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FABRICATION PLANT-MEDIATED FUNCTIONAL TIO_2 NANOPARTICLES USING CORIANDRUM SATIVUM LEAF EXTRACT

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Abstract: In the present study, titanium dioxide (TiO_2) nanoparticles were synthesized using *Coriandrum sativum* (coriander) leaf extract through a plant-mediated approach. The method provides an alternative to conventional synthesis by utilizing naturally occurring plant compounds during nanoparticle preparation. The synthesized material was characterized using Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) to investigate its functional groups, crystalline structure, and surface morphology. FTIR analysis indicated the presence of hydroxyl groups and Ti-O/Ti-O-Ti bonds, supporting the formation of TiO_2. The XRD pattern showed distinct diffraction peaks consistent with crystalline TiO_2, while SEM and TEM images revealed irregular to quasi-spherical nanoparticles with noticeable aggregation. These observations provide insight into the structural and morphological characteristics of the prepared material. The results highlight the potential of *Coriandrum sativum* leaf extract as a renewable resource for plant-mediated TiO_2 synthesis.

Keywords: *Coriandrum sativum; TiO_2 nanoparticles; plant-mediated synthesis; green synthesis; FTIR; XRD.*

Annotatsiya: Ushbu tadqiqotda titan dioksidi (TiO_2) nanozarrachalari *Coriandrum sativum* (kashnich) barglari ekstraktidan foydalangan holda o'simlik yordamida sintez qilindi. Bu usul nanozarrachalarni tayyorlash jarayonida tabiatda mavjud o'simlik birikmalaridan foydalanish orqali an'anaviy sintezga muqobil yechim taqdim etadi. Sintez qilingan materialning funksional guruhlari, kristall tuzilishi va sirt morfologiyasini o'rganish uchun Fure-

transform infraqizil spektroskopiyasi (FTIR), rentgen nurlari difraksiyasi (XRD), elektron skanerlovchi mikroskopiya (SEM) va transmission elektron mikroskopiya (TEM) yordamida tahlil qilindi. FTIR tahlili gidroksil guruhlari hamda Ti-O / Ti-O-Ti bog'lari mavjudligini ko'rsatib, *TiO_2* hosil bo'lganini tasdiqladi. XRD naqshlari kristall TiO_2 ga mos keladigan aniq difraksiya cho'qqilarini ko'rsatdi, SEM va TEM tasvirlari esa sezilarli darajada birikish (agregatsiya) holatiga ega bo'lgan noto'g'ri shakldagi va kvazisferik (sifatli sharsimon) nanozarrachalarni namoyon etdi. Ushbu kuzatishlar tayyorlangan materialning strukturaviy va morfologik xususiyatlari haqida ma'lumot beradi. Olingan natijalar *Coriandrum sativum* barglari ekstraktining o'simlik vositasida *TiO_2* sintezi uchun qayta tiklanadigan manba sifatidagi salohiyatini yoritib beradi.

Kalit so'zlar: *Coriandrum sativum*; *TiO_2* nanozarrachalari; o'simlik yordamida sintez qilish; yashil sintez; FTIR; XRD.

Аннотация: В данном исследовании наночастицы диоксида титана (TiO_2) были синтезированы с использованием экстракта листьев *Coriandrum sativum* (кориандра) с помощью растительного метода. Этот подход представляет собой альтернативу традиционному синтезу за счет использования природных растительных соединений при приготовлении наночастиц. Синтезированный материал был охарактеризован с помощью инфракрасной спектроскопии с преобразованием Фурье (FTIR), рентгено фазового анализа / рентгеновской дифракции (XRD), сканирующей электронной микроскопии (SEM) и просвечивающей электронной микроскопии (TEM) для исследования его функциональных групп, кристаллической структуры и морфологии поверхности. Анализ FTIR указал на присутствие гидроксильных групп и связей Ti-O/Ti-O-Ti, что подтверждает образование TiO_2. Рентгенограмма (XRD) показала четкие дифракционные пики, соответствующие кристаллическому TiO_2, в то время как изображения SEM и TEM выявили наночастицы от неправильной до квазисферической формы с заметной агрегацией. Эти наблюдения дают представление о структурных и морфологических характеристиках полученного материала. Результаты подчеркивают потенциал экстракта листьев *Coriandrum sativum* в качестве возобновляемого ресурса для синтеза TiO_2, опосредованного растениями.

Ключевые слова: *Coriandrum sativum*; наночастицы TiO_2; синтез с помощью растений; зеленый синтез; FTIR; XRD.

Introduction

Titanium dioxide (TiO_2) nanoparticles have gained considerable attention because of their useful physicochemical properties, good chemical stability, relatively low cost, and wide range of applications. They are widely studied for photocatalytic pollutant degradation, environmental remediation, antimicrobial applications, and self-cleaning surfaces [1–3]. The properties of TiO_2 nanoparticles depend on several factors, including crystal structure, particle size, morphology, surface characteristics, and optical behaviour. TiO_2 mainly occurs in three crystalline forms: anatase, rutile, and brookite. Among these, anatase is frequently investigated for photocatalytic applications because of its favourable surface properties and charge-carrier behaviour under

suitable conditions [1,2]. These characteristics make TiO_2 an important material for developing nanomaterials for environmental and technological applications. Several methods have been developed to prepare TiO_2 nanoparticles, including sol–gel, hydrothermal, solvothermal, and chemical precipitation techniques [2,3]. Although these methods can provide control over particle size and structural properties, some require organic solvents, chemical additives, high temperatures, or several processing steps. These limitations have encouraged researchers to explore more environmentally friendly synthesis methods that reduce the use of potentially harmful chemicals and simplify the preparation process without compromising the quality of the resulting material [3,4]. Plant-mediated synthesis has emerged as an interesting alternative because it uses plant extracts as renewable sources of naturally occurring compounds. Plant extracts contain phytochemicals such as polyphenols, flavonoids, terpenoids, carbohydrates, proteins, and organic acids. These compounds can interact with metal-containing precursors and influence nanoparticle formation, growth, aggregation, and surface characteristics [4,5]. During TiO_2 synthesis, plant-derived compounds may interact with the titanium precursor and influence hydrolysis and particle formation. Subsequent drying and heat treatment can help remove organic residues and promote the formation of crystalline TiO_2. However, the role of these compounds depends on the plant species, extraction procedure, precursor used, pH, and reaction conditions [4,5]. Therefore, selecting a suitable plant source and optimizing the synthesis conditions are important steps in obtaining TiO_2 nanoparticles with desirable properties.Among the available plant sources, *Coriandrum sativum* (coriander) is a promising candidate for green synthesis because its leaves contain naturally occurring phytochemicals that may influence nanoparticle formation. Previous studies have explored the preparation of TiO_2 nanoparticles using coriander leaf extract alongside extracts from other plants. Pushpamalini et al. compared TiO_2 nanoparticles synthesized using *Piper betle*, *Ocimum tenuiflorum*, *Moringa oleifera*, and *Coriandrum sativum* extracts, highlighting the importance of plant selection in determining the characteristics of the resulting materials [6]. Bhullar et al. also investigated plant-mediated TiO_2 synthesis using coriander, black pepper, and clove extracts, demonstrating the potential of botanical resources in nanoparticle preparation [7]. These reports provide a basis for further exploring coriander leaf extract as a sustainable medium for TiO_2 synthesis. The functional properties of TiO_2 nanoparticles are closely related to their structural, optical, and surface characteristics. Under suitable irradiation, TiO_2 can generate electron–hole pairs that participate in surface reactions and produce reactive oxygen species, such as hydroxyl radicals and superoxide radicals. These reactive species can help break down organic pollutants during photocatalytic treatment [8,9]. Plant-mediated TiO_2 nanoparticles have therefore attracted interest for applications in wastewater treatment and antimicrobial materials. However, their effectiveness depends on factors such as crystal phase, particle size, surface area, light source, and the nature of the target pollutant [8–10]. To understand these properties, characterization techniques such as X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), scanning or transmission electron microscopy (SEM/TEM), energy-dispersive X-ray spectroscopy (EDX), and UV–visible diffuse reflectance spectroscopy (UV–Vis DRS) are commonly used [4,5,11]. These techniques provide complementary information about crystal

structure, functional groups, morphology, elemental composition, and optical behaviour. Although previous studies have investigated coriander-mediated TiO_2 synthesis, further work can examine how synthesis conditions affect the properties and functional performance of the resulting nanoparticles. Parameters such as extract concentration, precursor-to-extract ratio, pH, reaction temperature, and calcination temperature may influence crystallinity, particle morphology, optical properties, and photocatalytic activity. Evaluating the stability and reusability of the prepared material is also important when considering its potential for practical applications [4,5,9,12].

In this context, the present study focuses on the plant-mediated fabrication of TiO_2 nanoparticles using *Coriandrum sativum* leaf extract. The prepared material is to be characterized using appropriate structural, spectroscopic, morphological, and optical techniques to examine its formation and physicochemical properties. Its potential functional applications, particularly photocatalytic degradation of organic pollutants, can then be evaluated through suitable experiments. Overall, this study aims to contribute to the development of a plant-assisted route for TiO_2 nanoparticle synthesis and to improve understanding of the relationship between synthesis conditions, material characteristics, and functional performance.

Materials

Titanium tetraisopropoxide (TTIP), isopropanol, and ethanol (Qualigen) from Avra Chemicals were utilised exactly as supplied. Experimental solutions were made using double-distilled water.

50g of air-dried *Coriandrum sativum* leaves were rinsed once with deionised water (DW) and again with tap water. In a 500 mL borosilicate beaker, we combined the ground leaves with 50 mL of DW and 50 mL of ethanol. We then heated the combination to 80ºC until the aqueous solution took on a darker green colour [16]. It was allowed to settle and then the supernatant liquid was passed through Whatmann filter paper and the extract was stored at 4ºC for further use.

Titanium tetraisopropoxide (TTIP) was dissolved in 60 mL of isopropanol, and the mixture was agitated for an hour at room temperature. Next, 20 mL of *Coriandrum sativum* extract was progressively added to the mixture. TiO_2 production was shown by the extract's little greenish shade. The solution turned dark green after 4 hours of stirring, indicating the formation of greenish TiO_2-NPs [17]. Centrifugation at 5000 rpm for 15 minutes allowed the precipitate to be separated from the solution. The resultant precipitate was dried for six hours at 80 °C in a hot air oven. White TiO_2 NPs were produced by calcining the obtained samples for five hours at 450°C. After that, these TiO_2 NPs were stored in a vacuum-sealed bag until further examinations could be performed.

The infrared (IR) spectra were recorded using the tidy method on an AVATAR-330 FT-IR spectrometer (4000-650 cm^{-1}). Using powder X-ray powder diffraction (XRD), the crystalline phase of the produced nanomaterials was determined over a 2θ range of 20 to 80º using Cu Kα radiation (λ=1.5418 Å). The surface morphology was analyzed using SEM (ZEISS EVO18) and HRTEM (Jeol/JEM 2100).

Results and Discussion The FTIR spectrum of the synthesized TiO_2 nanoparticles (**Fig. 1.**) helps identify the functional groups present on the surface and confirms the presence of titanium–oxygen bonds. A broad band in the region of approximately 3200–3500 cm^{-1} may be associated with the stretching vibrations of hydroxyl (-OH) groups arising from surface-bound water and hydroxyl groups. The weak bands around 1600–1700 cm^{-1} may be related to the bending vibrations of adsorbed water molecules. Small features in other regions could be due to residual plant-derived compounds or other surface species remaining after synthesis. The strong absorption below approximately 800 cm^{-1} is characteristic of Ti-O and Ti-O-Ti vibrations, supporting the formation of TiO_2 nanoparticles. Similar spectral features have been reported in studies of titanium dioxide nanomaterials [18]. Overall, the FTIR results suggest the presence of hydroxyl groups and titanium-oxygen bonds in the synthesized sample.

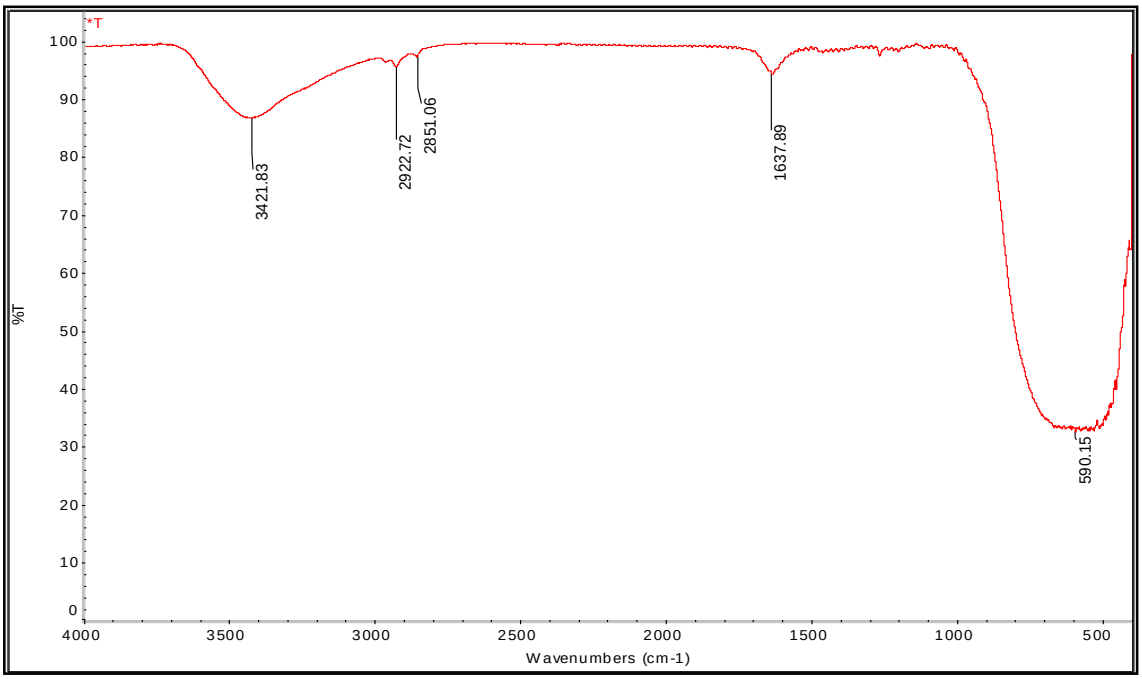


Figure. 1. FT-IR Spectrum of TiO_2

The X-ray diffraction (XRD) pattern of TiO_2 nanoparticles (**Fig. 2.**) synthesized using Coriandrum sativum leaf extract shows several distinct diffraction peaks, indicating the formation of a crystalline material. The intense peak around (2 theta = 25.3) can be assigned to the (101) plane of anatase TiO_2. Additional peaks at approximately 37.8°, 48.0°, 53.9°, 55.1°, and 62.7° are also characteristic of the anatase phase. These diffraction features can be compared with standard reference data to identify the crystalline structure of the prepared nanoparticles [18]. The sharp and intense peaks suggest good crystallinity, while the weaker reflections at higher angles may correspond to other crystallographic planes of TiO_2.Overall, the XRD results suggest that crystalline TiO_2 nanoparticles were obtained using coriander leaf extract. The plant extract provides a renewable synthesis medium and may influence particle formation and growth.

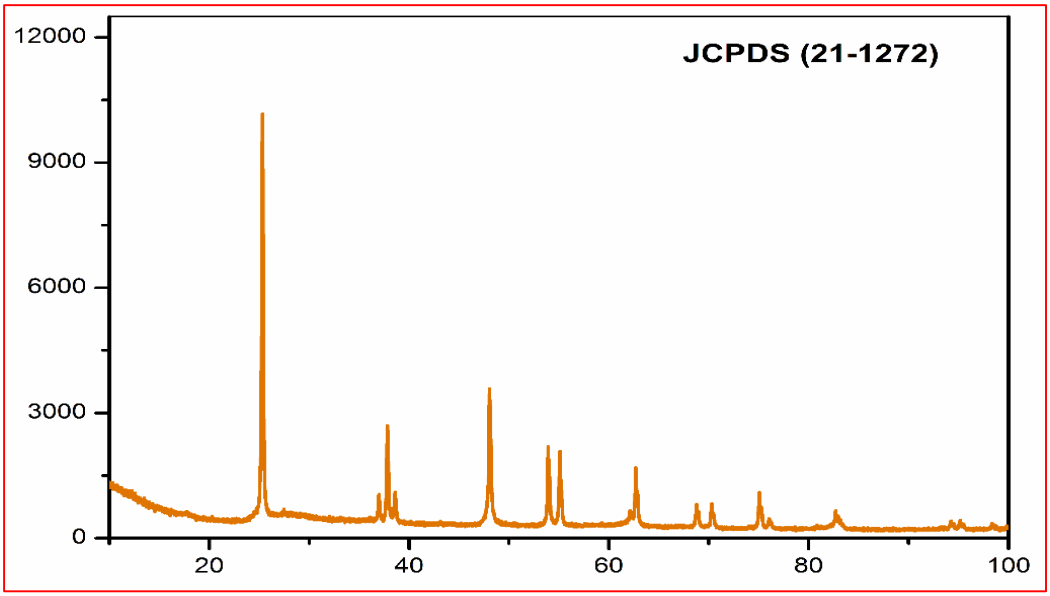


Figure. 2. XRD pattern of synthesized TiO_2

The scanning electron microscopy (SEM) images show the surface morphology of TiO_2 nanoparticles (**Fig. 3.**) synthesized using Coriandrum sativum (coriander) leaf extract. At lower magnification, the sample exhibits a rough and relatively compact surface with numerous fine particles distributed across the observed region.

The higher-magnification image reveals that the particles are irregular to approximately rounded in shape and tend to form clusters. This aggregation may be associated with interactions between neighbouring nanoparticles and their high surface energy. The observed particle clustering produces a non-uniform surface texture, with visible gaps between some of the aggregates. The morphology suggests that the coriander-mediated synthesis produced finely structured TiO_2 material. Overall, the SEM observations provide useful evidence of the surface morphology and aggregation of the prepared TiO_2 sample.

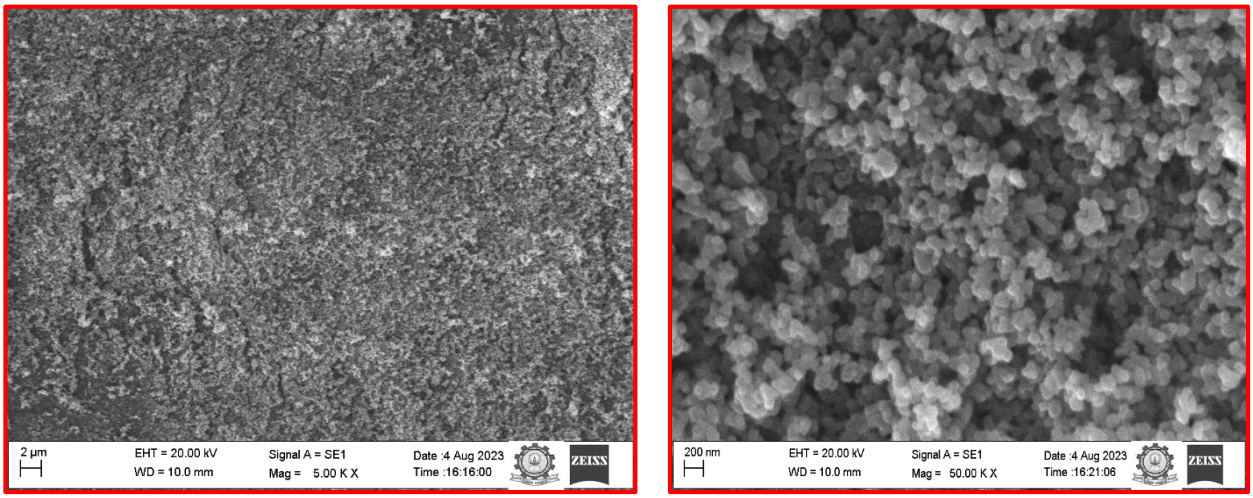


Figure 3. SEM images of TiO_2

The transmission electron microscopy (TEM) images provide a closer view of the size, shape, and distribution of TiO_2 nanoparticles (**Fig. 4.**) synthesized using Coriandrum sativum

(coriander) leaf extract. The lower-magnification image shows that the nanoparticles are distributed in clusters, forming irregular, chain-like aggregates. At higher magnification, the particles appear predominantly quasi-spherical to irregular in shape, with some variation in size. The particles are closely packed, and partial overlapping is visible in several regions, suggesting a tendency for aggregation. The higher-magnification image reveals distinct particle boundaries, indicating the presence of nanoscale particles. The observed aggregation may be related to the high surface energy of the nanoparticles and interactions between neighbouring particles during synthesis and sample preparation. Overall, the TEM images support the formation of nanoscale TiO_2 particles using coriander leaf extract.

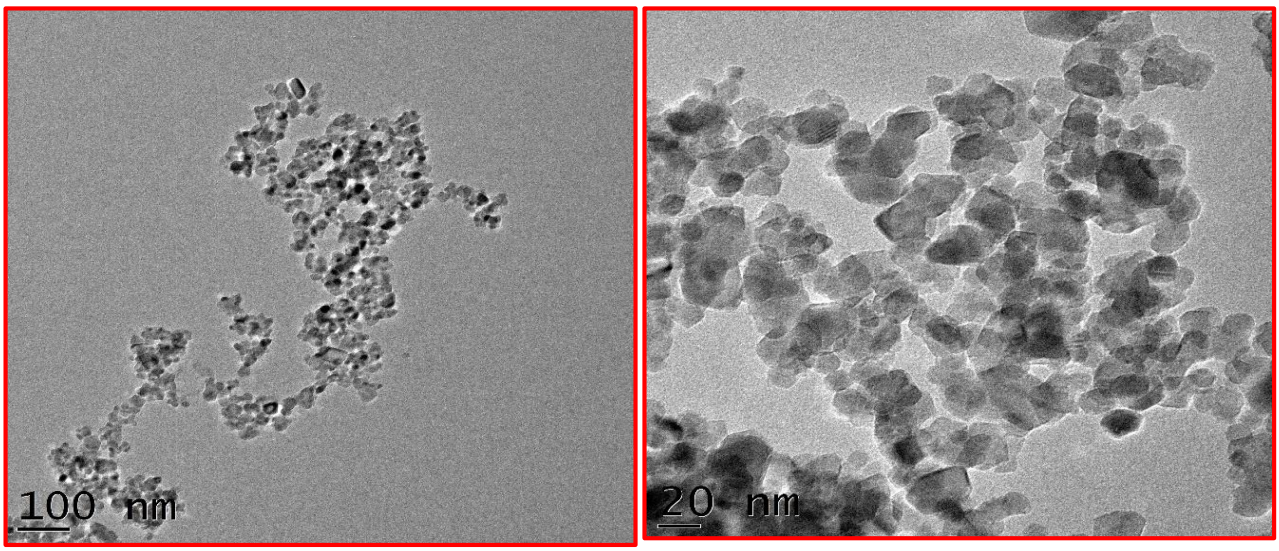


Figure 4. TEM images TiO_2

Conclusion:

In this study, TiO_2 nanoparticles were successfully prepared using *Coriandrum sativum* (coriander) leaf extract through a plant-mediated synthesis approach. The synthesized nanoparticles were characterized using FTIR, XRD, SEM, and HRTEM to understand their functional groups, crystalline structure, and morphology. The FTIR results indicated the presence of Ti-O/Ti-O-Ti bonds and surface hydroxyl groups, while the XRD pattern provided evidence of crystalline TiO_2. The SEM and HRTEM images revealed irregular to quasi-spherical nanoparticles with a tendency to form aggregates. These results demonstrate the feasibility of using coriander leaf extract as a renewable botanical resource for preparing TiO_2 nanoparticles. Overall, this approach offers a promising alternative for plant-mediated nanoparticle synthesis. Overall, the biogenic TiO_2 nanoparticles developed using *Coriandrum sativum*, which make them promising candidates for a variety of biomedical, environmental, and industrial applications such as water purification, cosmetics, food preservation, cement and pharmaceutical formulations.

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