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Sol-Gel Synthesis of Nitrogen-Doped Titanium Dioxide (N-Tio2) Nanoparticles as a Nano-Fertilizer for Plant Growth in Agriculture

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SOL-GEL SYNTHESIS OF NITROGEN-DOPED TITANIUM DIOXIDE (N-TiO2) NANOPARTICLES AS A NANO-FERTILIZER FOR PLANT GROWTH IN AGRICULTURE

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Abstract:

Nitrogen-doped titanium dioxide (N-TiO_2) nanoparticles were synthesised using the sol-gel method for sustainable agriculture as nano-fertilisers, which help plants to uptake soil nutrients. Pure TiO_2 nanoparticles and nitrogen-doped TiO_2 nanoparticles in different ratios (1:1 and 1:2) were synthesised. The structural, optical and morphological properties of nitrogen-doped TiO_2 (N-TiO_2) nanoparticles were investigated by X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR) spectroscopy, UV-vis Diffusion Reflectance Spectroscopy (UV-DRS), Scanning Electron Microscope (SEM) and Electron Dispersive X-Ray analysis (EDX). XRD peaks confirm the presence of anatase and brookite structures for the pure TiO_2 and N-TiO_2. The FT-IR analysis shows the presence of TiO_2 in the respective vibration. The SEM studies were carried out to examine the cube-shaped morphological features of N-TiO_2 nanoparticles. The purity of the sample and the atomic percentages of O (30.31) and Ti (69.69) were confirmed by compositional studies of EDAX analysis. The pH value and the total NPK availability were analysed for the pure and nitrogen-doped TiO_2 nanoparticles in different ratios (1:1 and 1:2), and the morphological and biological growth of the plants were observed.

Keywords: Titanium dioxide; Nitrogen-doped; sol-gel method; Plant growth.

1. Introduction:

Nanotechnology is one of the most rapidly advancing technologies of the 21st century, focusing on the design, synthesis, and application of materials at the nanoscale with unique physicochemical properties and enhanced performance. Owing to their exceptionally high surface area-to-volume ratio, nanomaterials exhibit superior optical, electrical, mechanical, catalytic, and biological properties compared with their bulk counterparts. As a result, nanotechnology has attracted considerable attention from researchers worldwide and has found extensive applications in diverse fields, including medicine, drug delivery, environmental remediation, electronics, energy, agriculture, food technology, and cosmetics. [1,2] Nanotechnology has

found extensive applications in [3,4], electrical and electronic industries, medicine, aerospace, and semiconductor devices. In recent years, nanomaterials have also demonstrated significant potential for sustainable agriculture. They are employed as nano-sensors to monitor environmental stress and crop health, as nano-pesticides to enhance resistance against biotic stresses, and as nano-fertilizers to improve nutrient utilization, promote plant growth, and increase crop productivity and yield [5–9]. Nutrient availability is a key factor influencing agricultural productivity. Crop growth, yield, and quality are strongly dependent on the availability of essential nutrients in the soil. The application of fertilizers enhances soil fertility by replenishing nutrient levels, thereby improving crop productivity. Consequently, the efficient use of fertilizers plays a crucial role in sustainable agricultural practices.

Recent studies have demonstrated that titanium dioxide (TiO_2) nanoparticles can serve as effective nanofertilizers by enhancing the uptake and utilization of soil nutrients by plants. The agricultural applications of TiO_2 nanoparticles have been extensively investigated due to their beneficial effects on plant growth and development. These nanoparticles improve photosynthetic efficiency by increasing the levels of photosynthetic pigments, including chlorophyll *a* and *b*, carotenoids, and anthocyanins. Furthermore, TiO_2 nanoparticles promote seed germination, stimulate root and shoot growth, enhance nutrient absorption, and improve plant biomass and crop yield. Owing to these advantages, numerous studies have reported the positive influence of TiO_2 nanoparticles on plant growth and agricultural productivity, highlighting their potential as sustainable nanofertilizers [10]. Other than fertilizers, Titanium dioxide (TiO_2) nanoparticles are also used nano pesticides and for nano sensors in sustainable agriculture. Titanium dioxide (TiO_2) nanoparticles regulate enzymes activity involved in nitrogen metabolism such as nitrate reductase, glutamate dehydrogenase, glutamine synthase, glutamic pyruvic transaminase. These activities help the plants to absorb nitrate and also in conversion of inorganic nitrogen to organic nitrogen in the form of protein and chlorophyl which increases plant biomass. Titanium dioxide (TiO_2) nanoparticles also used as photocatalyst and induces oxidation – reduction reaction [11]. Thus, this reaction promotes chlorophyl formation and stimulate Ribulose 1, 5-bisphosphate carboxylase (Rubisco) activity and increases photosynthesis in plants by inducing marker gene Rubisco activity (RCA) mRNA. Thus, Titanium dioxide (TiO_2) nanoparticles increases rate of photosynthesis of plants, enhance growth by a mass and crop yield by increasing nutrient uptake efficiency. Also, Titanium dioxide (TiO_2) nanoparticles used to increase the germination rate, length of root with improved growth rate [12,13]. Anatase Titanium dioxide (TiO_2) nanoparticles have special photocatalytic characteristic of high light absorbance and thereby transform light energy to electrical and chemical energy and also induces carbon dioxide assimilation [14]. Also, by the application of Anatase Titanium dioxide (TiO_2) nanoparticles there will be increase in whole chain electron transport, O_2 evolving, photophosphorylation activity of chlorophyll under both visible and ultraviolet light and photo reduction activity of photosynthesis II. Thus, application of titanium dioxide (TiO_2) nanoparticles (in low concentration) via roots and leaves will increase crop of certain enzyme activity, enhancing chlorophyll content and photosynthesis, promote mobilization of nutrient, biotic and abiotic stress tolerance and by improving crop yield and quality [15]. For the better light absorbance and for the shift from UV region to

visible light region nitrogen is doped with Titanium dioxide as it increases the photocatalytic activity. Nitrogen atoms are substituted in place of oxygen atom in lattice. Thus, the sol–gel method is a simple, cost-effective, and versatile technique for the synthesis of metal oxide nanoparticles with controlled composition and morphology[16]. In the present study, nitrogen-doped TiO_2 nanoparticles were synthesized using the sol-gel method with urea as the nitrogen source and titanium isopropoxide (TTIP) as the organometallic precursor. The synthesized nanoparticles were systematically characterized using appropriate physicochemical techniques, and their potential application as a nanofertilizer was evaluated by investigating their effects on crop growth and yield.

2. Experimental

2.1. Materials and methods

2.1.1. Chemicals

The chemicals used for the synthesis of Titanium isopropoxide ($C_{12}H_{28}O_4Ti$, 99.0%)), urea (99.5%) and glacial acetic acid from SRL from Merck (P) Ltd., India were procured. Deionized water was employed throughout the experimental procedure.

2.1.2. Synthesis of Titanium dioxide (TiO_2) nanoparticles:

Titanium dioxide (TiO_2) nanoparticles were synthesized by Sol-gel method. For the synthesis of Titanium dioxide TiO_2 nanoparticles, Titanium isopropoxide ($C_{12}H_{28}O_4Ti$) and Glacial acetic acid were used as a precursor. Thereby taking Glacial Acetic Acid, mixed with De ionized water in the molar ratio 10:200 M to form a precursor solution under magnetic stirrer. 1M of Titanium (IV) isopropoxide $C_{12}H_{28}O_4Ti$ was added to the stirrer solution and continuously mixed under magnetic stirrer until the white solution was formed and the gel is separated and subjected to hot air oven for about 7 hours. The dried crystal gel was grinded to powder and calcinated. Calcination was done using Muffle furnace at 500°C for about 5 hours. The prepared pure TiO_2 Nano Particles are collected in vial for further characterization. The preparation of Titanium dioxide (TiO_2) nanoparticles was shown in the **Fig.** 1.

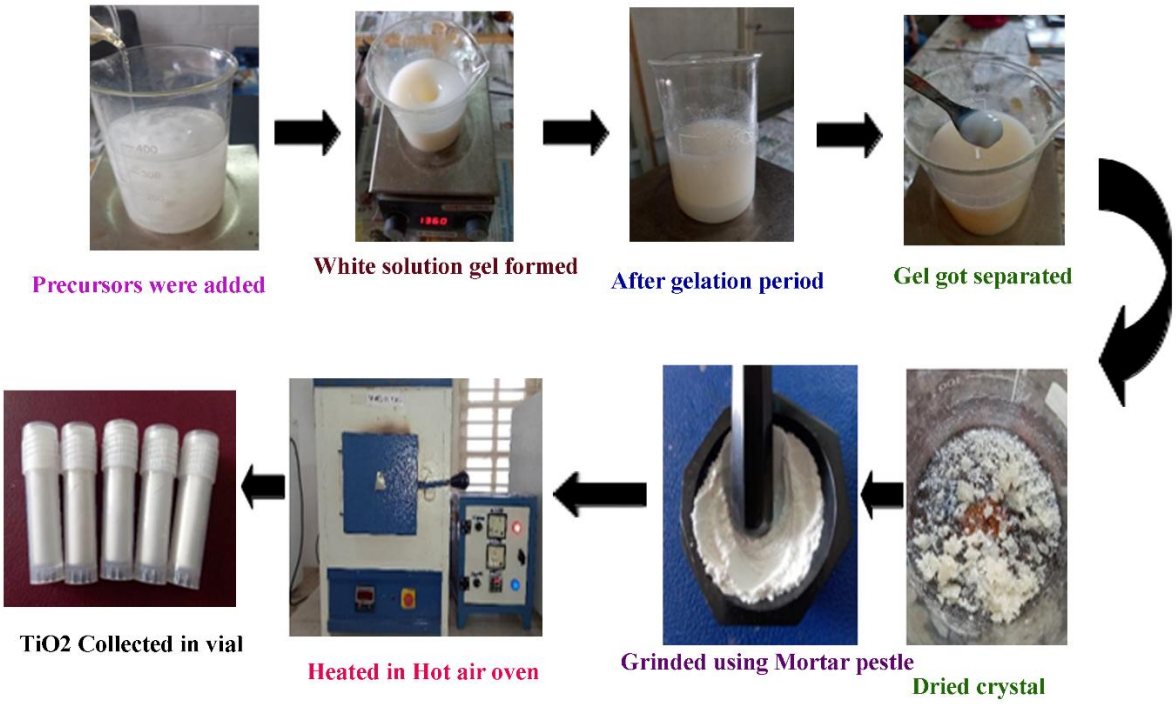


Fig. 1. Photographic procedure for the stepwise synthesis of TiO_2 nanoparticles.

2.1.3. Synthesis of Nitrogen-doped Titanium dioxide (N-TiO_2) Nanoparticles:

Nitrogen-doped titanium dioxide (N-TiO_2) Nanoparticles was prepared by adding Urea to the precursor solution which was said before [taking 10M of Glacial Acetic Acid, mixed with 200M of De ionized water and, 1M of Titanium (IV) isopropoxide $C_{12}H_{28}O_4Ti$]. It was mixed under magnetic stirrer. For the synthesis of dopant of nitrogen with TiO_2, Urea of different molar ratio 1:1, 1:2 (i.e) urea of 6.00 g for 1:1 ratio and urea of 12.01 g for 1:2 ratio was added to the precursor solution. White solution was formed and after the gelation period, the gel is separated and subjected to Hot air oven for about 7 hours. The dried gel (which is in crystal form) was grinded to powder and calcinated. Calcination was done using Muffle furnace at 500^oC for about 5 hours. The prepared N-TiO_2 Nano Particles are collected in vial for the further characterization. The preparation of N-TiO_2 nanoparticles was shown in the **Fig. 2.**

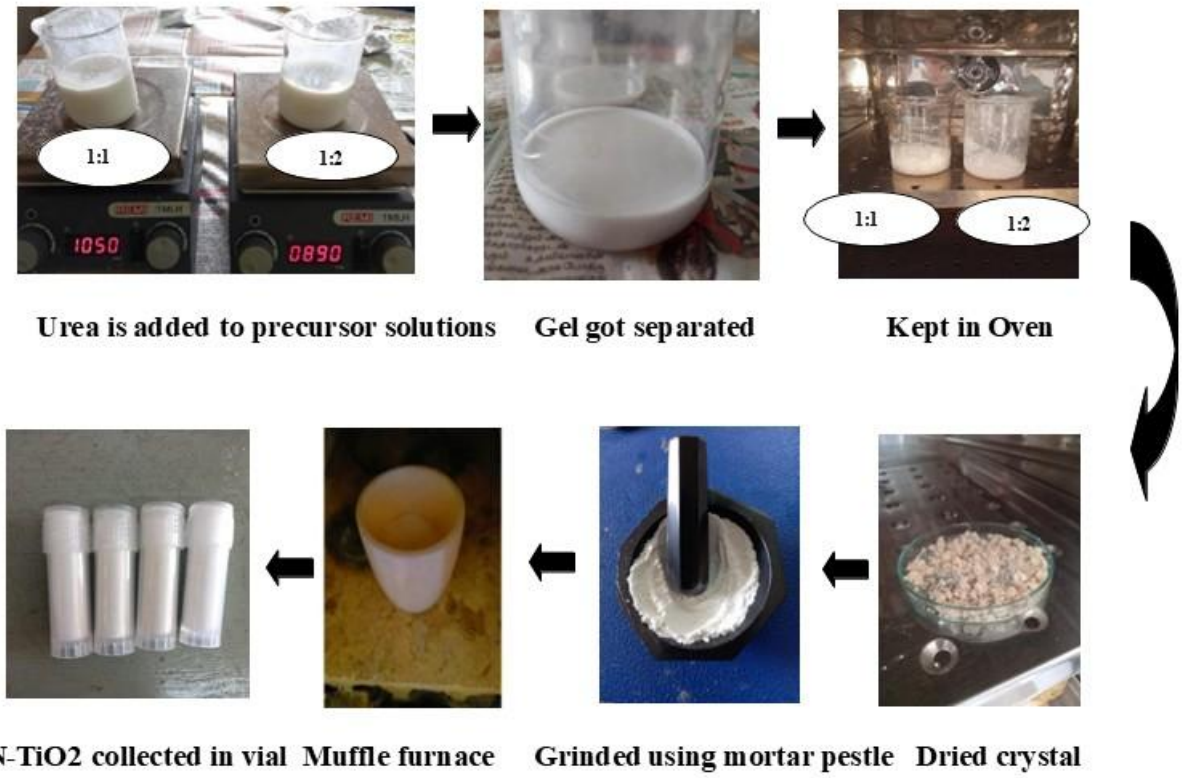


Fig. 2. Photographic procedure for the stepwise synthesis of N-TiO_2 of ratios 1:1 and 1:2.

3. Result and discussion:

3.1. Powder XRD analysis:

3.1.1. XRD analysis of TiO_2 nanoparticles:

X-Ray powder Diffraction (PXRD) studies were carried out to confirm the structure (Crystallinity) using X-ray diffractometer with copper (kα) radiation (λ=1.5418 A^0) in the range of 10^0- 90^0. The XRD Pattern of TiO_2 nanoparticles obtained is shown in **Fig.3.** The peaks in XRD pattern of as prepared TiO_2 sample observed at 25.32^o ,37.87^o, 48.07^o, 53.89^o, 62.84^o, 68.77^o, 75.11^o and 82.69^o. The result show that the structure is a tetragonal structure (**Anatase structure**). The results are match in with the JCPDS card

number (78 – 2486) [17] along with miller indices values (101), (103), (200), (105), (204), (116), (301) and (224) respectively [18]. The first plane of diffraction being (101) indicates that the crystal TiO_2 is a body centered cubic (BCC) crystal. XRD Pattern of the TiO_2 exhibits a predominant plane of (101) corresponds to 2θ equal to 25.32°. The sharp peak shows the high crystalline nature of the sample. The average crystallite size is calculated using Debye Sherrer's equation as mentioned below eq. 1.

$$D = 0.9\lambda/\beta \cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, λ is the wavelength of radiation used, β is the Full Width Half Maximum and θ is the Bragg's angle. D is the average crystalline size of the particles. The average crystallite size is found to be 20.61 nm for TiO_2 nanoparticles. The lattice parameter obtained is a = b = 6.203A° and c = 5.53A° [19].

3.1.2.XRD analysis for N-TiO2 (1:1 ratio) nanoparticles

The XRD Pattern of N - TiO_2 (1:1 ratio) nanoparticles obtained from sol-gel synthesis is shown in **Fig.3.** The major peaks for Nitrogen-doped TiO_2 nanoparticles are reported at 25.59°, 38.08°, 48.31°, 54.18°, 62.93°, 69.124° and 75.37° corresponding to the lattice planes (101), (004), (200), (105), (204), (220) and (215) planes respectively according to Nitrogen-doped TiO_2 JCPDS data of TiO_2 (21- 1272) [20]**.** The result show that the structure is a tetragonal structure (**Anatase structure**). The first plane of diffraction being (101) indicates that the crystal Nitrogen-doped TiO_2 is a body centered cubic (BCC) crystal. It indicates the compatibility of Nitrogen in the TiO_2 crystal planes. The average particle size is found to be 25.99 nm for Nitrogen-doped TiO_2 (1:1 ratio) nanoparticles. The lattice parameter hence calculated a = b = 6.29 A° and c = 5.55A°. The average crystallite size varies slightly for the Nitrogen-doped TiO_2 (1:1 ratio) nanoparticles. Also, the intensity of diffraction by the crystal planes varies for the samples. This possibly may be due the orientation of the planes to the incident X-radiations.

3.1.3.XRD analysis for N -TiO2 (1:2 ratio) nanoparticles

The XRD Pattern of N-TiO_2 (1: ratio) nanoparticles obtained from sol-gel synthesis is shown in **Fig.3**. The major peaks for nitrogen-doped TiO_2 nanoparticles are reported at 25.47°, 38.091°, 48.196°, 54.123°, 62.123°, 70.415° and 75.251° corresponding to the lattice planes (111), (311), (321), (131), (610), (040) and (214) planes respectively according to Nitrogen-doped TiO_2 JCPDS data (76- 1934). The result show that the structure is an orthorhombic structure (**Brookite structure**). The first plane of diffraction being (111) indicates that the crystal Nitrogen-doped TiO_2 is face centered cubic (FCC) crystal. It indicates the compatibility of nitrogen in the TiO_2 crystal planes. The average particle size is found to be 34.47 nm for nitrogen-doped TiO_2 (1:2 ratio) nanoparticles. The lattice parameter hence calculated as given a = 6.67A°, b= 6.25A° and c = 5.33A°.

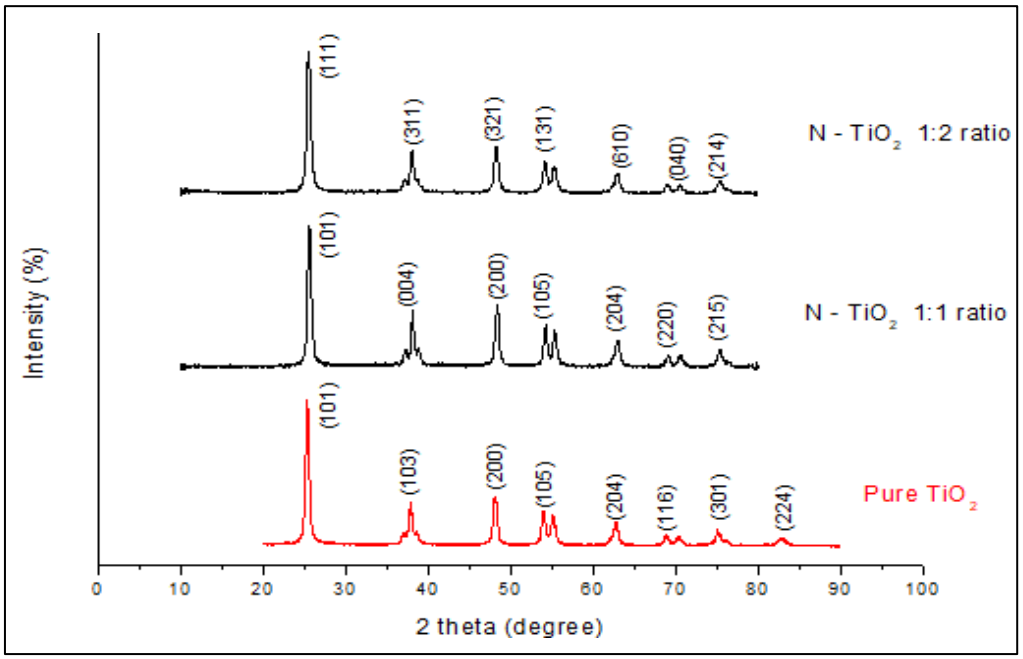


Fig. 3. XRD Spectral analysis of comparison of TiO_2 and Nitrogen-doped TiO_2 nanoparticles.

Fig. 3 represents the comparative diffraction pattern of Titanium dioxide (TiO_2) nanoparticles and Nitrogen-doped - TiO_2 (1:1 ratio and 1:2 ratio) nanoparticles. By keeping the axes for both samples as common, it is observed that the sharp peak for crystal planes (101) and (111) with respect to the as prepared TiO_2 shows a shift in the diffracting angles. This may be attributed to the squeezing of nitrogen atoms in the regular lattice of the TiO_2. On comparing the three XRD graph it was observed that the size of the particle increases with the nitrogen doping with TiO_2.

3.2.1. SEM analysis for TiO_2 nanoparticles

Scanning Electron Microscopy (SEM) was employed to analyses the morphology and growth features of aggregates of the as prepared TiO_2 nanoparticles with different magnification. In **fig. 4** it is observed that TiO_2 nanoparticles has a rough surface morphology with certain degree of non-uniformity of grain size. The SEM image is taken at x500, x1500, x3000, x7000 magnification. The images show TiO_2 particles are spherical like shape appearing to be agglomerated with rough cube-shaped nanoparticles. The

picture appears that each particle is an aggregate of number of small particles forming as clusters [21–23].

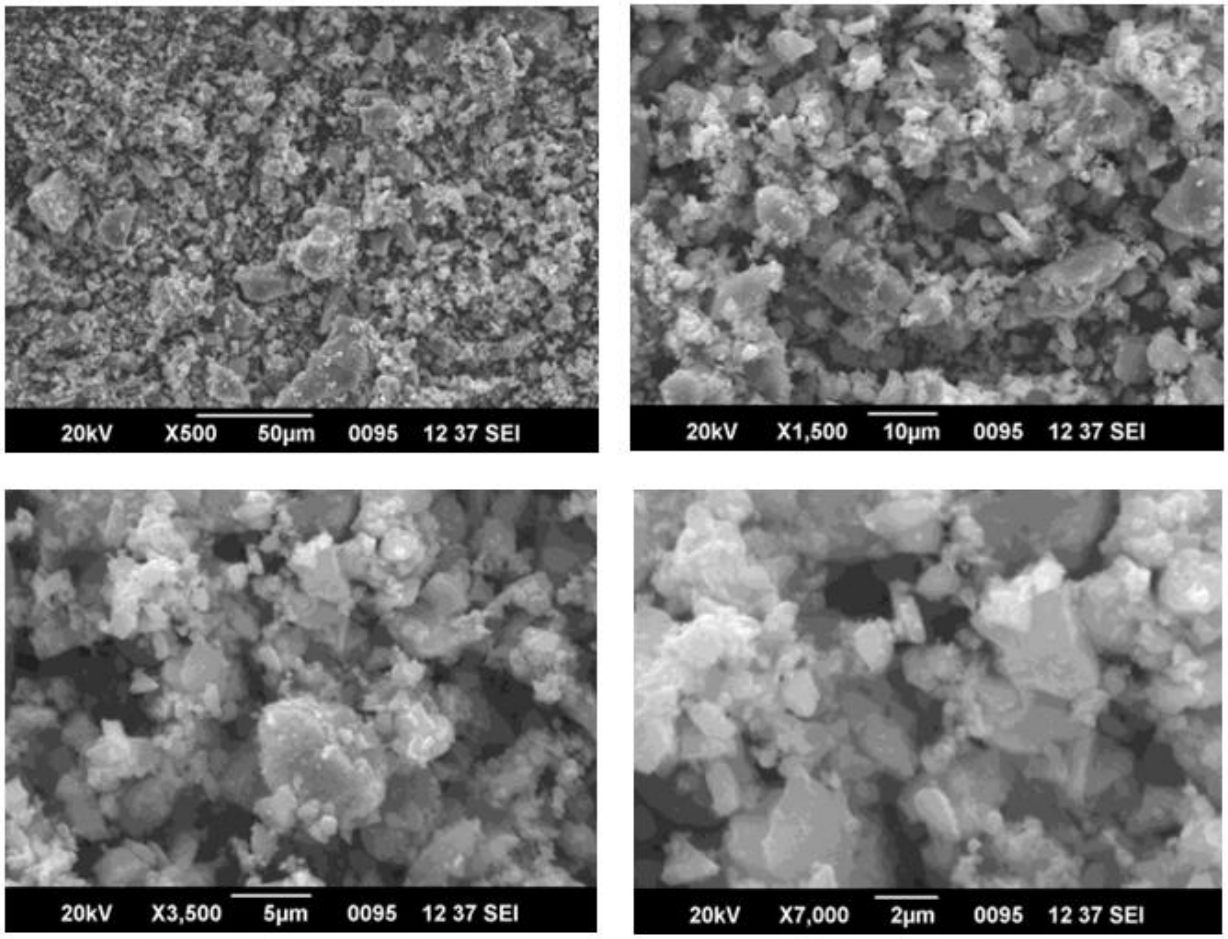


Fig. 4. SEM analysis of TiO_2 nanoparticles.

3.2.2. SEM analysis for Nitrogen-doped TiO2 nanoparticles (1:2 ratio)

In **fig. 5** it is observed that TiO_2 nanoparticles has a rough surface morphology with certain degree of non-uniformity of grain size. The images show TiO_2 particles are appearing to be agglomerated with cube-shaped nanoparticles. The picture appears that each particle is an aggregate of number of small particles forming as clusters.

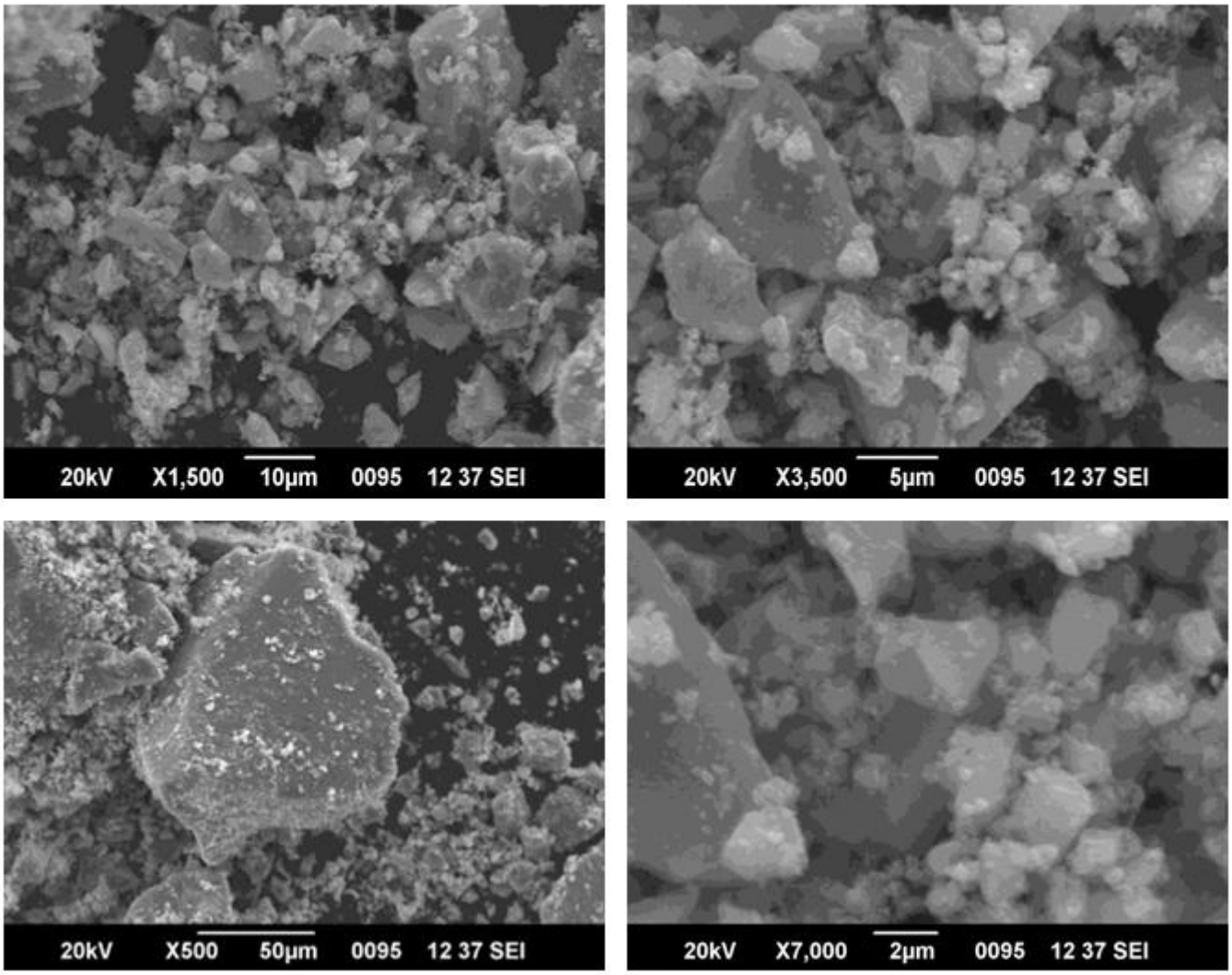


Fig. 5. SEM analysis of Nitrogen-doped TiO_2 nanoparticles (1:2 ratio).

3.3.EDX analysis

Fig. 6 shows the EDX results of as prepared TiO_2 nanoparticles. EDX quantitative analysis confirms the atomic percentage of Titanium and Oxygen in the prepared particles as 30.31% and 69.69% respectively. **Table** 1 represents the composition of Ti and O in the prepared nanoparticles[24].

Table 1. Elemental composition of TiO_2 nanoparticles

Element	Line Type	Wt %	Atomic %
O	K series	43.44	69.69
Ti	K series	56.56	30.31
	Total	100	100

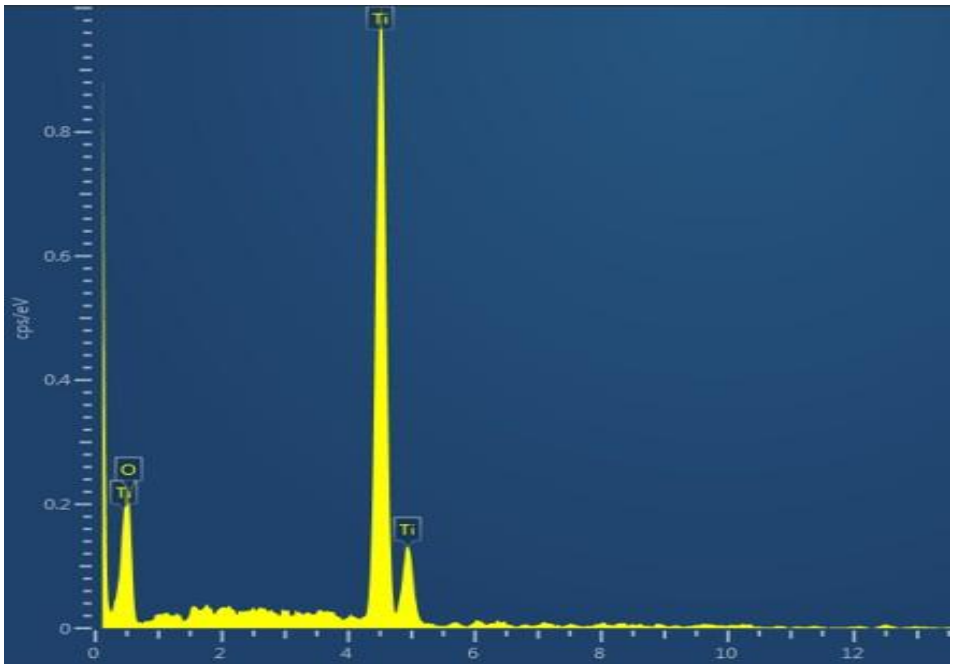


Fig. 6. EDAX analysis of TiO_2 nanoparticles.

3.4. FT-IR Analysis of TiO_2 and Nitrogen-Doped TiO_2 Nanoparticles

The FT-IR spectra of pure TiO_2 and nitrogen-doped TiO_2 nanoparticles synthesized with TiO_2 ratios of 1:1 and 1:2 are presented in **Figs. 7–9**. All the samples exhibited characteristic absorption bands in the low wavenumber region, confirming the successful formation of the TiO_2 framework. Pure TiO_2 showed a strong absorption band at 657.61 cm^{-1}, while the nitrogen-doped TiO_2 (1:1) and (1:2) samples exhibited corresponding bands at 649.89 cm^{-1} and 534.18 cm^{-1}, respectively, which are assigned to the Ti–O–Ti stretching vibration of the anatase phase. The gradual shift of this band toward lower wavenumbers after nitrogen doping suggests successful incorporation of nitrogen into the TiO_2 lattice, resulting in slight distortion of the Ti–O bond environment. Broad absorption bands observed in the range of 3458–3779 cm^{-1} for all samples are attributed to the stretching vibrations of surface hydroxyl (–OH) groups and adsorbed water molecules. The TiO_2, N– TiO_2 (1:1), and N– TiO_2 (1:2) samples exhibited these bands at 3458.71, 3731.58 cm^{-1}, 3460.30, 3700.73 cm^{-1}, and 3628.41, 3779.80 cm^{-1}, respectively, indicating the presence of surface hydroxyl groups, which are beneficial for photocatalytic and agricultural applications. The absorption bands observed at 1443.46 cm^{-1} for pure TiO_2, 1440.56 cm^{-1} for N– TiO_2, (1:1), and 1358.66 cm^{-1} for N– TiO_2 (1:2) are associated with Ti–O lattice vibrations, and the shift in these bands after nitrogen doping further confirms the formation of Ti–O–N linkages. The bands appearing around 1653–1654 cm^{-1} are attributed to the bending vibration of adsorbed water molecules or surface Ti–OH groups, whereas the peaks at 1737.55 cm^{-1} for TiO_2 and N–TiO_2 (1:1) and 1730.80 cm^{-1} for N–TiO_2 (1:2) correspond to the stretching vibration of residual carbonyl (C=O) groups. Weak absorption bands at 2353.69 cm^{-1} for pure TiO_2 and 2348.87 cm^{-1} for N–TiO_2 (1:2) are attributed to adsorbed atmospheric CO_2 or trace residual species. Notably, no absorption bands were observed near 2900 cm^{-1} in any of the samples, confirming the complete removal of organic precursors during calcination. Overall, comparison of the FT-IR spectra demonstrates that nitrogen doping does not alter the fundamental TiO_2 crystal framework but induces slight shifts in the characteristic Ti–O vibrational bands,

providing clear evidence for the successful incorporation of nitrogen into the TiO_2 lattice while preserving the anatase structure [25].

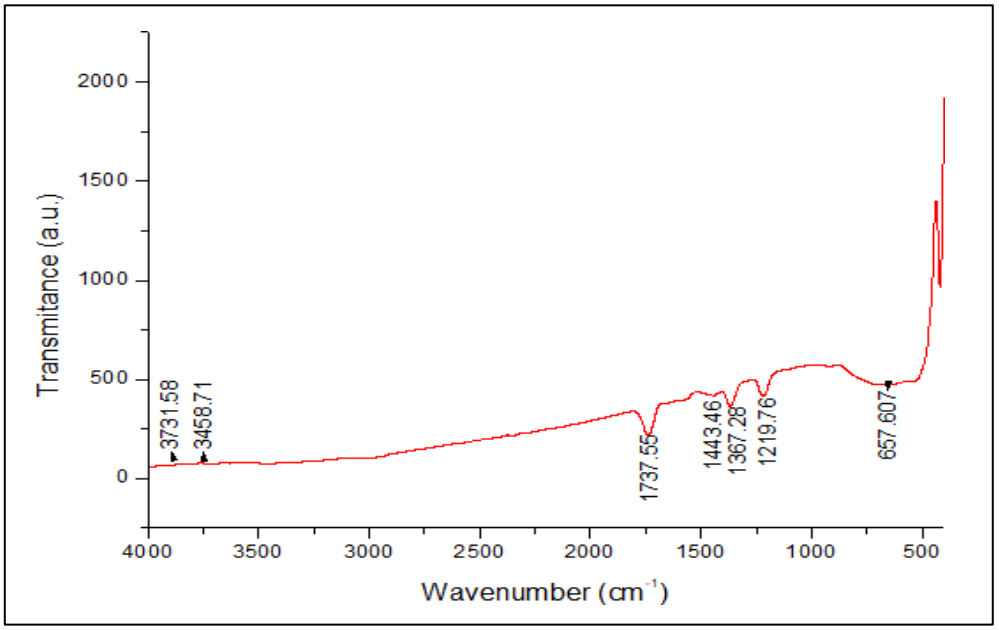


Fig. 7. FT- IR analysis of TiO_2 nanoparticles.

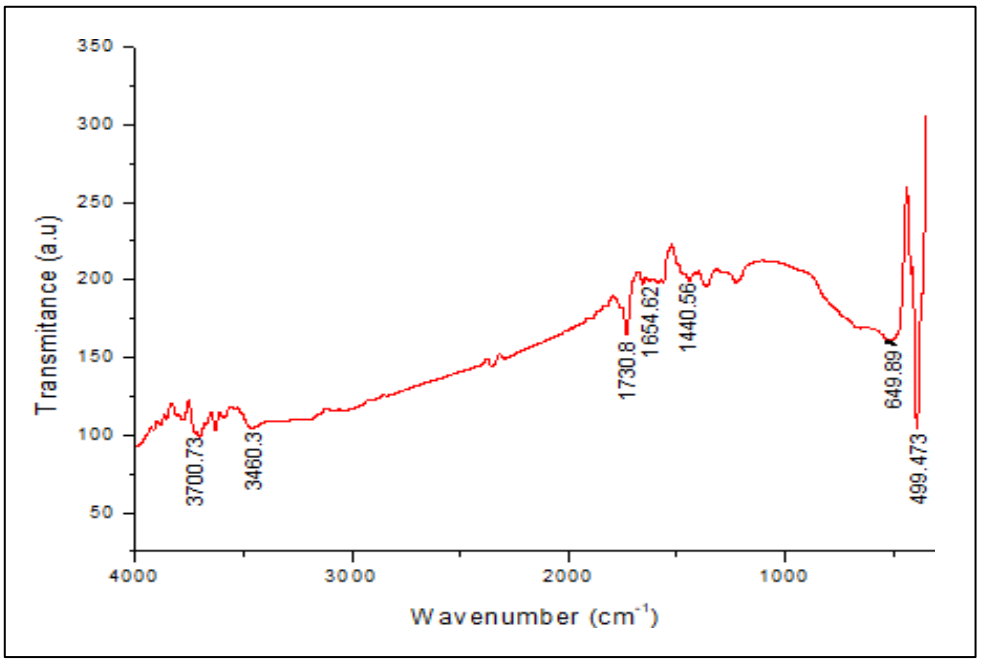


Fig. 8. FT-IR Spectrum of Nitrogen-doped TiO_2 (1:1 ratio)

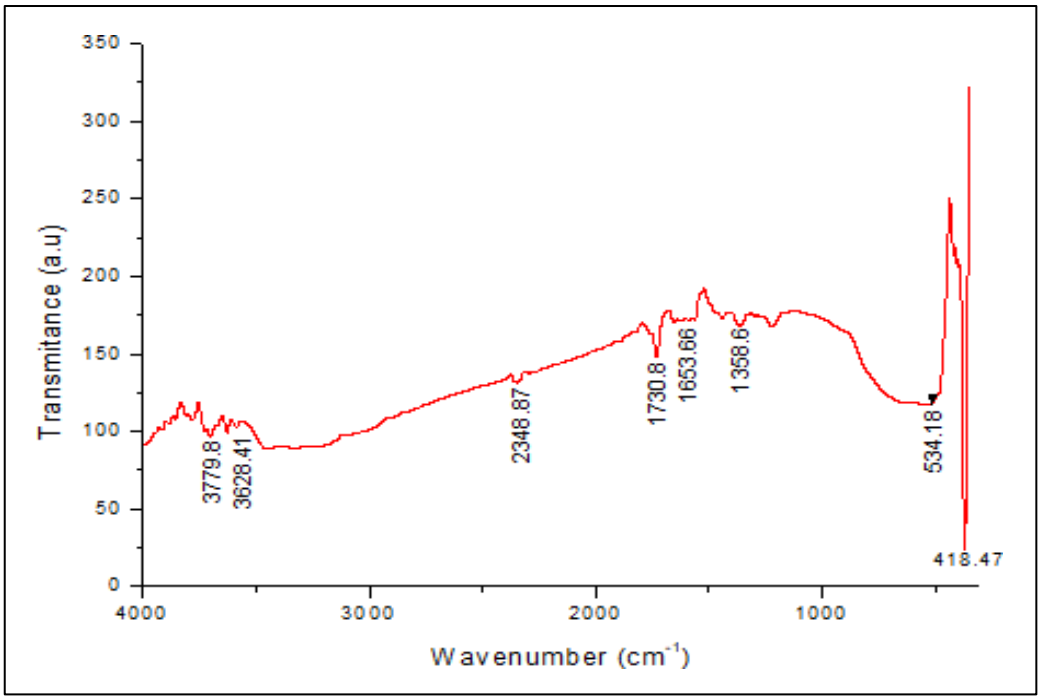


Fig. 9. FT-IR Spectrum of Nitrogen-doped TiO_2 (1:2 ratio)

3.5.1. UV-Vis analysis for TiO_2 nanoparticles

UV-Vis spectra of all the samples are recorded in the wavelength range 200 nm to 800 nm. The quantity of radiation absorbed in the UV and visible region is recorded. From the **Fig.10** it is found that firstly the absorbance decreases sharply with increase in wavelength. The peak was found in 425 nm. The band gap energy of TiO_2 nano materials may be estimated by using the formula

Band gap energy (E) = $\frac{hc}{\nu}$ where c is speed of light, $3x10^8$ m/s; h is Planks constant, $6.626x10^{-34}$ Js;

ν = wavelength in nm. Also, from the Tauc graph [plot of $(\alpha h\nu)^2$ verses hν], the band gap energy of TiO_2 nano materials is found to be 2.783 eV.

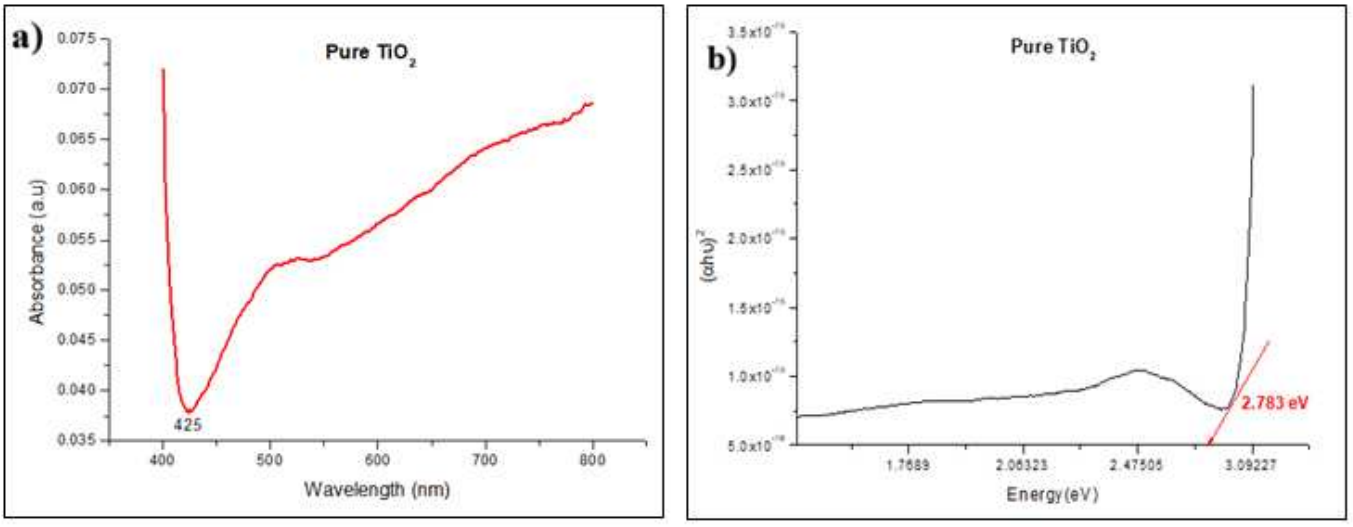


Fig. 10. a) UV visible spectroscopy analysis of pure TiO_2 b) Tauc plot of TiO_2 nanoparticles.

3.5.2. UV-Vis analysis for Nitrogen-doped TiO_2 (1:1 ratio) nanoparticles

UV Vis spectra of nitrogen-doped TiO_2 nanoparticles (1:1 ratio) is shown in the **fig. 11.** It was observed that the absorbance decreases sharply with increase in wavelength, near the band edge 430 nm to 460 nm The optical band gap energy value (E) for nitrogen-doped N-TiO_2 (1:1 ratio) nanoparticles is calculated from Tauc plot and found to be 2.68 eV.

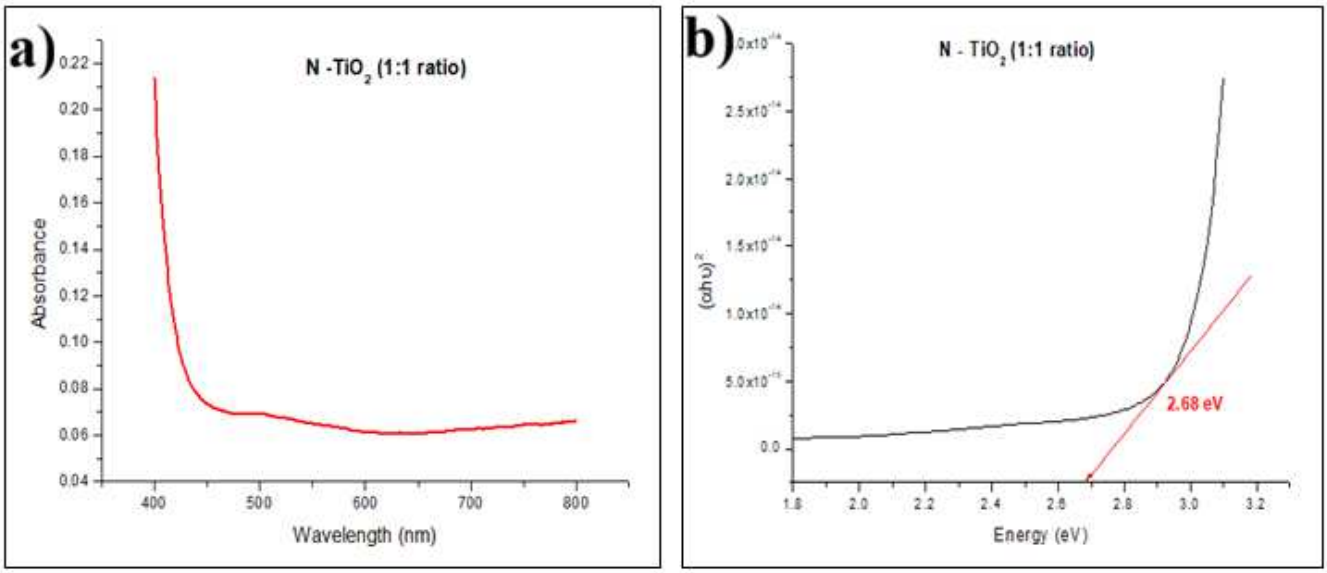


Fig. 11. a) UV-visible spectroscopy analysis of N-TiO_2 (1:1 ratio), **b)** Tauc plots of N-TiO_2 (1:1 ratio), nanoparticles

3.5.3. UV-Vis analysis for Nitrogen-doped TiO2 (1:2 ratio) nanoparticles

UV Vis spectra of Nitrogen-doped nanoparticles (1:2 ratio) is shown in the **fig. 12**. It was observed that the absorbance peak was found at 435 nm. The optical band gap energy value (E) for Nitrogen-doped N-TiO_2 (1:1 ratio) nanoparticles is calculated from Tauc plot and found to be 2.81 eV[26].

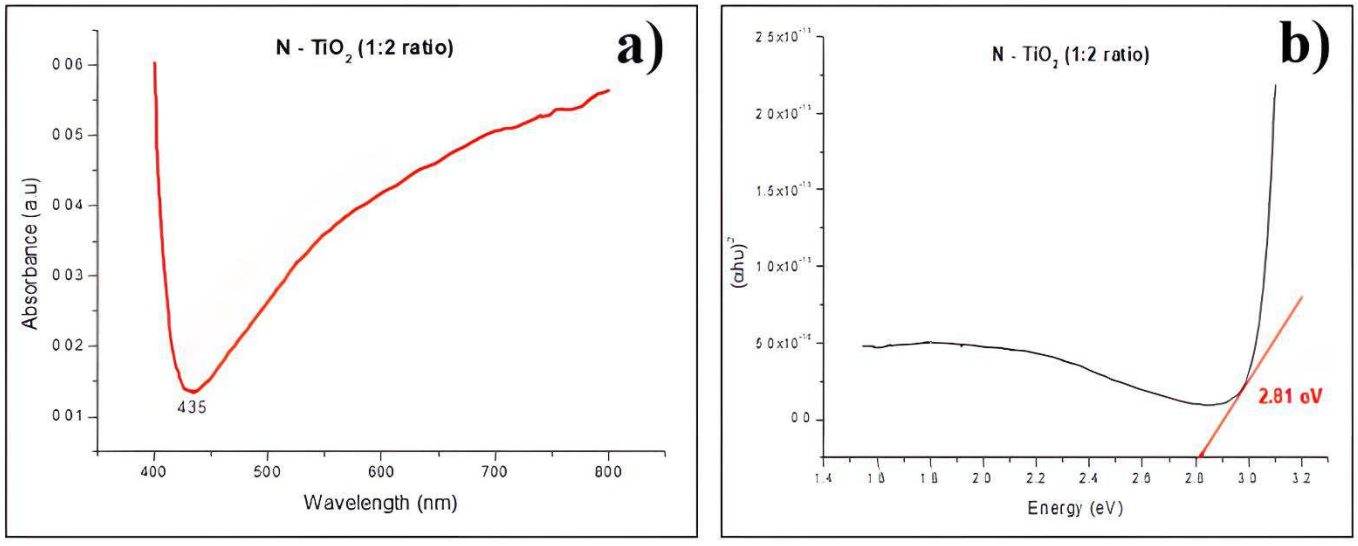


Fig. 12. a) UV-visible spectroscopy analysis of N-TiO_2 (1:2 ratio), **b)** Tauc plot of N-TiO_2 (1:2 ratio), nanoparticles

The increase in band gap may be attributed to the presence of additional energy levels of Nitrogen atoms for improving electrical conduction. **Table** 2 represents the band gap energy of the nanoparticles and their time duration of their calcination.

Table 2. band gap energy of the TiO_2 nanoparticles

Nanoparticles	Time duration of calcination	Band gap energy (eV)
TiO_2	5 h	2.78
N- TiO_2 (1:1 ratio)	5 h	2.68
N- TiO_2 (1:2 ratio)	5 h	2.81

3.6. SOIL ANALYSIS

3.6.1. Experimental Design

Step 1: Two varieties of seeds of green gram and Fenugreek were collected and was washed several times with distilled water. Good quality of soil was collected which was weighing 250 gram in each of the three containers. Green gram and fenugreek seeds were soaked in water previously. **Step** 2: The next day, 10 grams of soaked seeds are sowed in the soil equally in 3 soil container and prepared pure TiO_2 and nitrogen-doped TiO_2 of different ratio 1:1 and 1:2 were applied to the soil in the respective boxes. **Step** 3: The growth of the plants was monitored every day regularly. **Step** 4: After 6 days of plant growth, the soil samples were collected and tested for its pH value and its NPK availability (ie.) total Nitrogen Phosphorous and Potassium content presented in the samples (**Fig. 13 and 14**).



Fig. 13. Plant growth after 6 days of N-TiO2 treatment.

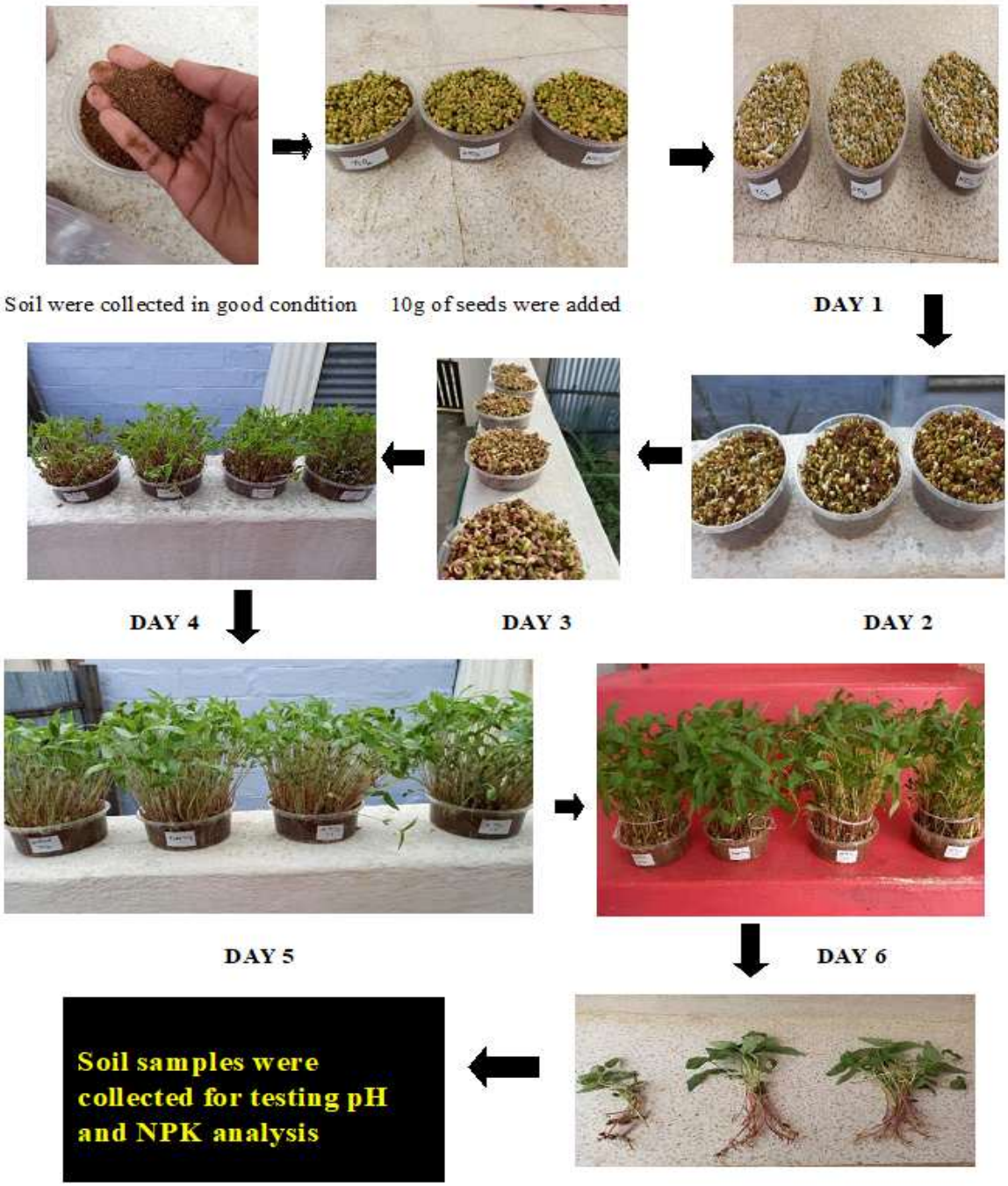


Fig. 14. Variation in the height of the plants

3.6.2. Morphological Parameter

The effects of TiO_2 and nitrogen-doped TiO_2 nanoparticles on the plants is studied. The common growth of green gram and fenugreek plants in well-watered was collected and analyzed. It was observed that the application of TiO_2 nanoparticles and nitrogen-doped TiO_2 nanoparticles in the ratio 1:1 and 1:2 significantly improved the height and compared to the biomass of plants. The increase in the length of root and shoot by the application of nitrogen-doped TiO_2 nanoparticles in the ratio 1:1 and 1:2 was 11%, 15% and 16% as compared to plant without any nanoparticles [27–31]. The height variation is given the **Fig.15.**

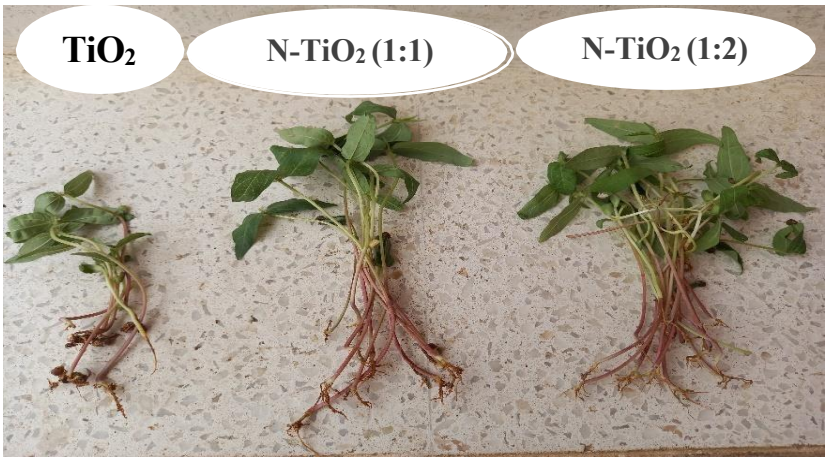


Fig. 15. Effect of nanoparticles on plant height variation.

3.6.3. Biological Parameter

The pH value of the soil was analyzed and compared with the normal values. The normal pH value was known to be 6 – 8.5. The observed pH value was graphically interpreted for TiO_2 and nitrogen-doped TiO_2 nanoparticles in the ratio 1:1 and 1:2 respectively. The graphically interpreted data is given in the **Fig.16.**

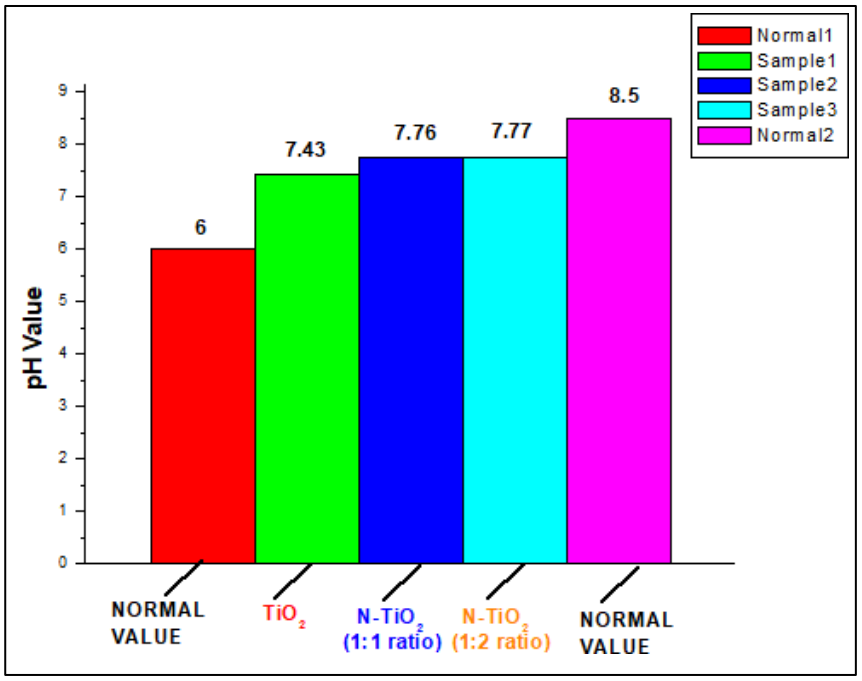


Fig. 16. pH of the soil after treatment with nanoparticles.

The concentration of potassium was measured in the sample by using a flame photometer. Phosphorus content was measured by the colorimetric method and nitrogen content was analyzed by the Kjeldahl method.

The uptake and accumulation of nutrients in the soil including Potassium (K), Phosphorus (P) and, Nitrogen (N) was also observed in this experiment and shown in the Table.3.4 The application of pure TiO_2 and Nitrogen-doped TiO_2 nanoparticles in the ratio 1:1 and 1:2 gave significant results in the soil. The application of 10 gram of pure TiO_2 and Nitrogen-doped nanoparticles helped the plant to uptake the nutrients of N, P and K as compared to normal soil. There is a fall in nitrogen level. This inferred that the synthesized nanoparticles help the plants to uptake the nitrogen content and helped in the conversion of inorganic nitrogen into organic nitrogen. The nutrients uptake efficiency increases the plant rate and quality. The soil application of TiO_2 and Nitrogen-doped TiO_2 nanoparticles (ratio 1:1 and 1:2) increased the uptake of these nutrients in plants but the difference among their mean values was significant with each other. The biological analysis of soil confirms the plant growth. Thus, these synthesized nanoparticles were used as nano fertilizer which enriches the nutrients to the plants.

Table 3.4. NPK availability in the soil percentage

Nanoparticles	**Nitrogen content (%)**	**Phosphorus content (%)**	**Potassium content (%)**
Normal value	0.5 – 4	0.5 – 3	0.5 -3
Pure TiO_2	0.112	0.625	0.218
N-TiO_2 (1:1 ratio)	0.192	0.225	0.7
N-TiO_2 (1:2 ratio)	0.156	0.175	0.953

Conclusion:

Nitrogen-doped titanium dioxide nanoparticles (N-TiO_2) were chemically synthesized using Glacial acetic acid and titanium isopropoxide as precursor solution by sol-gel Method. After the synthesis, the characterization of the sample was done for its structural, morphological and Agricultural analysis. The structural details of the titanium nanoparticles from XRD peaks confirms the tetragonal structure for pure TiO_2 and orthorhombic structure for N-TiO_2. The average value of crystalline size of TiO_2 calculated from Debye Scherrer formula was found to be 20.614 nm and the average crystalline size of N -TiO_2 1:1 and 1:2 was found to be 25.9 nm and 34.5 nm respectively. The FT-IR analysis shows the sharp peaks in the range of 1400 - 1600 cm^{-1} presence of TiO_2. The SEM morphological studies show the presence of rough cube-shaped agglomeration of particles in the synthesized sample. The Purity of the sample and atomic percentage of O and Ti was confirmed by compositional studies energy dispersive XRD, EDX. The

optical property of Nitrogen-doped TiO_2. Nanoparticles was verified by the increase of the absorbance. The agricultural analysis inferred that the pH level of the soil was in alkali in nature while there is a increases in pH level. The NPK availability in soil were analyzed and found to be a fall in NPK level which inferred that the NPK nutrient content is up taken by the plants for the plant growth. The scope of the work can be extended to the further agricultural application by varying the concentration using different method of synthesis. As chemical synthesis is an easy and economic method, it may be adopted for future work.

CRediT authorship contribution statement

Nepolraj A: conceptualisation, investigation, methodology, validation, writing - review and editing; **Sankar A**: data curation, visualisation, and writing – original draft; **Pavithra N**: validation, and writing – review and editing; **Hariharan V**: data curation and writing - review and editing.

Ethics declarations - No

Conflict of interest

The authors hereby declare that the submitted manuscript has no conflict of interest.

Ethical approval

The submitted manuscript is not currently being considered or published for any publication elsewhere.

Research Data Policy

The data available in the submitted manuscript having proper evidence in association with sharing may be encouraged

Data availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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