Plant-Mediated Biosynthesis of Nanoparticles Using *Cannabis Sativa* Extract: A Review

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Abstract

Biosynthetic approaches for nanoparticle production have garnered considerable attention amid growing interest in green and sustainable chemistry. Plant-derived materials have been used as an alternative method for synthesizing metal and metal oxide nanoparticles, as these approaches are eco-friendly, cost-effective, and energy-efficient, and they eliminate the need for toxic chemicals. Plant extracts have attracted the most interest among bio-entities because of their unique natural properties, which enable them to reduce and stabilize metal nanoparticles in a single-step synthesis. *Cannabis sativa* has emerged as a highly promising source of green nanoparticles, owing to its unique and diverse phytochemical profile, warranting thorough exploration of its benefits and mechanisms. In this review, we focus on the synthesis of certain metal and metal oxide nanoparticles (M/MO NPs) by using *Cannabis sativa* plant extract. It is a natural source that may serve as a stabilizing, capping, and reducing agent as it contains various bioactive phytochemicals. Cannabinoids and non-cannabinoid components are among the complex variety of secondary metabolites found in it, including non-cannabinoid phenols, flavonoids, terpenes, alkaloids, and other substances. These constituents result in smaller particles and significantly affect the activities of M/MO NPs.

Keywords: *Nanotechnology; Cannabis sativa; Phytochemicals; Green synthesis; Nanoparticles.*

1. Introduction

Nanotechnology is the most rapidly evolving discipline focused on the fabrication of nanoparticles (NPs) ranging from 1 to 100 nm. The Greek word “nano,” which meaning dwarf or small, is from where the term “nanoparticle” originated. It refers to a particle that is 10^{-9} in size, where one nanometer corresponds to one billionth of a meter [1,2,3]. The distinct physicochemical properties imparted by this nanoscale dimension differ significantly from those of their bulk counterparts [4,5]. Due to their distinctive characteristics, like superior thermal, a high surface area-to-volume ratio, and quantum confinement effects, mechanical, and electrical properties, nanomaterials have gained significant attention for applications in environmental remediation, antimicrobial treatments, targeted drug delivery, and biosensing technologies [4,6-12]. The unique characteristics of nanomaterials are determined by their size, shape, interactions with the surrounding media, stabilizers, and synthesis techniques. Therefore, a significant challenge in producing nanoparticles with improved properties is the precise control of their synthesis with respect to size, shape, and stability. Therefore, precisely controlling the synthesis of nanoparticles in terms of size, shape, and stability is a substantial difficulty in creating nanoparticles with better properties. Nanoparticles can be synthesized using three main approaches: chemical, physical, and biological (Fig. 1).

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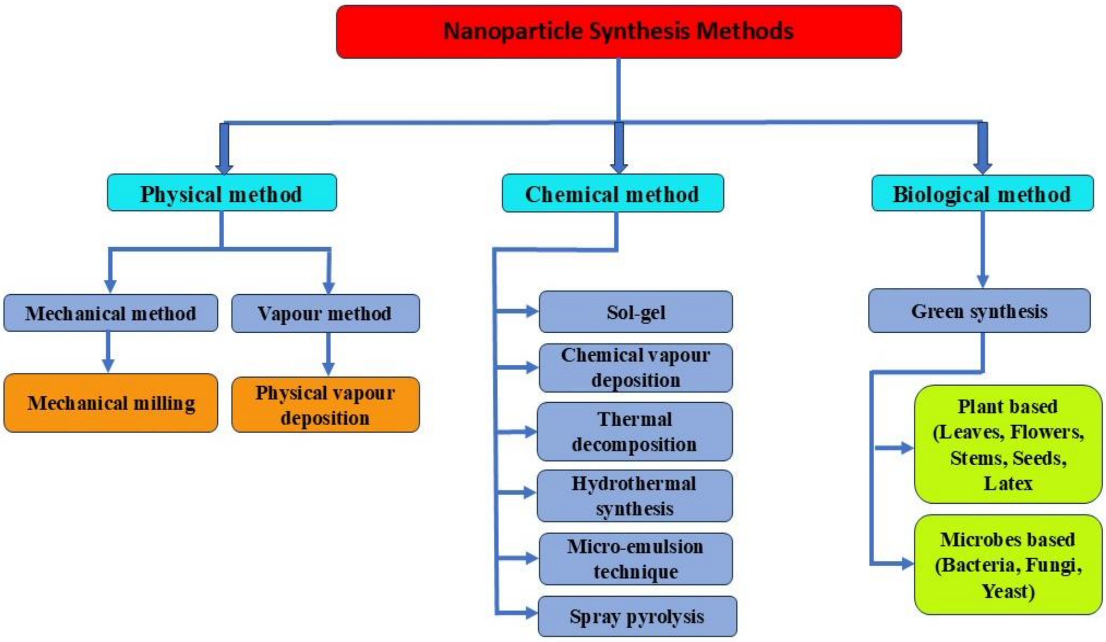

Figure 1: *Synthesis methods of nanoparticles*

The physical approach, also known as top-down approach, that includes breaking bulk material into nanosized particles [13]. Chemical and biological approaches are collectively referred to as the bottom-up approach, in which nanoparticles are built from atoms, ions, or molecules. Biological approaches are also known as green synthesis of nanoparticles [14]. Nanoparticles, along with precise shapes, sizes, and controlled properties, are frequently created by employing chemical and physical methods. Nevertheless, these techniques have several drawbacks, specifically the use of hazardous chemicals, high cost, complex purification procedures, low material conversion rates, unstable yields, high energy consumption, and environmental risks. These methods also require harsh reaction conditions, like extreme pH values, high pressure, and high temperatures, which makes them less appropriate for the production of ecologically benign and biocompatible nanomaterials. Due to the drawbacks of conventional techniques, green synthesis has emerged as a promising alternative that utilizes biological resources, like microbes, plant materials, enzymes, and various biowastes, including vegetable waste, eggshells, fruit peel waste, agricultural waste, and algae, to produce NPs under moderate conditions [15]. Green synthesis uses harmless materials that are more economical and environmentally beneficial due to their stabilizing and reducing-agent properties.

Plant extracts have attracted particular attention among several biological entities employed in green synthesis because they contain metabolites and phytochemicals, like terpenoids, flavonoids, proteins, alkaloids, peptides, and tannins, acting as stabilizing, capping, and reducing agents [4].

2. Plant extract-mediated green-synthesized nanomaterials

A promising and adaptable technique is the green synthesis of nanomaterials utilizing biological materials. Due to their environmental friendliness, scalability, low cost, and simplicity, plant extracts have attracted substantial interest. Unlike bacteria or algae, plant extracts speed up the process and eliminate the need for complex cell cultures [4]. They also reduce metal ions quickly and can be used on a larger scale. Plant extracts are easily available, stable, safe, affordable, and eco-friendly. The phytochemicals in plants, like flavonoids, phenolic compounds, terpenoids, and alkaloids, act as natural capping, reducing, as well as stabilizing agents. They help convert metal ions into NPs and prevent aggregation [4,5,16,17,18]. Plants are abundant, readily available, and can be cultivated under a variety of environmental conditions, offering significant potential for scaling up the production of metal nanoparticles. Since they produce useful phytochemicals, a variety of plant parts, particularly roots, seeds, fruits, leaves, and stems, are capable of being utilized extensively for green synthesis of nanoparticles [19]. The variety of phytochemicals present in plants not only makes it possible to create precisely shaped and sized NPs, but it also removes the need for hazardous chemicals that are frequently employed in traditional synthesis techniques. This technique offers several advantages, as shown in Figure 2, but these are influenced by the variations in the phytochemical composition across batches of plant extracts, which may affect nanoparticle

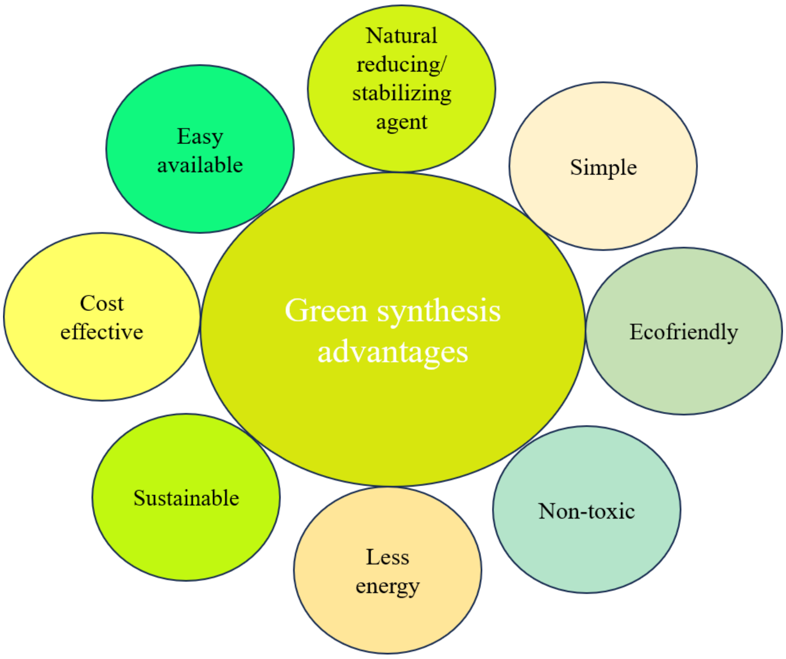

Figure 2: *Advantages of the green synthesis method.*

reduction, stabilization, and growth, leading to differences in nanoparticle properties. Recent studies show that green nanomaterials can be produced using various plant extracts. This review examines how Ag, Au, Mn, Fe, TiO_2, and FeO nanoparticles can be produced in an eco-friendly way utilizing Cannabis sativa extract. The unique phytochemical composition of *Cannabis sativa* enhances the stability and decreases toxicity of M/MO NPs, making it an interesting source for sustainable nanomaterial synthesis.

3. Biosynthesis of Metal Nanoparticles

The biosynthesis of M/MO NPs employing plant extracts comprises several steps. The process typically involves: (i) preparation of the plant extract, (ii) nanoparticle synthesis in which extract serves as stabilizing, capping, as well as reducing agent, and (iii) characterization of the synthesized nanoparticles for their functional and structural properties [20]. The part of the plant used for nanoparticle synthesis can be washed and boiled in distilled water. When we squeeze, filter, and add the appropriate solutions for the nanoparticles we want to synthesize, the solution colour changes, indicating nanoparticle formation, and then we can separate them. Green-synthesized M/MO NPs can be extensively characterized using a range of analytical techniques. These include Raman spectroscopy, ultraviolet–visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), thermogravimetric and differential thermal analysis (TG–DTA), transmission electron microscopy (TEM), energy-dispersive X-ray analysis (EDAX), dynamic light scattering (DLS), scanning electron microscopy (SEM), X-ray diffraction (XRD), atomic force microscopy

(AFM), attenuated total reflectance (ATR), field emission scanning electron microscopy (FE-SEM), X-ray photoelectron spectroscopy (XPS), photoluminescence (PL) analysis, and UV–visible diffuse reflectance spectroscopy (UV–DRS) [21]. Once characterized, the biosynthesized nanoparticles are evaluated for their potential applications in antimicrobial activity, cancer therapy, drug delivery, biosensors, and water treatment (Figure 3).

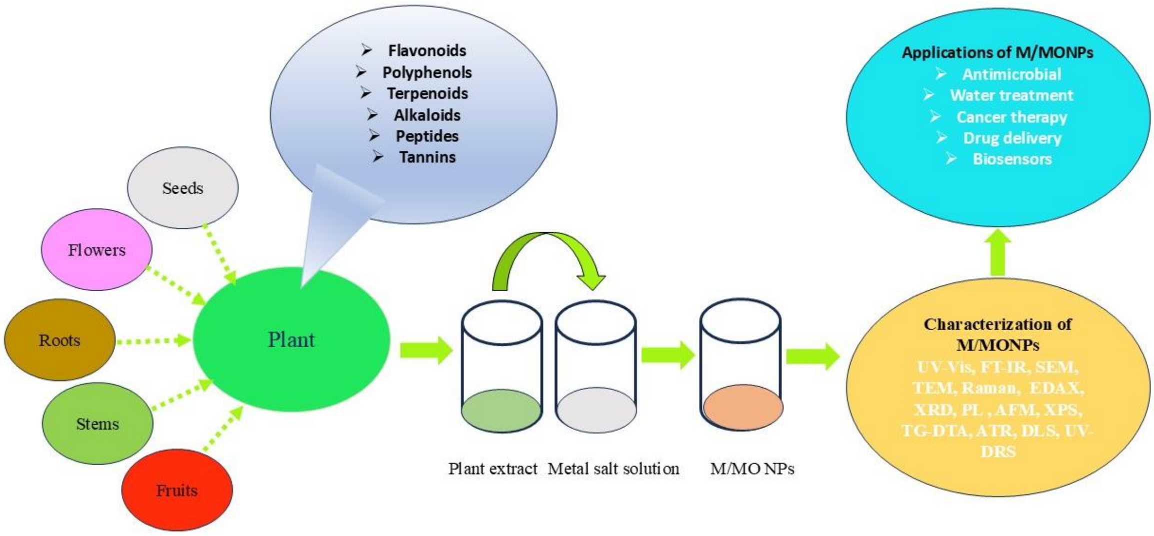

Figure 3: *Green synthesis of M/MO NPs by plant extract and metal salt solution, their characterization, and applications.*

Recent research shows that a variety of plant extracts have great potential for generating green nanoparticles. Extracts from various plants have been extensively documented for their effectiveness in synthesizing metallic nanoparticles for diverse applications, as shown in Table 1.

Table 1: Green-synthesized nanoparticles using different plant extracts and their applications.

Plant name	Plant part	Nanoparticle	Application	Reference
Aloe vera	Leaf	Titanium dioxide	Photocatalytic	[22]
Banana	Peel	Silver	Antibacterial	[23]
Carica papaya	Leaf	Iron oxide	Photocatalytic Antibacterial	[24]
Carica papaya	Peel	Silver	Antioxidant Antimicrobial	[25]
Hibiscus rosa- sinensis	Flower	Copper oxide	Antibacterial	[26]
Krameria sp.	Root	Copper	Antioxidant Antimicrobial	[27]
Moringa oleifera	Leaf	Vanadium	Antibacterial	[28]
Moringa oleifera	Leaf	Silver	Antibacterial Antifungal	[29]

Moringa oleifera	Leaf	Zinc oxide	Antibacterial Antioxidant	[30]
Murraya koenigii	Leaf	Silver	Antibacterial	[31]
Ocimum sanctum	Leaf	Silver Copper	Antibacterial Anticancer Antioxidant	[32]
Ocimum sanctum	Leaf	Silver	Antibacterial	[33]
Pisonia alba	Leaf	Zinc oxide	Antibacterial	[34]
Rubus ellipticus Sm.	Root	Silver	Antibacterial Antioxidant	[35]
Salvia officinalis	Leaf	Zinc oxide	Photocatalytic Antifungal	[36]

4. Cannabis sativa

Cannabis sativa is a flowering plant in the Cannabaceae family. It is typically an annual species with male and female flowers on separate plants, although both may occasionally be present on the same plant [37]. Several subspecies or variants, including Cannabis sativa ssp. sativa, Cannabis sativa ssp. indica, Cannabis sativa ssp. ruderalis, and Cannabis sativa ssp. afghanica are classified within the Cannabis genus. The ongoing debate among scientists continues regarding the subclassification of cannabis species and their respective variants [38-41]. McPartland and Small (2020) and McPartland (2018) are two recent molecular and phylogenomic investigations that support the classification of these kinds as a single polymorphic species, Cannabis sativa L. The most well-known subspecies are sativa, indica, and ruderalis, which enhance interdisciplinary communication and enable standardised botanical references. Cannabis sativa is known by various names worldwide, including Hashish in the Middle East, Djomba or Liamba in Central Africa and Brazil, Sodom, Tampl, Gum, Gauge, and Stuff in Kinshasa, Kif in North Africa, Swala and Whiskt in Ghana, Dogga in South Africa, Krori in Tunisia, Habak in Turkey, Grifa in Mexico, and Macohna in parts of South America [42-43]. The plant grows rapidly and features a distinctive fluted stem, reaching heights of 1 to 4 meters and diameters of 1 to 3 centimeters [38,44]. Its appearance varies with climate, soil, and environmental conditions [38,45]. The fruits, botanically termed achenes, are small, dry nuts with a smooth, round or slightly oval shape, measuring 2.5-3.5 millimeters in length and 2.5-3 millimeters in width [38].

A total of 565 natural compounds have been identified to date, 120 of which belong to the cannabis class [46-48]. The remaining phytochemicals found in cannabis are either secondary metabolites, including non-cannabinoid phenols, flavonoids, terpenes, alkaloids, and other compounds, as well as cannabinoids, or primary metabolites, including amino acids, fatty acids, and steroids. Humans have utilised *Cannabis sativa L.* since ancient times, and numerous historians have documented its various applications worldwide. This plant has been utilised for food, fibre, oil, recreation, and religious purposes, according to historical documents. Furthermore, over the years, several additional applications have been developed, including skincare, haircare, and animal feed [49].The medicinal value of *Cannabis sativa L.* for the treatment of inflammation, depression, and chronic pain was highlighted in numerous ethnobotanical surveys [44].Cannabis sativa is a widely used herbaceous medicinal plant in the field of agriculture, agrochemistry, beverages, bioenergy, biofuels, building materials, composites, cosmetics, environmental protection, food industry, furniture, hygiene, medicine, paper, ropes, textiles, and tech-textiles [50-51]. It is primarily used in medicine to treat neurological conditions and reduce pain [52].

5. Biosynthesis of Metal/ Metal oxide Nanoparticles using aqueous *Cannabis sativa* extract

Cannabis sativa plant extract is used as a capping, reducing, and stabilizing agent for the biosynthesis of metal/metal oxide nanoparticles such as AgNPs, AuNPs, FeNPs, MnNPs, TiO_2NPs, and FeONPs (Figure 4).

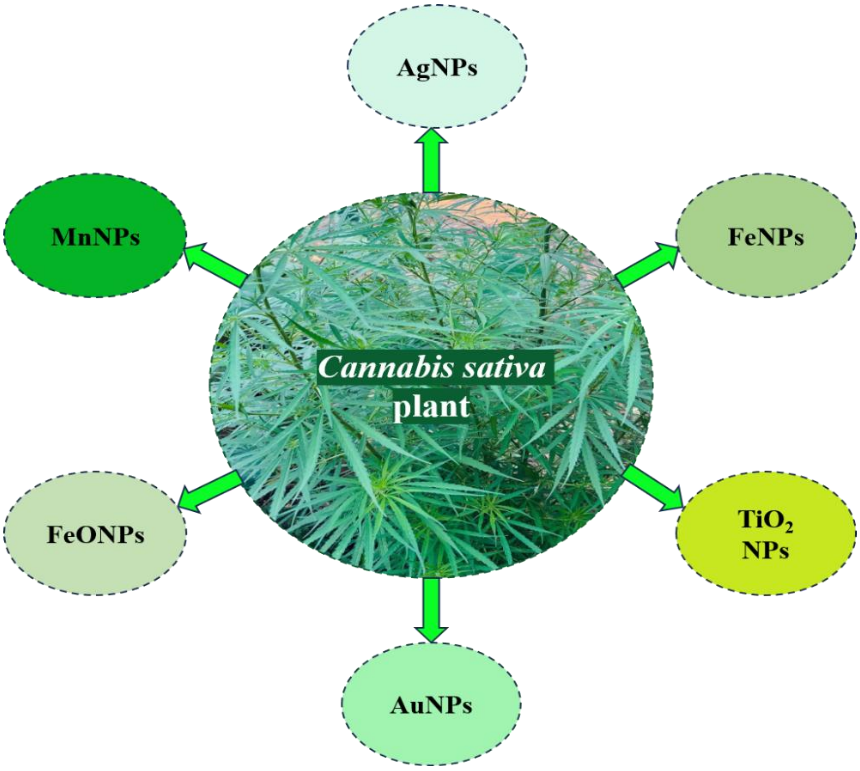

Figure 4: *Green synthesis of M/MO NPs using Cannabis sativa plant.*

5.1 Silver nanoparticles

Chouhan *et al.* (2020) employed green synthesis of silver nanoparticles using aqueous leaf extract of *Cannabis sativa* and evaluated their anti-yeast, antibacterial, and α-amylase inhibitory activities. Changes in optimization parameters affected nanoparticle synthesis, and the reaction mixtures exhibited characteristic colours and UV-visible spectra, which are particularly associated with AgNPs. According to FTIR, SEM, TEM, and UV-Visible spectroscopy, AgNPs were spherical and had an average size of 26.52 nm. The phytochemicals in *Cannabis sativa* extract, including phenols, flavonoids, and amino acids, served as capping and reducing agents. AgNPs showed the highest antibacterial activity against Escherichia coli and Micrococcus luteus, and lower activity against Bacillus subtilis, Staphylococcus aureus, and Klebsiella pneumoniae. The synthesized AgNPs also have considerable anti-yeast and α-amylase inhibitory activity [53].

Michailidu et al. (2025) described the use of *Cannabis sativa* waste extract for the synthesis of silver nanoparticles. AgNPs were detected using UV-Visible spectrophotometry, which showed a peak absorbance at 450 nm due to plasmon resonance. The functional groups in the stabilising layer of AgNPs were examined using Fourier-transform infrared spectroscopy. The concentration of the produced AgNPs dispersion was measured using atomic absorption spectrometry (AAS) and found to be 334.4 mg/L. The silver nanoparticles were primarily spherical or ellipsoidal, as observed by transmission electron microscopy (TEM). The surface layers of the AgNPs were found to contain carbon, oxygen, and silver, with relative compositions of 31.0%, 39.6%, and 29.4%, respectively, as determined by X-ray photoelectron spectroscopy. The produced nanoparticles exhibit strong antibacterial activity against strains of Pseudomonas aeruginosa known to be resistant to antibiotics in nosocomial infections [54].

Suman et al. (2022) employed the biosynthesis of silver nanoparticles using the ethanolic root extract of the Cannabis sativa plant. It shows antibacterial, antioxidant, and hemolytic potential of AgNPs. The synthesis of AgNPs was confirmed by UV-visible spectroscopy, which showed a reddish-brown colour with an absorption peak at 408 nm. FT-IR verified the presence of phytochemicals that help stabilize and reduce silver nanoparticles. AgNPs showed zones of inhibition of 39 nm, 38 nm, and 36 nm, respectively, against Methicillin-resistant Staphylococcus aureus (MRSA), E. Coli, and P. aeruginosa. AgNPs exhibited antioxidant activity, with a free-radical-scavenging efficiency of 58.01 ± 0.09% at 100 mg/mL. AgNPs demonstrated reduced cytotoxicity, with HEK 293 cells exhibiting a cell survival of 52.38 ± 0.6% at a very high dose of 500 mg/ml. Additionally, at a high dose of 200 mg/ml, RBCs showed very minimal toxicity (6.47 ± 0.04%) [55].

Mandal et al. (2021) described silver nanoparticles from *Cannabis sativa* (hemp plant) as stabilizing agents and studied their antibacterial activity. Silver nanoparticles were formed within 30 minutes of heating the mixture of hemp extract and silver nitrate without the use of any additional stabilizing agents or chemical reduction agents. Several optical spectroscopy and electron microscopy methods were used to characterize the resulting AgNPs. UV-Visible measurements based on AgNPs' surface plasmon resonance (SPR) at about 417 nm were used to determine the onset of AgNP production. ESEM images and EDS data were used to determine the precise size, shape, and elemental composition of AgNPs. The antibacterial activity of these nanoparticles against Gram-positive Staphylococcus aureus and Gram-negative Escherichia coli was investigated using disc diffusion and Minimum Inhibitory Concentration (MIC) assays. The synthesized AgNPs demonstrated strong potential against both Gram-positive and Gram-negative bacteria. AgNPs exhibited nearly comparable antibacterial efficacy against Gram-positive S. aureus and Gram-negative E. coli [56].

5.2 Gold nanoparticles

Gold nanoparticles (AuNPs) were produced via a green synthesis using *Cannabis sativa* waste extract, with a focus on their antibacterial activity against Gram-negative bacteria, particularly Pseudomonas aeruginosa. The gold NPs were characterized using UV-visible spectroscopy, TEM, AAS, X-ray diffraction (XRD), and FT-IR spectroscopy. The presence of AuNPs was verified by UV-visible spectroscopy, which showed a peak at 530 nm due to plasmon resonance. FT-IR showed a functional group in the stabilizing layer of AuNPs. AAS was used to determine the concentration of the synthesized AuNPs dispersion, which was found to be 381.9 mg/L. TEM was used to analyze the morphology of AuNPs, which showed primarily spherical particles with sporadic rod-like or triangular morphologies. The surface layers of the gold nanoparticles synthesized with *Cannabis sativa* extract were found to include carbon, oxygen, and gold with relative compositions of 43.3%, 37.8%, and 18.9%, respectively, according to X-ray photoelectron spectroscopy. This study demonstrates that agricultural waste can serve as a source of potent antibacterial agents, thereby advancing green nanotechnology and waste valorization within the circular economy. The results present encouraging avenues for combating antibiotic resistance and developing new approaches to infection management in medical settings [54].

Researchers synthesized gold nanoparticles by bioreduction of $HAuCl_4$ solutions using an aqueous leaf extract of *Cannabis sativa*. UV-visible, TEM, FE-SEM, and FT-IR were used to evaluate AuNPs. UV-visible spectroscopy confirmed the formation of AuNPs with peak absorbance at 538 nm. According to TEM & FE-SEM images, AuNPs were found to be spherical and with an average size of 18.6 nm. The synthesized gold nanoparticle exhibited favourable antioxidant and anticancer activities against acute lymphoblastic leukemia and acute T cells, without cytotoxicity towards the normal cell line [57].

5.3 Iron and Manganese nanoparticles

Naz *et al.* (2022) synthesized Fe and Mn nanoparticles using *Cannabis sativa* leaf extract as a stabilizing and capping agent. UV-visible spectroscopy of FeNPs and MnNPs showed maximum absorbance at 300 nm and 370 nm, respectively. FT-IR has identified specific functional groups in a range of leaf-extracted compounds that stabilize Fe and Mn nanoparticles. The crystallinity index and nano-dimensions of the produced nanoparticles were measured using XRD and SEM. The photocatalytic activity of the synthesized nanoparticles was evaluated using methyl orange and Congo red dyes, indicating that they can be a good commodity for water treatment in the textile industry [58].

5.4 Titanium dioxide nanoparticles

Korkmaz *et al.* (2025) synthesized titanium dioxide nanoparticles (TiO_2-NPs) using extracts from *Cannabis sativa* L. leaves. FT-IR, SEM, XRD, and EDX were used to characterize TiO_2 NPs. The nucleic acids were spherical, with sizes ranging from 21 to 29 nm, as determined by SEM. The crystalline structure, with an average size of 37 nm, was confirmed by XRD analysis. EDX analysis confirmed the synthesis of TiO_2 with 57.5% Ti and 40.7% O. Phytochemicals involved in the formation and stabilization of TiO_2 NPs were confirmed by FT-IR analysis. The generated TiO2 NPs had antibacterial activity, inhibited the growth of breast cancer cells, and had an AchE IC50 of 2.472 mg/ml [59].

5.5 Iron oxide nanoparticles

Korkmaz *et al.* (2025) used a sustainable single-step green synthesis method to synthesize iron oxide nanoparticles using *Cannabis sativa L.* leaf extract as the reducing and stabilizing agent. The synthesized nanoparticles were then characterized using UV-vis, FT-IR, XRD, SEM, and EDX. SEM imaging showed a particle size range of 12-21 nm with noticeable agglomeration and low crystallinity, consistent with an amorphous nanostructure (18.8 nm). The green-synthesized IONPs exhibited 99% production efficiency, as determined by EDX quantification. XRD analysis verified the high purity of iron oxide NPs. Bromophenol blue dye degradation illustrates its photocatalytic potential. The NPs also showed promising anticancer effects on cancer cell lines, as well as strong antibacterial and antifungal activity against a variety of microbial species. Their use in industrial dye degradation and wastewater treatment demonstrates their adaptability for environmental remediation [60].

Conclusion

This review highlights the several bioactive compounds present in *Cannabis sativa* plant extract that act as stabilizing, capping, and reducing agents during the synthesis of metal and metal oxide nanoparticles. The synthesis of these nanoparticles from *Cannabis sativa* extract reveals the plant's adaptability and highlights its potential across various nanotechnology applications. Many research studies have shown that *Cannabis sativa* can facilitate the production of metal and metal oxide nanoparticles due to its diverse phytochemical profile. This enables the synthesis of nanoparticles with controlled shape and size, enhanced bioactivity, and minimal environmental impact. Nanoparticle synthesis has made significant progress, but many questions remain unanswered. It is not yet clear how much these mechanisms differ from those in other plant sources, or whether the unique phytochemical profile of *Cannabis sativa* affects nanoparticle synthesis and its efficiency.

Furthermore, the potential benefits of *Cannabis sativa*—such as the roles of specific terpenes, flavonoids, and cannabinoids in shaping nanoparticle properties—are still not widely understood and are underrepresented in currently accessible reviews. To address these shortcomings, it is necessary to critically synthesize recent discoveries rather than aggregate them. This will help to clarify unexplained mechanisms, highlight comparable benefits, and highlight areas where the existing literature is significantly lacking.

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