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An Overview of Nanoparticles from Medicinal Plants: Synthesis, Characterization and Bio-Applications

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Abstract

Presenting and definition the most important points about nanoparticles for medicinal plants and the most important vital applications of them. The scoping review was performed according to systemic style. The research articles included the selected studies dealing with primary information on nanotechnology and medicinal plants published between 2000 and 2023. The search was at grassroots platforms such as Web of Science and PubMed. Many studies correlated the properties of plants' nanoparticles such as stability, surface area, and high reactivity, and their small size. It was found that nanoparticles (NPs) have size ranging from some nanometers to 100 nm and their morphology is controlled because of their tiny size, NPs have a big surface area, which makes them suitable for many applications. Green nanotechnology has the potential to become an industry with very high green credentials as it is increasingly commercialized. In general, nanoparticles derived from medicinal plants offer a promising avenue for various bio-applications. Their green synthesis, biocompatibility, and potential therapeutic properties make them an attractive area of research with the potential to impact fields ranging from medicine to agriculture.

Keywords

Nanotechnology, Medicinal Plants, Green Chemistry, Bio-Application

1. Introduction

Nanomaterials have a high value due to their physical, chemical, and biological properties. The size of this nanostructure material (1 - 100 nm) increases the surface-to-volume ratio, resulting in a significant surface reaction (**Table 1**).

Table 1. The size of nanoparticles compared to other particles.

Type of particle	*Size of Particle dimeter*
Nanoparticles	1 - 100 nm
Small molecules	0.1 nm
Fine particles	100 - 2500 nm
Coarse particles	2500 - 10,000 nm
Hair thickness	50,000 nm

Therefore, this technique is used in many fields ranging from materials science to biotechnology. Nanobiotechnology is the combination of biotechnology and nanotechnology for the development of biosynthesis. Environmentally friendly technology for the synthesis of nanomaterials. Advances in the use of nanoparticles for biological applications while considering the environmental aspect have encouraged the need for their synthesis using green chemistry strategies across biological systems. Nanotechnology deals with the matter on an atomic scale for producing new materials, structures, and devices. This technology strongly promises several scientific fields such as medicine, energy, consumer products, and manufacturing. Generally, nanotechnology is defined as engineered systems, structures, and devices. Nanomaterials begin exhibiting unique properties that affect chemical, physical, and biological behavior [1] [2].

From the above table, increasing surface area relative to their volume leads to several important consequences, one of which is a significant increase in surface reactions. In summary, the small size and high surface area of nanostructures makes them particularly interesting for a wide range of applications, especially in fields like materials science, chemistry, biology, and nanotechnology, where surface reactions and properties play a crucial role.

2. Synthesis of Nanoparticles from Medicinal Plants

Nanomaterials exist naturally, are created as by-products of some reactions such as combustion reactions, or are purposefully produced through engineering processes to achieve a specialized function. Generally, the nanoparticles are synthesized by top-down and bottom-up methods. The bottom-up method can involve the manipulation of separate atoms and self-build to form nanoparticles from separate components. Therefore, nanomaterials are prepared in a bottom-up way by collecting atoms by atoms, molecules by molecules or clustered by clustered, while, in the top-down way, normal materials are transformed into smaller nanomaterials [3] (**Figure 1**).

Nanostructured material can be synthesized in a self-build way, and then the components are either spontaneously or separately associated to make an ordered form. The reactions in the self-build way always are oleophobic effects and noncovalent, coordination interactions. Furthermore, intermolecular forces between the nanoparticles keep the spontaneous arrangement of molecules stable and

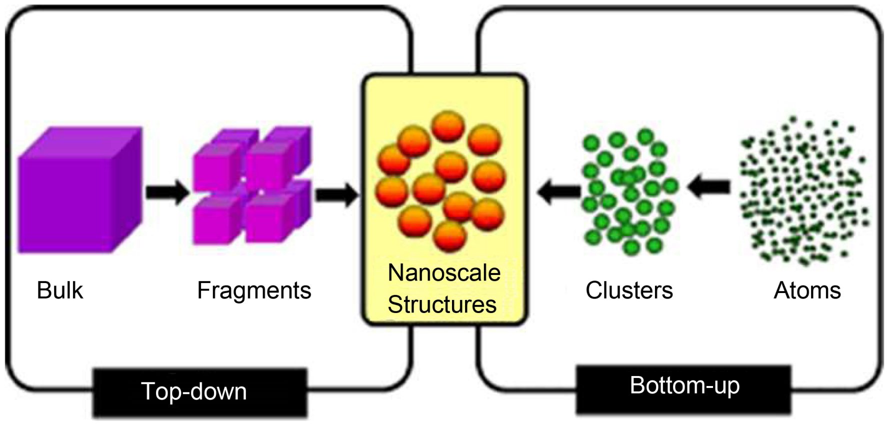


Figure 1. Top-down and bottom-up methods of nanoparticles synthesis [3].

precise cluster of nanostructures [3]. The synthesis of nanoparticles can be achieved through various methods, and two common approaches involve using plants and microorganisms. Various studies have suggested that plants appear to be the best candidates and are suitable for a wide range [3].

These methods are known as "green synthesis" because they are considered more environmentally friendly compared to traditional chemical synthesis methods. Here's an overview of each approach [4].

3. Green Synthesis of Nanoparticles Using Plants

This method involves using various parts of plants, such as leaves, stems, roots, or extracts, to synthesize nanoparticles. It is a cost-effective and eco-friendly approach. Here are the general steps involved:

- **Plant Material Selection**: Choose a plant species known for its ability to accumulate or reduce metal ions and has bioactive compounds that can act as reducing or stabilizing agents.
- **Preparation of Plant Extract**: Extract bioactive compounds from the chosen plant material. Common extraction methods include maceration, sonication, or Soxhlet extraction.
- **Nanoparticle Formation**: Mix the plant extract with a solution containing metal ions (e.g., silver nitrate, gold chloride) at an appropriate pH and temperature. The bioactive compounds in the plant extract act as reducing agents to convert the metal ions into nanoparticles.
- **Characterization**: Analyze the synthesized nanoparticles using techniques like UV-Vis spectroscopy, TEM (Transmission Electron Microscopy), XRD (X-ray Diffraction), and FTIR (Fourier Transform Infrared Spectroscopy) to confirm their size, shape, and composition.

4. Green Synthesis of Nanoparticles Using Microorganisms

This approach involves the use of microorganisms like bacteria, fungi, or algae to synthesize nanoparticles. Microorganisms have enzymes and metabolites that can reduce metal ions and facilitate nanoparticle formation. Here's a general outline of the process:

- **Microorganism Selection**: Choose a suitable microorganism that can reduce metal ions and withstand the conditions required for nanoparticle synthesis.
- **Cultivation**: Grow the selected microorganism in a suitable culture medium containing metal ions.
- **Nanoparticle Formation**: The microorganism will metabolize and reduce the metal ions, leading to the formation of nanoparticles. The nanoparticles may be intracellular or extracellular, depending on the microorganism used.
- **Isolation and Purification**: After nanoparticle formation, isolate and purify the nanoparticles from the culture medium and biomass.
- **Characterization**: Characterize the nanoparticles using techniques such as UV-Vis spectroscopy, TEM, XRD, and FTIR to determine their properties.

Both plant-based and microorganism-based green synthesis methods have gained significant attention due to their eco-friendliness, scalability, and potential applications in various fields, including medicine, electronics, and environmental remediation. The choice of method often depends on the specific nanoparticles required and the availability of suitable plant species or microorganisms.

The last developments in nanoscience appreciably modified how diseases are prevented, treated, and diagnosed. Using metal nanoparticles, such as silver nanoparticles (AgNPs), exist in bioscience. From a while to a while, several synthetic methods for the creation of AgNPs were reported. However, most are expensive and the physicochemical parameters that affect them such as temperature, surfactant, use of a dispersing agent, and others greatly influence the quality and quantity. Therefore, researchers worldwide try to synthesize NPs and are devising ways that are economical, easy to apply and eco-friendly. Among these strategies is the green method, where plants are used as a safe source of reducing and capping agents.

Biosynthesis of nanoparticles where the rate of synthesis is faster than that in the case of other organisms. Nanoparticles that are produced using microorganisms and plant extracts are highly stable and they can be monodispersed by controlling the synthetic parameters, like mixing ratio, pH, temperature, and incubation period. In recent years, biological nanoparticles found to be pharmacologically active more than physically and chemically synthesized nanoparticles [4].

Green synthesis of nanomaterials from medicinal plants is an eco-friendly, cost-effective, and non-toxic approach to the generation of nanoparticles generation to the chemical and physical approach. Medicinal plants have been very important in traditional medicine since old times and are good sources of bioactive compounds that have antiviral and antifungal activities. Using medicinal plants is more effective and secure than synthetic drugs in treating several diseases. Medicinal plants are very important in traditional medication in old times and are fine source of bioactive compounds that having antiviral and antifungal activities. These plants are a highly superior source of bioactive compounds including various primary and secondary metabolites such as terpenoids, alkaloids, phenolics, flavonoids, saponins, tannins, etc. The nanoparticles of them such as pachymahoelen, nndrographispaniculata, Olea eurolaea, Phyllanthusniruri, Swertiachirata, etc., have shown antiviral properties many times higher from the normal particals against viruses like dengue, herpes, and human immunodeficiency virus [5]. Bio nanoparticles are most diverse in size and shape compared to particles produced by organisms such as bacteria, fungi, and algae. Because many biologically active ingredients in plants such as alkaloids, flavonoids, terpenoids, amino acids, enzymes, vitamins, proteins, and glycosides can also be. As an example, the preparation of silver nanoparticles using starch, where a paste of starch with sodium hydroxide can be used as it dissolves starch with no modification and degradation of starch with very high molecular weight prevents the clumping of particles for a long time. In addition, another way of biosynthesis of silver nanoparticles is by using the extract of several plants such as carioca papaya peel and dalleprigiassiso leaves then evaluating the antimicrobial and antioxidant potentials of the nanoparticles against different human pathogens (**Figure 2**). Water-soluble antioxidant components found in these plant extracts were highly superintend for the transformation of silver ions to Nano-sized Ag particles [6] [7].

Moreover, there is nanoparticles synthesis using biodegradable polymers, such as a linear polysaccharide (sugar) that is gained from the rigid external skeleton of marine organisms (chitosan), which is much more valuable for the biosynthesis of silver nanoparticles because it behaves as a reductant and mediator in same time [8].

5. Nanoparticles Characterization

The nanoparticles characterization is a highly important field of nanometrology ways with the measurement, of the chemical and physical properties of nanoparticles. Nanoparticles differ from ordinary chemicals in their chemical composition and shape, and their concentration is not considered an adequate measure for full describing, because they different in many physical properties such as shape, size surface properties, lucid, and disbandment state. Because of their sizes

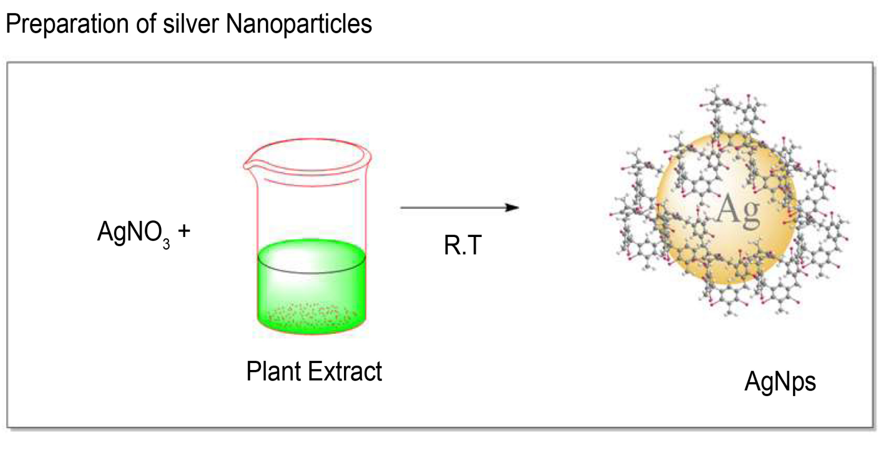


Figure 2. The biological synthesis of silver nanoparticles AgNPs [7].

are so much minor than the wavelengths of visible light (400 - 700 nm), nanoparticles cannot be normally shown under ordinary optical microscopes, thus, it requires the using of electron microscopes or microscopes with laser (**Figure 3**). They are powerful tools used to characterize nanoparticles and other nanoscale materials. They work on the principle of using a focused beam of electrons instead of light to image objects at extremely high resolutions. The main parts of SEM; A-a source of high-energy electrons called an electron cannon; B-Down column to transfer electrons using two or more electromagnetic lenses; C-the skew system which consists of scan files; D-Electron detector for secondary and scattered electrons; E-a sample chamber and F-The computer system which consists of a displaying screen to display the scanned photos and a keyboard to control the beam [9]. Nanoparticles must be characterized for several purposes, such as manufacturing process control and Nanotoxicology. There are many kinds of instrumentation to measure these properties, including spectroscopy methods, microscopy, and particle counters [9] [10].

Microscopy approaches make statues for separate nanoparticles to describe their size and shape, scanning probe microscopy and electron microscopy are the dominant methods. Because nanoparticles have a size under the diffusion limit of the visible light, popular optical microscopy is not used. Furthermore, microscopy depends on single-particle measurements, which means that large numbers of individual particles can be characterized to assess their volume properties. Nanoparticle Characterization Techniques: UV-Visible Spectroscopy, Transmission Electron Microscopy (TEM), Dynamic Light Scattering (DLS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Scanning Mobility Particle Sizer (SMPS), Matrix-assisted Laser Desorption/Ionization Mass Spectrometry (MALDI-MS) [11].

Figure 3. Scanning electron microscope (SEM) [10].

6. Chemical and Physical Properties of Nanoparticles

The properties of materials change when their size is approaching the atomic size. Because the increasing correlation between surface areas to volume, the surface of the material is controlling the material performance. Due to the highly small size of nanoparticles, they have a so large surface area to volume compared to normal material. This feature gives nanoparticles unexpected chemical, physical and optical properties. For instance, copper as a metal is a soft material, so it is possible for its atoms to cluster at the 50 nm scale to be bent. But copper nanoparticles that are smaller than 50 nm are so hard material, which means its differences in ductility and malleability compared to normal copper [12]. In addition, the difference in size also affects on melting properties; nanoparticles of gold are melting at low temperatures (300˚C) while the normal particles of gold are melting at high temperatures (1064˚C). In addition to several characteristics, which are:

1) They are deeply moving in the free area (e.g., in the absence of any other influence, a 10 nm-diameter nanosphere of silica under gravity has a deposit rate of 0.01 mm/day in water.

2) They have especial and enormous surface spaces (e.g., a teaspoon of 10 nm-diameter silica nanoparticle has more surface area than a 12 ones of tennis courts.

3) Quantum effects may exhibit. Therefore, nanoparticles have a wide range of compositions, according to the use or the product.

4) Magnetic properties of nanoparticles, which have varied applications ranging from data storage to diagnostic applications. These nanoparticles are manipulated by using of magnetic field. As an example, ferrite nanoparticles which have a size smaller than 128 nm can become superparamagnetic thereby preventing self-agglomeration.

5) Pharmaceutical stability. Where the nanoparticles of drugs exist in the final drug products either in the form of dry powder or suspension. Solid dosage forms have good storage stability profiles which is why a common strategy to make Nano suspension stability is to transform the suspension into solid.

6) Physical and chemical stability of drug nanoparticles [13].

7. Classification of Nanoparticle

Nanostructured particles can be classified based on their dimensions as vary classes; zero (0D), one (1D), two (2D) and three (3D) [14].

0D NSMs such as quantum dots particles, heterogeneous nanoparticles arrays, core-shell nanoparticles, hollow-cube nanoparticles, and Nanospheres (**Figure 4**) [15].

1D NSMs have performed an increasing achievement due to their importance and applications in development and research. It is known that 1D NSMs are perfect systems for exploring a high number of phenomena at investigating the size and dimensionality dependence of functions. There as several types of 1D

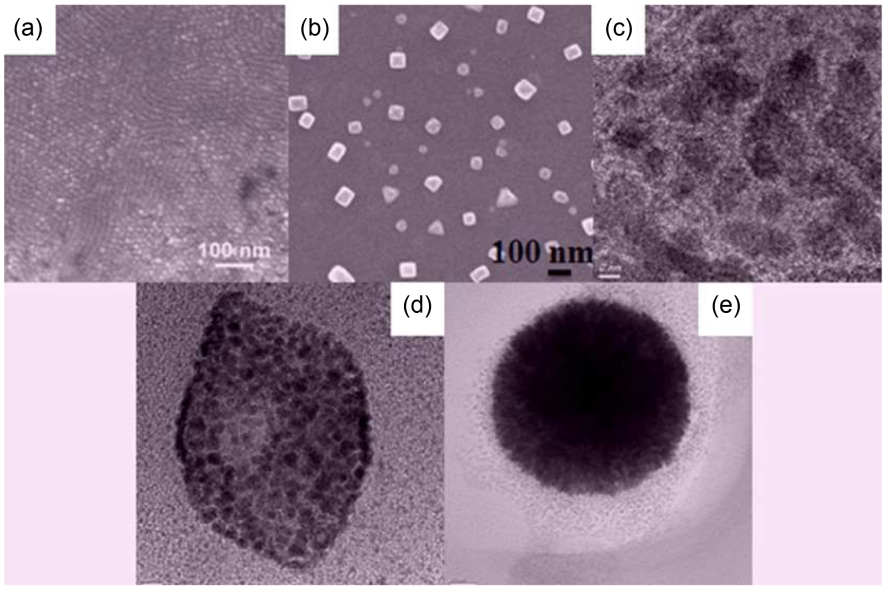


Figure 4. Typical scanning electron microscope (SEM) of 0D nanoparticles: (a) heterogeneous nanoparticles arrays (b) core-shell nanoparticles (c) hollow-cube nanoparticles (d) and nanospheres (e).

nanoparticles, shown in (**Figure 5**) [16] [17]. 2D nanostructures have two dimensions outside of the range of nanometric size. Recently, synthesis 2D NSMs have become a most focal field to use in materials research, 2D NSMs are a highly interesting field not only for the main understanding of the mechanism of the growth of nanostructure, but also for developing new applications in photocatalysts, sensors, nano-containers, and 2D templates for of other materials. Some 2D nanostructured particles are shown in (**Figure 6**) [18] [19] [20] [21]. For 3D NSMs: they have been synthesized in the 10 last years. It is highly known that the NSMs behaviors are based on their sizes, shapes, and morphologies.

Thus, it is of great interest to prepare 3D NSMs with a controlled morphology. Moreover, 3D nanostructures are strongly useful materials due to their several applications in the field of catalysis (**Figure 7**) [22] [23] [24]. Furthermore, there is another class of nanoparticles called "Liposome Nanoparticles". These are spherical vesicles with a membrane consisting of a lipid bilayer having an aqueous substance. The amphiphilic molecules that are used in the preparation of these vesicles are like the biological membranes for the improvement of safety and efficacy of different drugs [25] [26].

8. Bio-Application

The nanomaterials applications span along a wide variety of fields, from cosmetics and healthcare to air purification and environmental preservation. In this article, we will only focus on the bio-applications.

8.1. Medical Application

Nanotechnology has had strongly impact on medicine in last years; its applications

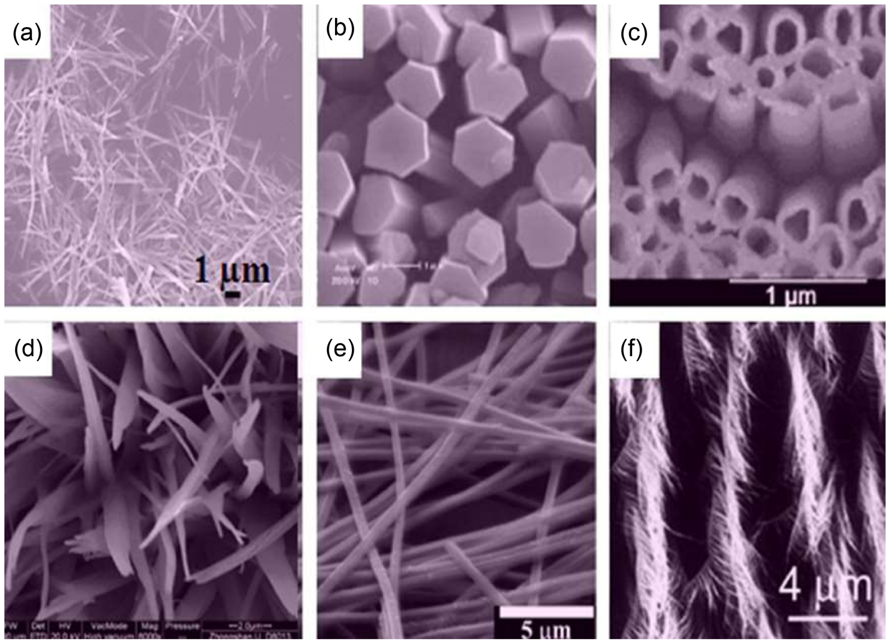


Figure 5. Typical scanning electron microscope (SEM) of 1D nanoparticles: (a) nanowires, (b) nanoords, (c) anotubes, (d) nanobelts, (e) nanoribbons, (f) hierarchical nanostructures.

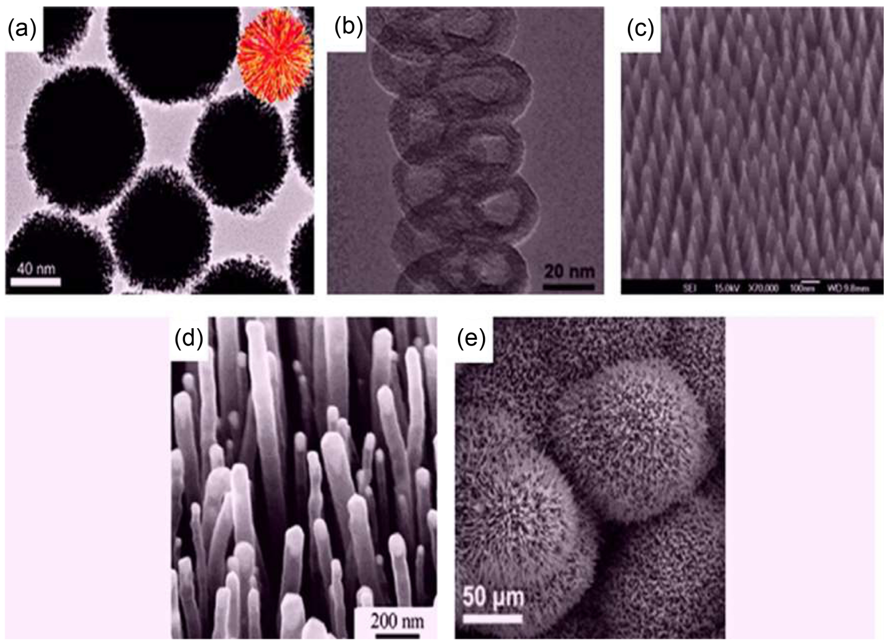


Figure 6. Typical scanning electron microscope (SEM) of 2D nanoparticles: (a) Junctions; (b) branched chains; (c) nanoplates; (d) nanosheets; (e) nanowalls; (f) nanodisks.

named as nanomedicine. Nanotechnology is used in the pharmaceutical and medical fields for several reasons, such as drug solubility, bioavailability, and delivery to sites of action. Also, employed for developing new therapeutic devices [27]. Many studies carried out on patents using the three keywords "Nano, meter" and "pharmaceutical", they shown that there has been a near-exponential increase in recent

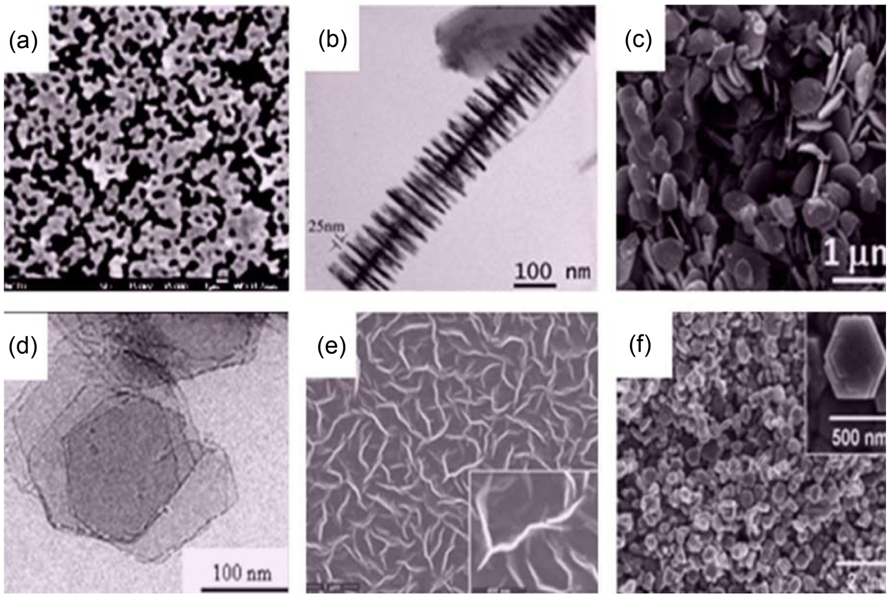


Figure 7. Typical scanning electron microscope (SEM) of 3D nanoparticles: (a) Nanoballs, (b) nanocoils, (c) nanocones, (d) nanopillers, (e) nanoflowers.

years in the number of patents in pharmaceutical Nano-searches. Having analyzed the details of the patent identified, there were be seen to be several general trends developing in the drug field. Which is drug delivery, especially using nanoparticles, dendrimers, Nanoemulsions, and increasing drug solubility and bioavailability [28].

Pharmaceutical nanotechnology shows revolutionary opportunities to fight against several diseases. It helps to detect diseases such as cancer, neurodegenerative diseases, and diabetes mellitus. Moreover, detection the viruses and microorganisms that are associated with infection. Nanotechnology in the pharmaceutical field covers the development of nanomedicine, nanorobots, tissue engineering, biomarkers, and biosensors. It provides opportunities for improvement of materials [29]. Nanoparticles in Medical Applications deals with emerging new technologies for drug delivery systems to develop customized solutions. The delivery systems of drugs must affect the rate of distribution, absorption, metabolism, and excretion of the drug or other chemical substances in the body. Moreover, the delivery system of drugs must allow the drug to bind to its target receptor and influence on receptor's activity and signaling. Delivery materials of drugs must be easy to bind with a particular drug, and able to be fragments after use. Nowadays, polymeric biodegradable nanoparticles have attracted the attention as potential drug delivery devices with the prospects of their applications in drug release controlling, their ability to target tissue and organs, as carriers of oligonucleotides in DNA in gene therapy and antisense therapy in their ability to distribute proteins [30] [31] [32] (**Figure 8**).

In medication science, nanotechnology offers several forms of nanoparticles, and these nanoparticles have long-acting and brain-targeted properties with minimal adverse effects and motor complications.

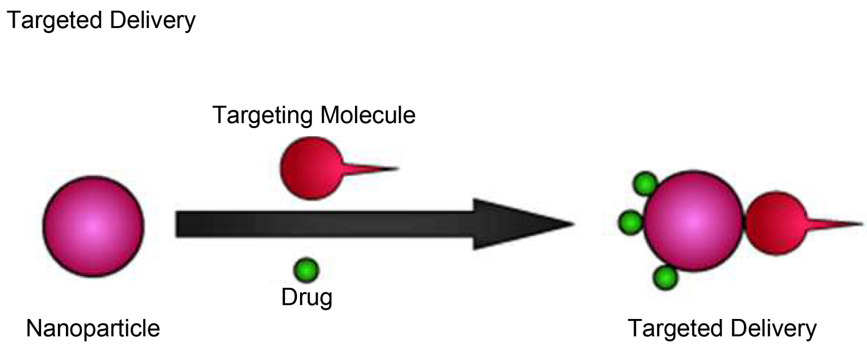


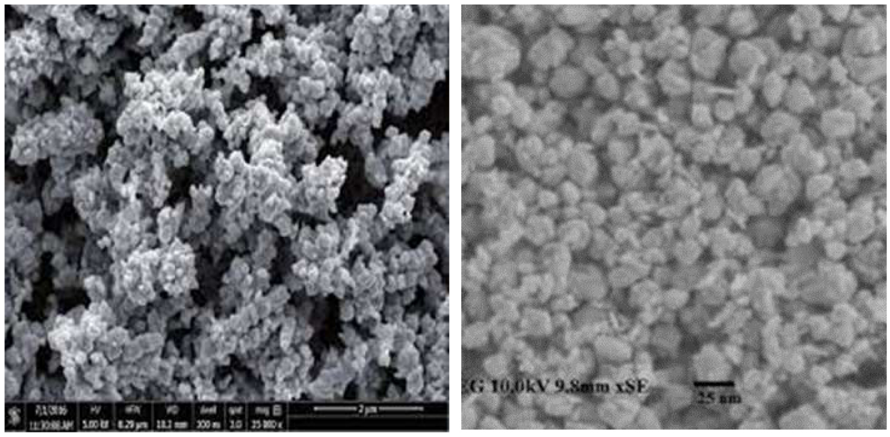
Figure 8. Schematic view for nanotechnology in drug delivery.

Additionally, many metal nanoparticles can be used as alternative antibiotics, such as nanoparticles of silver oxide, zinc oxide, titanium dioxide, and copper oxide, where, they have shown strongly effective antimicrobial activity in opposition to many types of microorganisms [33]. These approaches can give us a chance to replace antibiotics-based drugs with highly safe treatments. Furthermore, Nanomaterials are used as antibacterial complementary to antibiotics and are getting big attention as they may fill the holes where antibiotics sometimes fail. Nanoparticles as antimicrobial active particles reduce many kinds of bacterial resistance as the microbicide because the nature of nanoparticles results from straight contact with the specific bacterial cell wall, without the need to probe into the cell. Therefore, the advancing of antibacterial resistance to nanoparticles is less likely when they are considered antibiotics. As an example, green synthesized copper oxide nanoparticles were studied as antimicrobial potential against different bacterial and fungal pathogens. Where antimicrobial activities of copper oxide nanoparticles were compared with standard antibiotics norfloxacin and amphotericin B. Results indicated that CuO-NPs offer highly antimicrobial activities against the selected pathogens [34] (**Figure 9**).

The toxicity of such nanomedicines to animal tissues confirmed the potential of commercially available copper/silver nanoparticles and their combination in the decreasing of viability of mastitis-borne pathogens without toxic effects on mammary gland tissues [35]. Another medical field where the achievements of nanotechnology are utilized is the creation of artificial organs, cells, and tissues. Artificial cells are being actively used for utilized in the replacement of wrongly or defective functioning organs and cells, especially those related to metabolic functions. Where nanotechnology has achieved a high position in regenerative medicine. This includes the production of smart nanocomposite materials, nanoparticles fluorescent like quantum Dots and magnetic nanoparticles for stem cell tracking; and carbon nanotubes and graphene for enhancing the properties of the material [36].

8.2. In Nutrition Applications

Nanotechnology in the field of nutrition has revolutionized the world. The searches in this field have grown dynamically. In nutrition articles and research,



(a) (b)

Figure 9. SEM micrograph of copper oxide nanoparticles: (a) 100 Nm, (b) 10 Nm.

the applications of nanotechnology help in obtaining accurate and specific spatial data around the position of a bioactive food compound in a tissue, cell, or cellular organ [37].

Hypersensitive detecting of nutrients and increasing an understanding of biomolecular and nutrient in the tissues, could be workable and viable. Nowadays, specific applications of nanotechnology in nutrition and food include detecting of food pathogens; modifying color, taste, and texture of foods; and enhancement nutrition quality of foods, as well as serving to enable more elucidation of nutrient metabolism and physiology. For example, one food nanotechnology application involves coatings for foods and food packaging which serve as barriers to bacteria or that contain additional nutrients. Moreover, it is so important to recognize that the potential toxicity of nutrients affected by a changing in size of particles [38].

There is something known as Nano-capsules, which is a nanoscale membrane made of a nontoxic polymer, as well as they are vesicular matters made of a polymeric film that encapsulating an internal liquid core using the nanoscale (**Figure 10**) [39]. They are used for increasing the delivery of nutrients and drugs (vitamins, minerals, and salts) in the body. Differently, Nanocomposite, Nano-emulsification and Nano structuration highly used to encapsulate the materials in tiny forms for delivering the bioactive components most effectively (e.g., flavonoids and vitamins) (40). Nano-capsules are used also, as carriers for essential oils antioxidants, flavors, vitamins, minerals, and phytochemicals to improve the bioavailability in the human system. Moreover, the encapsulation of polyphenols by nanoparticles can prevent any oxidations and provide them with an acceptable taste [39] [40]. In industry of food, the applications of liposomal Nano-vesicles are found for the encapsulation of nutrients, enzymes, and antimicrobial compounds. Nanotechnology also improves the characteristics of bioactive particles in herbs and spices by enhancing their water solubility, bioavailability, and antioxidant properties. Besides, the Nanomaterials are increasing the bioavailability of important phytochemicals, such as genistein and curcumin

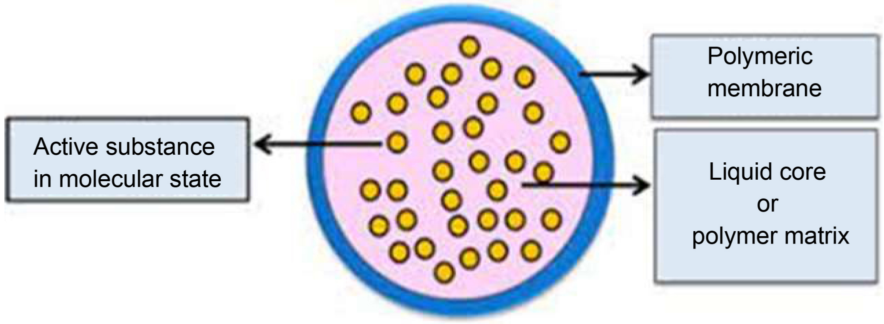


Figure 10. Schematic view for the Nano-capsule.

[41]. Furthermore, Nano nutraceuticals are bioavailable as dietary herbal products, supplements, and bioactive particles in Nano-formulations [42].

8.3. In Agriculture Applications

The major applications of nanotechnology in agricultural are Nano-formulated agrochemicals as an example, Nano pesticides, Nano fertilizers, Nano biocides, Nanosensors for improved efficacy, precise control of agrochemical and Nano-based veterinary medicines applications. Another major application of is the improvement of soil. The physical and chemical nature of soil highly has an impact on plant growth. Nanomaterial compounds produce zeolites and Nano clays that help in water retention in soil and liquid agrochemicals [43]. In addition, potable water is one of the important global challenges. In the developing countries. So, nanomaterials such as carbon nanofibers, nanotubes, and Nano sponges used as Nano filters in the purification of water to remove heavy metals such as arsenic, magnetic [44] [45].

Moreover, detection of pathogen from the water and soil and in agriculture is necessary to remove the dangerous contaminants. Therefore, nanotechnology-based detectors can be able to detect fraction of pathogen. Nano biosensors combine with novel technologies such as molecular biology, microfluidics, and nanomaterials for better sensitivity. Nanoparticles in Nano biosensor can selectively detect some concentration of analytics which having enhanced sensitivity. In addition, the detection of pesticide is achieved using enzyme-based Nano biosensor where, these nano biosensors developed by using nanoparticles of metaland modification of their surface with proteins and nucleotides to improve valuable biorecognition and properties of the biosensors [46].

9. Conclusions

In this review article, it has presented an overview around the bio nanoparticles, their types, characterizations, synthesis, chemical properties and finally applications. It was found that NPs have size ranging from some nanometers to 100 nm and the morphology of them is controlled because of their tiny size, NPs have big surface area, that make them suitable for so many applications. Green nanotechnology has the potential to become an industry with very high green credentials as it increasingly commercialized. In general, it may be stated that green is beneficial. In the pharmaceutical industry, nanotechnology entails difficult effort. However, in the end, it raises the standard of living, encourages environmental responsibilities, and promotes ethical behavior.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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