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Eco-Friendly Synthesis and Antimicrobial Evaluation of Vanadium Oxide Nanoparticles Mediated by Aqueous Leaf Extract of *Tridax Procumbens* L

Madhuri Patil[1], Dr. Neetu Shorgar[2] and Dr. Satish Ingale[3]
[1]Department of Chemistry, Pacific Academy of Higher Education and Research University, Udaipur-313001, Rajasthan, INDIA.
[2]Department of Chemistry, faculty of science, Pacific Academy of Higher Education and Research University, Udaipur-313001, Rajasthan, INDIA.
[3]Department of Chemistry, Shri Vile Parle Kelavni Mandal's, Mithibai College of Arts, Chauhan Institute of Science & Amrutben Jivanlal College of Commerce and Economics (Empowered Autonomous) Ville-Parle (West), Mumbai-400056, Maharashtra, INDIA.

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ABSTRACT
The aqueous leaf extract of Tridax procumbens was used to create vanadium oxide nanoparticles in an environmentally friendly manner. The mixture of extract, 5% NaOH, and vanadium oxide salts showed a distinct colour change, confirming nanoparticle formation. Their synthesis route strongly affects properties and performance in technological, medical, and environmental applications. Nanoparticle production was confirmed using UV-VIS spectroscopy. Additional nanoparticle characterisation was accomplished using FTIR, XRD, SEM, TEM, and EDX techniques. Nanoscale materials, also referred to as nanoparticles, have unique characteristics and abilities because of their small size and large surface area. Phytochemicals present in the plant extract served as capping agents, providing stability to the nanoparticles, as confirmed by FTIR analysis. X-ray diffraction (XRD) study uses the pattern to identify the crystal structure, phase purity, and crystallite size of nanoparticles. SEM analysis revealed a uniform distribution of the nanoparticles, although some agglomerates were also observed. TEM analysis provided detailed information about the morphology of the nanoparticles, while EDX confirmed the presence of vanadium within the particles and identified other elements. The synthesized vanadium oxide nanoparticles exhibited better antibacterial activity compared to the plant extract and were effective against all clinical bacterial isolates. This work presents a green synthesis technique that produces vanadium oxide nanoparticles without the use of chemicals, which can be used in cosmetic and medical applications. The use of plant-based extracts for nanoparticle synthesis is an eco-friendly and sustainable approach.

INTRODUCTION:

Nanoparticles, which are usually smaller than 100 nm in size, show unique physical and chemical properties that are quite different from their larger, bulk forms. These differences come from factors like their size, shape, and surface structure. Because of these characteristics, nanoparticles are generally divided into two main groups: organic types, such as dendrimers, liposomes, and polymer-based nanoparticles, and inorganic types, like fullerenes, quantum dots, and metallic nanoparticles. Metallic nanoparticles, in particular, have gained a lot of attention due to their many uses in areas like catalysis, medical imaging, healthcare, energy systems, and environmental protection[1]. Because of

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their special nanoscale properties, nanoparticles have become important materials in both scientific studies and industrial applications.

Their versatile capabilities, ranging from medical treatments to electronic innovations, have led to increased efforts to find sustainable and efficient ways to produce them[2]. In recent years, nanomaterials have been seen as powerful tools in modern medicine[3]. In this context, developing eco-friendly synthesis methods has become a key area of focus in nanotechnology[4]. Among the various methods available, using plant extracts for green synthesis has become very popular, mainly because it is non-toxic and kinder to the environment[5-7].

This article talks about making vanadium oxide nanoparticles (V_2O_3NPs) in a green way using the leaf extract of Tridax procumbens, also called "coat buttons" or "Dagadi Pala." This plant is common in tropical, subtropical, and temperate areas and grows widely in India. About 30% of the medicines we use today come from plants, and around 80% of people around the world still use plants as their main form of healthcare. Because they are safe and have worked well for a long time, medicinal herbs usually have fewer side effects compared to man-made drugs. In Ayurvedic medicine, Tridax procumbens has been used to treat liver problems. Recent studies also show it has many health benefits, such as boosting the immune system, fighting free radicals, helping control diabetes, reducing inflammation, fighting fungi, easing pain, and protecting the liver. Combining traditional knowledge with modern science is important for discovering new uses in the future[8-10].

Even though vanadium has been widely studied for its health benefits, nobody has looked into using it to make nanoparticles before. Vanadium is known for its many uses, like helping bones grow, stopping tumours, protecting the heart, and fighting microbes[11]. One important use is its ability to help control diabetes, as vanadium compounds act like insulin, helping manage sugar and fat levels in both animals and people[12-15]. The current study is the result of research that was done to use plant leaf extracts from Tridax procumbens to synthesize and analyse vanadium oxide nanoparticles which functioned as both a reducing and stabilizing agent. The synthesized nanoparticles were characterized by multiple techniques, FTIR spectroscopy helps identify the functional groups on the surface of the nanoparticle, while UV-V is spectrophotometry is used to evaluate their optical properties. They are thoroughly examined for size, shape, and structure using scanning electron microscopy (SEM) and transmission electron microscopy (TEM)[16-17].

Fig.1.Photograph of Tridax procumbens leaves

EXPERIMENITAL:

MATERIAL AND METHODS:

Collection of leaf:

Fresh leaves of Tridax procumbens were randomly collected from the Kaylan region of Thane district, Maharashtra, India. The plant is well known for its medicinal properties and is commonly available in this locality[18].

Preparation of plant extract:

To get rid of the dust, the gathered T. procumbens leaves were first cleaned with tap water and then with distilled water doing these two or three times. After that, the leaves were left to dry in the shade for two to three days at room temperature. Following drying, we used a mechanical grinder to prepare a powder. We sieved the powder through a 20-mesh sieve to achieve a uniform size and stored it in airtight glass bottles[19,20,21].

We took 5 grams of air-dried powder and added it to 100 ml of distilled water in a conical flask. We placed the flask on a magnetic stirrer at 500 to 600 rpm for 30 minutes. We stirred the mixture and let it cool to room temperature. We then filtered the obtained leaf extract using Whatman number 1 filter paper. The filtrate was used to create vanadium oxide nanoparticles.

Nanoparticles of vanadium oxide are created chemically:

To start the reaction preparation process, measure out 100 millilitres of the extract and place it in the proper container. Next, put 100 millilitres of a 5% sodium hydroxide (NaOH) solution into the same container. After accurately measuring the mixture, add 18 grams of vanadium oxide (V_2O_5). Once all the ingredients have been added, begin stirring and gradually warm the liquid until it is warm. Continue spinning under these conditions for about 30 minutes to ensure thorough mixing. After this initial warming stage, switch off the heat and leave the mixture to stir at room temperature for four hours. This promotes a thorough and consistent response. For four days, keep the mixture refrigerated. After being washed three times with distilled water, the resulting dark blue precipitate must be centrifuged for fifteen minutes at 12,000 rpm. After that, use

Whatman filter paper to separate the solid residue, completely dry it off, and put it in a sterile container for additional chemical analysis and biological activity evaluation[22].

Characterization of the Synthesized Vanadium Oxide Nanoparticles:

1.Spectroscopy in UV-Vis:

To trace the synthesis of vanadium oxide nanoparticles, the absorbance of the reaction mixture was monitored using a double-beam UV–V spectrophotometer (Model 2203). In order to monitor the synthesis process, absorbance values were recorded across the wavelength range of 200 to 800 nm [23].

2. FTIR, or Fourier-Transform Infrared Spectroscopy:

The surface structure of vanadium oxide nanoparticles was examined using FT-IR analysis. The dried extract's and the nanoparticles' FTIR spectra, which ranged from 4000 to 400 cm^{-1}, were obtained using an FTIR spectrophotometer[24,25].

3. X-Ray Diffraction Analysis (XRD):

X-ray One effective method for examining the crystalline structure of nanoparticles is diffraction. An X-ray beam is directed onto the sample, and the diffraction pattern that results provides details about the crystal orientation and lattice spacing. XRD can be used to identify and characterize materials by determining the composition, phase purity, and crystallinity of nanoparticles[26,27].

4. Analysis of Energy Dispersive X-rays (EDX):

Using EDX spectroscopy, the elemental composition of the generated nanoparticles was determined. This approach helped determine the relative concentrations of other related elements and confirmed the presence of vanadium 10 µL of the mixture was placed on a carbon-coated stub and allowed to air dry after the nanoparticle suspension had been diluted (1:100 in distilled water) for analysis. Spectral information was collected for 19 seconds at an accelerating voltage of 20 kV. For elemental mapping, pseudo-colour imaging was also employed to visualize the spatial distribution of elements. The experiments were carried out using a JEOL JSM 6360 scanning electron microscope equipped with an EDX detector[28].

5. Field emission scanning electron microscopy (FE-SEM)

Using a field emission Apreo 2S scanning electron microscope run at an accelerating voltage of 20–30 eV, in-depth morphological and structural analyses were conducted.

6. Analysis of Transmission Electron Microscopy (FE-TEM):

X-ray diffraction (XRD) analysis was performed using a Rigaku Miniflex II diffractometer equipped with a Cu Kα radiation source ($\lambda = 1.54056$ Å). The diffraction patterns were recorded over a 2θ range of 20° to 90° with a scan period of two seconds per step and a step spacing of 0.05°[29].

7. Antimicrobial Activity:

Data was obtained using the Antimicrobial Activity Agar Cup (Well Diffusion) Method.

Sterilized Nutrient Agar (NA) Petri dishes were used to produce cultures of Staphylococcus aureus and Escherichia coli. The antibacterial qualities of Tridax procumbens were tested using these bacterial strains. Sterile Petri plates, a sterile 6 mm cork borer to make wells, sterile micropipettes with sterile tips, sterile broth to make the bacterial suspension, sterile cotton swabs to disperse the inoculum evenly, and 37°C incubation were all used in the experiment.[30,31].

Antibacterial activity testing:

Agar was put into Nutrient Sterile Petri dishes and allowed to settle at room temperature. Escherichia coli and Staphylococcus aureus cultures were grown to the logarithmic phase (about 4-6 hours) and then evenly spread throughout the agar surface using sterile cotton brushes in order to produce a uniform bacterial lawn. Wells measuring 6 mm in diameter were created in the agar using a sterile cork borer, and the agar plugs were removed using sterile forceps. The control type and sample concentration were indicated on the labels of each well. 50–100 µL of each successive dilution of the test samples were added to the corresponding wells. The solvent acted as a negative control, and ciprofloxacin as a positive control. After 30 minutes of standing at room temperature to allow the samples to diffuse, the plates were incubated upside down at 37°C for 18 to 24 hours. To evaluate antibacterial activity, the zones of inhibition surrounding each well were determined after incubation[32].

RESULTS AND DISCUSSION:

An environmentally friendly method was used to create V_3O_3 nanoparticles using Tridax procumbens aqueous leaf extract. The nanoparticles were characterized using a range of physical and chemical techniques, including UV–Vis, FTIR, XRD, SEM, TEM, and EDX, along with antimicrobial assays. These analyses provided insights into how surfactant use and calcination temperature influenced the size, morphology, and structural properties of the nanoparticles.

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1.UV-visible spectroscopic analysis:

UV–Visible spectroscopy is a reliable method for preliminary characterization of the synthesized vanadium oxide nanoparticles and for monitoring their biosynthesis and stability in aqueous solutions. Vanadium oxide nanoparticles typically exhibit absorption peaks within the 200–800 nm range. In this study, the UV–V is spectra of the freshly prepared leaf extract showed a prominent peak around 457 nm, attributed to the surface Plasmon resonance and the collective electronic oscillations of V_2O_3 nanoparticles interacting with light.

Fig 2: UV-Visible spectra of biosynthesised vanadium oxide nano particles

2.Fourier transform (FT-IR) spectroscopic analysis:

FTIR spectroscopy was employed to investigate the surface composition and functional groups of vanadium oxide nanoparticles synthesized using Tridax procumbens leaf extract. This analysis helps identify biomolecules present on the nanoparticle surface that act as capping or stabilizing agents. The FTIR spectra of both the leaf extract and the biosynthesized V_2O_3 nanoparticles are shown in Fig. 3. The leaf extract exhibited absorption peaks at 3915.6, 3941.7, 3894.1, 3688.3, 3605.0, 3229.4, 3067.7, 1631.8, 1068.0, 974.7, and 810.0 cm^{-1}. In the nanoparticles, strong absorption bands were observed at 3942.45, 3851.80, 3749.57, and 3383.38 cm^{-1}, corresponding to O–H stretching vibrations, indicative of hydroxyl groups involved in hydrogen bonding or present in free form. These bands were more pronounced due to the reduction of vanadium ions by the leaf extract. Additionally, a band near 1000 cm^{-1} confirmed the presence of the V=O bond in the synthesized nanoparticles.

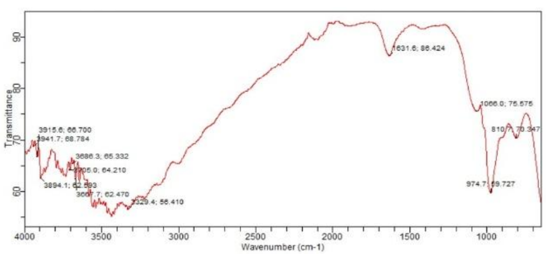

Figure 3: Biosynthesised vanadium oxide nanoparticles' FT-IR spectrum

3. Analysis of Scanning Electron Microscopy (SEM):

SEM was used to analyse the morphology of the generated vanadium oxide nanoparticles. Agglomerated clusters of nanoparticles ranging in size from 1 to 500 nm were visible in the photos. Figure displays representative SEM images.

Figure 4: SEM picture of nanoparticles of biosynthesised vanadium oxide

4.X-Ray Diffraction analysis (XRD) Analysis:

XRD analysis was performed to investigate the crystal structure and lattice characteristics of the biosynthesized vanadium oxide nanoparticles. The XRD pattern of V_2O_3 nanoparticles synthesized using Tridax procumbens leaf extract is shown in Figure 5. The observed 2θ values of 10.90, 20.00, 20.60, 30.10, 30.50, 40.90, and 50.10° correspond to Bragg reflections (76), (76), (82), (89), (75), (67), and (63), respectively, confirming the crystalline nature of the synthesized nanoparticles.

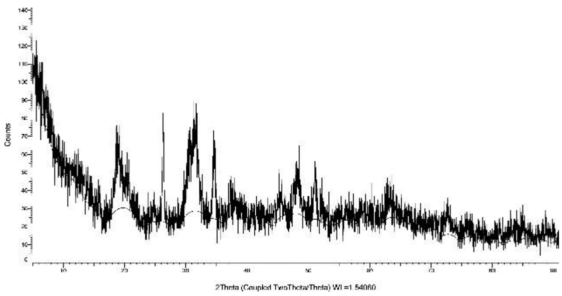

Figure 5: The vanadium oxide nanoparticle's X-ray diffraction behavior

5.Energy Dispersive X-ray spectroscopy (EDX) Analysis:

Energy Dispersive X-ray spectroscopy (EDX) analysis was used to confirm the presence of a signal that is typical of elemental vanadium. Figure 6 shows the energy dispersive absorption images of the derived V_2O_3 nanoparticles. All the vanadium peaks are clearly visible and have been assigned. The vanadium nanocrystals show an optical absorption peak at around 5 keV, which is common for metallic vanadium nanocrystals due to their surface properties. Oxygen elements are also detected in the analysis.

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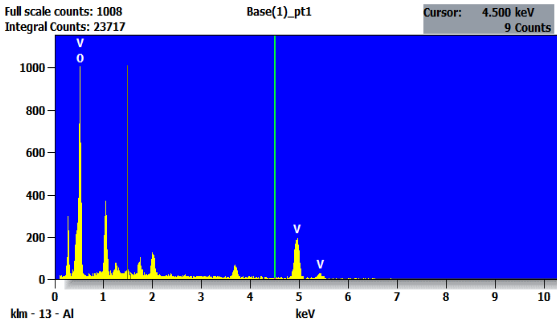

Figure 6: EDX spectra of nanoparticles of vanadium oxide demonstrating the presence of V_2O_3 elements

6. Analysis of transmission electron microscopy (TEM):

TEM images of the V_2O_3 nanoparticles revealed rod-shaped particles and ranged in size 50 to 500 nm. A corresponding size distribution histogram illustrates the variation in particle dimensions.

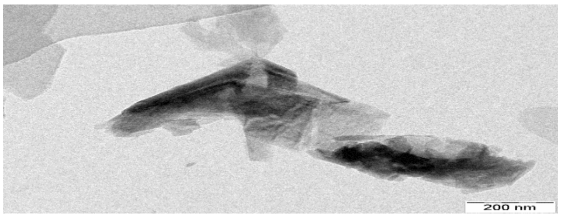

Figure 7: TEM picture of biosynthesised vanadium oxide nanoparticles

7. Antimicrobial Properties:

To investigate the antibacterial properties of the vanadium oxide nanoparticles, both Gram-positive (Staphylococcus aureus) and Gram-negative (Escherichia coli) bacteria were employed. The results demonstrated a significant increase in the zones of inhibition, as illustrated in the figure. Ciprofloxacin was used as a positive control to compare antibacterial efficiency. The nanoparticles produced inhibition zones of 38 mm for E. coli and 43 mm for S. aureus, indicating strong antibacterial activity.

Figure 8: Images of biosynthesised vanadium oxide nanoparticles' antibacterial activity following a 24-hour incubation period

The agar cup diffusion technique was used to test the antibacterial effects of the three samples on nutrient agar. The plates were inspected for areas of bacterial inhibition following the proper incubation period. The results showed that none of the tested substances exhibited antibacterial activity against E. coli or S. aureus.

CONCLUSIONS:

It has been shown that producing stable vanadium oxide nanoparticles quickly and effectively can be achieved by using an extract from Tridax procumbens. The structure and shape of these nanoparticles were studied using several methods, as UV spectroscopy, XRD, FTIR, SEM, TEM, and EDX. Positive results from tests on the nanoparticles' capacity to combat bacteria specifically, Escherichia coli and Staphylococcus aureus indicate that they may find value in medical settings.

The method is very affordable, uses little money, and does not release harmful gases into the air. It also produces a good number of nanoparticles. Using Tridax procumbens as a natural source for making these nanoparticles is a new and useful technique that uses cheap and easy-to-find materials.

This method is quick, simple, and environmentally friendly while adhering to the principles of green chemistry. Due to its affordability and promise for creating sustainable nanomaterials, the use of plant materials such as the leaves of Tridax procumbens as biological agents for nanoparticle synthesis is becoming more and more popular.

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