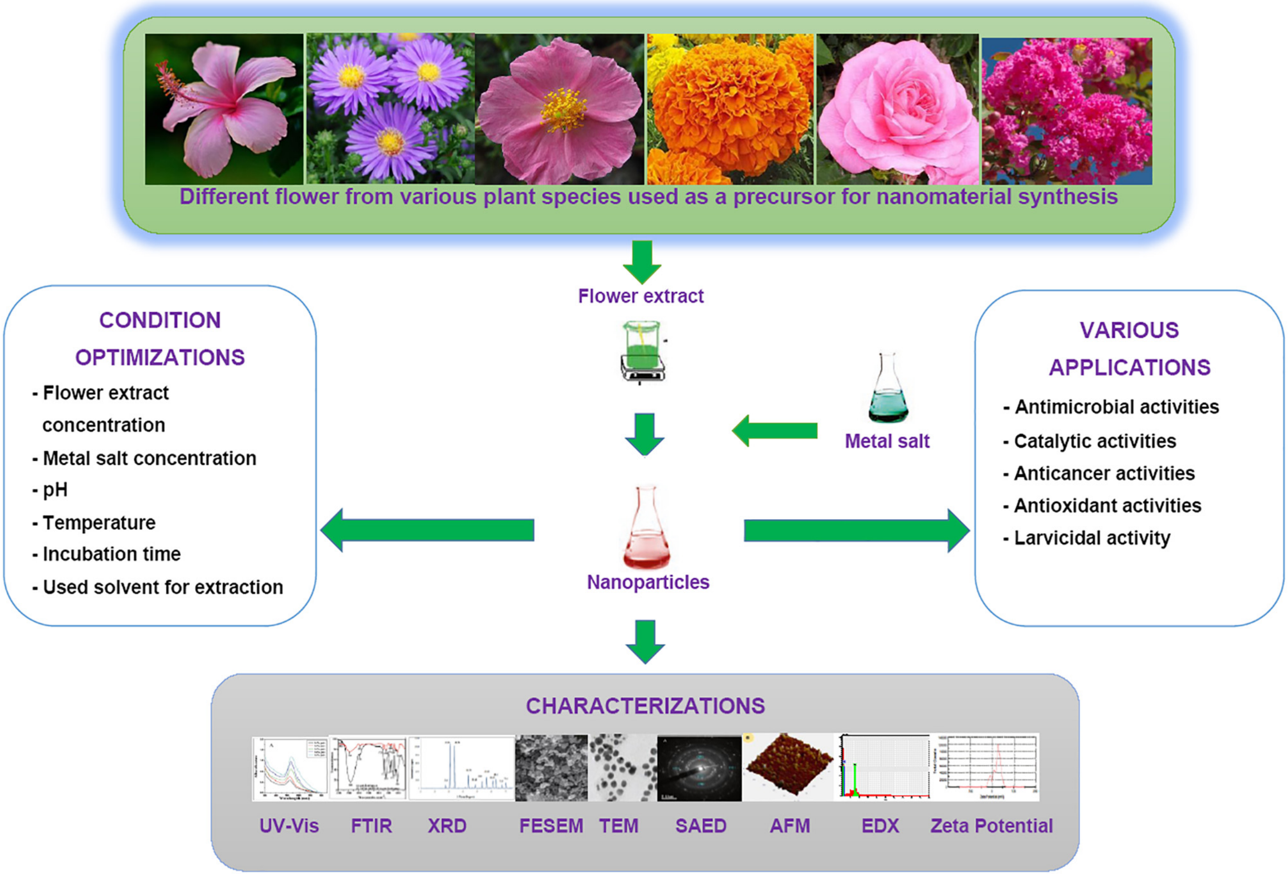

Fig. 2. Flower-mediated NP fabrication, characterization and their applications.

4.2. Antioxidant activities

Ag-NPs synthesized using *Bauhinia variegata* flower extract showed remarkable antioxidant and α-amylase enzyme activity inhibition (Johnson et al., 2018) and suggested as an effective nano-drug for the treatment of diabetic conditions. Pandurangan et al., (2018) studies a comparative observation on different biochemical compounds obtained from leaf, flower and fruit (*Couroupita guianensis*) and fabricated Ag-NPs using water, ethyl acetate, and chloroform crude extract. The result of the study showed significant antioxidant and antibacterial activity hence stating the presence of bioactive compounds. Further, flower extracts of *Couroupita guianensis, Allamanda cathartica* (Karunakaran et al., 2016) mediated Ag-NPs have shown potential antioxidant activities. Jamdade et al. (2019) reported that the novel Cu-NPs fabricated from *Gnidia glauca* and *Plumbago zeylanica* used as a promising antidiabetic agent; and have demonstrated that these particles are considered as a potential candidate in antidiabetic nanomedicine preparation.

4.3. Anticancer activities

Flower extract of *Peltophorum pterocarpum* used for ZnO-NPs fabrication; and further examined for their antimicrobial and cytotoxic activities; and reported as a remarkable application in treatment of some disease (Khara et al., 2018). Brine shrimp cytotoxic activities of plant extract determined their various pharmacological features (Hatano et al., 1989). Rajakumar et al. (2017) and studied for anti-cholinesterase, antibacterial and cytotoxic activities using *Millettia pinnata* flower extract mediated Ag-NPs and showed that synthesized NPs have potential cytotoxicity activities. Cytotoxic effects of NPs towards shrimp's larvae can linked with anticancer activity and the synthesized NPs could be alternative source of anticancer drugs. Gharpure et al. (2019) studies the non-antibacterial and non-anticancer activity of flower extract and its biosynthesized silver NPs. Synthesized Ag-NPs has not been shown remarkable toxicity even with increase in concentration, due to their biocompatible, hence can be a better candidate as the drug carrier. Further, Mameneh et al. (2019) also studied toxicity of Ag-NPs synthesized using aqueous flower extract of *Scrophularia striata* on MCF-7 human breast cancer cell line. Authors have demonstrated that Ag-NPs from *S. striata* flower extract as a potential therapeutic agent for human breast cancer treatment. One report is available on green synthesized of Au-NPs using flower-extract of *Lonicera japonica* were evaluated for the cytotoxic effect on normal embryonic kidney cells (HEK293) and cervix cancer (HeLa) cells. Result indicated that synthesized Au-NPs were safe to normal cell while inhibited the growth of cancer cells. Immunofluorescent staining studies of HeLa cells showed that condensation and fragmentation of nuclear material were observed that indicates apoptotic cell death (Patil et al. (2019). Another report for anticancer activity of flower extract of mediated NPs is given by Anand et al. (2016) in which biosynthesized Pd-NPs from *Moringa oleifera* flower extract antiproliferative activity in A549. *Tussilago farfara* flower bud extract used for Ag-NPs and Au-NPs synthesis (Lee et al., 2019) and both (Ag and Au) synthesized NPs were tested for anticancer activity against gastric adenocarcinoma cell, human colorectal adenocarcinoma cell (HT-29) and human pancreas ductal adenocarcinoma cells. The cytotoxic activity of synthesized Au-NPs was found higher. Among these examined cells, the highest cytotoxicity of synthesized NPs was noticed in human pancreas ductal adenocarcinoma cells. In a recent report, ZnO-NPs prepared from *Bougainvillea* flower extracts showed the anticancer activity against the breast cancer cell line (MCF-7) whereas cytotoxicity was not observed against healthy kidney cells (HEK-293) and erythrocytes were established their biocompatible nature (Rauf et al., 2019).

4.4. Catalytic activities

Flower-mediated NPs also exhibited the catalytic activity and thus supported by many investigations. For instance, *Mimosa pudica* flowers extract synthesized Au-NPs showed good catalytic activity in the model reduction reaction of 4-nitrophenol to 4-aminophenol. (Mapala and Pattabi, 2017). *Ipomoea digitata* extract flower mediated Ag-NPs also displayed a noticeable catalytic reduction for methylene blue dye in the presence of $NaBH_4$. It showed pseudo-first order kinetics with a rate constant of 0.1714 min^{-1} (Varadavenkatesan et al. 2018). Also, Ag-NPs prepared from flower of *Saraca indica* and have shown significant catalytic activity (Vidhu and Philip, 2014). Nayan et al. (2018) obtained AuNPs from flower extract of *Mangifera indica* displayed good catalytic property in the reduction of 4-nitrophenol to 4-aminophenol by $NaBH_4$ in aqueous phase. And, hence these NPs are useful for waste-waters treatment and also the effluents containing nitroarene treatment, for example 4-nitrophenol. Anand et al. (2016) produced Pd-NPs using *Moringa oleifera* flower extract and reported the reduction of methylene blue using $NaBH_4$ as a reducing agent. The dyes degradation by Pd-NPs was shown by the decolorization of the dye solution. Also, green synthesized Pd-NPs shown the catalytic reduction of p-nitrophenol to p-aminophenol by $NaBH_4$ (Table 1). *Cassia auriculta* flower extract was used for synthesis of CdO-NPs and tested for their photocatalytic activity for the degradation of methyl orange and methylene blue dyes and results indicated that synthesized CdO-NPs act as good photo catalyst (Gurulakshmi et al. 2019).

4.5. Miscellaneous application

The redox potential and electrocatalytic performance of FeO-NPs (prepared from flower extract of *Avicennia marina*) were established by using an electrochemical workstation (Karpagavinayagam and Vedhi 2019). Cd-NPs were fabricated from marigold petal extracts and have shown remarkable larvicidal activity of mosquito (Hajra et al., 2016). It was reported that the marigold flower petal extract along with 10 ppm of Cd-NPs shown 100% mortality after 72 h of incubation.

5. Conclusion

Flower-based NPs synthesis is ecofriendly, nontoxic, have distinctive properties, and are synthesized in a cost-effective manner. It has been found that the flowers are enriched with bioactive molecules such as flavonoids (anthocyanins catechins), terpenoids, coumarins, sterol, xanthones etc. that have great potential ability in the reduction of metal ions. These compounds acted as reducing and stablishing agent in the process of flower based green synthesis of NPs. A number of reports shows that the flower-mediated NPs synthesis under basic condition in the range of 45 to 70 ^{0}C were spherical in shape and have higher stability. The spherical NPs were suggested to have several applications and stable for a long time. In the characterization of the flower-mediated NPs some of the techniques such as SEM, TEM, DLS, XRD, AFM, EDX, TGA and Zetasizer were used along with UV–Vis, and FTIR were used. Some important points related with the NPs shape, size and their stability; and the precise mechanisms involved in fabrication process is still remain unresolved or partially resolved. However, taken together, flower mediated-NPs has showed potential application as an antibacterial, antioxidant, anticancer, catalytic agents and so on in different investigations. It is therefore anticipated that the biogenic fabrication of nanomaterials from flower-based chemical compounds will brighten the future prospect and enhance our knowledge for the effective formulation and applications in different discipline of science and technology.

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