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Review

A Review on Green Synthesis of Nanoparticles and Their Diverse Biomedical and Environmental Applications

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Abstract: In recent times, metal oxide nanoparticles (NPs) have been regarded as having important commercial utility. However, the potential toxicity of these nanomaterials has also been a crucial research concern. In this regard, an important solution for ensuring lower toxicity levels and thereby facilitating an unhindered application in human consumer products is the green synthesis of these particles. Although a naïve approach, the biological synthesis of metal oxide NPs using microorganisms and plant extracts opens up immense prospects for the production of biocompatible and cost-effective particles with potential applications in the healthcare sector. An important area that calls for attention is cancer therapy and the intervention of nanotechnology to improve existing therapeutic practices. Metal oxide NPs have been identified as therapeutic agents with an extended half-life and therapeutic index and have also been reported to have lesser immunogenic properties. Currently, biosynthesized metal oxide NPs are the subject of considerable research and analysis for the early detection and treatment of tumors, but their performance in clinical experiments is yet to be determined. The present review provides a comprehensive account of recent research on the biosynthesis of metal oxide NPs, including mechanistic insights into biological production machinery, the latest reports on biogenesis, the properties of biosynthesized NPs, and directions for further improvement. In particular, scientific reports on the properties and applications of nanoparticles of the oxides of titanium, cerium, selenium, zinc, iron, and copper have been highlighted. This review discusses the significance of the green synthesis of metal oxide nanoparticles, with respect to therapeutically based pharmaceutical applications as well as energy and environmental applications, using various novel approaches including one-minute sonochemical synthesis that are capable of responding to various stimuli such as radiation, heat, and pH. This study will provide new insight into novel methods that are cost-effective and pollution free, assisted by the biodegradation of biomass.

Keywords: biosynthesis; biocompatible; remediation; degradation; metal oxide; nanoparticles

1. Introduction

The exquisiteness of nanomaterials was reflected upon by Feynman (1960) as "there is plenty of room at the bottom" [1]. True to his speculation, the technology and science behind miniaturization has opened up innovative avenues for dealing with the synthesis and characterization of nanomaterials and their employment in society. The resulting scientific interest in NPs can be attributed to the fact that these entities serve as bridges to manage the gap between bulk constituents and atomic or molecular assemblies. Several well-characterized bulk materials possess interesting properties at the nanoscale. NPs have a high aspect ratio, facilitating improved reactivity as well as effectiveness compared to the majority of materials. Over time, researchers have demonstrated their competency and developed nano-sized complements for composites, along with exclusive nano-based materials [2–4]. Significant and important applications of nanotechnology include capturing higher resolution images, many nano-sized sensors for ecological contamination, a high quantity of optoelectronics strategies, and nano-engineered solar applications. Nanotechnology deals with the nanoscale range. There is evidence of the existence of nanostructures dating from the beginning of life [5–7]. A significant need for nanotechnology has arisen due to the cumulative claims for nanostructured materials in several fields such as catalysis. In the past few centuries, materials experts have discovered carbon-based materials and mineral elemental blends exhibiting potential optoelectronic and dimensional qualities that are greater than the majority of their complements [8–11]. Organic NPs include carbon in the arrangement of liposomes, fullerenes, dendrimers, and polymeric micelles, and inorganic NPs consisting of magnetic, noble metal, and semiconductor NPs [12–15]. Metallic NPs are important in research, due to the fact that their precise properties are not easily accessible in isolated molecules [16]. The development of metallic NPs serves as an active area in theoretical and, more importantly, "applied research" in nanotechnology [17]. This review focuses on contemporary research activities that deal with the green synthesis of inorganic NPs, which has advantages over traditional approaches that use chemical agents that are detrimental to the environment. The current article looks at traditional synthetic procedures, with a focus on recent developments of greener routes to manufacturing metal, metal oxide, and other important NPs. It then goes on to discuss formation mechanisms and the conditions that control the surface morphology, dispersity, and other properties of these biosynthesized NPs. The report finishes with a discussion of the current situation and future forecasts for nanoparticle production via various green techniques. Briefly, nanomaterials used for various applications ranging from biomedical to bioenergy are in very high demand, due to the fact that the nano size is accompanied by a high surface area that can facilitate loading of the molecule of interest for various scientific applications including drug delivery systems for various disease conditions, especially cancer. When using nanomaterials as a drug carrier, it is very important to analyze the toxicity of the carrier; this concept gave rise to the introduction of green synthesis, which can replace the chemical methods that produce toxic nanocarriers. A synthesis of a metal oxide that responds to multiple stimuli can be an effective way to target drug delivery to the required site. Other than drug delivery applications, these nanomaterials can also be efficiently used in bioremediation as they can degrade the pollutant without affecting the ecosystem, since the nanocarriers are synthesized from natural products. This study mainly focuses on the unique and advanced green synthesis methods for metal oxide nanoparticles that are sensitive to many stimuli, resulting in cost-effective and prominent nanomaterials that can be used for a wide variety of applications, along with their biodegrading capacity, which serves as the novelty of this work. This green synthesis not only produces highly efficient nanocarriers but also performs its specified work without disturbing living organisms or the environment.

2. Synthesis of NPs via Bio/Green Synthesis

Earlier investigations provided two methods for the development of metallic NPs: the top-down method and the bottom-up method. In top-down methods, the nanoscopic features are etched onto a substrate using electron rays, and subsequently by using appropriate engraving and deposition processes. The commonly adopted top-down approaches are physical methods such as evaporation–condensation and the technique of laser ablation.

In this technique, the major resources, i.e., most of the initial metal materials are evaporated using a radiator, and the evaporated vapor subsequently cools at a suitably high rate with the assistance of the steep temperature gradient in the vicinity of the heater surface. The rapid heating and cooling result in unstable NPs at high concentrations. While evaporation–condensation methods are carried out employing an inert gas, the laser ablation technique uses a laser to target a metallic material in solution. For example, silver nano-spheroids (20–50 nm) can be produced by laser ablation in water with femtosecond laser pulses at 800 nm. A major drawback is the inadequacy of the surface construction. Such flaws can have a substantial influence on physical properties and the exterior interactions of the metallic NPs, owing to the high feature relation [2–4]. The most popular approach is chemical reduction utilizing a variety of carbon-based and mineral-reducing mediators. In general, various reducing mediators such as sodium citrate, ascorbate, elemental hydrogen, sodium borohydride ($NaBH_4$), polyols, Tollen's reagent, N, N-dimethylformamide (DMF), and poly (ethylene glycol)-block copolymers are employed for the reduction of metal ions in aqueous as well as non-aqueous solutions, leading to the formation of zerovalent metal, followed by agglomeration into oligomeric clusters. These clusters eventually form metallic colloidal particles. It is also notable that most of these approaches employ protecting mediators (polymers) as stabilizers, to avoid the accumulation of NPs. The presence of surfactants and polymers (e.g., thiols, amines, acids, and alcohols) affects the functionalities for interactions within the particle surfaces, stabilizing particle growth and protecting particles from agglomeration, sedimentation, or loss of their surface properties. Most of these methods persist in the development stages, as the extraction and purification of the produced NPs for further applications still represent important hurdles [5–7]. Several mechanical and irradiation-assisted techniques have been employed for the synthesis of metallic NPs. Recently, green synthesis of metal oxides by the sonochemical method has gained popularity, as this is the only method that facilitates the mixing of the chemical constituents at the atomic level, as a result of an unusual chemical reaction caused by cavitation in aqueous media at a temperature of 5000 °C and a pressure of 1800 kpa. In 2021, Pérez-Beltrán synthesized a magnetic iron oxide nanoparticle using a high-energy sonochemical approach, considering an amplitude of 2826 J and time of 1 min as major factors. This novel one-minute green synthesis by sonochemistry produced nanoparticles of 11 ± 2 nm particle size and was used for the biosensing of mercury in water [8]. In another study, conducted by Goudarzi, it is stated that copper oxide nanoparticles can be ultrasonically synthesized using Dactylopius coccus and can be further thermally decomposed at 60 °C for drug release in breast cancer applications [9].

The sono-electrochemistry technique employs alternating sonic and electric pulses, ultrasonic power, and electrolyte configuration for the mechanical manipulation of the material. Recent advances in the synthesis of metallic NPs include photoinduced or photocatalytic reduction methods [10,11]. Table 1 reviews some of the common traditional approaches reported for the synthesis of metallic NPs.

Table 1. Traditional approaches reported for the synthesis of metallic nanoparticles.

Method	Characteristics	Nanoparticle	Size	Morphology	Advantages	Disadvantages	Reference
Physical Methods							
Plasma Synthesis	Gas–liquid interfacial plasma is produced in ionic liquid. Plasmas provide a rich source of chemically active species that react with a surface or react with each other to produce secondary, short-lived chemical precursors needed for thin film deposition.	Pd	20 nm	Nanorods	Low-temperature operation, non-destructive materials treatment capability.	High-pressure limit. Economic constraint.	[12]
Ball Milling	Arc melting followed by grinding. The milling process and handling of the starting powders and the milled particles are carried out in an oxygen-free inert environment.	FeCo	30 nm	Nanorods	Adaptable for toxic and abrasive materials.	Contamination of product.	[13]
Pulsed Laser Desorption	The precursor (liquid or gas) is ionized, dissociated, sublimated, or evaporated using a laser and then condensed.	Au	5.5 nm	Nanorods	Fewer defects, Homogenous chemical composition, narrow size distribution.	Scale-up is difficult, economic concerns.	[14]
Lithographic Techniques	Uses light or electron beam to selectively remove micron-scale structures from a precursor material called a resist.	Au	50 nm	Nanorods	Simple to implement, low cost. Large surface patterning.	Patterning accuracy and nanoparticle size variation due to diffraction effects.	[15]
Molecular Beam Epitaxy	Ultra-pure elements are heated in separate quasi-Knudsen effusion cells until they begin to slowly evaporate. The evaporated elements then condense on the wafer	Pa	250 nm	Nanowires	Precisely controllable operating conditions.	Expensive, complicated system.	[16]
Chemical Methods							
Electrodeposition	Deposition of metal nanoparticles on supported material performed in acidic or basic baths containing metal salts. Nanoparticle synthesis is accomplished by scanning between a few voltage ranges.	Pt	NA	Nanotubes	Porosity-free finished products. Low initial capital investment. High production rates with few shape and size limitations.	Complex operational conditions.	[17]
Chemical Vapor Deposition	Solid is deposited on a heated surface via a chemical reaction from the vapor or gas phase.	Ru	3.1 nm	NA	Is self-cleaning—extremely high purity deposits (>99.995% purity). Conforms homogeneously to contours of the substrate surface.	Chemical and particle contamination.	[18]

NA—Not assessed.

It can be seen that physical and chemical schemes for metallic NPs synthesis are exceedingly diverse, and the findings show that process parameters such as temperature and concentration, etc., greatly affect the morphology, stability, and physicochemical properties of the NPs. Moreover, the synthesis of NPs employing conventional methods involves expensive chemical and physical processes with the potential hazards of ecological damage, cellular toxicity, and carcinogenicity [19,20]. These arise due to the use of harmful materials such as organic solvents, reducing agents, and stabilizers for the prevention of unwanted agglomeration of the colloids. Certain NPs are lethal, owing to features such as their magnitude, chemical composition, form, and external interactions, resulting in the incidence of lethal agents in the manufactured NPs possibly preventing their use in clinical and biomedical applications. As a result, there is a requirement for evolving new, biologically compatible, and eco-friendly green processes for manufacturing NPs [21–23].

Biological agents that have extensively been used for metallic NPs synthesis include unicellular and multicellular organisms. A few notable examples are bacteria, fungi, plant extracts, algae, diatoms, viruses, yeast, and a few higher organisms such as earthworms. Numerous sources in the literature have elaborated on the various attempts to synthesize metallic NPs in biofactories. The biological factories act as clean, non-toxic, and environmentally friendly systems for synthesizing biocompatible NPs over a wide range of sizes, shapes, compositions, and physicochemical natures. Most biological entities act as templates that assist in the stabilization of the nanostructures with the aid of biological polymers. The biopolymers enhance the biocompatibility of these NPs and prevent their agglomeration into clusters. However, plant extracts provide a plethora of enzymes and reducing agents that assist in the straightforward synthesis of NPs. Figure 1 shows a schematic representation of the synthesis of NPs using plant extracts. Compared with microorganisms, the plant method is highly beneficial as it does not require separate, complex, or numerous procedures such as isolation, culture development, and culture preservation. In addition, synthesis using plants is quicker, more cost-effective, and easy to scale up for the manufacture of bulk quantities of NPs.

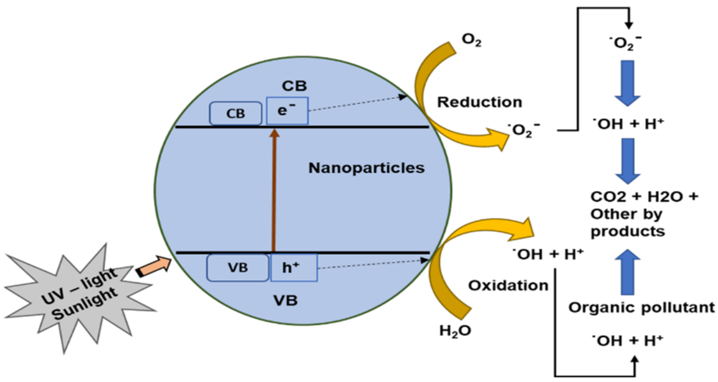


Figure 1. A schematic diagram for the production of reactive oxygen and hydroxyl radicals.

Table 2 shows a list of a few metal oxide nanoparticles synthesized from various plants and having various applications. In a relatively new report, quantum dots have been synthesized using the enzyme milieu in the midgut of earthworms. In summary, the utilization of biological resources for metallic NPs synthesis has increased exponentially over the past few years. The following sections elaborate on the interplay of operational conditions in bio-systems for the synthesis of NPs [24–26].

Table 2. Green synthesis of metal oxide nanoparticles using various plants, with applications.

Plant	Source of Nanoparticles	Metal Oxide	Size	Application	Reference
Ficus carica	Leaf	Fe_3O_4	43–57 nm	Antioxidant activity	[27]
Azadirachta indica	Leaf	CuO	NA	Anticancer property	[28]
Peltophorum pterocarpum	Leaf	Fe_3O_4	85 nm	Rhodomine degradation	[29]
Terminalia chebula	Seed	Fe_3O_4	NA	Methylene blue degradation	[30]
Punica granatum	Peel	ZnO	118.6 nm	Antibacterial property	[31]
Lactuca serriols	Seed	NiO	NA	Degradation of dye	[32]
Vitis rotundifolia	Fruit	CoO	NA	Degradation of acid blue dye	[33]

2.1. Influence of Various Parameters on the Synthesis of Nanoparticles

Several features control the nucleation and construction of stabilized NPs. A variety of claims for properties such as antioxidant, antimicrobial, anticancer, larvicidal, and antibiofilm properties have been made for crystalline NPs with different shapes and controlled sizes. These features (form and magnitude) are mostly reliant on the process limitations of the extract, along with the metal salt's response, pH, time of reaction, temperature, and ratio of plant extract to metal salts [34]. The following sections briefly discuss each of these factors in detail for the growth phase of the organism. Experimental efforts to optimize and enhance the synthesis of NPs have been reported by several authors. In 2011, Kalimuthu studied the effect of the growth phase of biomass on the synthesis of Ag NPs [21]. It was observed that during the stationary phase, the organism (*Bacillus* sp.) produced a relatively high number of NPs compared with the biomass obtained from other phases. Sweeney et al. demonstrated intracellular dense packing of NPs in E.coli in the stationary phase of bacterial growth [35]. According to the literature, the metal tolerance of fungus is enhanced during the stationary phase due to the release of enzymes and other chemical metabolites that reduce the metal stress. Furthermore, the metal tolerance capacity is reported to vary with the type of microbe and the metal under consideration. For instance, the presence of nickel in the growth medium has been shown to result in an extended mid-log phase in *Aspergillus* sp. However, the presence of chromium in the medium was reported to extend the stationary phase for the same organism [36]. Nevertheless, most of the studies in the literature suggest the preferential use of microbes in their stationary phase for NPs synthesis.

2.2. pH and Precursor Concentration

The molar ratios of reactants have also been reported to be important parameters that influence the NP size in chemical synthesis protocols. It is known that the concentration of reactants can directly influence the products in chemical synthesis. In this regard, Perumal Karthiga demonstrated that the shape of silver nanocrystals biosynthesized using silver nitrate and citrus leaf extract can be controlled systematically by varying the reactant concentration [37]. According to the authors, a $AgNO_3$: citric acid ratio of 1:4 (vol:vol) yielded spherical NPs. However, it was also reported that the production of bio-organics from plant extract increased the particle size of Ag NPs. Although a definite relationship between the precursor concentrations and the shape of the nanocrystal was not found, it could be noted that precursors at a higher molar ratio had a significant effect on the shape of the NPs. The pH was also stated to have a profound effect on the reduction reaction of the metallic ions. Pandian analyzed the effect of varied pH conditions on the synthesis of CdS nanocrystallites by *Brevibacterium species* [38]. The pH of the incubation mixtures was subjected to adjustments using 1 M HCl and 1 M NaOH solutions. It was observed that the size of the NPs varied greatly with pH. In general, an alkaline pH assisted the possibility of accessible functional groups in the reaction mixture, which in turn aided nucleation and NPs formation. The alkaline environment was previously found to aid the synthesis of various NPs in association with protein molecules [25]. Kowshik checked the pH stability of the biosynthesized NPs. It was observed that acidification of the nanocrystallites from pH 7 to 6 led to particle agglomeration [39]. In another study, Ag NPs synthesized from extract of *Cinnamon zeylanicum* bark increased in number with cumulative concentrations of bark extract and at greater pH values (pH 5 and above). Furthermore, pH values below 6 resulted in the precipitation of nanocrystals out of the solution. Due to their low toxicity, lower production of pollutants, and energy conservation, biomanufacturing methods for metal/metallic nanomaterials with ordered micro/nanostructures and programmable functionalities is critical in both fundamental investigations and practical applications. Microorganisms, as effective biofactories, have a significant ability to biomineralize and bioreduce metal ions, which can be obtained as nanocrystals of varied morphologies and sizes. The advancement of nanoparticle biosynthesis improves the safety and sustainability of nanoparticle production [31].

2.3. Temperature

Numerous studies indicate the predominant influence of temperature in the morphology and distribution of nanocrystals. Most of the studies in the literature report that elevated temperature conditions result in a size reduction in NPs. For instance, researchers reported a size reduction in biosynthesized Ag NPs from 35 nm to 10 nm when the reaction temperature was increased from 25 °C to 60 °C [40]. The biosynthesis was initiated using sweet orange peel extract. The reaction rate and particle formation rate increased with an increase in reaction temperature, although the average particle size decreased and the particle change rate progressively increased on increasing the temperature. In this context, it is also important to consider the temperature tolerance profile of the biological entity being considered for the synthesis of the NPs. Many researchers have reported the production of heat shock proteins by microorganisms at the elevated temperature conditions that aid NPs synthesis [41].

3. Applications of Nanoparticles

NPs possess tremendous advantages for use in many areas of day-to-day activities. Therefore, it is important to explore NPs in depth. Figure 2 shows a schematic representation of nanoparticle synthesis methods and the applications of NPs discussed in this review. NPs for use in the human body include biosynthesized noble metal NPs, which have many important applications. They make use of the molecular engine to address medicinal difficulties, and molecular information is used to support and advance human fitness at the molecular scale. This leads to the protection and development of human health. Fernández-Llamosas biosynthesized selenium NPs, which have many benefits for human health, using *Azoarcus* sp. *CIB*, [42]. The classification of different nanoparticle synthesis methods and their applications is depicted in Figure 2.

Regarding uses in biomedical research, the medicinal field still has unsolved issues, and NPs are the key to certain issues. The synthesis of NPs using extracts of leaves (plant) and/or bark provides more extensive applications in biotechnology [43], sensors [44], medicine [45], catalysis [46], optical devices [47], coatings [48], drug delivery [49], water remediation [50], and agriculture [51]. The NPs have micro and/or nanomolar sensitivity and can be detected via imaging instruments, which makes them suitable for imaging, therapy, and the delivery of drugs [52]. NPs of different dimensions have different biomedical uses. NPs have even been loaded onto TiO_2 nanotube implants for use as orthopedic implant materials. The NPs increase the biocompatibility of the implants, ultimately leading to a longer life span and greater effectiveness of the implant.

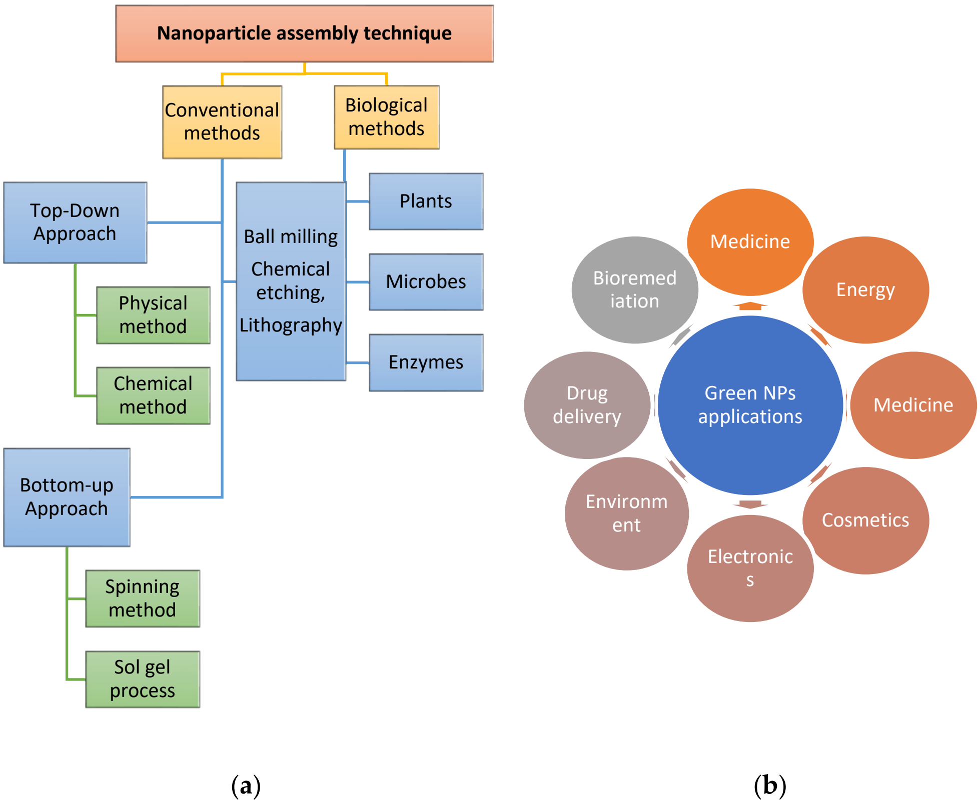


Figure 2. Classification of different nanoparticle synthesis methods (**a**) and their applications (**b**).

3.1. Anti-Inflammatory Properties of Nanoparticles

Nanoparticles have been developed as anti-inflammatory mediators in recent years. NPs have a large surface-area-to-volume ratio and are used for obstructing substances accompanying inflammation such as cytokines and inflammation-supporting enzymes, associated with other complements. Numerous metal-based NPs have been reported with excellent anti-inflammatory properties, such as those based on silver, gold, copper, and iron oxide. In this review, we demonstrate the mechanism for constructing anti-inflammatory properties in NPs. Figure 3 depicts the mechanism of nanoparticles in anti-inflammatory systems. Swelling is the body's instant response to interior damage, contagion, hormone inequity, and failure in the interior structures or external features, such as in an attack by pathogenic microorganisms or an external element. This leads to overweight, food allergies, or interactions with ecological contagions. Distinctive resistant cells possess antigen receptors capable of sensing biochemical signs. Swelling is caused by cellular and tissue injury resulting from an imbalance in the signals controlling the inflammation [53]. Upon injury or infection, muscles invoke an inflammatory response that leads to the deployment of macrophages and killer cells [54,55]. Macrophages have the main role in auto-modifiable inflammatory processes. Macrophages are large, mononucleated phagocytes produced in the bone marrow and originate as moveable white blood cells (WBCs) called monocytes in the bloodstream [56]. These monocytes then drift to various locations in numerous tissues and form macrophages. Macrophages are of two kinds: pro-inflammatory M1 macrophages whose manufacture encourages inflammation and M2 macrophages that are alternatively activated as an anti-inflammatory response and stimulate the remodeling of the swollen tissues and organs. Macrophages are able to sustain the inflammatory process by inducing changes among the two phenotypes contingent on the retarder's disorder [57,58]. Through swelling, the macrophages overwhelm cellular and tissue damage by phagocytosis and lead to inflammation via activation signals stimulating the macrophages.

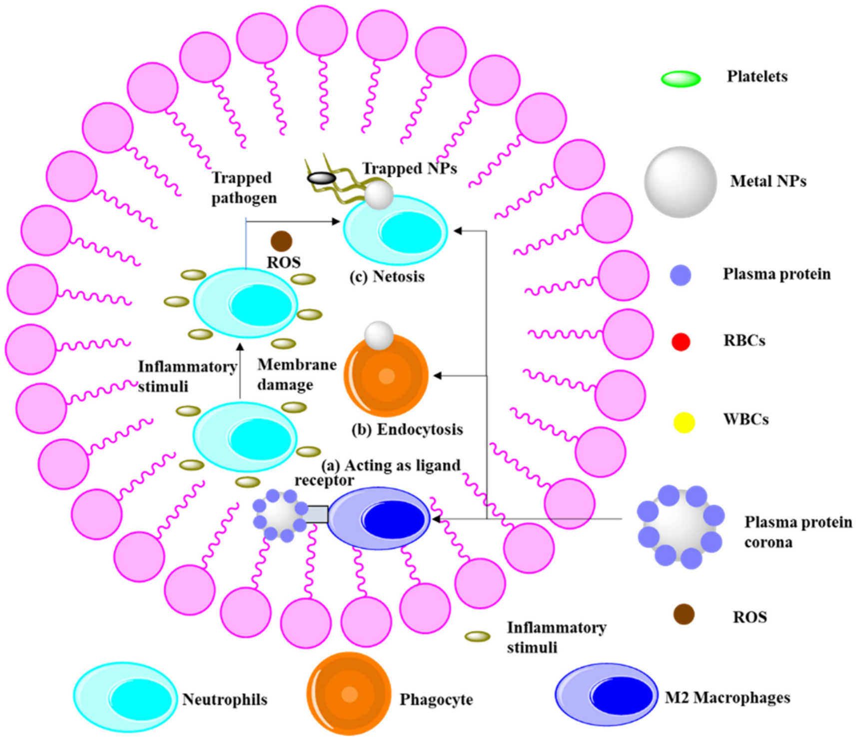
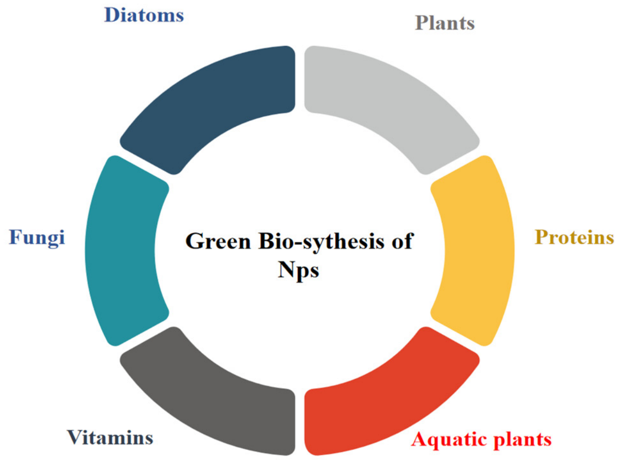


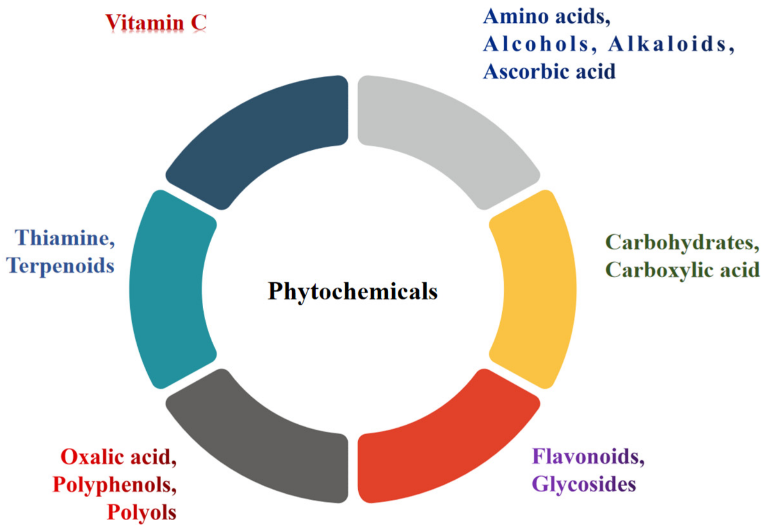
Figure 3. Anti-inflammatory mechanism adopted by various nanoparticles.

3.2. In Therapeutics

NPs are the ultimate platform for biomedical uses and therapeutic interventions. Cancer is a notorious and deadly disease and still stands as one of the principal health issues of the 21st century. Hence, there is an urgent need for anti-cancer medicine. The current advances in therapeutic options for cancer have lagged in differentiating between cancerous and normal cells, failing to produce a complete anti-cancer response [59]. In recent times, researchers have found that metal oxide NPs such as Zn and Ce oxide NPs hold considerable promise as anti-cancer medicines [60,61]. Cerium nanoparticles (CeO NPs) consisting of a cerium core enclosed by an oxygen lattice have shown extensive potential as a therapeutic agent [62]. Silver (Ag) NPs synthesized using *Abelmoschus esculentus* (L.) pulp extract have shown potential therapeutic uses and efficacy in killing Jurkat cells in vitro. The anticancer activity of Ag NPs was found to be strongly associated with higher levels of reactive oxygen species (ROS) and reactive nitrogen species, with a loss of integrity in the mitochondrial membrane [63]. More recently, the anti-cancer activity of Ag NPs synthesized from Punica granatum leaf extract (PGE) was investigated against a liver cancer cell line (HepG2). The results showed that the PGE-AgNPs showed greater efficacy in killing cancer cells. Figure 4 shows a schematic representation of the killing of cancer cells using AgNPs. Yet another report by Saratale showed that AgNPs synthesized from the common medicinal plant dandelion (Taraxacum officinale) had a high cytotoxic effect against HepG2 [64]. It is clear that in the future, NPs could be personalized for patient care. Furthermore, AgNPs developed using Olax scandens leaf extract showed anti-cancer activities with respect to different cancer cells (B16: mouse melanoma cell line, A549: human lung cancer cell lines, and MCF7: human breast cancer cells) [65].



(**a**)



(**b**)

Figure 4. Several natural resources for synthesizing green NPs (**a**) and a few important bio-reductants found in plant extracts (**b**).

It was reported recently that iron oxide NPs have the dual capacity to act as both magnetic and photothermal agents in cancer therapy. This dual action was found to yield complete apoptosis-mediated cell death. Furthermore, these iron oxide NPs can be combined with laser therapy, showing complete regression of tumor cells in vivo [66]. Studies showed that photothermal therapy using green synthesized iron oxide nanoparticles loaded with the drug temozolomide with near-infrared light irradiation resulted in the death of glioblastoma cancer cells [67]. Bilici stated that superparamagnetic iron oxide nanoparticles act as a highly efficient photothermal therapy agent. Indocyanine-green-coated iron oxide nanoparticles were irradiated using laser treatment at 795 nm. This photothermal effect efficiently reduced the breast cancer cell line MCF7 when the ICG was free [68]. Green synthesized metal oxides play an important role in photothermal therapy as the metal oxide nanoparticles are irradiated by the light and can help in targeted drug release with a controllable dose. In 2013, Geetha synthesized gold NPs from the flower of the tree *C. guianensis* and explored their antileukemic cancer activity [69]. Fazal reported green synthesized anisotropic and cytocompatible gold NPs without any capping agent and studied its effectiveness along with photothermal therapy [70]. Their report found that the anisotropic particles exhibited a good photothermal effect for femtosecond laser exposure at 800 nm on A431 cancer cells, with low influence. Parida prepared metallic gold NPs, stabilizing them with ethanolic extract of clove (*Syzygium aromaticum*) and studying their anti-cancer potential and biomechanism using the human SUDHL-4 cell line. They found that the gold NPs could decrease the growth and viability of the SU-DHL-4 cell line and increase apoptosis [71]. The synthesis protocol and the important bio-reductants found in plant extracts are shown in Figure 4b.

3.3. In Drug Delivery Systems

Management of infections of the frontal section of the eye using commercially obtainable ocular drug delivery schemes has low efficiency. NPs have been designed for employment in preparations for eye drops or injectable solutions. Drugs loaded with NPs possess good drug pharmacokinetics, non-specific toxicity, pharmacodynamics, immunogenicity, and biorecognition, thereby improving the efficacy of the drugs [72]. Chitosan based polymeric NPs can act as drug carriers, paving the way for the growth of numerous dissimilar colloidal delivery vehicles. These NPs can cross biological barriers and protect macromolecules such as peptides, oligonucleotides, proteins, and genes from the degradation of biological media, allowing the delivery of drugs or macromolecules to the target site followed by precise release [73]. NPs are a promising strategy for the controlled delivery of a drug against human immunodeficiency virus (HIV) named lamivudine, which acts as a potent and selective inhibitor of type 1 and type 2 HIV [74]. Superparamagnetic iron oxide NPs (SPIONs), together with the drug, have been used for site-specific delivery of drugs. The drug can readily bind to the SPION surface and can be guided with an external magnetic field to the desired site, where the NPs can enter the target cell and deliver the drug [75]. The SPION is exposed to another cell once the drug is dissolved inside the target cell, which can reduce the absorption time, the quantity of the drug, and the interaction of the drug with non-target cells. Sripriya reported a sophisticated technique for the fabrication of multifunctional polyelectrolyte thin films in the loading and delivery of therapeutic drugs. The Ag NPs biosynthesized from the leaf extract of *Hybanthus enneaspermus* were found to be effective reducing agents with significant potential for remotely activated drug delivery, antibacterial coatings and wound dressings [48].

3.4. Medical Diagnosis, Imaging, and Sensors

In recent times, NPs have played a vital role in multimodal and multifunctional molecular imaging. Owing to the nanoscale sizes, high agent loadings, tailored surface properties, and controlled release patterns, as well as the enhanced permeability and retention effect, nanotechnology has emerged as a promising strategy for cancer diagnosis. Magnetic NPs such as iron oxide have gained tremendous attention in drug delivery systems and magnetic resonance imaging, as well as in magnetic fluid hyperthermia for diagnosis and cancer therapy [76]. Critical information regarding the progress of a deadly cancerous disease can be obtained readily via imaging of the sentinel lymph nodes (SLNs). The naked carbon NPs obtained from food-grade honey can be effectively employed in SLN imaging, which is attributed to their strong optical absorption in the near-infrared region, smaller size, and rapid lymphatic transport. This has great potential for faster resection of the SLN and also decreases complications in axillary investigations using low-resolution imaging techniques [77]. Fluorescent carbon NPs were synthesized using grape juice via chemical-free simple hydrothermal treatment with high water stability, lower toxicity, and excellent stability. These NPs can be employed as excellent fluorescent probes for the cellular imaging process and could be a promising alternative to traditional quantum dots [78]. The medicinal applications of green synthesized metal oxide nanoparticles are shown in Figure 5.

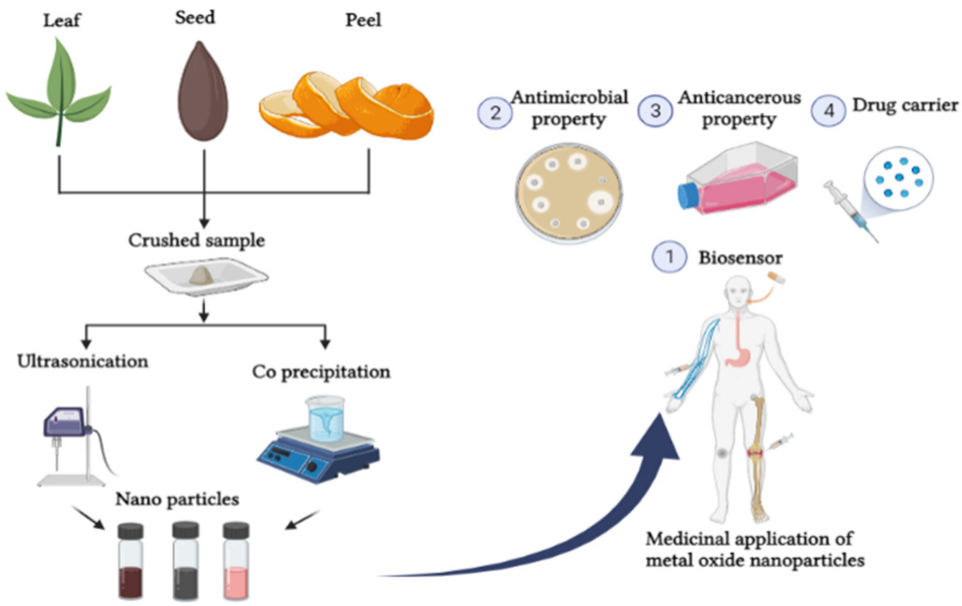


Figure 5. Medicinal applications of green synthesized metal oxides (created on 14 April 2022 by BioRender.com).

Fluorescent-nanoparticle-based imaging probes are equipped with current labeling technology and are also expected to be used in new medical diagnostic tools, due to their superior brightness and photostable properties compared to conventional molecular probes [79]. Raja prepared Ag NPs using *Calliandra haematocephala* leaf extract for the detection of H_2O_2. The results showed that the Ag NPs could be successfully used to detect the concentrations of H_2O_2 present in various samples [80]. Zheng prepared Ag NPs via a green biochemical method employing *Corymbia citriodora* leaf extract as an effective reducing and stabilizing agent and also explored the application of biosynthesized zinc oxide NPs in constructing an H_2O_2 biosensor [81]. The results showed that the fabricated electrochemical H_2O_2 sensor could potentially be employed in the pharmaceutical field and in clinical trials. In recent years, food adulteration has become a serious issue; for instance, adulteration of milk makes it hazardous to drink. Varun synthesized Ag NPs for sensing melamine in milk [82]. Monitoring aquatic ecosystems is important because potentially toxic metal ions such as Cu^{2+} and Hg^{2+} can have severe effects on human health as well as on the environment. Ag NPs synthesized using the juice extract of *Citrullus lanatus* (watermelon) exhibited good ability to detect these ions in aqueous solutions [83]. Moreover, biosynthesized Ag-NPs using *Camellia sinensis* (green tea) aqueous extract possessed good properties for sensing Cu^{2+} and Pb^{2+} ions in aqueous solutions [84]. Gold NPs synthesized from *Osmundaria obtusiloba* extract proved to be an excellent agent with good optical properties that could be employed as a suitable candidate for sensor applications [85]. Polluted water is a major threat to both quality of life and public health. Ag NPs prepared by green synthesis using *Achyranthes aspera* L. extract and protected by chitosan could be employed as a sensor for removing thiocyanate ions present in contaminated water [86].

4. Environment and Energy

Nanomaterials are of prime importance in environmental remediation and green processes. They have potential in cleaning hazardous waste sites as well as in the treatment of pollutants. Figure 6. shows the photocatalytic degradation of Acid Blue-74 by the nanoparticles. The self-cleaning nanoscale surface coatings can eliminate several chemicals for cleaning purposes employed in maintenance routines. Fe NPs have gained interest owing to rapidly developing applications for the disinfection of water, as well as remediation of heavy metals in the soil. NPs serve as alternatives to pesticides in the control and management of plant disease and act as effective fertilizers that are eco-friendly and capable of increasing crop production. Magnetite (Fe_3O_4) and the siliceous material produced by employing bacterial cells and diatoms have been successfully employed in coating optical instruments for solar energy applications [87].

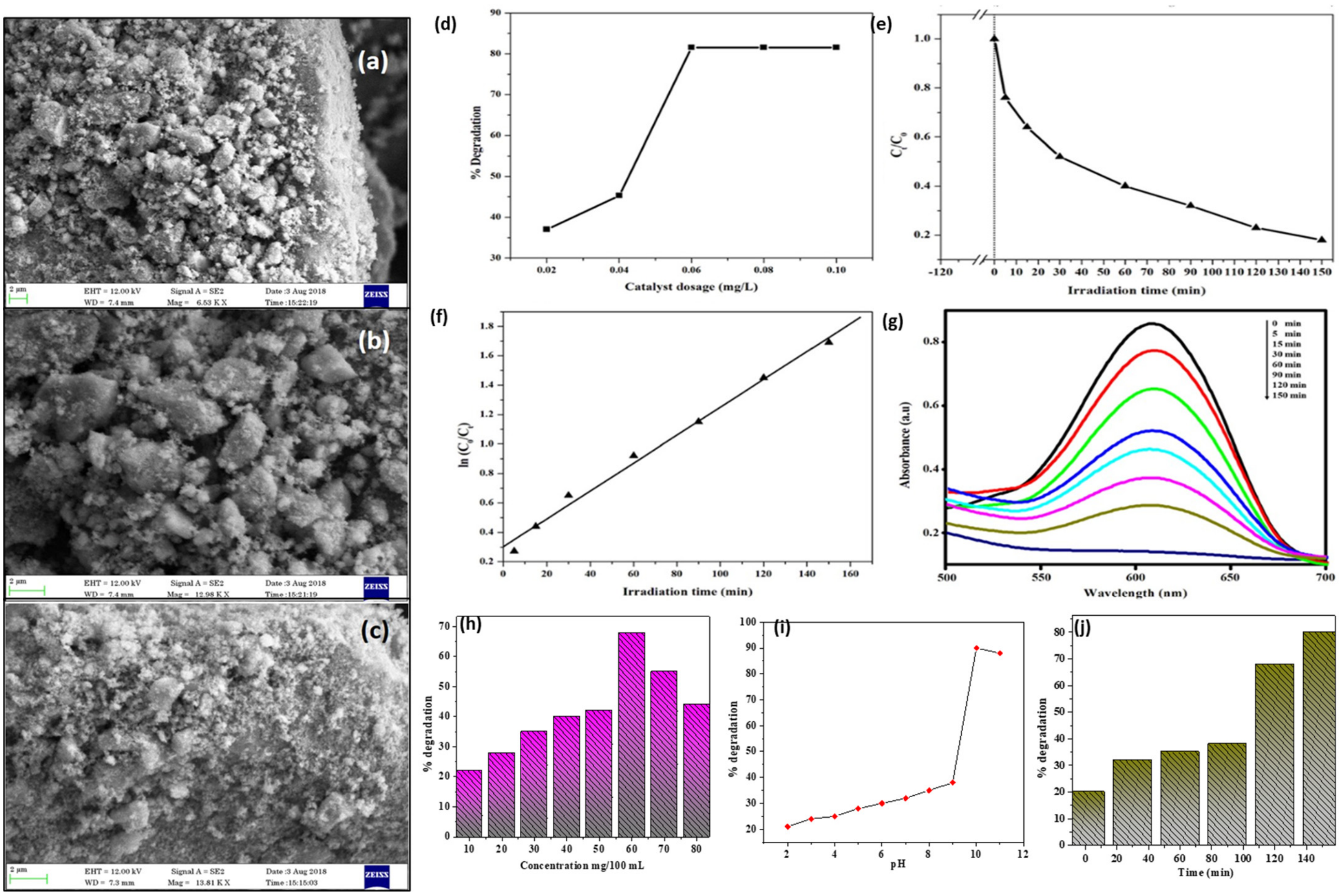


Figure 6. (**a**–**c**) FESEM micrographs of green synthesized GGCo-NPs nanoparticles. (**d**) Effect of initial catalytic dose. (**e**) Photocatalytic degradation of AB-74 by GCo-NPs under irradiation by sunlight. (**f**) Pseudo-first-order reaction kinetic model for GCo-NPs as an NP photocatalyst. (**g**) Absorption spectrum of photocatalytically degraded AB-74 at different time intervals. Photocatalytic degradation of AB-74, with varying initial dye concentrations (10 mg/100 mL–80 mg/100mL) (**h**), pH (2–12) (**i**), contact time (0–150 min) (**j**) [33].

4.1. Remediation and Degradation

Remediation solves the problem. "Bioremediation" refers to a process involving the use of biological agents such as bacteria, fungi, protists, or their enzymes for the degradation of environmental contaminants into less-toxic versions [88,89]. Bioremediation provides many advantages over conventional treatments as it is more economically feasible, has a high competence level, minimizes chemical and biological sludge, is selective to specific metals, has supplementary nutrient requirements, and has the possibility of regeneration of the biosorbent and metal recovery [90,91]. There are multiple reasons for the employment of different NPs in bioremediation; for example, when materials are at the nanoscale, the surface area per unit mass of the material increases, and as a result, a larger amount of the material comes into contact with the surrounding materials, thereby affecting the reactivity. NMs have the potential to exhibit a quantum effect with less activation energy for accessing the chemical feasibility of the reactions. Surface plasmon resonance is another phenomenon that is exhibited by NPs, and this can be employed for the detection of toxic materials [92]. Regarding shape and size, various metallic and nonmetallic NMs with different morphologies have been employed in environmental clean-up processes. For example, various single-metal NPs, carbon-based NMs, and bimetallic NPs can be used. Bioremediation processes use agents in solid waste, groundwater and wastewater management, petroleum and petroleum goods management, uranium remediation, soil remediation, and remediation of heavy metal pollution. The study of the ability of NMs to combat contamination is advancing and could potentially result in revolutionary changes in the ecological field. The various uses of NPs include the following:

- Nanoscale zero-valent iron (nZVI) has been produced and verified for its ability to efficiently remove As (III), which is an exceedingly lethal, mobile, and major arsenic species in anoxic groundwater.
- Engineered polymeric NPs have been employed for the bioremediation of hydrophobic contaminants.
- PAMAM dendrimers with special structures and properties have been employed in water treatment, as they are efficient as well as innoxious as a water treatment agent.
- Engineered polymeric NPs have been employed for soil remediation.

NPs could have a deeper impact on biodegradation. With the increased development of the textile trade, major anxieties have arisen regarding the pollution of the environment with dye contaminants, leading to serious conservational contamination as well as detrimental consequences to health, given their variety, toxic nature, and ability to persist. Most of these dyes have complex compositions and high chemical stability, facilitating their persistence for extended distances in flowing water and thereby retarding photosynthetic action, inhibiting the development of aquatic biota by the blockage of sunlight, and inhibiting the utilization of dissolved oxygen, leading to a decreased recovery rate of the watercourse. Degradation of the dyes in the manufacturing wastewaters has gained considerable attention due to the bulk production, less decoloration, slower biodegradation and high toxicity. Metal oxides can adopt a huge number of physical geometries and have an electronic assembly that can exhibit metallic, semiconducting, or insulating features and can therefore perform efficient roles in many areas of science. In the past few decades, enormous interest has been shown in heterogeneous photocatalysis technology with the incorporation of metal oxides, owing to their possible applications in both ecology and organic synthesis. Several attempts to study the photocatalytic activity of different metal oxides such as ZrO_2, SnO_2, and CdS have been made. Titanium dioxide (TiO_2) and zinc oxide (ZnO) have been characterized as having chemical stability, eco-friendly properties, and a lack of toxicity, and they can be produced relatively cheaply. They have been employed in diverse areas of photochemistry ranging from large-scale products to more advanced applications. For instance, in the case of environmental remediation, they have been used in the photoelectrolysis of water and in dye-sensitized solar cells. Sunlight is an abundantly accessible resource that can be used to irradiate semiconductors in photon-based degradation of polluting agents, and these techniques are economically relatively feasible [93]. Worldwide soil contamination is severe, damaging normal ecological services and preventing human activities Traditional approaches for dealing with dirty soils include excavation followed by discarding or ex-situ action such as soil washing or thermal desorption. However, these approaches can be expensive and time-consuming, and they lead to large quantities of secondary contamination. Therefore, low-influence in situ actions such as inoculation with NPs are increasingly preferred. Numerous effective NPs are stated to have better activity over a wide range of contaminants including heavy metals and organic contaminants.

4.2. Wastewater Treatment

Water contamination is one of the key problematic issues faced by the world today, as the survival of the species relies on the presence of water fit for consumption. Contamination of water has highly detrimental consequences affecting the environment as well as human health, along with multiple impacts on socioeconomic progress. Many commercial and non-commercial techniques are available for combatting this problem, which is increasing due to technological progress [94]. Nanotechnology has also proved to be one of the best and most advanced strategies for the treatment of wastewater. NPs have high adsorption, interaction, and reaction capacities owing to their small size and high proportion of atoms at the surface [95–98]. They can also be suspended in aqueous solutions, to behave as colloids. These particles achieve energy conservation owing to their small size, and this can ultimately lead to cost-effectiveness. NPs possess great advantages for treating water at large depths and in any location that has not been cleared by the available conventional technologies [10,96,99,100]. Green nanomaterials possess a wide range of abilities for the treatment of water that is contaminated by toxic metal ions, organic and inorganic solutes, and pathogenic microorganisms. Advanced research and commercialization of various nanomaterials (nanostructured catalytic membranes, nanosorbents, bioactive NPs, nanocatalysts, biomimetic membranes, and molecularly imprinted polymers (MIPs)) has been undertaken, in order to eradicate toxic metal ions, pathogenic microbes, and organic and inorganic solutes from water [101,102].

5. Nanosorbents

Nanosorbents possessing high and specific sorption potential are widely exploited for the purification of water and for remediation purposes, as well as in treatment processes, e.g., carbon-based nanosorbents such as Captymer™. Nanocatalysts, e.g., silver (Ag) nanocatalyst, AgCCA catalyst, etc., have been widely employed as they can increase the catalytic activity at the surface owing to their special characteristics of possessing a high surface area with a shape-dependent property for the enhancement of the reactivity, as well as the degradation of contaminants. Figure 7 shows the degradation of 4-nitrophenol by the AgNPs. Nanostructured catalytic membranes are employed widely for the purpose of treating contaminated water, and this is facilitated due to several advantages such as high uniformity of the catalytic sites, the potential for optimization, the limited contact time of the catalyst facilitating sequential reactions, and the ease of industrial scale-ups. Examples include immobilization of the metallic NPs onto membranes such as cellulose acetate, chitosan, polyvinylidene fluoride (PVDF), polysulfone, etc.

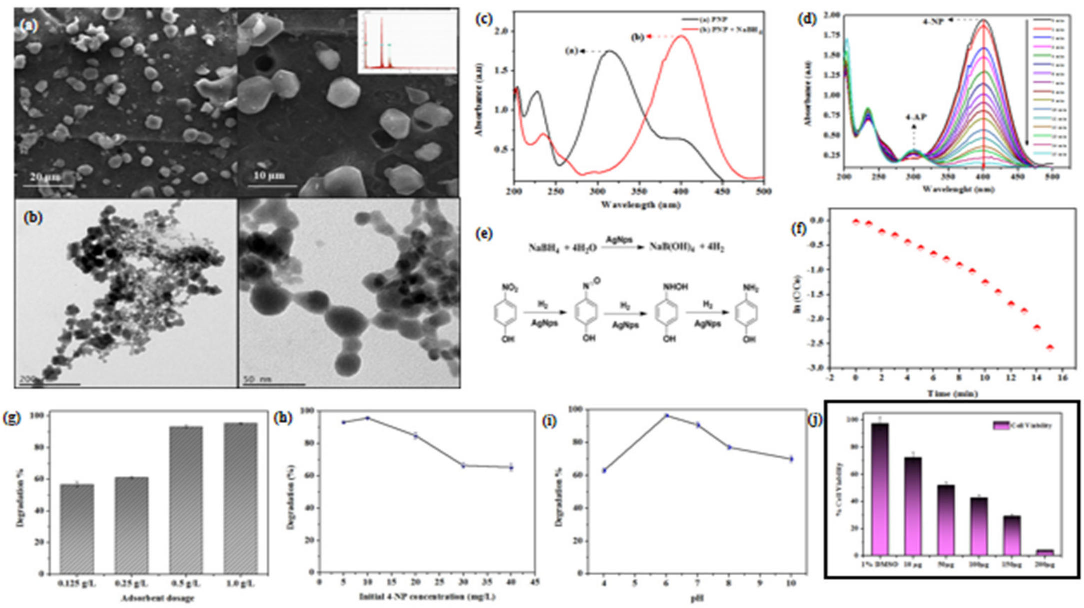


Figure 7. (**a**) SEM analysis. The EDX insert shows that the formed nanoparticles are silver. (**b**) TEM image showing the synthesized AgNPs using B. amyloliquefaciens. (**c**) Absorption spectra of 4-nitrophenol in aqueous medium and 4-nitrophenol+$NaBH_4$ in aqueous solution. (**d**) Absorption

spectra for reduction of 4-nitrophenol by $NaBH_4$ in aqueous medium in presence of biosynthesized AgNPs as catalyst. (**e**) Kinetic modeling of the 4-nitrophenol reduction in the presence of biosynthesized AgNPs. (**f**) Mechanism of reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) using biosynthesized AgNPs catalyst. (**g**) Effect of adsorbent dosage on the degradation of 4- NP. (**h**) Effect of initial dye concentration on the degradation of 4-NP (experimental conditions: H_2O_2: 40 mM; AgNPs: 0.5 g/L; initial pH: 5.5). (**i**) Effect of initial pH on the degradation of 4-NP (experimental conditions: 4-NP: 10 mg/L; AgNPs: 0.5 g/L; H_2O_2: 40 mM). (**j**) Effect of hydrogen peroxide (H_2O_2) on the degradation of 4-NP (experimental conditions: 4-NP: 10 mg/L; AgNPs: 0.5 g/L; initial pH: 6. Effect of biosynthesized AgNPs on A549 lung carcinoma epithelial cells at 50–200 µg for 24 h [11].

Silver nanoparticles (AgNPs) with a very high antibacterial potential can be synthesized extracellularly by employing the bacterium *Bacillus cereus*. Nanotechnologies have facilitated several sophisticated solutions for counteracting issues of water contamination and are likely to produce many strategies composed of enhancements in the future. Treatments based on nanotechnology offer highly effective, durable, efficient and eco-friendly approaches. These strategies are cost-effective, less time-consuming, and energy-efficient, with much lower waste generation than conventional bulk-materials-based technologies. However certain precautions are necessary for avoiding threats to human health or the environment [103].

6. Cosmetics and Food Industry

Applications of nanotechnology and nanomaterials are widely present in several cosmetic products such as moisturizers, hair care products, makeup accessories, and sunscreen. The main uses for nanotechnology in cosmetics are as follows. NPs are employed in cosmetics as UV filters. TiO_2 and ZnO are the key compounds used in these applications. Organic substitutes for these have also been established. Nanotechnology is also used for delivery. The cosmetic industry takes advantage of liposomes as vehicles for delivery. Novel structures comprising solid lipid NPs and nanostructured carriers composed of lipids have been reported to perform better than liposomes. NPs also enhance and facilitate penetration. Encapsulation or suspension of the key ingredients in nanospheres or nanoemulsions facilitates skin penetration. Regarding NPs in hair-related products, the employment of nanoemulsions for the encapsulation of desired substances facilitates their delivery into the deeper hair shafts. In sunscreen lotions, the employment of zinc and titanium micronized NPs results in transparency, a less greasy texture, and less odor, and makes the lotions highly absorbable into the layers of the skin [103].

Nanotechnology has emerged as an important strategy for several food-related applications. In these types of applications, NPs of a core type are introduced into a specified food-related product for the development of certain desirable properties in the food. Nanotechnology has become an integral part of research and development for the large-scale manufacturing of agricultural products and processed foods, as well as in food packaging sectors across the world. In recent decades, the use of nanotechnology has increased tremendously, revolutionizing technology in the food sector. The emergence of demands from consumers concerning the quality of food and hygienic aspects of health have shifted the focus of researchers to developing strategies for the enhancement of food quality without any implications for the nutritional value. The demand for NP-based materials has increased in the food industry, as most of them contain essential elements and are also non-toxic and stable at high temperatures and pressures [104]. Nanotechnology can offer a wide array of solutions at various stages ranging from the manufacturing of food to processing and packaging. They have the potential to make a great difference not only in terms of food quality and safety but also in the terms of the health benefits that the food provides. Several research and industrial organizations are investigating novel techniques, methodologies, and products involving a direct application of nanotechnology in the food science sector. The applications of nanotechnology can be fitted into two main groups: nanostructured food ingredients and the nanosensing of food. Nanostructured food ingredients are widespread, in areas from the processing of food to the packaging of food. In the processing of food, these nanostructures are employed as additives for the food, antimicrobial agents, carriers for the smart delivery of nutrients, anti-caking agents, fillers that improve the mechanical strength and durability of the packaged material, etc. In the case of food nanosensing, they are employed to achieve a better quality of food and for safety evaluation purposes [104]. Several reports have stated that nanomaterials are possible candidates for improving food safety by enhancing the efficacy of packaging and the shelf life, with no alterations to the nutritional value, along with additives that do not alter the taste and physical features of the food products. Although they have the potential to help create innovative products along with the production processes prevailing in the food sector, nano techniques face a major challenge regarding the employment of cost-effective processing operations for the synthesis of edible and non-toxic nanoscale delivery systems and the efficient development of effective formulations that are considered safe for human consumption. Thus, owing to the increased employment of NSMs, mounting apprehensions in terms of developing biocompatible, safe, and non-toxic nanostructures from food-grade ingredients have emerged with respect to the use of the modest, greener processes as well as the cost-effective processes utilizing layer-by-layer technology [37]. Despite the application of nanotechnology in terms of green synthesized NSMs for numerous technologies in the food sector, the use of NSMs has led to controversies in a few instances, as they are scientifically uncertain and could have a long-term detrimental effect on human health, as well as on the environment. In this context, the complexity and the limitations of nanotechnology in terms of toxicity and accumulation could be overruled by the elucidation of the physiochemical and biological properties of the NSMs through extensive large-scale research.

Unique $CoNi_2S_4$ nanoparticles have been synthesized using a one-step solvothermal technique. When used as supercapacitor electrode materials, $CoNi_2S_4$ nanoparticles, with their lower manufacturing costs, exhibit better electrochemical characteristics such as higher specific capacitance, higher rate capability, and higher energy density, making this a promising candidate electrode material for next-generation supercapacitors.

Porous carbon electrodes are ideal for energy storage systems. A simple in situ reduction approach used gold nanoparticles to improve the electrochemical performance of carbon materials. Scanning electron microscopy, transmission electron microscopy, and the Brunauer–Emmett–Teller method all confirmed that the porous carbon microspheres coated with gold nanoparticles had a 3D honeycomb-like structure with a high specific surface area of roughly 1635 m^2g^{-1}. The electrochemical performance of the as-synthesized porous carbon microspheres as electrode materials for supercapacitors was demonstrated; they were shown to have a high specific capacitance of 440 F g^{-1} at a current density of 0.5 A g^{-1} and excellent cycling stability, with a capacitance retention of 100 percent after 2000 cycles at 10 Ag^{-1} in 6 M KOH electrolyte. The method paved the way for the gold-nanoparticle-decorated synthesis of porous carbon microspheres and could be used to create porous carbon microspheres with a variety of nanoparticle decorations for a variety of applications such as energy storage devices, enhanced absorption materials, and catalytic sites [105,106].

7. Summary and Conclusions

Apprehension over the secondary effects related to the development of NPs and an increasing desire for greener technologies have arisen in the field of green and maintainable remediation. The acceptance of green synthesis promises not only to avoid secondary conservational contamination but also to reduce manufacturing costs. However, there are still gaps in the research that should be addressed to assist the development of the field. For example, an explanation of the precise mechanisms involved in green synthesis remains essential to advance additional expected outcomes. Most studies rely on sensible norms, but detailed assessments of the precise mechanisms remain subtle. The current green synthesis research has produced NPs with several geometric structures, but methods that can produce more composite forms with more detailed surface areas are still required.

Moreover, varying the crystal-like construction of greener NPs, to discover innovative properties that vary from their majority material is an additional future avenue for green synthesis investigators. Nanotechnology has emerged as an attractive tool capable of revolutionizing several fields. It is a technology that functions on the nanometer scale and deals with atoms, molecules, and macromolecules approximately in the 1–100 nm range, to synthesize and employ materials that possess novel properties. Nature is the best coach for teaching us mechanisms for the synthesis of miniaturized functional materials. Despite being a methodological approach, the synthesis of metal oxide NPs with microorganisms or plant extracts, using biological mechanisms, opens up tremendous opportunities to produce biocompatible and cost-effective particles with potential applications in the healthcare sector.

Synthesizing of NPs via the bio-green route has attracted a great deal of attention as it involves no harmful chemicals in its synthesis method. Hence, bio-green synthesized NPs could be promising materials, opening up new prospects in clinical, energy, and environmental research. One of the most important areas calling for attention is cancer therapy and the use of nanotechnology to improve existing therapeutic practices. Cancer is a leading cause of mortality and morbidity worldwide, and the use of traditional chemotherapeutics is often limited by the adverse side effects they cause. The need for a novel strategy to combat this is important for effective cancer therapy. Recent progression in the nanotechnology sector offers many strategies for combating cancer with innovative and personalized treatments that are capable of overcoming the barriers encountered with traditional drugs. Nanomaterials have been known to enhance the efficacy of food processing and its nutritional value as additives, without changing the characteristics of food products. They are also effective agents of bioremediation and have been used in wastewater treatments. Nanotechnology has found applications in a variety of areas and will form an important strategy for solving several problems.

8. Future Perspectives

- Nanotechnology is highly recommended for future perspectives since it replaces dangerous solvents in green synthesis and process approaches, improves catalytic efficiency and selectivity, is cost-effective, and involves less toxic waste disposal.
- The primary advantages of the greener techniques are low cost and the use of antimicrobial nanoparticle combinations, which allows for the use of local plant extracts without harmful chemical reducing agents, as well as additional applications such as antibacterial bandages.
- It is necessary to have a thorough understanding of a variety of microbial/biochemical constituents as well as the various pathways involved in laboratory synthesis, including the isolation and tracing of components that are precisely used in the reduction of several metallic salts to the required materials.
- Future difficulties and current accomplishments linked with green perspectives for nanomaterial production must be addressed, extending laboratory-based compliance to an achievable industrial standard by considering current/past issues in terms of health and environmental repercussions.
- However, a greener approach technique based on bio-derived materials or nanomaterials is required and will be widely used in the field of environmental remediation as well as other broad fields such as the food, cosmetics, and pharmaceutical industries.
- Furthermore, biomaterials made from marine plants and algae found in specific locations remain undiscovered. As a result, there are still many opportunities for the development of novel green pathway strategies based on biogenic synthesis.
- To enable the industrial production of such green nanomaterials, a great deal of scientific research is required. The eventual release of such nanomaterials into the environment might cause odd behavior, and this is a concern that must be investigated further.

- Toxicity evaluation must be undertaken for nanoparticles and effective risk management processes provided for their synthesis, materials handling, storage, and disposal.

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Abbreviations

J	Joule
M	Molar
Zn	Zinc
Pb	Lead
As	Arsenic
Se	Selenium
Ag	Silver
Cu	Copper
Hg	Mercury
Pd	Palladium
Pt	Platinum
Ru	Ruthenium
Kpa	Kilopascal
Nm	Nanometer
Fe_3O_4	Iron oxide
NPs	Nanoparticles
ZnO	Zinc oxide
SnO_2	Tin oxide
NiO	Nickel oxide
CuO	Copper oxide
CeO	Cerium oxide
CoO	Cobalt oxide
$AgNO_3$	Silver nitrate
NMs	Nanomaterials
TiO_2	Titanium dioxide
ZrO	Zirconium oxide
HCL	Hydrochloric acid
WBCs	White blood cells
NaOH	Sodium hydroxide
H_2O_2	Hydrogen peroxide
SLN	Sentinel lymph nodes
$NaBH_4$	Sodium borohydrate
$CoNi_2S_4$	Cobalt nickel sulfite
KOH	Potassium hydroxide
DMF	N-Dimethylformamide
nZVI	Nanoscale zero-valent iron

PGE	Punica granatum leaf extract
HIV	Human immunodeficiency virus
SPIONS	Superparamagnetic iron oxide
MIPs	Molecularly imprinted polymers
NCMs	Nanostructuured catalytic membranes

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