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BIOSYNTHESIS OF TITANIUM DIOXIDE NANOPARTICLES USING CALENDULA OFFICINALIS EXTRACT FOR ANTIFUNGAL APPLICATIONS

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Abstract

The present study investigated the green synthesis, physicochemical characterization, and antifungal activity of titanium dioxide nanoparticles (TiO_2 NPs) using Calendula officinalis *extract. Nanoparticles were synthesized by reacting titanium isopropoxide with aqueous plant extract under controlled conditions, followed by drying and calcination. The synthesized nanoparticles were characterized using UV–visible spectroscopy, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric analysis (TGA), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX). UV–visible analysis revealed a prominent spectral peak near 378 nm, while FTIR confirmed characteristic hydroxyl and Ti–O vibrations. XRD analysis indicated a crystalline anatase structure, whereas SEM revealed agglomerated, nearly spherical particles with rough surfaces. EDX confirmed titanium (59.25 wt%) and oxygen (36.08 wt%) as major constituents. Antifungal activity was evaluated against five fungal strains using the agar diffusion method. Maximum inhibition was observed against* Penicillium glabrum *(45 mm), followed by* Aspergillus niger *(37 mm),* Trichoderma harzianum *(31 mm),* Candida albicans *(30 mm), and* Mucor circinelloides *(20 mm). Overall, the findings suggest that* Calendula officinalis*-mediated TiO_2 nanoparticles possess species-dependent antifungal potential, supporting further investigation of their applications in environmentally sustainable antimicrobial formulations and related technologies.*

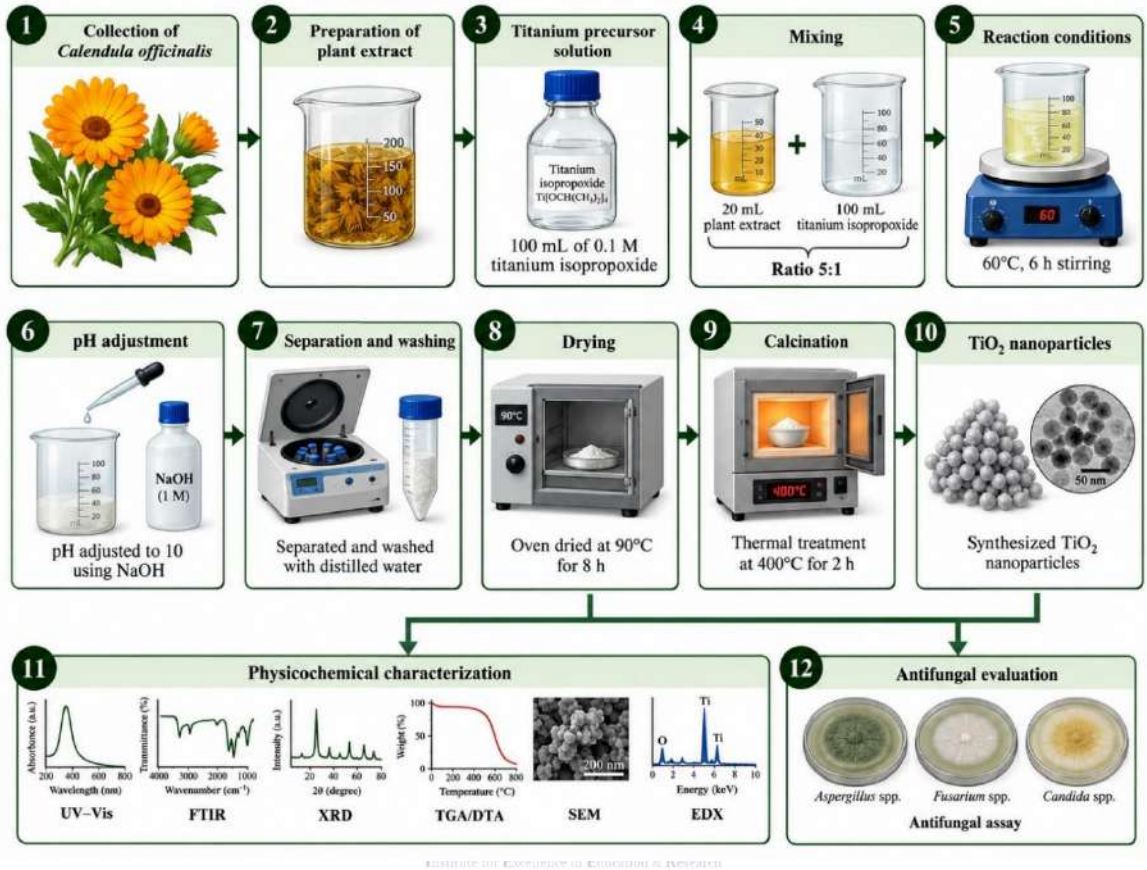


Figure 1: Schematic Abstract

1. Introduction

Nanotechnology has emerged as an important interdisciplinary field, offering innovative approaches for developing materials with improved physicochemical and biological properties. Nanoparticles possess distinctive characteristics resulting from their small dimensions, high surface-area-to-volume ratios, and enhanced surface reactivity. Among metal oxide nanomaterials, titanium dioxide nanoparticles (TiO_2 NPs) have received considerable scientific attention because of their chemical stability, photocatalytic properties, relatively low cost, and potential applications in environmental remediation, agriculture, pharmaceuticals, and antimicrobial technologies [1]–[5]. Titanium dioxide primarily exists in three crystalline polymorphs: anatase, rutile, and brookite. Among these, anatase is particularly important in photocatalytic applications because its electronic structure and surface properties support light-induced chemical reactions [6], [7].

Conventional TiO_2 nanoparticle synthesis involves several physicochemical techniques, including sol–gel processing, hydrothermal synthesis, precipitation, and chemical vapor deposition. Although effective, certain methods require hazardous chemicals, high temperatures, specialized equipment, or energy-intensive processing. Consequently, green synthesis has attracted increasing interest as an alternative approach incorporating renewable biological materials [8]–[12]. Plant-mediated synthesis utilizes naturally occurring phytochemicals that may influence precursor hydrolysis, nanoparticle nucleation, particle growth, and surface stabilization. Such methods offer opportunities to reduce chemical consumption and improve

synthesis sustainability, although environmental benefits depend on the complete manufacturing process [13]–[15].

Calendula officinalis L., commonly known as pot marigold, belongs to the Asteraceae family and is widely recognized for its traditional medicinal applications. The plant contains numerous bioactive phytochemicals, including flavonoids, phenolic acids, carotenoids, triterpenoids, saponins, and other secondary metabolites [16]–[19]. These compounds contribute to its reported antioxidant, anti-inflammatory, wound-healing, and antimicrobial properties. Previous investigations have also demonstrated antifungal activity in certain C. officinalis extracts and essential oils [20], [21]. The abundance of phytochemicals makes C. officinalis a promising biological resource for nanoparticle synthesis, potentially influencing nanoparticle surface chemistry and aggregation behavior.

The development of effective antifungal materials has become increasingly important because fungal pathogens cause infections in humans, animals, and agricultural crops. Moreover, antifungal resistance, environmental contamination, and the limited availability of effective treatments present considerable challenges [22], [23]. Titanium dioxide nanoparticles have demonstrated antifungal potential against several fungal organisms, including Candida, Aspergillus, and agriculturally important phytopathogens [24]–[27]. Their antifungal activity may involve interactions with fungal cell surfaces and the generation of reactive oxygen species (ROS), particularly under suitable illumination conditions. These reactive species can potentially damage cellular membranes, proteins, and other essential biological components. Nevertheless, antifungal effectiveness depends on nanoparticle concentration, crystalline phase, particle morphology, fungal species, and experimental conditions [28], [29].

Previous research has demonstrated the feasibility of synthesizing TiO_2 nanoparticles using *Calendula officinalis* extract and evaluating their physicochemical and biological properties [30]. However, further systematic investigation of their antifungal performance against diverse fungal species remains valuable. Establishing relationships between structural characteristics, elemental composition, thermal stability, and antifungal activity may provide additional insight into their potential applications.

Therefore, the present study focuses on the biosynthesis of TiO_2 nanoparticles using aqueous *Calendula officinalis* extract and the evaluation of their physicochemical characteristics and antifungal activity. The synthesized nanoparticles are characterized using UV–visible spectroscopy, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric analysis (TGA), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX). Their antifungal performance is investigated against Aspergillus niger, Mucor circinelloides, Trichoderma harzianum, Penicillium glabrum, and Candida albicans. The investigation aims to assess the potential of plant-mediated TiO_2 nanoparticles as alternative antifungal materials and contribute to research on environmentally conscious nanomaterial fabrication.

2. Materials and Methods

2.1. Collection and Preparation of *Calendula officinalis* Extract

Fresh *Calendula officinalis* flowers was collected from Dhodial, Mansehra. The flowers was thoroughly washed with distilled water to remove dust and impurities, followed by drying at room temperature. The dried material was ground into a fine powder. Subsequently, 2 g of powdered plant material was mixed with 100mL of distilled water and extracted at 60°C under continuous stirring for 6 h. The resulting extract was filtered to remove insoluble residues and stored under appropriate conditions until further utilization. The aqueous extract was used as a biological medium for titanium dioxide nanoparticle synthesis.

2.2. Biosynthesis of Titanium Dioxide Nanoparticles

Titanium dioxide nanoparticles (TiO_2 NPs) were synthesized using *Calendula officinalis* extract through a plant-mediated synthesis approach. Briefly, 100mL 0.1 M titanium isopropoxide was prepared and mixed with the 20mL plant extract at a ratio of 5:1. The reaction mixture was maintained at 60°C under continuous stirring for 6hrs, with the pH adjusted to 10 using NaOH, where applicable. The resulting material was separated, washed with distilled water, and dried in Oven at 90°C for 8hrs. Subsequently, the dried product was subjected to thermal treatment at 400°C for 2hrs. The synthesized nanoparticles were collected and stored for subsequent physicochemical characterization and antifungal evaluation.

2.3. Characterization of TiO_2 Nanoparticles

The synthesized TiO_2 nanoparticles were characterized using various analytical techniques. UV–visible spectroscopy was employed to examine optical characteristics within the wavelength range of 250–450 nm. Fourier-transform infrared spectroscopy (FTIR) was used to identify surface functional groups and chemical bonding characteristics over 400–4000 cm^{-1}. X-ray diffraction (XRD) analysis was performed across a 2θ range of 10–90° to investigate crystallinity and phase composition. Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were used to evaluate thermal decomposition and stability. Scanning electron microscopy (SEM) was employed to examine surface morphology, particle aggregation, and structural features. Energy-dispersive X-ray spectroscopy (EDX) was performed to determine elemental composition and investigate the presence of titanium, oxygen, and other detectable elements.

2.4. Evaluation of Antifungal Activity

The antifungal potential of the synthesized TiO_2 nanoparticles was evaluated against five fungal species: *Aspergillus niger*, *Mucor circinelloides*, *Trichoderma harzianum*, *Penicillium glabrum*, and *Candida albicans*. Antifungal activity was assessed using an agar diffusion assay. The TiO_2 nanoparticle preparation, positive control, and negative control were evaluated under comparable experimental conditions. The fungal cultures were obtained from Department of Microbiology, Hazara University, Mansehra-21300 Pakistan, and the assay conditions, including nanoparticle concentration, medium, inoculum preparation, incubation conditions, and replicate numbers, were documented according to the protocol. Following incubation, inhibition zones were measured in millimeters. The observed inhibition zones were compared with those produced by the positive (Fluconazole) and negative controls (water) to assess differences in antifungal activity among the tested fungal species [31].

3. Results

3.1 UV-visible Spectroscopy

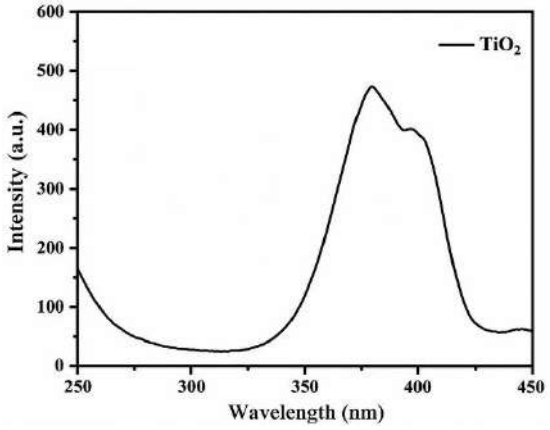


Figure 2. UV–visible spectral intensity profile of TiO_2 nanoparticles.

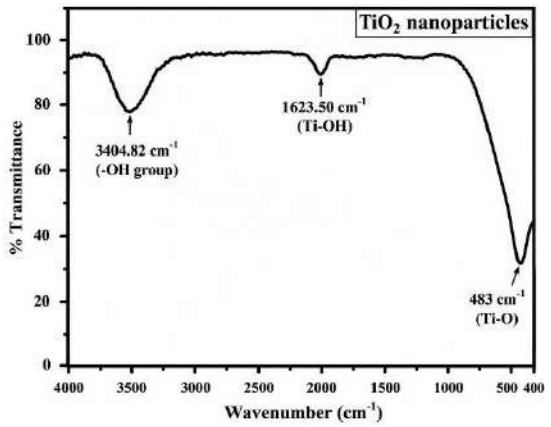


Figure 3. FTIR spectrum of TiO_2 nanoparticles.

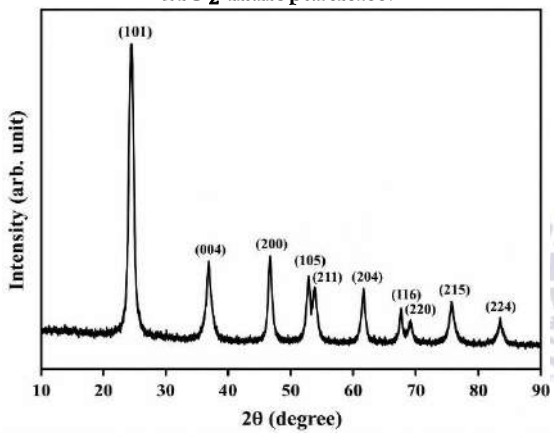


Figure 4. XRD pattern of TiO_2 nanoparticles.

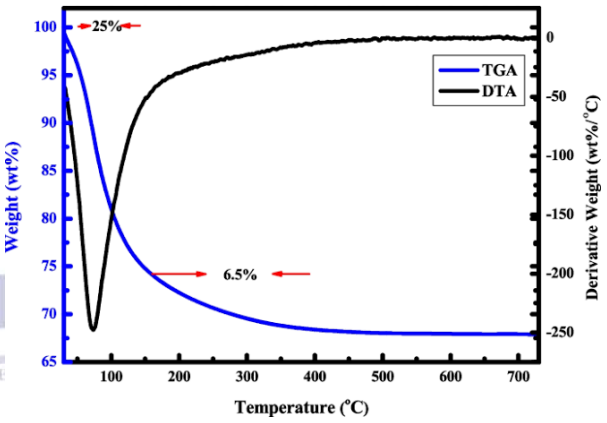


Figure 5. TGA and DTA profiles of TiO_2 nanoparticles.

3.1 UV–Visible Spectroscopic Analysis of TiO_2 Nanoparticles

UV–visible spectroscopy was employed to investigate the optical characteristics of titanium dioxide (TiO_2) nanoparticles synthesized using *Calendula officinalis* extract. The recorded spectrum, spanning 250–450 nm, exhibited distinct wavelength-dependent intensity variations. Initially, the spectral intensity decreased gradually from approximately 160 a.u. at 250 nm to a minimum near 310 nm. Subsequently, a pronounced increase was observed, reaching a maximum intensity of approximately 470 a.u. at 378 nm. A secondary shoulder appeared around 400 nm, followed by a sharp decline beyond 410 nm. These optical features may reflect electronic transitions, nanoparticle aggregation, and surface-related effects. The phytochemical constituents of *Calendula officinalis* could influence nanoparticle formation and optical behavior through interactions with the titanium precursor. However, the observed intensity spectrum alone cannot establish nanoparticle formation or determine the optical band gap. Therefore, complementary structural and morphological characterization is essential to confirm the formation and physicochemical properties of synthesized TiO_2 nanoparticles conclusively [32].

3.2 Fourier Transform Infrared Spectroscopic of TiO_2 Nanoparticles

Fourier transform infrared (FTIR) spectroscopy was employed to investigate the functional groups and chemical bonding characteristics of titanium dioxide (TiO_2) nanoparticles synthesized using *Calendula officinalis* extract. The FTIR spectrum, recorded over 400–4000 cm^{-1}, exhibited three characteristic absorption bands. The broad absorption band at 3404.82 cm^{-1} was attributed to O–H stretching vibrations, indicating the presence of surface hydroxyl groups or adsorbed moisture. The band observed at 1623.50 cm^{-1} was associated with H–O–H bending vibrations of adsorbed water, potentially overlapping with vibrations from surface-associated organic compounds. Furthermore, the prominent absorption band at 483 cm^{-1} corresponded to Ti–O lattice vibrations, supporting the formation of titanium oxide structures. These spectral features suggest that phytochemical constituents of *Calendula officinalis* may influence nanoparticle surface chemistry during green synthesis. Overall, FTIR analysis provides evidence of hydroxyl functionalities and Ti–O bonding, although complementary XRD analysis is required to confirm the crystalline titanium dioxide phase [33].

3.3 X-Ray Diffraction Analysis of TiO_2 Nanoparticles

X-ray diffraction (XRD) analysis was performed to investigate the crystalline structure and phase composition of titanium dioxide (TiO_2) nanoparticles synthesized using *Calendula officinalis* extract. The diffraction pattern exhibited several distinct peaks within the 2θ range of 10–90°, indicating crystalline material. The most intense diffraction peak appeared near 25.3°, corresponding to the (101) crystallographic plane of anatase TiO_2. Additional reflections were observed around 37.8°, 48.0°, 53.9°, 55.1°, 62.7°, 68.8°, 70.3°, 75.0°, and 82.7°, indexed to the (004), (200), (105), (211), (204), (116), (220), (215), and (224) planes, respectively. These reflections are consistent with the characteristic tetragonal anatase crystal structure. The relatively sharp diffraction peaks suggest appreciable crystallinity, while their widths may provide information regarding crystallite dimensions. Overall, the observed diffraction pattern supports the presence of crystalline anatase TiO_2. However, quantitative crystallite size determination and phase purity assessment require peak fitting and comparison with reference diffraction data [34].

3.4 Thermogravimetric and Differential Thermal Analysis of TiO_2 Nanoparticles

Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were employed to evaluate the thermal stability and decomposition behavior of titanium dioxide (TiO_2) nanoparticles synthesized using *Calendula officinalis* extract. The TGA curve exhibited an initial rapid weight loss of approximately 25% below 150°C, potentially associated with the evaporation of adsorbed moisture and volatile compounds. A subsequent gradual weight loss of approximately 6.5% occurred between 150 and 400°C, suggesting the decomposition of residual phytochemicals and surface-associated organic constituents. Beyond 400°C, the sample demonstrated relatively stable mass retention, indicating improved thermal stability at elevated temperatures. The black derivative thermal curve displayed a pronounced minimum near 70°C, corresponding to the region of rapid mass loss. This feature may reflect the removal of moisture and volatile substances. Overall, the thermal behavior suggests the presence of removable surface-associated constituents, while the remaining inorganic material exhibits relatively high thermal stability under the investigated conditions [35].

3.5 Morphological and Elemental Characterization of TiO_2 Nanoparticles

Scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) analyses were employed to examine the morphology and elemental composition of the biosynthesized titanium dioxide nanoparticles. The SEM micrograph

revealed densely agglomerated, rough-surfaced, and porous nanostructures composed of fine nearly spherical primary particles. Such agglomeration is commonly observed in plant-mediated TiO_2 nanoparticles because high surface energy promotes particle–particle interaction during drying and calcination. The irregular clusters and porous texture indicate a large surface area, which may enhance catalytic and antibacterial performance by providing more active sites for interaction with bacterial cells. EDX analysis confirmed the elemental composition of the prepared nanoparticles, showing strong characteristic signals for titanium and oxygen, which verify the formation of TiO_2. Quantitative EDX data indicated 59.25 wt% Ti and 36.08 wt% O, while carbon was detected at 4.67 wt%. The presence of carbon may be attributed to residual phytochemical constituents from *Calendula officinalis* extract or carbon tape used during analysis. The dominance of titanium and oxygen peaks, together with SEM observations, suggests successful formation of TiO_2 nanoparticles with agglomerated nanoscale morphology suitable for further antibacterial investigations. Overall, these findings support the structural integrity and purity of the synthesized material, although additional techniques such as XRD and FTIR remain essential [36-38].

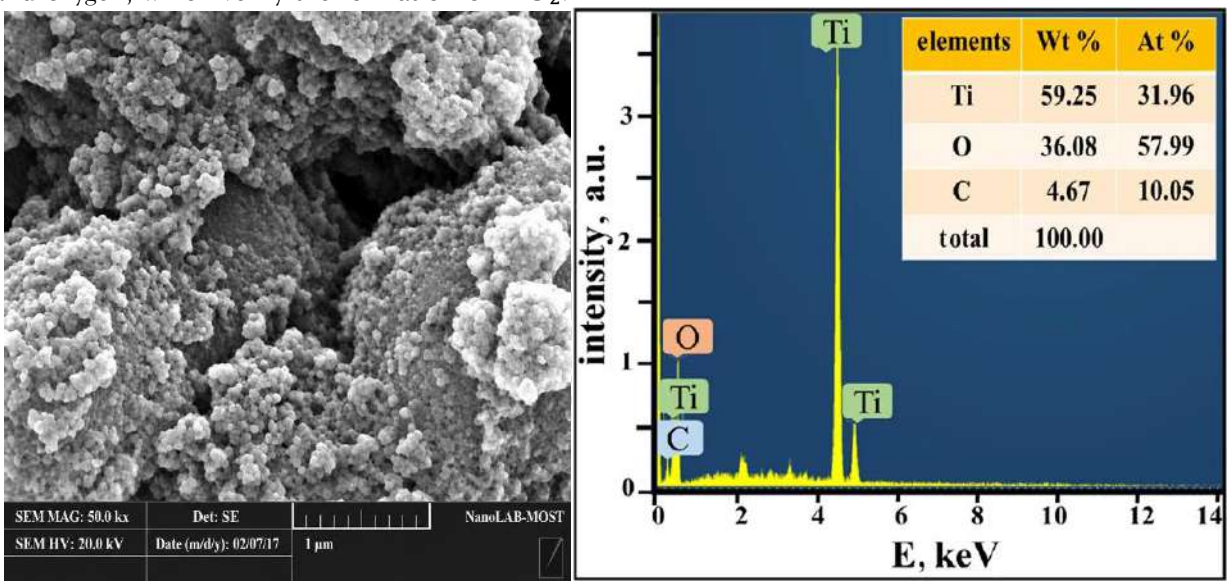


Figure 6. SEM micrograph and EDX spectrum of *Calendula officinalis*-mediated TiO_2 nanoparticles.

3.6 Antifungal Activity of TiO_2 Nanoparticles

The antifungal activity of titanium dioxide nanoparticles (TiO_2 NPs) was evaluated against five fungal strains using the agar diffusion method. The inhibition zones demonstrated variable antifungal effectiveness depending on the fungal species. The highest inhibition zone was observed against Penicillium glabrum (45 mm), compared with 38 mm for the control, indicating enhanced antifungal activity. Similarly, Candida albicans exhibited an inhibition zone of 30 mm, exceeding the control value of 26 mm. Moderate activity was recorded against Aspergillus niger (37 mm), slightly higher than the control (36 mm). Conversely, Mucor circinelloides and Trichoderma harzianum showed smaller inhibition zones of 20 mm and 31 mm, respectively, compared with their corresponding controls (23 mm and 32 mm). These variations suggest species-dependent susceptibility to TiO_2 nanoparticles. Potential antifungal mechanisms include reactive oxygen species generation, membrane disruption, and oxidative damage to essential cellular components [39]. However, these mechanisms require experimental verification. Overall, the

findings indicate selective antifungal activity, particularly against P. glabrum and C. albicans. Further investigations involving minimum inhibitory concentration determination, appropriate controls, and statistical analysis are necessary to validate antifungal efficacy and establish the potential applications of TiO_2 nanoparticles in antimicrobial formulations [40-41].

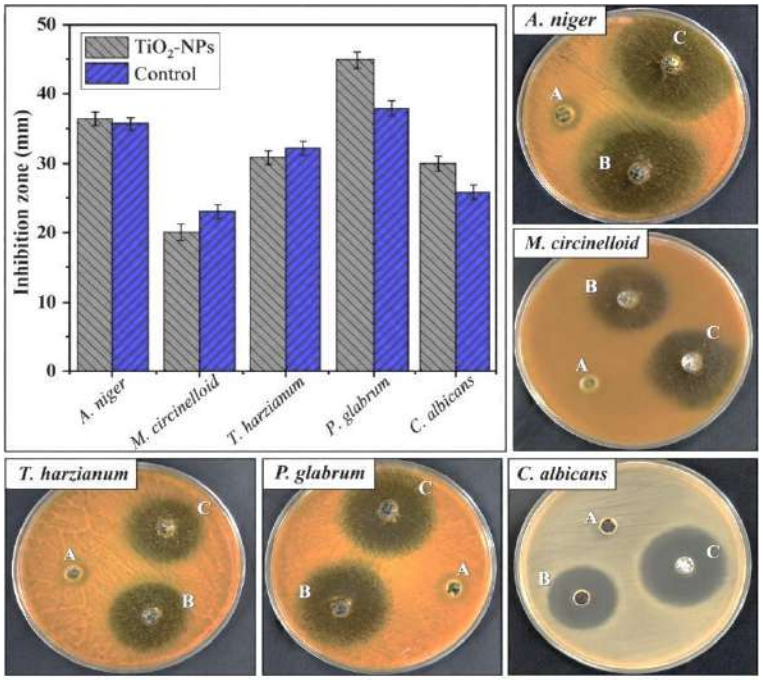


Figure 7. Antifungal activity of TiO_2 nanoparticles against five fungal strains showing inhibition zones and controls.

Table 1. Antifungal inhibition zone (mm) of TiO_2 Nanoparticles Against Selected Fungal Strains

S.No	Fungal strains	TiO_2 NPs	Positive Control	Negative Control
1	*Aspergillus niger*	37	36	0
3	*Mucor circinelloides*	20	23	0
3	*Trichoderma harzianum*	31	32	0
4	*Penicillium glabrum*	45	38	0
5	*Candida albicans*	30	26	0

4. Conclusion

The present study investigated the green synthesis, physicochemical characterization, and antifungal potential of titanium dioxide nanoparticles (TiO_2 NPs) using *Calendula officinalis* extract. The plant-mediated synthesis approach demonstrated the potential of botanical extracts as environmentally conscious alternatives in nanoparticle fabrication. UV–visible spectroscopy revealed characteristic optical behavior, while FTIR analysis identified hydroxyl functionalities and Ti–O vibrations. XRD analysis indicated the formation of crystalline TiO_2 with a predominantly anatase structure. Thermogravimetric analysis demonstrated relatively high thermal stability following the initial decomposition stages. SEM observations revealed agglomerated, nearly spherical nanostructures with rough surfaces, whereas EDX analysis confirmed the presence of titanium and oxygen as major elemental constituents. The synthesized TiO_2 nanoparticles exhibited variable antifungal activity against five fungal strains. Maximum inhibition was observed against

Penicillium glabrum (45 mm), followed by *Aspergillus niger* (37 mm), *Trichoderma harzianum* (31 mm), *Candida albicans* (30 mm), and *Mucor circinelloides* (20 mm). Enhanced inhibition compared with positive controls was observed for three fungal species, suggesting species-dependent antifungal effectiveness. Overall, the findings highlight the potential of *Calendula officinalis*-mediated TiO_2 nanoparticles as alternative antifungal materials. Further investigations involving toxicity assessment, minimum inhibitory concentration determination, mechanistic studies, and improved synthesis optimization are recommended to establish their practical applicability and safety.

REFERENCES

X. Chen and S. S. Mao, "Titanium dioxide nanomaterials: Synthesis, properties, modifications, and applications," Chemical Reviews, vol. 107, no. 7, pp. 2891–2959, 2007. doi: 10.1021/cr0500535.

U. Diebold, "The surface science of titanium dioxide," Surface Science Reports, vol. 48, nos. 5–8, pp. 53–229, 2003. doi: 10.1016/S0167-5729(02)00100-0.

A. Fujishima and K. Honda, "Electrochemical photolysis of water at a semiconductor electrode," Nature, vol. 238, pp. 37–38, 1972. doi: 10.1038/238037a0.

M. R. Hoffmann, S. T. Martin, W. Choi, and D. W. Bahnemann, "Environmental applications of semiconductor photocatalysis," Chemical Reviews, vol. 95, no. 1, pp. 69–96, 1995. doi: 10.1021/cr00033a004.

A. Fujishima, X. Zhang, and D. A. Tryk, "TiO_2 photocatalysis and related surface phenomena," Surface Science Reports, vol. 63, no. 12, pp. 515–582, 2008. doi: 10.1016/j.surfrep.2008.10.001.

J. Schneider et al., "Understanding TiO_2 photocatalysis: Mechanisms and materials," Chemical Reviews, vol. 114, no. 19, pp. 9919–9986, 2014. doi: 10.1021/cr5001892.

D. A. H. Hanaor and C. C. Sorrell, "Review of the anatase to rutile phase transformation," Journal of Materials Science, vol. 46, pp. 855–874, 2011. doi: 10.1007/s10853-010-5113-0.

R. Daghrir, P. Drogui, and D. Robert, "Modified TiO_2 for environmental photocatalytic applications: A review," Industrial & Engineering Chemistry Research, vol. 52, no. 10, pp. 3581–3599, 2013. doi: 10.1021/ie303468t.

S. Iravani, "Green synthesis of metal nanoparticles using plants," Green Chemistry, vol. 13, pp. 2638–2650, 2011. doi: 10.1039/C1GC15386B.

S. Ahmed, M. Ahmad, B. L. Swami, and S. Ikram, "A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise," Journal of Advanced Research, vol. 7, no. 1, pp. 17–28, 2016. doi: 10.1016/j.jare.2015.02.007.

M. Aslam, A. Z. Abdullah, and M. Rafatullah, "Recent development in the green synthesis of titanium dioxide nanoparticles using plant-based biomolecules for environmental and antimicrobial applications," Journal of Industrial and Engineering Chemistry, vol. 98, pp. 1–16, 2021. doi: 10.1016/j.jiec.2021.04.010.

N. E. Sunny et al., "Green synthesis of titanium dioxide nanoparticles using plant biomass and their applications—A review," Chemosphere, vol. 300, art. no. 134612, 2022. doi: 10.1016/j.chemosphere.2022.134612.

"A review of recent developments in green synthesis of TiO_2 nanoparticles using plant extract: Synthesis, characterization and photocatalytic activity," Inorganic Chemistry Communications, vol. 165, art. no. 112531, 2024. doi: 10.1016/j.inoche.2024.112531.

I. J. Lithi, K. I. A. Nakib, A. M. S. Chowdhury, and M. S. Hossain, "A review on the green synthesis of metal (Ag, Cu, and Au) and metal oxide (ZnO, MgO, Co_3O_4, and TiO_2) nanoparticles using plant extracts for developing antimicrobial properties," Nanoscale Advances, vol. 7, pp. 2446–2473, 2025. doi: 10.1039/D5NA00037H.

G. R. Silva et al., "Green-synthesized titanium dioxide nanoparticles: Systematic review of antimicrobial efficacy and biocompatibility," Mini-Reviews in Medicinal Chemistry, published online, 2026. doi: 10.2174/0113895575454226260126093115.

D. Arora, A. Rani, and A. Sharma, "A review on phytochemistry and ethnopharmacological aspects of genus Calendula," Pharmacognosy Reviews, vol. 7, no. 14, pp. 179–187, 2013. doi: 10.4103/0973-7847.120520.

B. P. Muley, S. S. Khadabadi, and N. B. Banarase, "Phytochemical constituents and pharmacological activities of *Calendula officinalis* Linn (Asteraceae): A review," Tropical Journal of Pharmaceutical Research, vol. 8, no. 5, pp. 455–465, 2009. Publication.

K. Shahane et al., "An updated review on the multifaceted therapeutic potential of *Calendula officinalis* L.," Pharmaceuticals, vol. 16, no. 4, art. no. 611, 2023. doi: 10.3390/ph16040611.

D. N. Olennikov and N. I. Kashchenko, "Marigold metabolites: Diversity and separation methods of Calendula genus phytochemicals from 1891 to 2022," Molecules, vol. 27, no. 23, art. no. 8626, 2022. doi: 10.3390/molecules27238626.

Z. C. Gazim et al., "Antifungal activity of the essential oil from *Calendula officinalis* L. (Asteraceae) growing in Brazil," Brazilian Journal of Microbiology, vol. 39, no. 1, pp. 61–63, 2008. doi: 10.1590/S1517-838220080001000015.

E. Efstratiou et al., "Antimicrobial activity of *Calendula officinalis* petal extracts against fungi, as well as Gram-negative and Gram-positive clinical pathogens," Complementary Therapies in Clinical Practice, vol. 18, no. 3, pp. 173–176, 2012. doi: 10.1016/j.ctcp.2012.02.003.

World Health Organization, WHO Fungal Priority Pathogens List to Guide Research, Development and Public Health Action. Geneva, Switzerland: WHO, 2022. WHO publication.

P. Chauhan and A. Tapwal, "Green synthesis of nanoparticles using botanicals and their application in management of fungal phytopathogens: A review," Archives of Microbiology, vol. 205, no. 3, art. no. 94, 2023. doi: 10.1007/s00203-023-03431-0.

Y. Xing et al., "Green synthesized TiO_2 nanoparticles: Structural characterization and photoinduced antifungal activity against P. steckii," Journal of Food Science, vol. 88, no. 1, pp. 328–340, 2023. doi: 10.1111/1750-3841.16419.

N. M. Alabdallah et al., "Synthesis, characterization and antifungal potential of titanium dioxide nanoparticles against fungal disease (Ustilago tritici) of wheat (Triticum aestivum L.)," Environmental Research, vol. 228, art. no. 115852, 2023. doi: 10.1016/j.envres.2023.115852.

G. Nabi, T. Anjum, Z.-E.-H. Aftab, H. Rizwana, and W. Akram, "TiO_2 nanoparticles: Green synthesis and their role in lessening the damage of Colletotrichum graminicola in sorghum," Food Science & Nutrition, vol. 12, no. 10, pp. 7379–7391, 2024. doi: 10.1002/fsn3.4297.

R. Saini, R. K. Mishra, and P. Kumar, "Sustainable green synthesis of TiO_2 nanoparticles using the Azolla pinnata plant for enhanced photocatalytic and antimicrobial activity," RSC Advances, vol. 16, no. 34, pp. 33184–33195, 2026. doi: 10.1039/D6RA01924B.

Y. Nosaka and A. Y. Nosaka, "Generation and detection of reactive oxygen species in photocatalysis," Chemical Reviews, vol. 117, no. 17, pp. 11302–11336, 2017. doi: 10.1021/acs.chemrev.7b00161.

V. Lazić, V. Nikšić, and J. M. Nedeljković, "Application of TiO_2 in photocatalytic bacterial inactivation: Review," International Journal of Molecular Sciences, vol. 26, no. 21, art. no. 10593, 2025. doi: 10.3390/ijms262110593.

X. Wei, Y. Liu, A. El-kott, A. E. Ahmed, and A. Khames, "*Calendula officinalis*-based green synthesis of titanium nanoparticle: Fabrication, characterization, and evaluation of human colorectal carcinoma," Journal of Saudi Chemical Society, vol. 25, no. 11, art. no. 101343, 2021. doi: 10.1016/j.jscs.2021.101343.

S. M. Gupta and M. Tripathi, "A review of TiO_2 nanoparticles," Chinese Science Bulletin, vol. 56, pp. 1639–1657, 2011. doi: 10.1007/s11434-011-4476-1.

W. Ahmad, K. K. Jaiswal, and S. Soni, "Green synthesis of titanium dioxide (TiO_2) nanoparticles by using Mentha arvensis leaves extract and its antimicrobial properties," Inorganic and Nano-Metal Chemistry, vol. 50, no. 10, pp. 1032–1038, 2020. doi: 10.1080/24701556.2020.1732419.

S. Subhapriya and P. Gomathipriya, "Green synthesis of titanium dioxide (TiO_2) nanoparticles by Trigonella foenum-graecum extract and its antimicrobial properties," Microbial Pathogenesis, vol. 116, pp. 215–220, 2018. doi: 10.1016/j.micpath.2018.01.027.

M. Narayanan et al., "Synthesis and characterization of TiO_2 NPs by aqueous leaf extract of Coleus aromaticus and assess their antibacterial, larvicidal, and anticancer potential," Environmental Research, vol. 200, art. no. 111335, 2021. doi: 10.1016/j.envres.2021.111335.

T. Santhoshkumar et al., "Green synthesis of titanium dioxide nanoparticles using Psidium guajava extract and its antibacterial and antioxidant properties," Asian Pacific Journal of Tropical Medicine, vol. 7, no. 12, pp. 968–976, 2014. doi: 10.1016/S1995-7645(14)60171-1.

M. A. Irshad et al., "Synthesis and characterization of titanium dioxide nanoparticles by chemical and green methods and their antifungal activities against wheat rust," Chemosphere, vol. 258, art. no. 127352, 2020. doi: 10.1016/j.chemosphere.2020.127352.

A. Saka et al., "Biosynthesis of TiO_2 nanoparticles by Caricaceae (Papaya) shell extracts for antifungal application," Scientific Reports, vol. 12, art. no. 15960, 2022. doi: 10.1038/s41598-022-19440-w.

D. Castillo-Hernández, M. Pérez-González, S. A. Tomás, J. L. Jiménez-Pérez, J. F. Sánchez Ramírez, and Z. N. Correa-Pacheco, "Synthesis of sol-gel TiO_2 nanoparticles and assessment of their antifungal activity for the eventual conservation of historical documents," Applied Materials Today, vol. 35, art. no. 101999, 2023. doi: 10.1016/j.apmt.2023.101999.

M. Rajamehala, S. Renugaa, A. Pandian, B. Gopalakrishnan, and V. P. M. Singh, "Green synthesis of titanium dioxide and its application on anti-fungal activity," Research Journal of Pharmacy and Technology, vol. 15, no. 2, pp. 695–700, 2022. doi: 10.52711/0974-360X.2022.00115.

D. Sushmitha and P. R. Jeyaramraja, "Bio-assisted synthesis, characterization, and antibacterial efficacy of titanium dioxide nanoparticles mediated by Pterolobium hexapetalum leaf extract," Discover Nano, vol. 21, art. no. 161, 2026. doi: 10.1186/s11671-026-04608-4.

A. Zeenath, M. S. Kairon Mubina, S. M. Abdul Kader, and M. Anisha Nashrin, "Green synthesis of TiO_2 nanoparticles: A promising tool for wastewater treatment," Journal of Chemistry and Technologies, vol. 33, no. 2, 2025. doi: 10.15421/jchemtech.v33i2.319532.

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