A Comprehensive Review on Nanoflowers: Synthesis, Characterization and Applications

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Abstract

Nanoflowers are among the most promising materials, and they have been linked to significant advancements in nanobiotechnology. When compared to other nanoparticle morphologies, nanoflowers which resemble flowers, have a higher surface area to volume ratio. For nanotechnology, the synthesis of complex nanostructures is crucial. Because they are simple to create using both chemical and physical techniques, nanoflowers are excellent choices for a range of biomedical uses. The final synthesized product's stability, biocompatibility, and consequently their utility, can be influenced by the precise control of reaction duration, size, and structure. A range of nanomaterials can be produced swiftly and economically by creating organic, inorganic, and hybrid nanoflowers. The use of nanoflowers in solar cells, water purification, and biosensors has been well documented in the literature. They can also be a great choice for drug or gene conjugation, drug delivery, and personalised treatment because of their shape and increased surface area. The synthesis, morphologies, and uses of nanoflowers in several biomedical fields are covered in this review. In addition to discussing current and upcoming trends, the biocompatibility and nanotoxicity of these structures are also highlighted.

Keywords: Nanoflowers, Nanomaterials, Nanotoxicology, Nanobiotechnology, Biocompatibility, Flowers.

1. Introduction

Nanotechnology is a large and interdisciplinary field of study and development that has grown rapidly worldwide in recent years. This technology reaches the gap between the molecular and macroscopic levels, offering novel possibilities to create nanostructured materials with unique size, shape, and functions. The morphology, size, form, and dimensionality of nanostructured materials influence their physicochemical properties. As a result, the development of innovative materials of various sizes and forms is a key focus of study [1]. Even though nanotechnology is a relatively new scientific discipline, its promise was evident when physicist Richard Feynman delivered his famous speech “There’s Plenty of Room at the Bottom”. In his address, Feynman mentioned the large margins that the rules of nature leave for controlling matter at the atomic level [2]. Nanotechnology is a multidisciplinary field that integrates the creation of nanoscale materials with their technological applications. Because of their smaller size, nanomaterials exhibit distinct features from their bulk counterparts. Nanotechnology has numerous applications, and its impacts can be seen on multiple levels, addressing complicated challenges. Electronics, cosmetics, the food sector, biotechnology, and pharmaceuticals all have a wide range of uses [3-5]. The explosion of nanotechnology, which began in the last decade of the 20^{th} century, has led to the discovery of numerous types of nanoparticles and nanoaggregates. They include nanopowders, nanotubes, nanowires, nanorices, nanolines, nanodumbbells, clusters, sheets, nanorods, nanodots, nanoalloys, nanobelts, nanoribbons, nanoplates, nanoneedles, nanocones, and nanofilms. These materials have a wide range of uses, including as chemical sensors, catalysts, magnetic materials, nanocomposites, nanodevices, and even potential carriers of isotopes for use in medicine. It can be challenging to assign formed nanostructures to a certain group above; the synthesis circumstances often determine the capability of forming different nanoforms [6]. Researchers are more enthusiastic in the geographical features of nanoflowers among these novel nanostructures because they have a greater surface-to-volume ratio than round nanoparticles, which enhances the surface effectiveness of nanomaterials. In the 100–500 nm nanoscale range, nanoflowers (NF), a recently discovered class of microscopic particles, have structural similarities to plant flowers [7–10]. Scientists have been very interested in studying nanoflowers because of their unusual morphologies, easy ways to create them from organic and inorganic materials, and occasionally even a hybrid combination of both to increase the stability and efficiency of surface reactions, as well as their physicochemical characteristics, which include high surface-to-volume ratios, improved charge transfer, carrier immobility, and increased surface reaction efficiency. Nanoflowers are made up of multiple layers of petals to provide a bigger surface area in a compact structure. As a result, advanced experimental examinations such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffraction spectroscopy (XRD) are required to characterise the nanoflowers. These NFs have numerous applications in catalysis, magnetism, nanodevices, sensing, biosensing, and biomedicine [11-15]. This study discusses recent breakthroughs in the synthesis routes of several NFs and their applications.

1.1. Advantages and Disadvantages of Nanoflowers:

Advantages:

1. The high surface to volume ratio of nanoflower enhances surface adsorption, which speeds up reaction kinetics. A greater quantity of adsorption sites was found in the zinc oxide nanoflowers, and this finding is important for determining surface-enhanced Raman spectroscopy (SERS).
2. Because of their enormous surface area, nanoflowers showed improved charge transfer and carrier immobility. For SERS sensitivity, the zinc oxide nanoflowers coated with silver had improved charge transfer and carrier immobility.
3. The three-dimensional structure of nanoflowers increases the effectiveness of surface reaction. Zinc oxide nanoflowers' three-dimensional shape increased the number of adsorption sites, which improved their efficacy for SERS sensing [7].
4. Simple, non-toxic, and economical synthetic techniques such as ionotropic gelation, precipitation method, and green synthesis can be used to make nanoflowers [8].
5. Because proteins and enzymes are unstable, immobilising them on the metal's surface improves stability. Calcium is a metal ion that the enzyme-like glucose oxidase immobilised on concanavalin A's surface needs to boost its stability [9].

Disdvantages:

1. It is exceedingly difficult to manage the structural characteristics of the nanoflower, such as its dimensions and petals, both before and after the reaction is completed [10].

2. Toxic materials or byproducts may occur during the severe temperatures of 80–550 °C used to make nanoflowers in synthetic reactions.
3. Compared to other techniques such ionotropic gelation, precipitation, green synthesis, etc., hydrothermal approaches for the fabrication of nanoflowers required a higher temperature.
4. Compared to their free forms, protein and peptide immobilisation reduces their therapeutic activity. In order to determine whether E. coli is a food pathogen, glucose oxidase's therapeutic efficacy may be diminished by immobilisation [16].

1.2. Comparative aspects of microflower and nanoflower:

The floral portion of a plant that primarily aids in reproduction is its flowers. The following sections of the flower are classified:

1. Petals: Colored part of the flower, also called modified leaf and when in bunch called corolla.
2. Stigma: Part of a flower where pollen grains germinate.
3. Anther: Part of the flower where pollens are produced.
4. Filament: Thread-like portion of the flower that supports the anther.
5. Style: Part which joins stigma and ovary.
6. Ovule: Reproductive part of a flower.
7. Sepal: Outermost leaf-like part of a flower.
8. Receptacle: Part of the stalk where whole flower is attached.

Among these various plant parts, petal-like structures can be seen under a microscope in microflowers and nanoflowers. The order of the floral sizes is essentially plant flower > microflowers > nanoflowers. Microflowers are small-scale particle systems that mimic the composition of plant flowers [17, 18]. The micro- and nano-flowers are compared in Table 1 based on characterization criteria such as size, diameter, petal size, etc.

Table 1. Comparative aspects of microflower and nanoflower.

Parameters	**Microflower**	**Nanoflower**
Size	3–10 μm	100–500 nm
Diameter	3–5μm	2–5 nm
Petal size	10–20 μm	0.1–5 μm
Surface area to volume ratio	Low	High
Efficiency of surface reaction	Low	High
Immobilization efficiency	Low	High
Applications	Bone regeneration, improve electrochemical performance, enhance scattering, etc.	Removal of heavy metal from water, biosensor for detection of pathogens in food, purification of enzyme, etc.

2. Types of Nanoflowers

Nanoflowers are classed according to their composition as inorganic, organic, or hybrid (containing both organic and inorganic components) (Fig. 1).

2.1. Inorganic nanoflowers:

Inorganic nanoflowers are made entirely of inorganic elements, such as metals, metal oxides, alloys, and metalloids, or they are coated or doped with metalloids, carbon, nitride, sulphide, phosphide, selenide, and telluride [19-30]. Vesicles containing gemini amphiphiles that guided the creation of Au nanoflowers were described [31]. NiO are synthesised via a straightforward surfactant-free hydrothermal process that involves $Ni(NO_3)_2$ and triethylamine, followed by calcination. Using urea instead of triethylamine in NiO Nanoflower production resulted in nanoparticles or nanoslices at temperatures of 400 and 600 ◦C, respectively [32]. Imura et al. described a method for preparing silica-coated Au nanoflowers on alumina that prevents nanoflower aggregation and precipitation. Carbon-coated Fe_3O_4 nanoflowers were synthesised using a one-pot solvothermal method as biosensors in lateral flow immunoassay [26, 27].

2.2. Organic nanoflowers:

Organic nanoflowers are made entirely of organic molecules or include inorganic elements as part of the medium, with organic molecules serving as the primary components [33-37]. For example, carbon nanoflowers synthesised in water using an electric arc discharge method were reported; the resulting carbon nanoflowers were made up of highly crystalline graphene nanosheets organised in the shape of flowers [38]. Zheng's group developed nitrogen-, phosphorus-, and fluorine-doped carbon nanoflowers by ultrasound-induced polycondensation and pyrolysis [39]. Furthermore, organic nanoflowers have been created from a range of molecules (guests) using fixed supramolecular hacky sacks (hierarchically structured particles) as templates. Nanoflowers with spiky and wide petals were created by employing small/rigid molecules (e.g., doxorubicin) and large/flexible biomacromolecules (e.g., proteins and plasmid DNA) as guests [40].

2.3 Hybrid nanoflowers:

Hybrid nanoflowers, often referred to as organic–inorganic hybrid nanoflowers, are described as nanoflowers in which all inorganic nanostructure components are linked to organic materials [41]. Enzymes, proteins, amino acids, biopolymers, DNA, and peptides having amide or amine groups that can form complexes with metal ions through coordination interaction are generally considered organic components. The majority of inorganic materials are made up of divalent metals including Mn^{2+}, Fe^{2+}, Ca^{2+}, Zn^{2+}, and Cu^{2+} [42]. The first hybrid nanoflowers were found by Ge and colleagues [43], demonstrating that proteins and Cu^{2+} ions may be combined to create new kinds of nanoparticles. Carbonic anhydrase, laccase, lipase, and α-lactalbumin were used to make the four different kinds of hybrid nanoflowers. $Cu_3(PO_4)_3{\cdot}3H_2O$ and glucose oxidase and lipase were used as the inorganic components, and the creation of dual enzyme inorganic hybrid nanoflowers was described [44]. As a biocatalyst for the chiral resolution reaction, Li et al. synthesised lipase–Ca/Fe/Cu nanoflowers embedded in carbon nanotubes [45].

Inorganic nanoflowers, i.e., the nanoflowers made from inorganic elements, have piqued researchers' interest since the early 2000s due to their distinct nanostructural characteristics, as well as their excellent catalytic efficiency and optical properties, which vary depending on their composition, crystal structure, and localised surface plasmon resonance (LSPR).

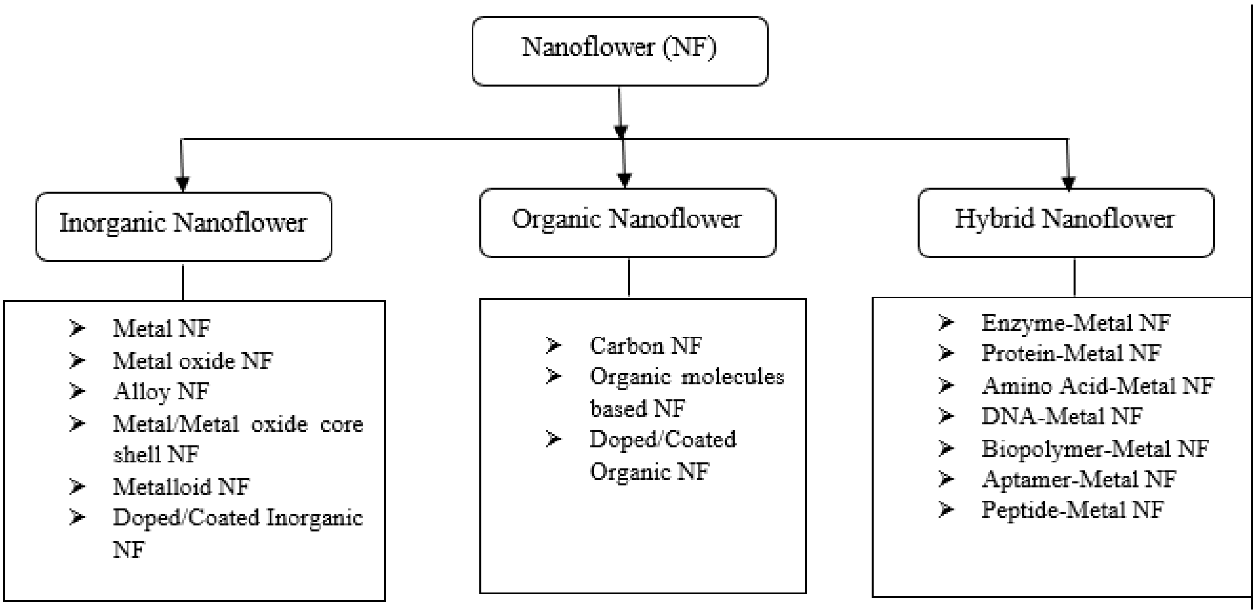

Figure 1: Types of nanoflower according to its composition.

3. Synthesis of Nanoflowers

Based on previously described technologies for the synthesis of nanomaterials, a variety of techniques have been used to create inorganic nanoflowers: chemical, biological, physical, and hybrid approaches [46]. Vapour technology is a primary example of the physical technique, which is the earliest technology [47]. The second synthesis technique, chemical synthesis, has been used most frequently to create inorganic nanoflowers. Studies on the production of inorganic nanoflowers have examined the use of colloidal, sol-gel, inverse micelles, hydrothermal, solvothermal, electrodeposition, and microwave synthesis techniques [48–58]. Third, the use of plant extracts (e.g., leaves of *Azadirachta indica*, *Dodonaea angustifolia*, and *Kalanchoe daigremontiana)* in the biological synthesis approach known as "green synthesis" [58–62] is one of the other biological nanomaterial synthesis techniques. The hybrid nanomaterial synthesis method, a multistep synthesis method that combines various physical, chemical, and biological methods like electrochemical deposition, chemical vapour deposition, high-energy ball-milling hydrothermal treatment, and the solution-immersion RF-sputtering method, is the last example of synthesis technology for flower-shaped inorganic nanomaterials [63–67].

Comparable synthesis technologies were employed to create organic and inorganic nanoflowers. The methods that were disclosed were chemical vapour deposition, microwave-assisted high-temperature/hydrothermal carbonisation etching, reduction pyrolysis–catalysis pathway, electric arc discharge method, and ultrasound-induced polycondensation and pyrolysis [68-71].

A mild and direct coprecipitation approach was established to synthesise hybrid protein–copper phosphate nanoflowers in the case of the organic–inorganic hybrid nanoflower that was initially published in 2012. Subsequently, a variety of hybrid nanoflowers have been produced through the coprecipitation method. This involves combining organic components (like proteins, enzymes, amino acids, and so forth) with metal ions (like Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}, and Co^{2+}) either directly with metal phosphate or in the presence of phosphate-buffered saline. The mixture was subsequently sonicated or incubated [72–77].

In short, based on previously published nanomaterial synthesis strategies, four types of synthesis technologies (e.g., physical, chemical, biological, and hybrid methods) are generally used to make inorganic nanoflowers.
The synthesis process, experimental settings, composition ratio, and architectures all affect the form, size, and thickness of the petals of nanoflowers, so developing new synthesis methods is crucial. There has also been a description of the particular synthesis strategies for biomedical purposes. The initial illustration involves creating nanoflowers using a colloidal technique (utilising a difficult template).

4. Characterization of Nanoflowers

In nanotechnology, one of the vital stages is to adequately characterise the synthesised metallic nanoflowers. NFs are primarily characterised by spectroscopy techniques such as UV-Visible, Fourier Transform Infrared (FTIR), Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), and X-Ray Diffraction (XRD). Regarding metal and metal oxide nanoparticle stability, structure, size, morphology, elemental content, crystal structure, and size distribution, all of these methods offer information [78]. To confirm that petals are forming on nanoflowers, UV-visible spectroscopy is employed. The existence of a surface plasmon ratio (SPR) peak in the UV-visible spectrum, accompanied by an absorption maximum peak, and the initial colour shift of the solution are indicative of the production of NFs. With an increase in metal salt solution content, SPR absorbance rises. To identify the different functional groups that are present in metal NFs, an FTIR spectrophotometer is utilised. According to a number of reports, the main causes of the distinctive peaks in the plant extract's FTIR spectra at different wavelengths are aromatic C-C and C=C stretching, N-O for a nitro group, C-O stretch for alcohol/carboxylic acid/ester/ether, and -OH group for alcohol/phenol. The morphology, structure, and size of the synthesised NFs are shown by the SEM and TEM images. According to SEM and TEM analyses of different data, the majority of the synthesised NFs have a spherical form and range in size from 2 to 50 nm. Using the Debye-Schrrer equation, XRD analysis is used to evaluate the average particle size and crystal structure of metal NFs. Strong and narrow diffraction peaks primarily showed the well-crystalline character of the manufactured MNPs. The crystalline plane is the most common orientation for NFs, meaning that all NFs are crystalline by nature, according to the results of XRD examination from several sources [79].

5. Applications of nanoflowers (NFs)

This article introduces nanoflowers, which have a wide range of uses. These include chemical sensors, magnetic materials, nanocomposites, catalysts, water purification, breakdown of hazardous chemicals, and even potential isotope carriers for medical purposes. Figure 2 below illustrates some of the uses for nanoflowers.

5.1. Biomedical applications of nanoflowers:

5.1.1. Biosensors:

Nanoflowers have a variety of applications in biosensors, including imaging, biocatalysis, tissue engineering, and more. A rapid and affordable approach to identify different analytes is needed in biomedicine. Biosensors are analytical tools that translate biological reactions into electrical signals. Because of their high surface-to-volume-area ratio, nanoflowers have been used in biosensors. For analyte binding, their petals make excellent active sites [80]. Biosensors using Pt and CuS nanoflowers have been used to detect glucose. H_2O_2 has been detected by graphene nanoflowers. Biosensors using

ZnO and CuO nanoflowers have also been used to detect H_2O_2. The analytes acetylcholine, choline, and ascorbic acid have also been reported in the literature [81–89]. 5.1.2. Theranostics and Imaging:
To enhance diagnostic methods, nanoparticles with theranostics applications are being developed. Iron oxide nanoparticles have been widely reported as contrast agents in imaging for these purposes. Magnetic resonance imaging, phototherapy, and the use of Fe_3O_4, FeO, and Fe_3O_4/Au-macrophage nanoflowers for therapeutic and diagnostic applications have all been explored [90, 91].

5.1.3. Administration of medication:

The high surface-to-volume ratio of nanoflowers makes them perfect nanomaterials for applications involving the delivery of drugs. These special nanomaterials' petals have the ability to conjugate genes and pharmaceuticals. Au@Si core shell nanoflowers were loaded with doxorubicin for anti-tumor therapy. Lakkakula et al. created synthetic organic nanoflowers to deliver the medication cyclodextrin. Titanate was used to decorate graphene, an excellent material for binding drug molecules, in order to create a drug delivery system. Biocompatible nanomaterials can also be produced from DNA hybrid nanoflowers [92–95].

5.1.4. Biocatalysis:

The surface of nanoparticles can serve as a catalyst for a variety of biological processes. Adenosine Diphosphate (ADP) was produced from Adenosine Monophosphate (AMP) using a hybrid nanoflower of polyphosphate kinase and Cu3(PO4)23H2O. Furthermore, it has been documented that steroids and cholesterol can be converted. Arastoo et al. used collagenase-$CO_3(PO_4)_2$ nanoflowers to generate collagen hydrolysates. Catalysis of harmful substances like bisphenol-A, methylene blue, and other azo dyes is one of its additional applications [96–102].

5.1.5. Tissue engineering:

Tissue engineering is a scientific field spanning multiple disciplines that endeavors to investigate and fabricate tissues or organs. ZnO nanoflowers have been applied to angiogenesis, neurogenesis, and Osseo integration in tissue engineering. Xiaocheng et al. have reported skin tissue regeneration. Cu_2S nanoflowers were added to membranes in this study to treat skin wounds following surgery [102, 103].

5.1.6. Antimicrobial activity:

Plant extracts, conjugated organic molecules, and Fenton-like reactions on the surface of nanoflowers can all produce antimicrobial activity. Nanoflowers have demonstrated their antimicrobial activity against *Salmonella typhi*, *Escherichia coli*, *Staphylococcus aureus*, and *Aeromonas caviae. Trigonella foenum-graecum* seed extract and green tea extract are two examples of plant extracts that have antimicrobial properties [104–108].

5.2. Purification:

5.2.1. Self-assembled nanoflower for enzyme purification:

More focus is being paid to enzyme-enclosed nanoparticles because of their unique structural and functional characteristics. Enzyme immobilization involves the use of nanomaterials with a higher surface area as a substrate, which increases the activity of the enzyme. The enzyme soybean peroxidase (SBP) is present in the roots, leaves, and seeds of soybeans. A variety of organic and inorganic substrates can be oxidized by SBP. SBP are becoming more and more popular these days because of their many benefits in a variety of industries, including waste water treatment, biosensors, and diagnostic testing. Conventional methods of SBP purification are expensive, have limited applicability, and require a laborious, time-consuming process. Hence, self-enclosed nanoflowers were created in order to streamline the purification process, lower costs, and improve activity. Using saline phosphate buffer and copper sulfate solution, SBP inorganic hybrid nanoflowers were created. SBP enclosed in a hybrid nanoflower exhibited higher enzymatic activity than SBP [109].

5.2.2. Utilizing nanoflowers to extract heavy metals from water:

Heavy metals that are bad for the environment, such as zinc, lead, chromium, copper, nickel, etc., are found in waste water. Metals need to be removed from water in order to protect the ecosystem. Adsorption is the most efficient method for removing metals from water out of all the ones available. Although its primary application is as an adsorbent, activated carbon has regeneration and desorption problems. Utilizing their unique surface qualities, titanates and silicates were employed to address this problem. Utilizing concentrated sodium hydroxide solution and thin nanosheets, titanate nanoflowers were created. The removal of toxic metals from waste water is improved as a result of the rise in surface area efficiency [109–119].

5.2.3. An effective dye removal method using graphene oxide enzyme nanoflower:

These days, enzyme technology is very popular because it is an extremely energy-efficient method that doesn't harm the environment. Biocatalysts are employed in food processing, drug synthesis, biosensing, and pollution removal. The primary disadvantage of bio entities is their instability and reusability. The progress of biocatalysts is further enhanced by enzyme immobilization. The stability and reusability of the enzyme are increased by immobilization. While carbon nanotubes and graphene oxide demonstrated the ability to immobilize enzymes, they did so at a lower catalytic mass per unit volume per unit area than conventional metal catalysts. 3D structure is created in order to overcome this restriction. Copper sulfate was added to graphene oxide and carbon nanotubes to create a three-dimensional structure that improves loading properties, stability, and enzyme immobilization [120].

5.3. Miscellaneous Applications:

5.3.1. Platinum cobalt nanoflowers with enhanced redox reaction:

These days, people are paying more attention to direct menthol fuel cells (DMFCs) because of their high power density and simple handling. This process involves the oxidation of methanol on the anode and the reduction of oxygen on the cathode as the two main reactions. Platinum serves as the anode and a platinum-based catalyst serves as the cathode in this system. Ostwald's ripening and the intermediates produced during the process cause poisoning, which reduces the durability of the platinum-based catalyst in this method. Aside from all of these, platinum's expensive price is its biggest drawback. The best method to increase the catalytic activity of platinum is to prepare 3D transition metal by alloying platinum with less expensive metal, which increases stability. Since catalysis always takes place on the surface of the catalyst, catalysts with large surface areas exhibit higher catalytic activity. Because of their large surface area, platinum cobalt nanoflowers prepared by co-reduction have been shown to increase stability and electro-catalytic activity [110, 121, 122].

5.3.2. Enhanced photocatalytic activity demonstrated by zinc oxide nanoflower:

Zinc oxide (ZnO) nanoparticles are inexpensive semiconductors with a narrower band width. ZnO only absorbs UV light and has greater stability and photosensitivity. As a result, there is little variation in photo-response and photo-quantum activity. Doping is the intentional introduction of impurities into semiconductors to alter their electrical characteristics. Cadmium-doped ZnO functions by absorbing photogenerated electrons, forming a cavity on the surface, and preventing carrier recombination. Zinc oxide's photocatalytic activity is enhanced by doping it with cadmium, which also increases ZnO's spectral response in the visible region and solar energy utilization [123].

5.3.3. Gas sensing of nanoneedle and nanosheet using nickel oxide nanoflower:

A semiconductor with a larger band width (3.6–4 eV) and high thermostability is nickel oxide (NiO). Because NiO has electrical, magnetic, and optical properties, it can be used in a variety of applications such as gas sensing, glucose sensing, battery cathoding, catalysis, supercapacitor electrode, and semiconductor. Unlike conventional nanoparticles, nanoflowers demonstrated distinct physicochemical properties. 1D and 2D structures have less of an effect on gas sensing than 3D structures. Nanosheet and nanoneedle graded assembly by hydrothermal method and calcination were used to prepare nanoflowers of NiO to improve gas sensing [124–131].

5.3.4. Silver nanoflower and zinc oxide (ZnO) for surface enhanced Raman spectroscopy (SERS):

Surface-enhanced Raman spectroscopy has drawn interest because of its high resolution techniques for identifying compounds at extremely low concentrations. Applications for SERS include drug delivery, chemical agent detection, and biosensing. Two methods were used to observe scattering: chemical enhancement and surface resonance. When noble metal and semiconductor elements were combined, they demonstrated enhanced electromagnetic and chemical properties as well as an increased scattering rate. Because of their larger surface area, three-dimensionally structured nanoflowers made of zinc oxide and silver exhibit an increased degree of detection of small quantities of substance [132–138].

5.3.5. Using nanoflowers of titanium dioxide (TiO_2) as photoanodes for solar cells with dye sensitivity:

A type of solar cell that is part of the thin film solar cell family is the dye sensitizing solar cell (DSSC). These are inexpensive photo-electrochemical systems that are based on semiconductors that are formed between the anode and the electrolyte. Due to their eco-friendly nature, ease of fabrication, and good performance in low light, DSSCs are currently receiving a lot of attention. Due to its large band width, increased stability, and low cost, TiO_2 is typically utilized as the photo anode in DSSCs. Previous annealing methods were used to prepare photoanodes and prepare TiO_2 nanopowders for coating on electric substrates. However, the main drawback of this approach was the increased internal resistance of the solar cells and the poor adhesion of TiO_2. In order to get around this issue, TiO_2 nanoflowers were created by growing them directly on an electrical substrate, which increased both the adhesion and photoelectric conversion efficiency. Due to their large surface area, TiO_2 3D nanoflowers can also be prepared, which will increase the dye absorption for DSSC [139–147].

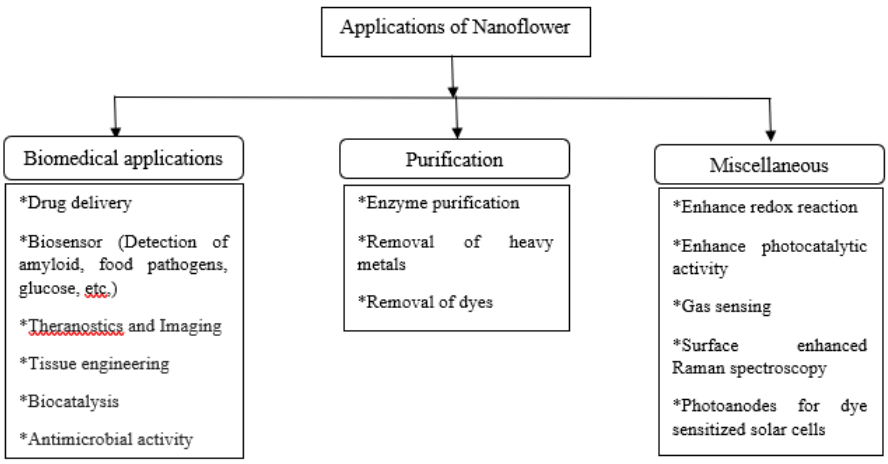

Figure 2: Various applications of nanoflowers

6. Nanotoxicology of Nanoflowers

Determining the harmful effects of nanomaterials on the environment and human health is the main goal of nanotoxicology. Toxicology, biology, chemistry, physics, material science, geology, exposure assessment, pharmacokinetics, and medicine are among the multidisciplinary teams that must work together to establish and identify the risks associated with engineered nanomaterials. The fields of automotive and aerospace (car tires, glass, fuel cells), agriculture (food processing, production, packaging, storage), construction (cement-based material, insulation, exterior, self-cleaning glass and paint, etc.), energy (thermoelectric, solar cells, long-life batteries, fossil fuel, nuclear energy), health and medicine (diagnosis, treatment, regenerative medicine, surgery, implant), information and communication (flat TV screens, electronic devices), security and defense industry (detection, protection, localization, unmanned combat vehicles), textiles (self-cleaning or stain-free products), cosmetics (sunscreens, toothpaste, make-up products), etc. Since each nanostructure has a unique toxicological profile, research on animals must be conducted to guarantee the security and biocompatibility of the structures. While it is employed in the field of biomedicine for the diagnosis and treatment of illnesses, questions have started to surface regarding its potential to cause illness. NFs were also called into question by people's painful experiences with products that they initially believed to be harmless but were actually carcinogenic, such as asbestos and tobacco products. The question "Can nanoparticles be asbestos in the future?" arose because some NFs have long, thin, fibrous structures that resemble asbestos and exhibit fibrogenic and toxic effects. When evaluating the toxicity of nanomaterials, variables like exposure duration, dose, aggregation and concentration, particle size and shape, surface area, and charge are crucial [148–152]. By adding nanoparticles to a core-shell structure, a material can become more biocompatible and less hazardous to nanoscale materials. Solvents and byproducts of chemical synthesis can also cause toxicity in nanomaterials, as they do in all nanomaterials. One important way to address that issue is to use plant extracts or green chemical synthesis techniques as solvents [153–155].

7. Future prospects

Currently, there are several main groups of mostly inorganic compounds that are known to form nanoflower type nanostructures: carbon, elemental metals, their alloys, and compounds containing elements from the V and VI Groups of the Periodic Table, along with a small number of coordination and organic compounds. The primary techniques used in their production are the reduction of metal salts, the oxidation of elemental metals, thermal breakdown of relatively unstable compounds, and hydrothermal or electrochemical processes. They have a high surface to volume ratio that improves surface reactions and can be attained using environmentally friendly methods. The formation of nanoflowers is often characterized by competition or equilibrium with other nanoforms, contingent upon temperature, reagent ratio, and other factors. However, it is challenging to maintain control over their structures during the reaction. Protein and peptide activity may be decreased during the fabrication process, along with the production of hazardous materials and byproducts. Many of the previously listed nanoforms for inorganic and organic compounds and materials are now reported on a monthly basis during the current wave of nanotechnology boom. Clearly, compared to other nanoforms, research on nanoflowers is still in its infancy. However, we anticipate that this field will continue to grow rapidly, and we anticipate that a greater number of fascinating examples will represent the organic nanoflowers, which are currently virtually unknown. It is also necessary to research environmentally friendly synthesis techniques. It is anticipated that new synthesis principles, hybrid nanoflower varieties, and intricate mechanisms will appear. Growing attention should be paid to the use of nanoflowers in bio-catalysis and enzyme mimetics, tissue engineering, and the development of extremely sensitive biosensing kits. Additionally, advanced industrial bio-related devices with controls over multiple syntheses, biocompatibility, and modifications of hybrid nanoflower structures and properties should all be considered. The removal of hazardous chemical byproducts during synthesis and the biocompatibility of structures must also be prioritized.

8. Conclusion

Because of their distinctive morphologies, simple synthesis processes, and physicochemical characteristics like a high surface-to-volume ratio, improved charge transfer and carrier immobility, and increased surface reaction efficiency, nanoflowers—flower-shaped nanomaterials—have drawn a lot of interest from scientists. The primary use of nanoflowers, which are made from a combination of organic and inorganic materials (hybrids), is in biomedicine. Notwithstanding the fact that biosensors, tissue engineering, biocatalysis, drug delivery, and inorganic and hybrid nanostructures can all benefit from their use. Only a small number of studies on inorganic nanoflowers have been published to date; most research has been done on hybrid nanoflowers. In this review, we have compiled all the reports on the biomedical uses of inorganic nanoflowers in the literature. We also go over the most recent developments in their preparation techniques and biomedical applications. Lastly, we offer an overview of the prevailing patterns and prospective future avenues for nanoflower research. Despite the stability of these nanoparticles, further research is necessary to increase the stability of the finished products. In the synthesis of nanomaterials, reproducibility from batch to batch is also a crucial parameter.

9. Conflict of Interest:

Authors declare no conflict of interest.

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