



# Green Synthesis Of Titanium Dioxide Nanoparticles Using *Balanites Aegyptiaca* Fruit Pulp Extract And Its Characterization

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## Abstract:

This study reports the green synthesis of *Balanites aegyptiaca* fruit pulp extract with Titanium dioxide (TiO<sub>2</sub>) nanoparticles. The biosynthesized extract from the fruit pulp resulted in a solution with a honey-like colour. UV-Vis spectroscopy revealed a sharp absorption peak at 304 nm, characteristic of bioactive compounds present in fruit pulp extract. The FTIR spectrum of biosynthesized fruit pulp extract with TiO<sub>2</sub> Nps clearly shows different bioactive compounds (flavonoids, alkaloids, terpenoids, phenolic compounds, etc) present in the green synthesized fruit pulp extract of *Balanites aegyptiaca*. XRD showed anatase-phase TiO<sub>2</sub> with an average crystallite size of 10–30 nm. The SEM revealed a highly porous nanostructured surface with pores and particles in oval shape, sizes in the range of 50–100 nm. while EDS confirmed elemental purity with a Ti:O atomic ratio close to 1:2, suggesting the presence of oxygen vacancies that can enhance photocatalytic activity. The results establish green synthesis as a sustainable and efficient approach for producing biosynthesized products with potential applications in photocatalysis, antimicrobial activity, anticancer, anti-inflammatory, antioxidant etc.

**Keywords:** *Balanites aegyptiaca* fruit pulp extract, Titanium dioxide nanoparticles.

## Introduction:

Global research studies give a great interest to green nanotechnology, as green nanotechnology is a resultant field and nascent branch of nanotechnology. Green nanotechnology is the perfect solution to decrease the negative effects of the production and application of nanomaterials, lowering the nanotechnology riskiness [1]. Nanoparticles exhibit improved and new features based on certain traits like size, distribution, and form. Due to their small size and unique features relative to the material's bulk form, nanoparticles have been greatly advanced in the disciplines of biosensors, biomedicine, and biotechnology [2]. The eco-friendly synthesis of nanoparticles has seen tremendous progress in nanoscience and its application in a wide range of fields, such as catalysis, antimicrobial [3], anticancer [4], target-specific drug delivery [5], and agriculture [6]. Recently, several biosynthesis methods have been suggested in order to develop potential sustainable synthesis techniques to reduce the use of hazardous materials for nanomaterials [7]. The structure of inorganic nanoparticles, showing significantly novel and enhanced features due to their nanoscale sizes, has gained great interest [8,9].

TiO<sub>2</sub> is well known among metal oxides as a multifunctional material that plays an essential role in a variety of applications due to its good physical stability and non-toxicity [10]. Anatase, rutile, and brookite are the three main polymorphs of TiO<sub>2</sub> nanostructure. Anatase TiO<sub>2</sub> has a high catalytic activity due to its large surface area, high molecular oxygen adsorption capacity, and low rate of electron-hole pair recombination [11].

This study demonstrates that the synthesis of TiO<sub>2</sub>NPs using *Balanites aegyptiaca* fruit pulp extract is reported for the first time. *Balanites aegyptiaca* is commonly known as a "desert date" or Hinghot. It persists in dry areas and shows growth in very low-lying areas. It can grow in a wide variety of soils, from sand to heavy clay. It belongs to the Zygophyllaceae family. It is commonly observed in northern and eastern Africa, including Egypt, and in India, its primary presence is in Rajasthan and near the Aravali Hills of Haryana, India. While it can adapt to various environments, it flourishes in low-lying, semidesert regions with deep sandy loam and unobstructed access to water, such as depressions, riverbanks, or the base of rocky hillsides. The phytochemicals in *Balanites aegyptiaca* are responsible for several medicinal properties like antioxidant, [12–17] antimicrobial, anticancerous activities, antidiabetic [18,19] and several other protective activities. There is no report of the use of *Balanites aegyptiaca* fruit pulp extract for the synthesis of TiO<sub>2</sub>NPs.

## Materials and methods:

### Sample collection: (Materials)

The Fruits of *Balanites aegyptiaca*, used as the green source in this synthesis process (Fig. 1), were procured from an authenticated ayurvedic shop, Kurnool. It was taxonomically authenticated by Dr Dande Swana Sree, Department of Botany, and a voucher specimen was deposited in the Herbarium of Cluster University, Silver Jubilee Government College (A), Kurnool. The collected fruits were stored at room temperature until further use. The chemicals were used as received from the vendor without further purification.



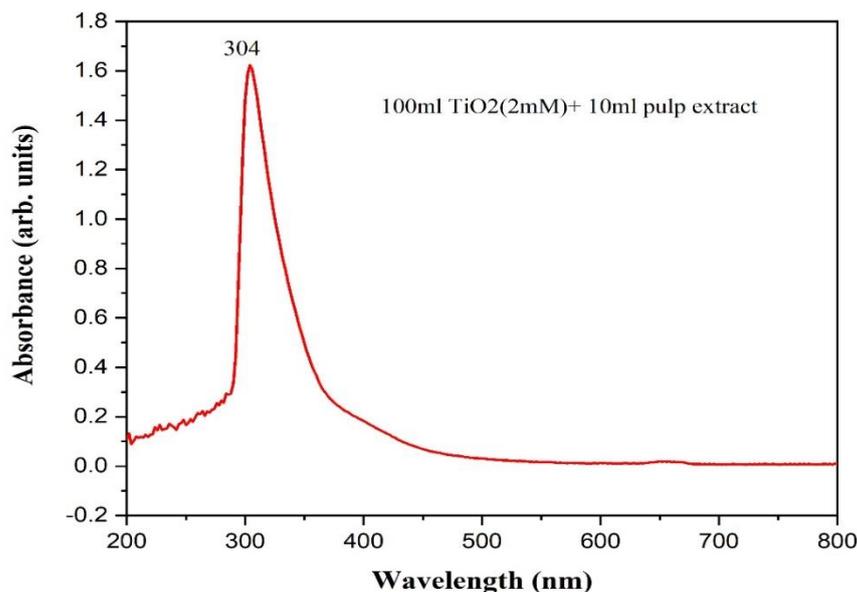
Fig 1. *Balanites aegyptiaca* fruits, pulp, Fruit pulp extract Biosynthesized TiO<sub>2</sub>NPs

### Preparation of the *Balanites aegyptiaca* fruit pulp extract:

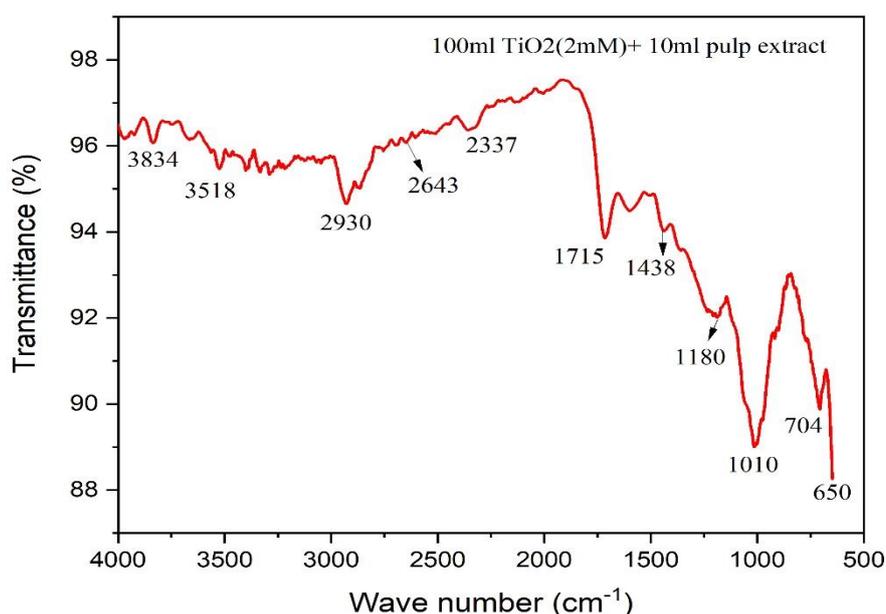
The *Balanites aegyptiaca* fruit pulp was scratched from the fruits using a sharp-edged knife, as shown in Fig. 1. The collected fruit pulp was stored in a container. Then, 50 g of fruit pulp was macerated in 300 mL of ethanol for 20 days for solvent extraction. Then the extract was taken out, and excess ethanol was removed by a simple distillation method. The ethanolic fruit pulp extract of *Balanites aegyptiaca* was stored in a refrigerator at 4°C for further use. The fruit pulp extract colour was a dark maroon red colour.

### Biosynthesis of *Balanites aegyptiaca* Fruit pulp extract with Ethanolic solution TiO<sub>2</sub> NPs:

The prepared *Balanites aegyptiaca* fruit pulp extract was utilized for the biosynthesis of TiO<sub>2</sub> NPs. We first prepared 100 mL of a 2 mM ethanolic solution of TiO<sub>2</sub>. A partial turbidity solution was formed, so 10 mL of HCl was added for solubility. Then, 10 mL of isolated fruit pulp extract was placed into a conical flask. The flask was then placed on a magnetic stirrer. 100 mL (2 mM) of TiO<sub>2</sub> nanopowder solution was added dropwise to the pulp extract. The biosynthesis of *Balanites aegyptiaca* fruit pulp extract dark maroon red colour changes to honey-like colour. The biosynthesized *Balanites aegyptiaca* with TiO<sub>2</sub> NPs product solution was further analyzed for characterisation of UV, FT-IR, XRD, and SEM, EDS.

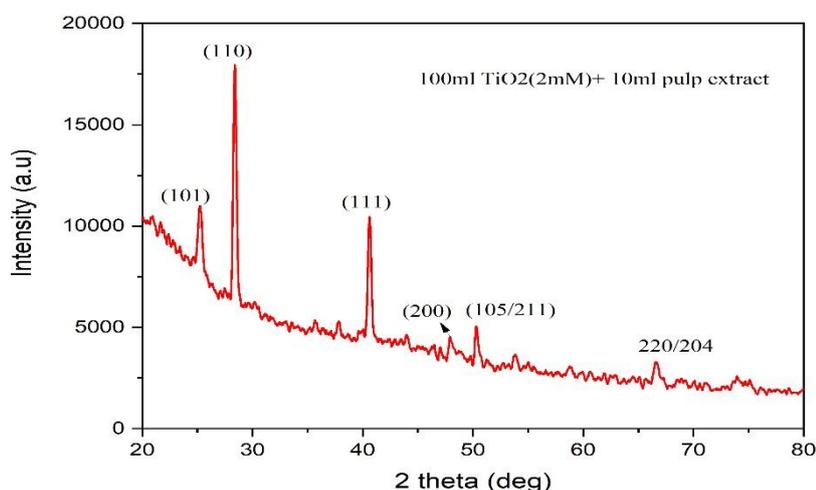
**Results and discussion:****UV–Visible Spectroscopic Analysis:****Fig. 2 UV–Vis spectrum of fruit pulp extract of *Balanites aegyptiaca* biosynthesised with TiO<sub>2</sub> Nps**

UV–Vis spectrum of fruit pulp extract of *Balanites aegyptiaca* biosynthesised with TiO<sub>2</sub> Nps was shown in Fig. 2. UV–Visible spectral analysis of fruit pulp extract of *Balanites aegyptiaca* biosynthesized with TiO<sub>2</sub> NPs reveals that the surface plasmon resonance (SPR) sharp absorption peak at 304 nm wavelength, which confirms the successful honey-like colour fruit pulp extract biosynthesis of TiO<sub>2</sub> NPs. The position and intensity of the absorption peak correlate with nanoparticle size and some times shape, and sharper peak shows that uniform and smaller particles. While broader peak indicate dispersity or agglomeration. Shifts in the SPR peak over time may indicate aggregation or stability of nanoparticles in fruit pulp extract medium. The fruit pulp extract has biomolecules, phenolics, flavonoids, and terpenoids act as reducing and capping agents. Their interaction can cause shift or intensity changes in the UV-VIS spectrum, providing indirect evidence of stabilization of biosynthesized nanoparticles.

**Fourier Transform Infrared Spectroscopic Analysis (FTIR):****Fig. 3 FTIR spectrum of fruit pulp extract of *Balanites aegyptiaca* biosynthesised with TiO<sub>2</sub> Nps**

The FTIR spectrum of fruit pulp extract of *Balanites aegyptiaca* biosynthesized with TiO<sub>2</sub> Nps was shown in Fig.3. FTIR spectroscopic data shows that the fruit pulp extract of *Balanites aegyptiaca* mediated nanoparticle synthesis mainly indicates about the functional groups of biomolecules involved in reduction, capping and stabilization of TiO<sub>2</sub> nanoparticles. The FTIR spectrum of biosynthesized fruit pulp extract with TiO<sub>2</sub> Nps clearly shows different bioactive compounds present in the green synthesized fruit pulp extract of *Balanites aegyptiaca*. The FTIR spectrum exhibited a broad absorption band at 3834 cm<sup>-1</sup> & 3518 cm<sup>-1</sup>, corresponding to O–H stretching vibrations of hydroxyl groups (alcohols, phenols). This suggests the presence of plant phytochemicals and surface hydroxyl groups on TiO<sub>2</sub>, and peaks at 2930 cm<sup>-1</sup> & 2643 cm<sup>-1</sup> corresponding to the C-H stretching of alkanes from bioactive compounds (such as flavonoids, alkaloids, terpenoids, glycosides). The sharp peak at 1715 cm<sup>-1</sup>, corresponds to the C=O stretching vibration of carbonyl groups, present in aldehydes, ketones, esters, or carboxylic acids (common in flavonoids, phenolic, alkaloids, terpenoid compounds). Peak at 1438 cm<sup>-1</sup> shows C–C stretching of aromatic rings or O–H bending of phenolic groups. The peaks at 1180 cm<sup>-1</sup> and 1010 cm<sup>-1</sup> indicates C–O stretching vibrations of alcohols, esters, or ethers often come from polysaccharides and other phytochemicals acting as capping/stabilizing agents and the peaks at 704 cm<sup>-1</sup> and 650 cm<sup>-1</sup> indicates strong peaks in the low wavenumber region correspond to Ti–O–Ti stretching vibrations, confirming the formation of TiO<sub>2</sub> nanoparticles [20].

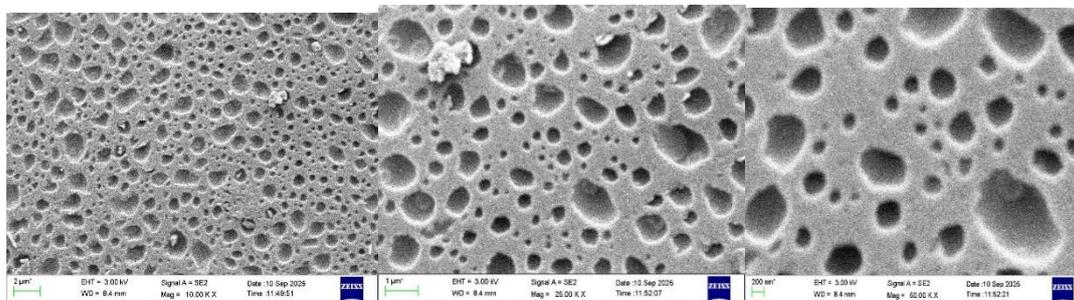
### X-ray Diffraction (XRD):



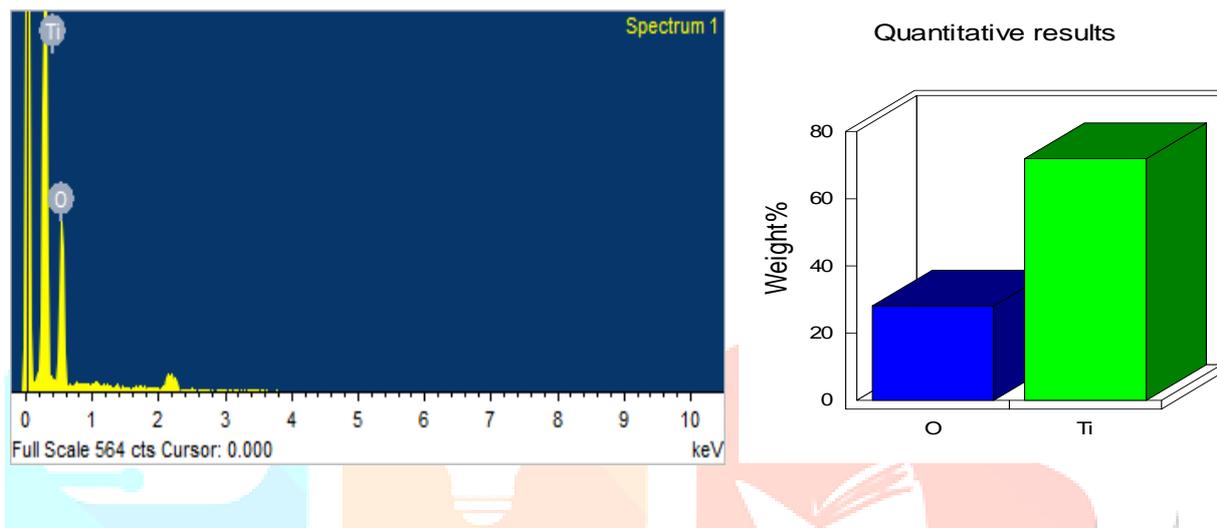
**Fig. 4 XRD pattern of fruit pulp extract of *Balanites aegyptiaca* biosynthesized with TiO<sub>2</sub> Nps**

The analysis of the X-ray diffraction of the fruit pulp extract of *Balanites aegyptiaca* biosynthesized with TiO<sub>2</sub> Nps shown in Fig. 4. The X-ray diffraction analysis mainly indicates about the crystalline nature and size of TiO<sub>2</sub> NPs. The sharp and intense diffraction peaks at (110) and (111) confirm the formation of highly crystalline nanoparticles. The Bragg diffraction angle and XRD peaks have Miller indices of  $2\theta = 25.19, 28.36, 40.72, 47.94, 50.30,$  and  $66.72$  for (101), (110), (111), (200), (105/211), and (220/204) respectively, which confirms the crystalline nature of the fruit pulp extract biosynthesized TiO<sub>2</sub> NPs. By matching experimental peaks with XRD data the phase anatase, rutile was identified. The most intense peaks to calculate the average crystallite size was found to be in the range of 10 – 30 nm, for green synthesized and the diffraction pattern revealed the anatase phase of the developed TiO<sub>2</sub> fruit pulp of *Balanites aegyptiaca* with TiO<sub>2</sub> nanoparticles by the Scherrer equation.

## Scanning Electron Microscope (SEM):



**Fig. 5 SEM images of fruit pulp extract of *Balanites aegyptiaca* biosynthesised with TiO<sub>2</sub> Nps**



**Fig. 6 EDS (Energy Dispersive X-ray Spectroscopy)**

Field Emission Scanning Electron Microscopy (FESEM) was employed to examine the morphology, surface features fruit pulp extract of *Balanites aegyptiaca* biosynthesised with TiO<sub>2</sub> NPs at various magnifications, as shown in Fig. 5. The micrograph revealed a highly porous nanostructured surface with pores and particles of varying sizes, in the range of 50–100 nm. The distribution of pores and the presence of agglomerated clusters indicate that the plant extract played a crucial role in controlling the growth and stabilization of the nanoparticles. Such mesoporous morphology provides a higher surface area and more active sites of TiO<sub>2</sub> NPs.

The elemental composition was confirmed by Energy Dispersive X-ray Spectroscopy (Fig. 6). The spectrum showed two major peaks corresponding to titanium (Ti) and oxygen (O), with no additional impurity peaks detected, confirming the purity of the synthesized material. Quantitative EDS analysis revealed Ti (71.88 wt%, 46.06 at%) and O (28.12 wt%, 53.94 at%), giving an approximate atomic ratio of 1:2 (Ti:O), which is consistent with stoichiometric TiO<sub>2</sub>, suggesting the presence of oxygen vacancies. These defects are known to enhance the photocatalytic efficiency of TiO<sub>2</sub> by improving charge carrier separation and increasing surface reactivity. Overall, the SEM and EDS analyses confirm that the synthesized nanoparticles are porous, nanostructured, and compositionally pure TiO<sub>2</sub> with beneficial oxygen vacancies that may enhance their functional performance in environmental and biomedical applications.

### Conclusions:

In this study, the fruit pulp extract of *Balanites aegyptiaca* biosynthesized with TiO<sub>2</sub> nanoparticles were successfully synthesized via a green route. The present work successfully demonstrated an eco-friendly, cost-effective, and sustainable approach for the biosynthesis of titanium dioxide nanoparticles using fruit pulp extract *Balanites aegyptiaca* as a natural reducing and stabilizing agent. The nanoparticles were confirmed by UV–Vis, FTIR, XRD, SEM, and EDS analyses. The surface plasmon resonance (SPR) sharp absorption peak at 304 nm wavelength, which confirms the successful honey-like colour fruit pulp extract biosynthesis of TiO<sub>2</sub> NPs. The FTIR spectrum of biosynthesized fruit pulp extract with TiO<sub>2</sub> Nps clearly shows different bioactive compounds (flavonoids, terpenoids, alkaloids, glycosides) present in the green

synthesized fruit pulp extract of *Balanites aegyptiaca*. XRD data showed anatase, rutile phase was identified, and most intense peak to calculate an average crystallite size of 10–30 nm. The SEM revealed a biosynthesized product morphology and high surface features were highly porous nanostructures, and porous nanoparticles sizes, in the range of 50–100 nm. while EDS confirmed elemental purity with a Ti:O atomic ratio close to 1:2, suggesting the presence of oxygen vacancies that can enhance photocatalytic activity. The study establishes that *Balanites aegyptiaca* fruit pulp extract-assisted synthesis provides an eco-friendly, cost-effective, and sustainable green route for producing TiO<sub>2</sub> nanoparticles with desirable structural and functional properties for potential applications in biomedical fields.

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