SciTech Research Journal, 8(3) : September-December 2025
(ปีที่ 8 ฉบับที่ 3 กันยายน-ธันวาคม 2568)

The Biopreparation and application of titanium dioxide nanoparticles from *Moringa oleifera Lam.* Leaf extracts

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Received	Reviewed	Revised	Accepted
27/06/2025	25/11/2025	07/12/2025	08/12/2025

Abstract

This research to study the preparation of titanium dioxide nanoparticles (TiO2 NPs) using leave extracts of *Moringa oleifera Lam*. The synthesized titanium dioxide nanoparticles were characterized by using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and Zeta particle size analysis. The formation of the synthesized TiO_2 nanoparticles from the XRD spectra when compared with the confirmed standard spectra of titanium particles formed in the present experiments was in the form of nanocrystals, as evidenced by the peaks at 2theta of 24.9157° and 27.9629°. The FTIR spectrum of TiO_2 nanoparticles displayed a prominent peak at 593 cm^{-1}. SEM analysis of the synthesized TiO_2 nanoparticles clearly showed that they were in clusters and irregular shape. The particle size analysis was found to be 238.9–381.5 nm. The degradation of methylene blue dye, titanium with nanoparticle size was tested. Can remove up to 97.4% of dye. This method represents a new alternative method for preparing environmentally friendly and low-cost nanoscale metals.

Keywords: Titanium dioxide nanoparticles; Green synthesis; *Moringa oleifera* Lam; Photocatalytic activity

Introduction

Nanotechnology involves the science and technology of designing, manipulating, fabricating, and characterizing materials, devices, and systems at the nanoscale, typically ranging from 1 to 100 nanometers. The field encompasses the development of tools and techniques for the precise positioning of atoms and molecules, enabling the highly accurate construction of structures at the atomic or molecular level. Nanostructures often exhibited unique physical, chemical, or biological properties that differ significantly from those of bulk materials, opening up a wide range of applications in areas of medicine, electronics, energy, and materials science (Girigoswamia, *et al*., 2024; Atiek, *et al*., 2024).

Among various metal oxide nanoparticles, titanium dioxide (TiO_2) nanoparticles are particularly interesting semiconductors due to their unique properties and wide-ranging technological applications. These include the chemical degradation, biosensing, photocatalysis, memory devices, solar cell sensors, superhydrophilicity, and antibacterial activity. The anatase phase of TiO_2 specifically exhibits a lower electron-hole recombination rate and higher surface adsorption capacity compared to the brookite phase, making it a more effective photocatalyst. Furthermore, doping TiO_2 with alkali metal oxides has been shown to enhance its catalytic efficiency. Such doping introduces defects into the crystal lattice, which serve as active sites that improve photocatalytic performance by facilitating better charge separation and increasing surface reactions (Teerakarunwong, 2012), Sérgio Antunes Filho et al., 2023). Plant extracts and essential oils contain diverse bioactive molecules that can be used in the synthesis of nanomaterials. These natural products have garnered considerable attention due to their role in green synthesis processes, which aim to reduce the adverse impacts associated with the use of hazardous or toxic chemicals commonly involved in conventional synthesis methods. Although plant extracts and essential oils have been used in certain cases for the synthesis and stabilization of nanomaterials, the inherent chemical complexity of these natural substances remains a challenge. There is still limited research specifically identifying the individual molecules within these extracts or oils that play a critical role in enhancing the efficiency of the synthesis process and influencing key characteristics of nanomaterials, such as size, morphology, and stability. Therefore, a deeper understanding of the relationship between the chemical composition of natural extracts and the resulting properties of nanomaterials is essential for the development of more environmentally friendly and efficient nanotechnology solutions (Busani Moyo et al., 2011)

Moringa (*Moringa oleifera* Lamarck) is a deciduous tree native to South Asia, belonging to the family Moringaceae. This rapidly growing, drought-tolerant tree thrives even in poor soil, reaching heights of up to 15 meters with a trunk diameter of 20–40 cm at breast height. Moringa produces dry, triangular-shaped pods that facilitate easy wind dispersal of its seeds. This plant is found both in the wild and widely cultivated in lowland areas, particularly in fences and home gardens. It grows best in tropical island climates.

Moringa is an important food crop, widely recognized as a "natural food of the tropics." Its leaves, fruits, flowers, and young pods are consumed as highly nutritious vegetables in many countries, particularly India, Pakistan, the Philippines, Hawaii, and various parts of Africa. Reports indicate that moringa leaves are a rich source of beta-carotene, protein, vitamin C, calcium, and potassium, and serve as a good source of natural antioxidants. These antioxidants, including ascorbic acid, flavonoids, phenolics, and carotenoids, help extend the shelf life of fat-containing foods. Additionally, moringa can be used to increase breast milk production in women and is sometimes prescribed for anemia (Velayutham et al., 2012)

In this study, TiO_2 nanoparticles were synthesized using *Moringa oleifera* Lam. leaf extract and characterized by using various photophysical techniques. These included scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), UV-visible spectrophotometry, and zeta potential analysis to evaluate their stability in an aqueous environment. Phytochemical analysis of the *Moringa* leaf extract was also performed, and the biocompatibility of the synthesized nanoparticles was assessed.

Methodology

Materials

The materials were used in the research as distill water. The leaves of *Moringa oleifera.* were collected from Mahasarakham province, Thailand. Titanium dioxide (TiO_2 purity 99.0%) was purchased from Carol Erber.

Synthesis of titanium dioxide nanoparticles

To prepare the *Moringa* leaf extract, 10 g of washed leaves were removed from their stems and placed into a 250 ml Erlenmeyer flask. One hundred milliliters of sterile double-distilled water was added, and the mixture was boiled for 10 minutes. The extract was then filtered using Whatman No. 1 filter paper and stored at −15°C for up to one week. For nanoparticle synthesis, 20 ml of the prepared extract was combined with 80 ml of 5 mM solution (39.94 mg TiO_2 powder in 100 ml Milli-Q water) in an Erlenmeyer flask. This mixture was stirred continuously at 50°C for 4 hours. After stirring, the sample flask was left to allow precipitation, and the supernatant was decanted. The remaining precipitate was transferred to a Petri dish and incubated at 50°C for 72 hours (Velayutham, *et al*., 2012).

Photocatalytic activity

The photocatalytic degradation of methylene blue was performed by green synthesized titanium dioxide nanoparticles (TiO_2 NPs). methylene blue solution 50 ppm in distilled water. Frist step, 0.1 g of TiO_2 NPs was added in 5 ml of methylene blue solution. Set aside at room temperature at different time intervals for 1, 5,10,15 and 20. In our photocatalytic degradation experiment, bright sunlight acts as a major light source. At different time intervals, the collected samples were centrifuged at 4,000 rpm for 15 min. The absorption spectra of the reaction solution were recorded at room temperature using Perkin-Elmer double beam spectrophotometer in the range of 250-750 nm. The rate constant of the absorbance at 665 nm a function of time**.** Then change from TiO_2 NPs to TiO_2 control.

Characterization

Powder X-ray diffraction (XRD) patterns were collected using a Bruker D8 ADVANCE diffractometer with monochromatic Cu K**α** radiation. Diffuse reflectance spectra were recorded on a Perkin-Elmer double beam spectrophotometer. Infrared spectra were measured using the KBr disk method on a Perkin-Elmer Spectrum One FT-IR spectrophotometer. Scanning electron microscopy (SEM) images were obtained from a Coax Group Corporation LTD. Model TN3030 S/N 145045-05. Particle characteristics, including zeta potential, were measured using an Electrokinetic Analyzer for Solid Surface Analysis: SurPASS 3

Results and discussion

Scanning electron microscopic (FE-SEM) : Surface characterization of the synthesized nanoparticles using FE-SEM. The microscopic images showed nanoscale TiO_2 particles with detailed surface morphology of nanoparticles (NPs). The nanoparticles had irregular morphology, were poorly dispersed, and were agglomerated. The agglomeration made it difficult to study individual nanoparticles. The particle size distribution was shown in **Figure 1.** Therefore, the size of titanium at the nanoscale was studied using Zetasizer Nano ZS analysis technique.

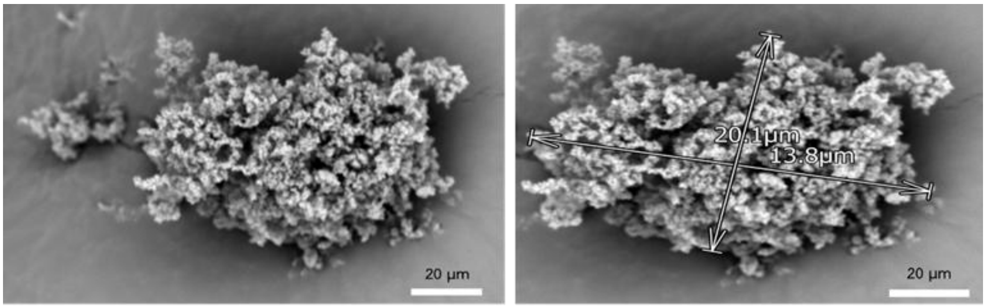

Figure 1. Scanning electron microscopic observation of synthesized TiO_2 nanoparticles

Zetasizer Nano ZS analysis : Bio-reduction activity of leaf extract of *Moringa oleifera* Lam. resulted in synthesis of TiO_2 NPs is found average particle size to be 238.9–381.5 nm, Pdi 0.351-0.398. **Figure2.** demonstrated the size and irregular shape at 50 °C. TiO_2 nanoparticles can be synthesized at room temperature in aqueous medium by Kaempferol (flavonoids) and Anthocyanin (Nweze et al., 2014), Piyush Kashyap et al. 2022) reduction *Moringa oleifera* Lam. leaf extract acts as an electron donor and stabilizer to prevent aggregation into larger particles.

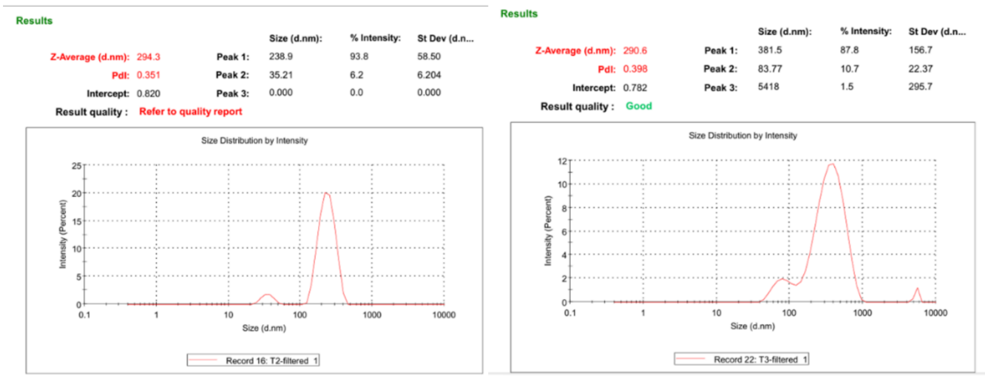

Figure 2. Zetasizer Nano ZS analysis of titanium dioxide nanoparticles.

Kaempferol and anthocyanins possess strong antioxidant properties and are therefore likely to play an important role in reducing Ti^{4+} to Ti^{0}. The hydroxyl groups in the structures of anthocyanins and kaempferol act as electron donors to Ti^{4+}, facilitating the reduction reaction. During this process, the hydroxyl groups on the flavonoid compounds are oxidized (Somchaidee and Tessri, 2018) Show in **Figure 3.**

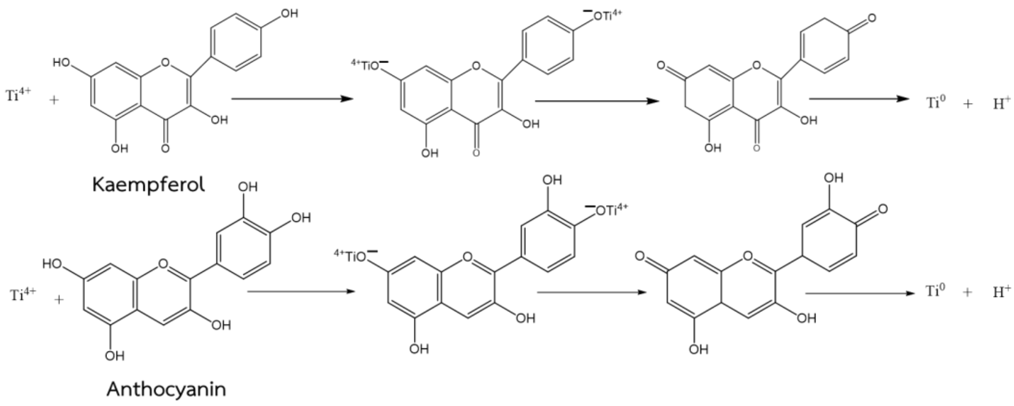

Figure 3. Reduction reaction of Ti^{4+} using Kaempferol (flavonoids) and anthocyanin as electron donors.

Fourier transform infrared (FT-IR) spectra analysis : The FT-IR spectra was record at 400-4000 cm^{-1}. The absorption peak between 500–600 cm^{-1} corresponds to the Ti-O stretching **(Figure4(a))** (J M Abisharani et al. (2020)). The FT-IR spectra of extracts from leaves of *Moringa oleifera* Lam.-TiO_2 which confirmed the presence of various function groups, which involved the structure of flavonoids absorption at 3306.81-3424.62 cm^{-1} namely O-H stretch, 3445 cm^{-1} N–H stretching, 1626.69-1733.13 cm^{-1} C=O bending vibrations, 593 cm^{-1} are contributions to Ti–O stretching vibrations **(Figure4(b-c)** (Thummajitsakul & Silprasit., 2022, Renu Sankar et al., 2015)

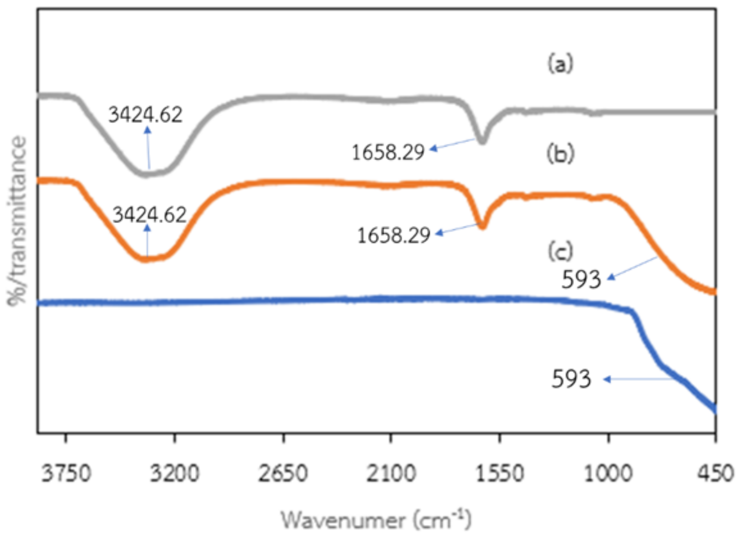

Figure 4. Fourier-transform infrared spectroscopy (FT-IR) spectrum of of extract of *Moringa oleifera* Lam.(a), extract of *Moringa oleifera* Lam.-TiO_2 (b), TiO_2(c)

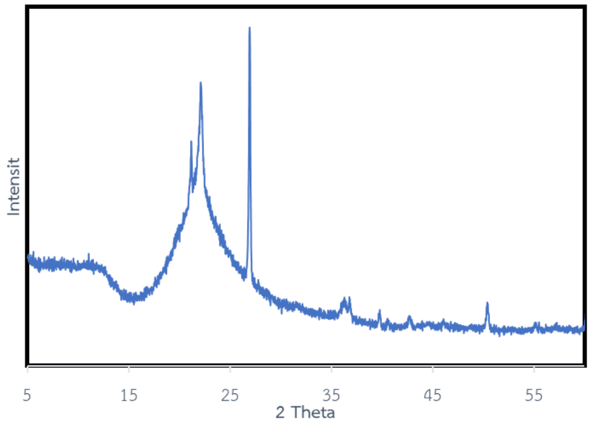

Figure 5. XRD patterns of TiO_2 nanoparticles.

Figure5. show the XRD patterns of TiO_2 NPs. The X-ray diffraction peak at 24.9157° is indicative of the crystal plane of anatase (TiO_2) (L.F.A. Anand Raj et al., 2025) and peak at 27.9629° indicating TiO_2 in the rutile phase. All observed XRD peaks match well with the standard diffraction patterns of TiO_2, as referenced by JCPDS No. 88-1175 and 84-1286 (Thamaphat et al., 2008)

Photocatalytic activity

The photocatalytic reduction of Methylene Blue (MB) using 0.1 g of TiO_2 (control) and TiO_2 nanoparticles (NPs) was evaluated by monitoring the absorbance at 664 nm. The study was conducted at an initial MB concentration of 50 ppm. After 20 minutes of light exposure, 97.4% of MB remained when treated with TiO_2 NPs, compared to 85.15% remaining with the TiO_2 control (**Figure6**.). These results indicate that TiO_2 NPs exhibit superior photocatalytic degradation performance compared to the bulk TiO_2. This improvement is attributed to the smaller particle size of the TiO_2 NPs, which leads to a higher surface area and consequently enhances photocatalytic efficiency.

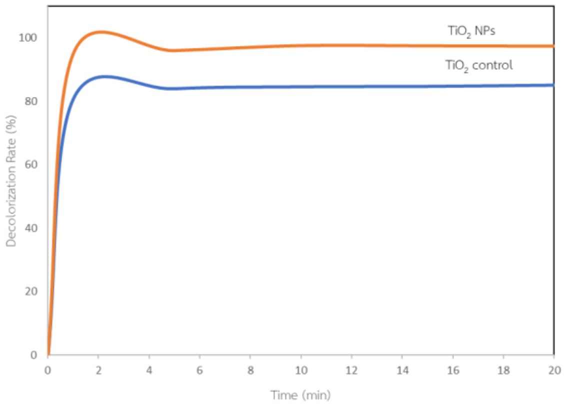

Figure 6. Degradation efficiency of TiO_2 (control) and TiO_2 nanoparticles (NPs).

Conclusion

In the present biosynthesis, *Moringa oleifera* Lam. an environmentally benign and renewable resource, was utilized as an effective reducing agent for the green synthesis of TiO_2 nanoparticles (NPs). This biological approach represents a promising and sustainable alternative for metal nanoparticle production, supporting the development of clean, non-toxic, and eco-friendly synthesis methods. The use of plant-based systems, including higher plants, offers a scalable and environmentally acceptable route to nanoparticle fabrication. The resulting TiO_2 NPs demonstrated high stability and exhibited notable antiparasitic activity.

Acknowledgements

This research was supported by Department of chemistry, Faculty of Science and Technology and Research and Development Institute, Rajabhat MahaSarakham University, MahaSarakham, Thailand

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