GREEN SYNTHESIS AND BIOMEDICAL APPLICATION OF TITANIUM OXIDE NANOPARTICLES

R. Venkateswari, Department of Medical Biochemistry, University of Madras, Taramani Campus, Chennai, Tamil Nadu.
Email: vengiteja06@yahoo.co.in
S. Chinnadurai, Department of microbiology, Excel College for Commerce and Science, Komarapalayam, Namakkal, Tamil Nadu.
Email: drchinnaduraiphd@gmail.com
P. Mouliraj, Department of Microbial Biotechnology, Bharathiar University, Coimbatore, Tamil Nadu.
Email: moulirajpalanisamy@gmail.com
B. Dhanasree, Department of Biochemistry, KVR Govt College for Women(A), Cluster University, Kurnool, Andhra Pradesh.
Email: drdhanasree867@gmail.com
***B. Eswara Priya**, Department of Biotechnology, St. Michael College of Engineering and Technology, Kalayarkoil, Sivaganga District, Tamil Nadu.
Email: eswarapriya@gmail.com
M. I. Niyas Ahamed, Department of Biochemistry, Sacred Heart College (Autonomous), Tirupattur, Tamil Nadu.
Email: driniyasahamed@shctpt.edu

***Corresponding author:** eswarapriya@gmail.com

Abstract

The study of nanotechnology is rapidly developing and has numerous potentials uses in many different disciplines. Nanoparticles (NPs) can be made by a number of different chemical and physical methods. Recently, green synthesis methods have been refined to be more user-friendly, long-lasting, and inexpensive. There has been a lot of focus on developing eco-friendly methods for synthesizing titanium dioxide nanoparticles (TiO2 NPs) in the most recent three months. Biologically active compounds found in plants and microbes, for example, aid in the bio-reduction and capping procedures. In this overview, we will talk about how to make TiO2 NPs biologically, as well as the various synthesis techniques and mechanistic viewpoints. TiO2 NPs can be synthesized using a variety of naturally occurring reducing agents like proteins, enzymes, phytochemicals, and others. Photocatalysis and antimicrobial applications were also examined at length, as were the underlying physical mechanisms. Finally, we discuss the state of the art and future directions for research into physiologically mediated platforms based on TiO2 nanostructures with potential industrial applications.

Keywords: Dyes photodegradation; green synthesis; photocatalysis; antimicrobial activity.

Introduction

Atoms and molecules at the super molecule scale are the focus of nanotechnology. The physicochemical properties of nanomaterials undergo a radical transformation at this scale because of the increasing surface area to volume. Mechanical, electronic, imaging-specific targeting, and molecular diagnosis are just a few of the many businesses that can benefit from nanotechnology because of its size, structure, physicochemical, and biological features. Medical, cosmetic, pharmacological, and even industrial applications are expanding daily to include the usage of nanoparticles (NPs). There are two primary categories of NPs: organic and inorganic. Organic nanoparticles (NPs) include things like micelles, liposomes, chitosan, ferritin, dendrimers, and a host of others. There are three types of inorganic NPs: metal, semiconductor, and magnetic. TiO2 nanoparticles in particular have found widespread application thanks to their fascinating thermal, optical, electrical, and magnetic properties [1-3].

Only titanium dioxide, or titania, is found in nature. TiO2 is a colourless, odourless powder that is hydrophobic under typical conditions. It's an opacifier that's also incredibly stable. TiO2 NPs are widely used as a semiconductor material due to their advantageous qualities, such as low price, strong oxidizing strength, high chemical stability, high refractive index, and the presence of oxygen-containing functional groups in their lattice. Over 10,000 tonnes of TiO2 were produced worldwide in 2011. Microbes including bacteria, viruses, and cancer cells can all be biodegraded with their help. They can be found in products as diverse as toothpastes, papers, food colourants, paints, plastics, and inks, and even UV-resistant oxides. As the most effective solar collectors, TiO2 NPs may capture up to 4% of the sun's rays. Because of this, they are widely used as photocatalysts for the removal of harmful chemicals from water and the generation of hydrogen. TiO2 NPs have unique surface characteristics and topologies. TiO2 is an inert, solid, white metal oxide. TiO2 NPs contain three different polymorphs: anatase, rutile, and brookite. Anatase and rutile share the same geometric symmetry (tetragonal) and physical properties (gloss, stiffness, and density). TiO2 is a metal oxide that is insoluble, has great thermal stability, and is not considered hazardous. TiO2 has 22 atoms from the IV B group element titanium and 8 atoms from the VI A group element oxygen. It also possesses favourable properties, such as hydrophobicity and a large bandgap. There are a wide variety of industrial applications for dye-sensitized solar cells, including those in self-cleaning, photocatalysis, charge-spreading devices, chemical sensors, microelectronics, electrochemistry, antimicrobial products, and textiles. Hydrocarbons are oxidised catalytically to degrade hazardous chemicals. The outstanding capabilities of TiO2 NPs in photocatalytic, antimicrobial, and antibacterial applications have attracted the most attention from the scientific community. Photocatalytic wastewater treatment using nano-sized TiO2 is an effective approach for breaking down and removing tough organic and inorganic pollutants [4-6].

TiO2 NPs are typically produced using chemical vapour deposition (CVD), electrochemical deposition, the sol-gel process, hydrothermal crystallization, or chemical precipitation. Manufacturing and possible medical uses are constrained since all of the aforementioned procedures are expensive and time-consuming, and require the use of dangerously high temperatures, pressures, and chemicals. The manufacturing of NPs hence relies heavily on the green synthesis method. In order to synthesize NPs on a wide scale, green synthesis has emerged as a viable option. The reducing agents in plant extracts can be used to create a wide range of metallic nanoparticles. Leaves, roots, fruits, seeds, and beans are all viable plant extract options for synthesis of NPs. Green TiO2 nanoparticles with many functions are generated from a variety of extracts. Nanoparticles derived from plants may have use in the pharmaceutical, nutritional, catalytic, and personal care product sectors. Previous research has shown that the use of green sources as a stabilizer and reducing agent in the manufacturing of NPs with structured shape and size is universal.

This article presents a comprehensive analysis of the green synthesis of TiO2 NPs using biological sources, such as plants and microorganisms. First, many different biological extracts' green synthesis has been extensively discussed. Secondly, the morphological and structural properties of NPs are investigated in detail by conducting a complete characterization study on green synthesized TiO2 NPs. Finally, the advantages of green synthesis are reviewed, with a focus on its use in photocatalysis and antimicrobial applications. The conclusion and outlook have been covered at last. We also collected data on paper publication from PubMed (Figure 1), which demonstrates the growing interest in green synthesis of TiO2 NPs among academics.

IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876

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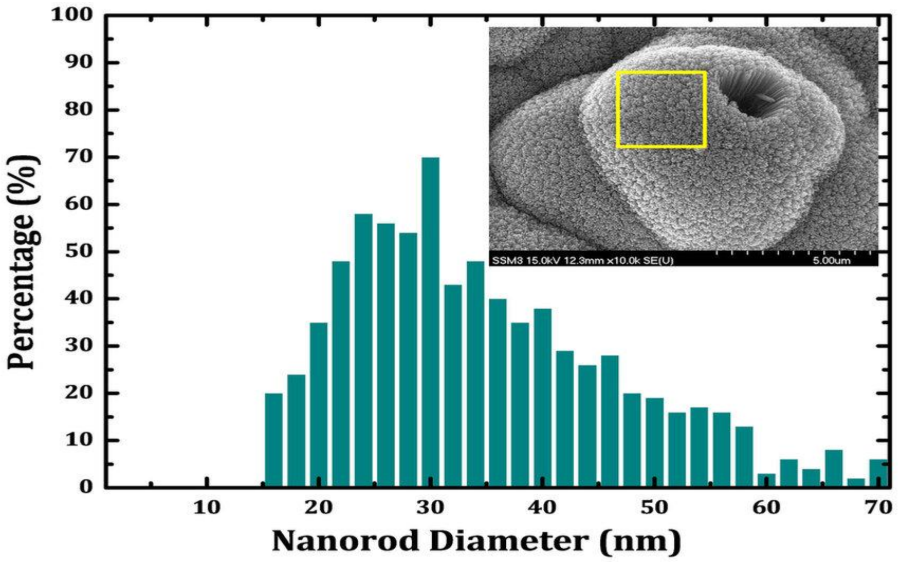

Figure 1. Histogram shows the proportion of papers published on green techniques for TiO_2 NPs.

Synthesis of TiO_2 NPs by Different Methods

The two primary methodologies for the synthesis of nanomaterials are top-down and bottom-up approaches as shown in Figure 2.

a. Top-down: size reduction from bulk materials
b. Bottom-up: material synthesis from the atomic level.

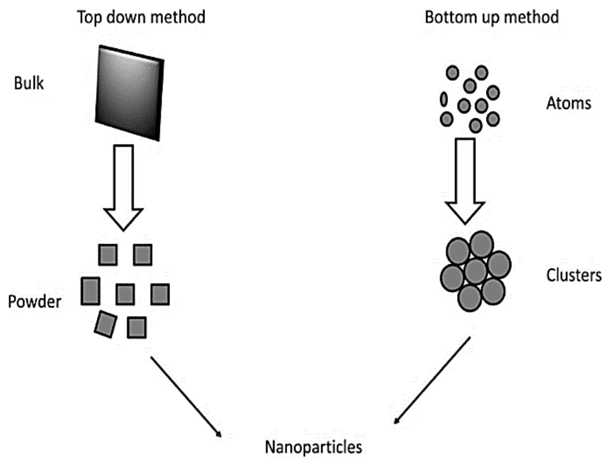

Figure 2. Nanoparticle synthesis methods.

Top-Down Approach

A top-down approach is used to transform a bulk substance into a nano product. Physical and chemical methods were used for size reduction. Some of the techniques used in top-down manufacturing include sputtering, pulse wire discharge, physical milling/ball milling, etching, evaporation-condensation reaction, pulse laser ablation, and lithography. approach. But there are drawbacks to the top-down method, the most prominent of which is that flaws are introduced into the finished product at the very top. The surface and other physical qualities of the product may be altered as a result [7-10].

Bottom-Up Approach

In the bottom-up method, the materials were constructed from the ground up, one layer at a time. This method is used to synthesize the vast majority of nanostructures that have the potential to achieve homogeneity in terms of size and morphology. Numerous methods, including chemical vapour deposition, solvothermal synthesis, polymer condensation, the sol-gel method, aerosol approach, electrochemistry, pyrolysis, thermal decomposition, frameworks, plasma, and spinning, are available for chemical synthesis. Additionally, accessible Green synthesis, in particular bottom-up synthesis process control to reduce particle formation. Since the bottom-up approach is so important in developing nanostructures and nanomaterials, scientists may confidently say that it is at the heart of these fields. Nearly every one of these strategies is used to create nanomaterials, but when all factors are considered, the bottom-up strategy is the best because it is advantageous and leads to atomic-level perfection. Because the use of non-toxic, cost-effective, and ecologically friendly matter is considered essential to the green synthesis pathways' viability, the bottom-up approach is also applied. Green synthesis uses natural, plant-based ingredients. In green chemistry, a plant extract is combined with a simple precursor salt to act as a capping and reducing agent. In this way, the phytochemicals in the plant extract can serve to both weaken and stabilise the nanomaterials. Many efforts have been made in green synthesis to produce a wide range of metal NPs since the beginning of the industrial revolution, including Cu, Pt, Pb, Ag, Au, Zn, and so on. In this overview, we will talk about the phyto-synthesis of TiO2 NPs using different plant extracts. Recent literature reviews have been published to summarise these studies.

Green Synthesis

It is widely agreed that green synthesis plays an important role in modern engineering and research. Because of their unique characteristics, biosynthesized nanomaterials are employed in the purification of water and remediation of polluted areas.

Extremely small size, high surface area to volume ratio, surface modifiability, and size-dependent features are only a few of the unique characteristics that make nanoparticles of interest. The medical and pharmaceutical fields also demonstrated interest in these nanoparticles. These days, the biological system is the subject of intensive study. Bacteria, fungus, yeast, and plants were all utilized in the biological synthesis of nanomaterials. These methods of synthesis have attracted a lot of attention since they can save a lot of money. Antibacterial, antifungal, high catalytic, and photochemical activities are only some of the many uses for biologically synthesized nanoparticles in the field of pollutant remediation. The biomedical uses of gold and silver NPs are extensive, making them two of the most often manufactured NPs. Nanoparticles made of Au and Ag showed strong photocatalytic activity. The most promising areas of study include nanotechnology and biotechnology, which deal with microorganisms such as bacteria, fungi, yeasts, algae, and plants. One possible process for making nanoparticles is found in the usage of microorganisms.

The inorganic nanoparticles were successfully manufactured with the aid of the aforementioned biological creatures. The resistance of the bacterial cell to reactive ions is influenced by its solubility. Microbiological synthesis of NPs is a time-consuming process, and there are few options for producing NPs with the desired size and form. Plants' natural nanomaterial routing processes are straightforward and economical. High pressure, hazardous chemicals, or extreme heat are not required in these processes. This means that these processes have a low impact on the planet. The use of plants to create NPs ensured their stability, as well as their correct shape and size. Green synthesis has the added bonus of having a low potential for contamination. Phytochemicals abound in plant foods and aid in nanomanufacturing and NP synthesis. The creation of nanomaterials and nanoparticles makes extensive use of phytochemicals, which plants give in abundance. The phytochemicals contribute significantly to the photocatalytic activity applications where they are used. They aid organic dyes' photocatalytic activity by facilitating oxidation and reduction processes [11-15].

Plant-Based synthesis of Titanium Dioxide NPs

As plant extracts include a rich source of metabolites, they have been the focus of green synthesis research. The concept for making nanoparticles from plant extract is depicted in Figure 3. In 2016, Kashale et al. used $TiCl_4$ (titanium tetrachloride) as a precursor to make TiO_2 NPs from an extract of Cicer arietinum L. According to their findings, preparing biosynthesized TiO2 (Bio-TiO2) NPs is a valuable approach to the fast synthesis of NPs. Raman spectroscopy, X-ray diffraction (XRD), thermogravimetric analysis (TGA), transmission electron microscopy (TEM), and the BET surface area measuring system were all used to learn more about the crystalline structure and other features of Bio-TiO2 NPs. In 2015, Rao et al. used Aloe Vera leaf extract to produce TiO2 NPs. In addition to its rich vitamin and mineral content, the Aloe Vera plant is one of the oldest known herbal medicines. It's not just for nails and toenails, either. The SEM pictures showed that the synthesized. NPs had an irregular particle structure and were between 60 and 80 nm in size. Crystalline nature was confirmed by TEM in terms of both shape and structure arrangement. Using an aqueous extract of Annona squamosa fruit peel, rutile TiO2 NPs were biosynthesized. Rutile TiO2 NPs can be cheaply and easily produced by a green synthesis method that uses agricultural waste. TEM imaging reveals that rutile TiO2 NPs are round and approximately 23 2 nm in size. SEM, UV, XRD, and EDS analyses are also a part of this investigation. The SEM's closed-view of the nanoparticles shows that the powder particles are slightly agglomerated. The UV-Vis spectrophotometer found that the addition of TiO2 NPs induced a sharp increase in surface plasmon resonance at 284 nm, indicating a speedy reaction. Similar findings to those found in the JCPDS data (File No. 99-101-0954) were found in the XRD data. TiO2 NPs were synthesized by Madadi and Lotfabad in 2016 using an aqueous extract of Acanthophyllum laxiusculum. This method of synthesizing nanomaterials does not negatively impact the environment.

The highest concentrations of triterpene glycosides (saponins) are found in plants belonging to the genus Acanthophyllum. Sol-gel synthesis is used to create TiO2 NPs. The sol-gel technique is frequently used to create titanium dioxide NPs. Hydrolysis of the Ti precursor in acidic or basic mediums is the first step in the sol-gel process, followed by polycondensation of the hydrolyzed products. Surfactants, such as the NSACs used in this study, can inhibit polycondensation and hence preserve solvent efficiency. As a result, a supportive environment is created in which the TiO2 NPs can persist. SEM, TEM, UV, EDAX, XRD, and other techniques were utilized to examine the nanoparticles of TiO2. Particle sizes of 20-25 nm were seen by scanning electron microscopy (SEM) and corroborated by transmission electron microscopy (TEM). An absorption band at 350 nm, corresponding to an optical band gap of 3.5 eV, was seen in the UV spectrum. O—Ti—O bonding in anatase morphology was eventually validated

ISSN PRINT 2319 1775 Online 2320 7876
  UGC CARE Listed (Group -I) Journal Volume 11, Iss 12, 2022

by the FTIR, as indicated by peaks at 457, 470 cm1. Similarities between the XRD data and JCPDS (File No. 21-1272) [35] were discovered. Santhosh Kumar et al. also used Psidium guajava extract in their TiO2 NPs production. In 2014. The disc diffusion method was used to evaluate synthesised TiO2 NPs against human pathogenic microorganisms. X-ray diffraction analysis showed that the crystalline planes of the TiO2 NPs were for the anatase form and for the rutile form. The prominent peaks were found at 2 = 27.57 and 41.37, respectively. Absorption peaks for C-H alkynes (3410 cm1), 1578 cm1, 1451 cm1, and C-O (1123 cm1) may be seen in FTIR spectra of synthesized TiO2 NPs. Morphological analysis with FESEM showed that the synthesized TiO2 NPs were spherical and aggregated into particles with an average size of 32.58 nm. The presence of organic molecules on the surface of metal nanoparticles is proof that they have been adsorbed from the extracellular environment.

In EDX analysis, the following elements were found to be present: carbon, oxygen, magnesium, and chlorine. TiO2 NPs were initially produced in 2012 by Hudlikar et al. using an aqueous extract of Jatropha curcas L. The samples of TiO2 NPs were characterized with XRD, SAED, TEM, EDAX, and FTIR spectroscopy. TiO2 NPs were measured to have an average size between 25 and 100 nm. The XRD data agreed with the JCPDS (File no. 84-1285), and the TEM study confirmed that TiO2 was really nanocrystalline. The XRD-observed concentric Scherrer planes in TiO2 NPs were corroborated by SAED. The capping ingredient may be a peptide, as suggested by the FTIR analysis. The amide II and III bonding exhibits C-H stretch, (N-H) stretch, and carbonyl (-C-O-C-) or (-C-O-) stretch vibrations before being treated with 1% sodium dodecyl sulphate [53]. Hydrothermal synthesis of TiO2 NPs was used by Hunagund et al. (2016), who relied on a novel biogenic source (extract from Piper betel leaves) and a chromogenic source (nitric acid) to serve as capping and reducing agents, respectively. The optical, structural, morphological, and compositional properties of the synthesized TiO2 NPs were investigated using UV-vis spectrophotometry, XRD, FTIR, TEM, and energy dispersive X-ray spectroscopy (EDS).

The NPs were found to be spherical with an average size of about 8-75 nm. XRD patterns unambiguously demonstrated the formation of the rutile phase of TiO2, which has a tetragonal crystal structure. According to Hunagund et al., the capping agent stabilizing the nanoparticles can be inferred from the presence of specific sharp Bragg's peaks in the XRD patterns. The presence of capping agents may account for the strong

Bragg's reflection observed in the crystalline phase. The hydrothermal production of TiO2 NPs using M. citrifolia leaves extract was studied by Sundrarajan et al. (2017). Scientists found that TiO2 NPs were more effective than other antimicrobials against pathogenic infections because they were more effective against Gram-positive bacteria. TiO2 NPs were analysed using XRD, FTIR, UV-Vis diffuse reflectance (UV-Vis DRS), UV-Vis spectroscopy, Raman spectroscopy, and SEM with EDX. According to the XRD analysis, the average crystalline size of the NPs is 10 nm, and the peaks at 27.3 correspond to the (110) lattice plane of the tetragonal rutile TiO2 phase. SEM imaging with EDAX spectra verified the synthesis of pure TiO2 nanopowder, and clearly showed the NPs' size to be between 15 and 19 nm. It has been hypothesized that the biological importance of the reduced band gap energy of green-produced TiO2 nanoparticles compared to bulk pure TiO2 nanoparticles is a result of the quantum-confinement effect. TiO2 NPs were developed in 2013 by using extract from Solanum trilobatum, which inhibits the growth of Pediculus humanus capitis, Hyalomma anatolicum, and Anopheles subpictus. The TiO2 NPs made environmentally were analyzed using XRD, FTIR, SEM, EDAX, and AFM.

It was Sankar and coworkers. Under pH and temperature-dependent conditions in 2014, TiO2 NPs were produced from aqueous leaf extract of Azadirachta indica, and their characterization was confirmed by UV-Vis spectroscopy and Fourier transform infrared spectroscopy. Dynamic light scattering (DLS) and scanning electron microscopy (SEM) analyses revealed the spherical, interconnected TiO2 NPs with a mean particle size of 124 nm and a zeta potential of 24 mV. The use of Catharanthus roseus aqueous extract in the synthesis of TiO2 NPs for use against Hippobosca maculata and Bovicola ovis was originally described in 2011 by Velayutham et al. Clustered, irregularly shaped NPs of synthesised TiO2 ranging in size from 25 to 110 nm were seen by scanning electron microscopy (SEM). Soaked Bengal gramme beans (Cicer arietinum L.) from the collected kitchen trash were employed to synthesise TiO2 NPs in this TiCl4 used as precursor. Kashale et al. (2016) conduct research in this area. X-ray diffraction, Raman spectroscopy, transmission electron microscopy (TEM), thermogravimetric analysis (TGA), and the BET surface area measurement system were all used to examine Bio-TiO2 in depth [48]. Green synthesis of TiO2 NPs using extract from Cinnamomum Tamala leaves (as the reductant) was reported in 2013 by Gautam Kumar Naik et al. X-ray diffraction, UV-visible diffuse reflectance, Fourier transform infrared (FT-IR), and transmission electron microscopy were used to investigate the nanocomposites' structural and morphological features. Because of its reducing agent properties and high citric acid content, Orange Peel extract was used as a byproduct in the preparation of TiO2 NPs by Kandregula et al. peel. X-ray diffraction, particle size analysis, Fourier transform infrared spectroscopy, and thermo gravimetric and differential thermal analysis all showed the same thing. In 2016, Chatterjee et al. created TiO2 NPs using extract from the plant Vigna radiata. The reductant for the production of these NPs can be obtained from Vigna radiata. The results demonstrated the viability of biological synthesis of oval-shaped TiO2 NPs, which were found to be efficient against Gram-positive and Gram-negative bacteria. The FTIR spectra showed peaks at 1631.78 cm1 and 1641.42 cm1 indicative of O-Ti-O bonding and at 3000 cm1 due to -OH stretching [16-20].

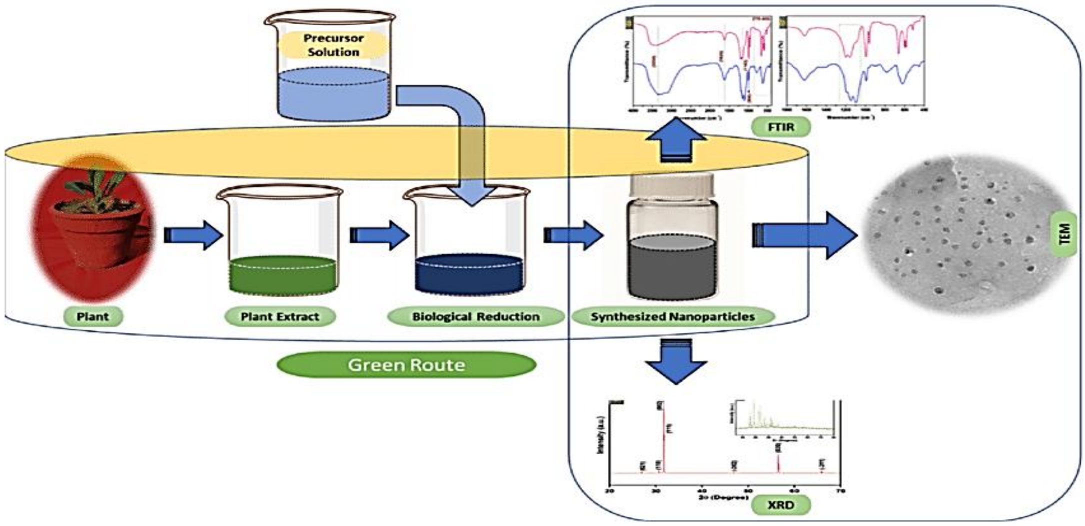

Figure 3. Schematic diagram of the preparation process of nanoparticles via plant extract.

Preparation of Plant Extract

When the fresh leaves have been thoroughly rinsed and dried, they are sliced very thinly and placed to a pot of boiling distilled water, where they will remain until the water is filtered and the plant extract is ready to use. Burning leaves accelerates the breakdown of the phytochemicals they contain. The plant extract is used for the phytochemicals it contains during the reduction and stabilisation processes. These include phenolic acids, alkaloids, proteins (including enzymes), and carbohydrates.

Precursors for titanium dioxide nanoparticles (TiO2 NPs) include titanium tetra isopropoxide (TTIP), titanium chloride (TiCl4), metatatitanic acid (TiO(OH)2), and titanium oxysulphate (TiOSO4). The most common solvents for dissolving TiO2 particles in bulk are ethanol and distilled water. Add the extracted ingredient to the mixture very slowly, drop by drop. To keep the solution at the right consistency, it was heated and stirred continuously. Changes in solution colour are seen during NP formation.

Filtration, washing in distilled water, drying, and calcining are the next steps after isolating NPs. After synthesis, the NPs are calcined between 400 and 800 degrees Celsius to remove any remaining organic groups that aren't necessary. Phytoconstituents in plants are assumed to accomplish at least one of the following functions according to the standard green chemistry notion: metal salt reduction; hydrolysis of the Ti4+ precursor; solubilization; polymerization of numerous intermediates.

Titanium dioxide nanoparticles synthesized using microorganisms

Biosynthesis of NPs by microorganisms has gained appeal in recent years as an environmentally preferable alternative to conventional synthesis. These are low-cost reagents that require only light heat and pressure. Producing NPs with microbes is an innovative approach for several types of metal and metal oxide. Researchers were interested in NPs synthesised with microbes because of their optical, chemical, photoelectrochemical, and electrical properties. Synthesis of metal nanoparticles using microbial cell production of nanoscale materials shows promise. Synthesis by microorganisms can form and flourish in high-metal settings. Metal ions can be converted into metal by a number of microbes. Figure 4 is a simplified flowchart depicting the microbial production of TiO2 NPs. TiO2 NPs have been characterised in a wide variety of shapes and sizes in recent years. Green TiO2 NP synthesis (green review) was developed using bacterial extracts. Plant extracts and bacterial metabolites both contribute significantly to TiO2's bioreduction and stability. The production of NPs in the size range of 28-54 nm using an extract of Aeromonas hydrophila resulted in a significant reduction in the growth of both Staphylococcus aureus (33 mm inhibition zone) and Staphylococcus pyogenes (31 mm inhibition zone). The employment of fungi in the synthesis of metallic NPs has garnered considerable interest because of the purported benefits of this method over other bacterial manufacturing procedures. Despite the fact that TiO2 NPs were produced using the Lactobacillus bacterium during the combined action of oxidoreductase enzymes and glucose at moderate pH, commercialization prospects are low due to the potential for pathogenicity and the difficulty of bacterial production. Mukherjee et al. found that the NPs they developed were quite effective advantages, such as a large

ISSN PRINT 2319 1775 Online 2320 7876

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surface area, low cost, and the potential to scale up production. Fungi are capable of reducing salt to its atomic or ionic state via enzymatic processes or metabolites. In this research, it was shown that Aspergillus flavus extracts may be used to convert Ti ions precursors into TiO2 NPs. These NPs were found to be highly effective in killing E. coli. Figure 5 is a simplified flowchart depicting the biological route to TiO2 NPs, complete with information on their characterisation and potential uses. TiO2 NPs were also synthesised using Saccharomyces cerevisiae extract, with a size of 12.6 nm as determined by scanning electron microscopy. FTIR analysis verified the presence of quinines and lipid reductases in the organisms. TiO2 NP synthesis also depends on the surface characteristics and ionic strength of the growth media. Fungi-made TiO2 NPs, like bacterial ones, have their own set of safety parameters. In contrast, nonpathogenic strains will render the threat moot and may be monetized. Different microorganisms are shown in Table 1 to produce TiO2 NPs.

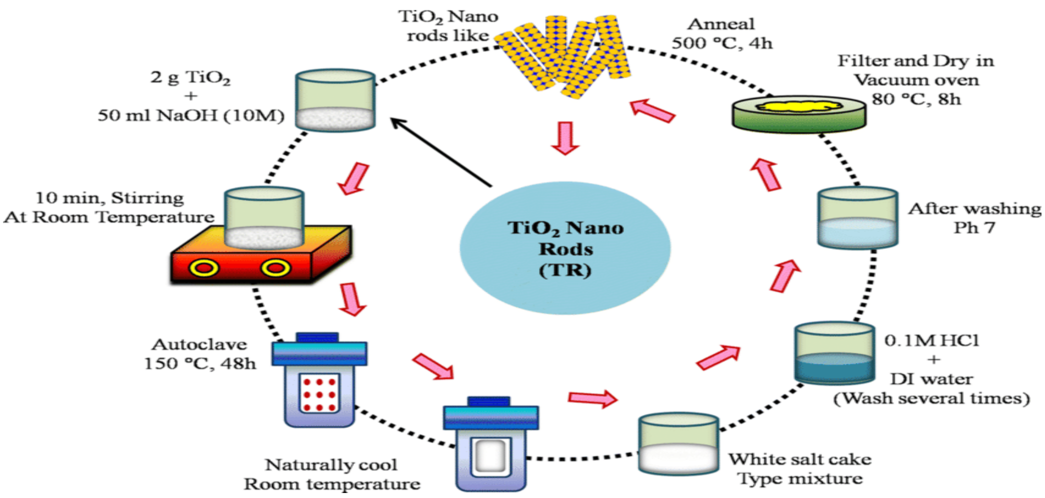

Figure 4. Schematic diagram of the synthesis process of TiO_2 NPs using microorganisms.

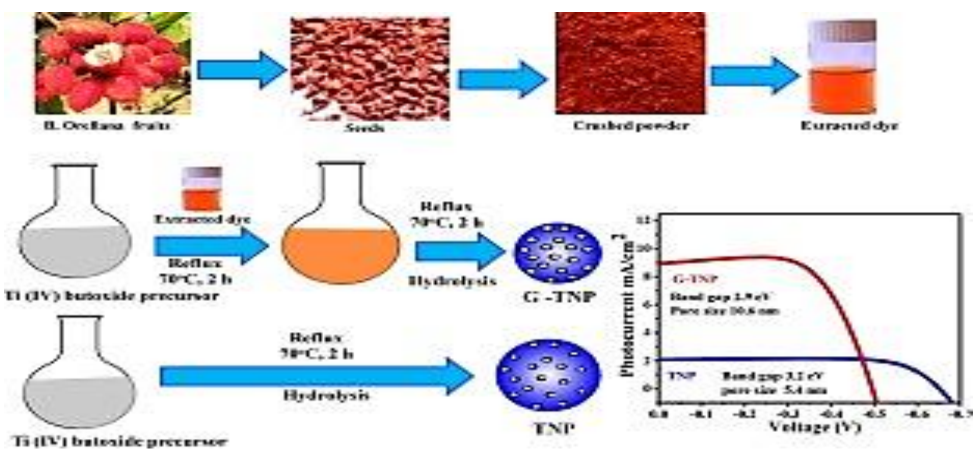

Figure 5. Green synthesis of TiO_2 NPs.

Table 1. TiO_2 NPs produced by several bacterial communities.

S/N	Bacterial Species	Shape	Size (nm)	Ref.
1.	*Aeromonas hydrophila*		40–50	[80]
2.	*Bacillus amyloliquefaciens*	Spherical	22.1–97.2	[78]
3.	*Bacillus subtilis*		30–40	[85]
4.	*Bacillus subtilis*		66–77	[86]
5.	*Bacillus subtilis*		10–30	[75]
6.	*Lactobacillus*		8–35	[82]
7.	*Lactobacillus*	Spherical	40–60	[87]
8.	*Planomicrobium*		100	[88]
9.	*Aspergillus niger*		73.58	[89]
10.	*Fusarium oxysporum*		10	[90]
11	*Aspergillus flavus*		62–74	[79]
12.	*Bacillus mycoides*	Polydisperse	40–60	[74]
13.	*Fusarium oxysporum*	Quasi–spherical	9.8	[91]
14.	*Aspergillus tubingensis*	-	<100	[92]

Applications of Biogenic TiO_2 NPs

The mechanical, electrical, and physical sciences, as well as health and engineering technologies, can all benefit from the Green method of NP creation. The microbial species' synthesis of NPs demonstrated fewer relevant applications than the biogenic TiO2 NPs. However, when compared to physical and chemical methods of production, green synthesis of NPs shows considerable promise. Common applications for photo-catalytic nanomaterials include purifying water and clearing the air of contaminants. The electrical, energy generation device, battery, and sensor industries can all benefit from the use of environmentally friendly TiO2 NPs . Other biomedical applications of biosynthesized TiO2 NPs include photodynamic cancer therapy, antileishmanial drugs, and antibacterial medications. Following are discussions of TiO2's photocatalytic activity, antibacterial efficacy, and the most common biomedical applications that make use of mechanistic techniques.

Nanoparticle TiO2 Photocatalysis

The electrons fill the valence band's full energy level, while the conduction band's empty energy level keeps it separate from the valence band. An electron from the valence band enters a vacant hole in the conduction band. TiO2 NPs are photocatalytic because electrons from the valence band are moved to the conduction band. Since TiO2 is a semiconductor, it generates electron-hole pairs when exposed to light of a high enough energy. When UV light was absorbed by the TiO2 NPs, electrons from the valence band migrated into the conduction band, filling the holes. Reactive oxygen species (ROS), hydroxyl radicals, and superoxide ions are produced when electrons and holes from the conduction band react with water and oxygen in the environment.

Photocatalytic oxidation of nanoparticles results in the generation of free radicals such as hydroxyl and superoxide, as well as hydrogen peroxide and singlet oxygen. All of these radicals are very corrosive and can quickly demolish organic molecules upon contact. The toxic and destructive compounds found in modern home and industrial wastes include: harmful dyes and nitroarene compounds that release toxic chemicals into the air and contaminate water sources. To explain their pervasiveness and danger to aquatic life, harmful dyes and other noxious compounds have weak solubility and high stability. Newly synthesized metallic NPs with a tailored structure and potent catalytic potential. These metallic NPs are excellent heterogeneous catalysts due to their large surface area. One more perk of nanostructured catalysts is that they can be recycled together with the reaction mixture after they have served their purpose. Crucial features of the NPs include their toxicity and their ability to aggregate. TiO2 NPs have been widely used in catalysis due to their excellent stability, low toxicity, optical characteristics, and photocatalytic potential. Green-mediated TiO2 NPs have been proposed for use in photo-catalytic reduction of a variety of dyes and chemicals.

The data was generated by using 0.001 mol of TTIP precursor and achieved remarkable success with significantly reduced particle sizes of wavelength of 64.18 nm, which is indicative of high-quality photocatalytic performance. Maximum photocatalytic activity was demonstrated by the incubation composite, which also degraded the rhodamine B dye. When comparing the photocatalytic potential of green mediated NPs with chemically generated TiO2 NPs, the former performed better. Phytochemicals in plants, the type of dye used, and the temperature all play a role in a plant's reducing potential. Doping TiO2 NPs with other metallic NPs increased their catalytic capability. The photocatalytic efficiency of TiO2 NPs synthesized with various plant extracts is presented in Table 2.

Antimicrobial Potency of TiO_2 NPs

TiO2 is also used in antimicrobial applications. TiO2 powder catalysts subjected to ultraviolet light (1800 E m2 s1) killed 99 percent of E. coli bacteria in 0.27 hours, according to research published in 1988 by Matsunaga et al. A photo-sterilization system, as depicted in Figure 6, is one such method. Numerous studies have been done to determine which bacteria are most affected by TiO2 NPs catalysts. E. coli K-12 cells were shown to be killed by a lipid peroxidation reaction triggered by the formation of reactive oxygen species (ROS) on the surfaces of TiO2. Bacteria cells such as Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Enterococcus hirae, and Bacteroides fragilis have been killed by the effects of TiO2 nanoparticles when exposed to UV light.

Table 2. Photocatalytic effect of Titanium dioxide nanoparticles using different plant extracts.

S/N	Dye	Concentration	Catalyst Dosage	Exposure Time	Percentage Removal	Ref.
1.	**methylene blue (MB)**	**6, 10, 20, 40**	**0.1–0.4 g**	**6 mg. L^{-1} of**	**13.3%**	[113]
2.	alizarin red, crystal violet, and methyl orange	10 mg/L	50 mL	6 h	86.79%, 76.32%, 77.59% and 69.06%	[115]
3.	methyl orange	-	1 g/dm^3	150 min	94%	[24]
4.	RO–4 dye	-	15 mg, 20 mg, 25 mg and 30 mg	180 min at 3.5 pH	91.19%	[116]
5.	methyl red	10 ppm and 20 ppm	1 g/L	60 min	89% and 83%	[117]
6.	**methyl red**	50 mL	10 mg	120 min	-	[56]
7.	**Methyl Blue**	200 mL	10 mg	75 min	-	[118]
8.	**indigo blue dye**	**1 ppm at pH 6.0**	-	**150 min**	**75%**	[119]

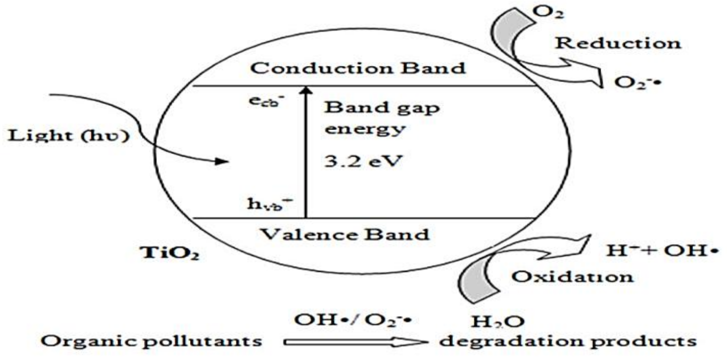

Figure 6. TiO_2 NPs driven photocatalytic process in the presence of light.

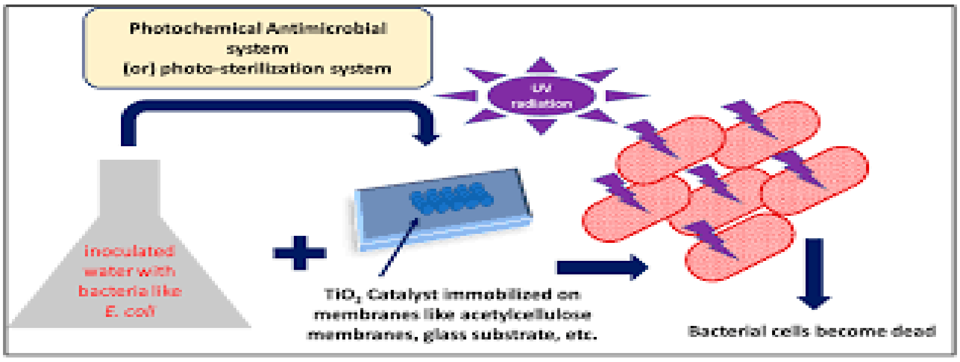

Figure 7. Simple experimental scheme for photochemical antimicrobial mechanism of TiO_2 catalyst.

Several strains of bacteria have been shown to be susceptible to biosynthesized TiO2 NPs, which were mediated and used in the literature. Biosynthesized TiO2 NPs have a high oxidising potential, are safe for the environment, and have medical applications. Biosynthesized TiO2 NPs have been used to combat many different types of microbes, including antibiotic-resistant strains of bacteria, fungi, algae, viruses, and microbial toxins. The photochemical antibacterial mechanism of the TiO2 catalyst is depicted in Figure 7 as a straightforward experimental approach. Figure 8 shows a potential mechanism by which TiO2 NPs affect microorganisms. TiO2 NPs react with bacteria and other microorganisms to produce ROS. The bacteria were killed by reactive oxygen species (ROS) that disrupted the integrity of their cell walls, inhibited the ability of respiratory cytosolic enzymes to alter the structures of macromolecules, and had other

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profound effects on cellular structure and gene expression. Inhibition of cellular communication and phosphate uptake has also been observed. Bio-synthesized NPs exhibited higher antibacterial activity than both environmentally friendly and chemically manufactured TiO2 NPs. Plant-derived capping agents have been lauded for their potent antibacterial effects. Structure, membrane biology, and bacterial species all play roles in determining whether or not NPs will be effective against a given pathogen. Although Gram-positive bacteria are less reactive than Gram-negative bacteria due to their structural complexity, green TiO2 NPs are used to slow both types of bacteria.

UV and fluorescent light irradiation of bio-mediated TiO2 NPs enhances their antibacterial activity. TiO2 NPs made using environmentally friendly methods showed increased antileishmanial activity, decreased cell viability, and slowed the growth of Leishmanial cells. DNA strand breaks, and cell division. When compared to conventional antibiotic discs, TiO2 NPs performed better [21-25].

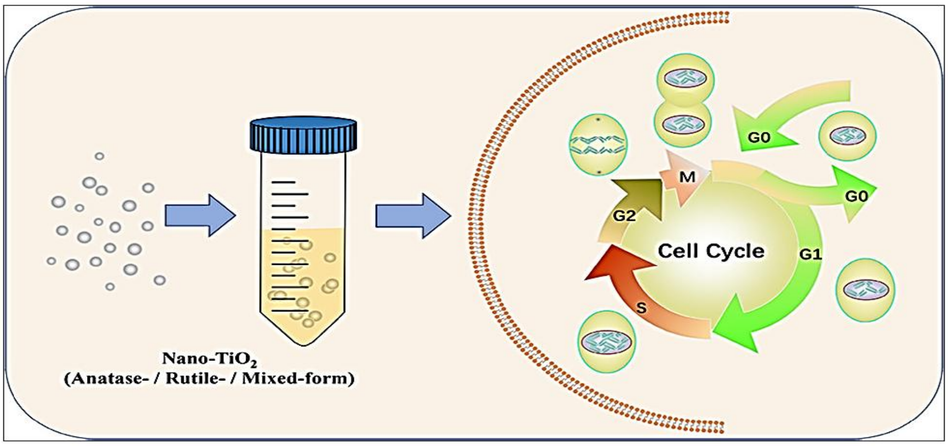

Figure 8. The impact of TiO_2 NPs on microbes is depicted as a proposed pathway.

Future Challenges

Strain separation and growth issues make synthetic procedures incorporating fungi, bacteria, and other creatures complicated. Maintaining the culture media and the necessary physical and chemical conditions makes these procedures challenging as well. Plants are chosen primarily for their ease of extraction and their abundance. By altering the experimental settings, it may be possible to control characteristics such as size, shape, and crystalline structure. Even still, only a select few plants are used in the phyto-synthesis of TiO2 NPs, and more research into this area is desperately needed. These phyto-synthesized nanoparticles are fully compatible with chemically generated nanoparticles, meaning they can be used safely in any application. This includes biomedical ones. As was previously said, NP's size and form are defining characteristics. Therefore, future challenges will involve trying to use the same biological processes to create shapes like triangles, cubes, truncated ellipses, pyramids, and ovals. There are a lot of obstacles and unknowns involved in taking NP production from the lab to the commercial scale. There are still two more challenges to face. Cost, dependability, waste, energy consumption, recycling opportunities, material safety, and hazard level should all be considered throughout the production process. Furthermore, nanomaterial characteristics may shift with increased size. When working with big volumes, some of the control may be lost [26-28].

Summary

This study looks at the current state of research into the biogenic synthesis of TiO2 NPs utilizing plants and microorganisms. It also goes into greater detail regarding the method of Photosynthesis using TiO2 NPs. Scientists have proposed novel ways for designing nanostructures due to the cytotoxicity, high cost, and time-consuming manufacture of metallic nanoparticles created by various physicochemical processes. There has been talk about how plants, bacteria, and other bioproducts can all contribute to the production of titanium dioxide nanoparticles. In addition, the process by which plants take them up, move them around, and store them is investigated. TiO2's possible effects have also been noted. There are many substantial benefits to green synthesis, which is why it is being advocated. By altering the experimental settings, it may be possible to control characteristics such as size, shape, and crystalline structure. Even still, only a select few plants are used in the phytosynthesis of TiO2 NPs, and more research into this area is desperately needed. These phytosynthesized nanoparticles are fully compatible with chemically generated nanoparticles, meaning they can be used safely in any application. This includes biomedical ones. More research is needed to determine how phyto-synthesized NPs can be used in other sectors besides biomedical and environmental remediation. In sum, the article argues that the development of effective and sustainable methodologies for nanoparticle synthesis with desirable characteristics, which can be used in a wide range of disciplines, can be greatly aided by the insights provided by green technology via biosynthesis, as discussed in the article.

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