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 protocols 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 stabilizing 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.

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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 nanoparticle (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; Chandran et al., 2006; Su et al., 2000). Moreover, the tea flower extracts were utilized for gold NPs (Au-NPs) synthesis (Raghavan et al., 2015). 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 (Rhapodendron arborium flower). Flowers are easily available (a sustainable and ecofriendly resource), contain huge amount of phytochemicals. 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 blossoms (Khoo et al., 2017). Anthocyanins have many biological activities for instance antioxidant, antitumor 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 (flavanoid) a phytochemical present in many flowers was used for gold NPs (Au-NPs) synthesis (Raghavan et al., 2015).

Another phytochemicals 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 brevifolin-carboxylate (Wang et al., 2006), triterpenes - oleonolic 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]-5-(iii) delphinidin 3-O-β-D-glucoside-5-(6-O-malonyl-β-D-glucoside) (iv) delphinidin 3,5-di-O-β-D-glucoside were isolated from flowers of Chichorium intybus (Nerbäk et al., 2002). These anthocyanins are responsible for imparting color to flowers. Delphinidin, pelargonidin,peonidins and petunidin are example of such anthocyanins (Katsumoto et al., 2007; Bakowska-Barczak, 2005; Tanaka et al., 1998; Yabuya et al., 1997). Four prenylated flavonanes (1) 5,7,4'-trihydroxy-8-prenylflavone, (2) 5,4'-dihydroxy-7-methoxy-8-prenyl flavone (3) 5,7,4'-trihydroxy-3',8'-diprenylflavane (4) and 5,7,4'-trihydroxy-3',5'-diprenylflavone were isolated from the
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 stabilizing 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 stabilizing 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 flower extract of *Aglaia elaeagnoides*. TEM analysis showed spherical shape of synthesized Au-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. elaeagnoides* flower extract worked as reducing as well as stabilizing 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 carboxyl 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 found 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 polydisperse 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 mala-bathricum_ (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 Au³⁺ 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 used 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. Particle size were 8.8 nm. Elements present in synthesized NPs were confirmed by EDS which showed Mg 35.95% 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, TEM, 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_ (Karpagavayayagam 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 (TiO₂-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 monodisperse 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 gigantea_ for TiO₂-NPs synthesis. XRD revealed the average size of synthesized TiO₂-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 mimosaefolia_. 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 pterocarpuum_ 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

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**Table 1:**

| Flower Plant Extract | Metal-NP Composition | Average Size (nm) |
|----------------------|----------------------|------------------|
| **Ag-NPs**           |                      |                  |
| **Au-NPs**           |                      |                  |
| **FeO-NPs**          |                      |                  |
| **MgO-NPs**          |                      |                  |
| **ZnO-NPs**          |                      |                  |

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**Table 2:**

| Metal-NP Type | Flower Plant Extract |
|---------------|----------------------|
| **TiO₂-NPs**  |                      | 10.52 ± 3.2 nm     |
| **ZnO-NPs**   |                      | 51.2 ± 3.2 nm      |

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Table 1
Flow-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, biomedical, medical textiles, wound dressing and antimicrobial activities | Chinyerewa 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 °C for 10 min | 6–25 | Spherical | UV–Vis, FTIR and TEM | – | Antibacterial activity | Manisha et al., 2014 |
| Ag        | Bauhinia variegata (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 °C | 5–10 | Spherical | UV–Vis, SEM, XRD, EDX, TEM SEM, XRD, and EDX | Aromatic amines, amides, | Antibacterial activity | Hemmati et al., 2019 |
| Ag        | Ipomoea digitata (Convolvulaceae) | Heated in a water bath (80 °C) for 10 min | 100 | Spherical | UV–Vis, SEM, XRD, DLS and FTIR | Aromatic amines, amides, carbonyl groups, polyphenols, | Catalytic and antibacterial activities | Varadavenkatesan et al., 2018 |
| Ag        | Couroupita guianensis (Lecythidaceae) | @70 °C for 15 mins 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) | Incubated for 24 h at 270 °C at 120 rpm | 8–12 | – | GC–MS, UV–Vis, FESEM, XRD and FTIR | (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 °C for 30 min | 16–38 | Spherical | UV–Vis, XRD, SEM, TEM and FTIR | Alcohols, phenols, alkanes, | Antibacterial and cytotoxicity activities | Rajakumar et al., 2017 |
| Ag        | Scrophularia striata (Scrophulariaceae) | Incubated for 24 h at 27 °C at 120 rpm | 2–22 | Spherical | FTIR, XRD, TEM and TGA | Alcohols and group the aldehyde group, primary amines and carbonyl group | Antimicrobial, antioxidant and cytotoxic activities | Moteriya and Chanda, 2017 |
| Ag        | Caesalpinia Pulcherina (Fabaceae) | Boiling timing was 5 min for flower extract, 1 mM silver nitrate con., pH 8, and reaction time was 24 h | 15–25 | Nearly-spherical in shape | UV–Vis, FTIR, XRD, DLS and TEM | Alcohols, amines and aldehydes | Antibacterial and anticancer activities | Nasser et al., 2019 |
| Ag        | Spartium junceum (Fabaceae) | Heated @ 80 °C and pH = 9 for 20 min | 15–25 | Spherical | UV–Vis, FTIR, XRD, TEM and TGA | Alcohols, amines and carbonyl groups | – | – |
| Ag        | Albizia lebeck (Fabaceae) | @ room temperature | 25 | – | UV–Vis, FTIR, GC–MS and NMR | Amides, aromatic monosubstituted benzene and vinyl disubstituted alkenes | Antibacterial and anticancer activities | Gharpure et al., 2019 |
| Ag        | Tagetes erecta (Asteraceae) | @ room temperature | 10–90 | Spherical | UV–Vis, FTIR, SEM, TEM, SAED, EDX and zeta potential | Alkanes and group the | Antibacterial activity | Padalia et al., 2015 |
| Ag        | Hydrangea paniculata (Hydrangeaceae) | @ 25 °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 °C | 5–30 | Spherical | UV–Vis, TEM and XRD | – | Mladenova et al., 2018 |

(continued on next page)
| Metal NPs | Plant name (Family) | Synthesis condition | Size (nm) | Shape | Characterization techniques | Responsible phytochemical | Applications | Key reference |
|----------|---------------------|---------------------|-----------|-------|----------------------------|---------------------------|-------------|--------------|
| Ag       | Rosa santana rose petals () | Heated at 80 °C for 60 min | 6.5–25.2 | Nearly spherical | UV–Vis, FTIR, XRD, TEM, and Zeta-size analyzer | Functional group containing –OH, C=H, – C = C and –S = O Sesquiterpenoids | Antimicrobial activity, and cytotoxic effect | Jahan et al., 2019 |
| Ag       | Tussilago farfara (Asteraceae) | 80 °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       | Gnidia glauca (Thymelaeaceae.) | Ø tem 50 °C, 20 min, with 0.7 mM of AuCl₄⁻ | ~10 | Spherical | UV–Vis, TEM, HR-TEM, XRD, EM and DLS | Hydroxyl group in alcoholic, phenolic and amine group methyl, methylene and methoxy groups | Catalytic | Ghosh et al., 2012 |
| Au       | Alhagi maurorum (Fabaceae) | Ø35 °C for 15 min | 12–24 | Spherical | UV–Vis, TEM and FTIR | Polyphenols or flavonoids such as mangiferin, quercetin and gallic acid | Catalytic | Nayan et al., 2018 |
| Au       | Mangifera indica (Anacardiaceae) | Ø different temp (25, 30, 45, 60 °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 | |
| Au       | Mimosa pudica (Fabaceae) | Ø100 °C and at 30 °C, | 24 | Spherical | UV–Vis, SEM, TEM, XRD, DLS, Zeta size and FTIR | Hydroxyl stretching group | Catalytic | Mapala and Pattabi, 2017 |
| Au       | Lonicera Japonica (Caprifoliaceae) | Incubated Ø 60 °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 °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) | Ø 25 °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 dihydroxyanthelene and phytol acetate | Antioxidant potential and antibacterial activities | Karunakaran et al., 2017 |
| Pd       | Moringa oleifera (Moringaceae) | 1 mM Pd acetate, 20 min | 10–50 | Spherical | UV–Vis, SEM with EDX, FTIR & DLS, GC–MS coupled with FTIR and NMR | Polyphthalate compounds | Catalytic and antimicrobial activities | Anand et al., 2016 |
| Metal-oxide NPs | Plant name (Family) | Synthesis condition | Size (nm) | Shape | Characterization techniques | Responsible phytochemical | Applications | Key reference |
|----------------|---------------------|---------------------|-----------|-------|----------------------------|---------------------------|-------------|--------------|
| CdO            | Cassia auriculata (Caesalpiniaceae) | Heated on magnetic stirrer at 70 °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 |
| CeO₂           | 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 flavonoids, monoterpenoids, tannins and triterpenoids | Antimicrobial activity | Thovhogi et al., 2015 |
| Cr₂O₃          | 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-FTIR, X-Ray and Raman spectroscopy | Flavonoids, monoterpenoids, tannins and triterpenoids | Antimicrobial activity | Sone et al., 2016 |
| FeO            | Avicennia marina (Acanthaceae) | – | 30–100 | Irregular | UV–Vis, SEM, FTIR, XRD and AFM | Aromatic and aliphatic C-H stretching | Electro catalytic Nano-catalyst | Karpagavinayagam and Vedhi, 2019 |
| Fe₃O₄          | Polpala (Amaranthaceae) | Heated @ 60 °C until reduced | 38        | Irregular | UV–Vis, FTIR, XRD and SEM | Alcohol, aldehydes and amine | –           | Clarina et al., 2018 |
| HgO            | Callistemon viminalis (Myrtaceae) | Boiled for 10 min at 80 °C | –          | Flower - shaped | 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 °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 °C for 4 h | 40.5–124.0 | – | UV–Vis, FTIR, XRD, TEM, and EDS | Terpenes, saponins, alkaloids, flavonoids, tannins, glycosides and carbohydrates | Antibacterial activity | Ogunyemi et al., 2019 |
| ZnO            | Peltophorum pterocarpum (Fabaceae) | Heated @ 80 °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 °C) | 60–70 | Spherical | UV–Vis, FTIR, XRD, XRD, TEM and total reflection X-ray fluorescence analysis | – | – | Debrucka 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 °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 remarkably 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 ± 0.36 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. 2019). 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 neoforms, 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 (Courea pita guainensis) 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 guainensis, 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 Milletia 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. Choparde 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 Lonicer 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 anti-proliferative 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 Bougainvillaae 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 flower mediated Ag-NPs also displayed a noticeable catalytic reduction for methylene blue dye in the presence of NaBH4. 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 NaBH4 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 NaBH4 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 NaBH4 (Table 1). Cassia auriculata 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 (Karpagavayagam 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 stabilizing 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 °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 shown potential application as an antibacterial, antioxidant, anticancer, catalytic agents and so on in different investigations. It is therefore anticipated that
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