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Green Synthesis of V_2O_5 Nanoparticles using Spermacoce Hispida Plant Shows Remarkable Photo Physical and Antibacterial Activities

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ABSTRACT: A critical challenge in this realm is the fabrication of nanomaterials, which requires precision and expertise. This divergence in properties facilitates a wide range of applications in disciplines such as chemistry, physics, materials science, and biomedical science. This study focuses on the green synthesis of V_2O_5 nanoparticles, which were produced utilizing a method that incorporates environmentally friendly practices. The synthesis involved the reaction of sodium meta vanadate with an extract derived from the Spermacoce Hispida plant. The V_2O_5 nanoparticles obtained were characterized by their distinctive brownish-green crystalline appearance and achieved a substantial yield of 92%. Characterization techniques were employed to analyze the nanoparticles further. An absorption peak was identified at 313 nm, a hallmark indicative of bismuth, confirming the successful synthesis of V_2O_5. Additionally, scanning electron microscopy (SEM) analysis provided insights into the morphology of the nanoparticles, revealing their spherical shape and lack of aggregation, with a measured average size of approximately 38 nm. Furthermore, the antibacterial properties of the synthesized vanadium oxide nanoparticles were assessed. The results indicated that these nanoparticles exhibited significant antibiotic activity, notably at very low concentrations of just 8 µg/mL. This antibacterial efficacy was observed against a range of pathogenic bacteria, including Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), Escherichia coli (E. coli), and Klebsiella pneumoniae (KP). These findings underscore the potential applications of V_2O_5 nanoparticles in medical and environmental fields, particularly in combating bacterial infections.

KEYWORDS: Vanadium nanoparticle, antibacterial activity, SEM analysis, Green nanoparticle.

I. INTRODUCTION

Nanotechnology is widely used in translational research [1]. One important area of focus is the development of metallic nanoparticles using biological materials in an eco-friendly manner [2]. Nanotechnology deals with particles ranging in size from 1 to 100 nm, including their synthesis and manipulation [3]. This field combines natural sciences such as chemistry, physics, biological sciences, engineering, materials science, and computational sciences for the formulation of nanostructures [5,6]. Nanostructures have various applications based on their size, distribution, and morphology, leading to new or enhanced properties. Nanotechnology has wide-ranging applications in fields such as biomedical research, catalysis, chemical industries, cosmetics, drug delivery, electronics, environmental science, energy, food and feed, healthcare, mechanics, optics, space industries, MRI contrast agents, Solar energy optimization, non-linear optical devices, single-electron transistors, and photoelectrochemical applications [7-13]. Metallic nanoparticles are particularly promising for these applications. Nano-scale drug carriers function as single units with specific properties and transport capabilities [14-17]. These nanoclusters have a narrow size distribution and at least one dimension between 1 and 10 nanometers. Agglomerates of ultrafine particles, nano-clusters, or nanoparticles, are known as nano-powders, while nanocrystals are crystals of nanoparticle size [18]. Synthesis of nanomaterials typically involves two general strategies: the top-down approach, where a larger structure is broken down into smaller pieces using chemical, physical, and biological energy; and the bottom-up approach, where the material is synthesized from the atomic level using various

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chemical, physical, or biological reactions to build a large nanostructure [19-22]. Chemical and biological methods are primarily used to construct nanostructured carriers (NC), while physical and chemical strategies are employed for the synthesis of nanoparticles. Although the utilization of toxic chemicals could pose potential hazards such as carcinogenicity and toxicity, nanoparticles have various factors affecting their synthesis, and possible mechanisms are employed, along with potential applications, for the nanoparticles formed using biological factories.

II. EXPERIMENTAL

The process of reducing plant extracts to synthesize nanoparticles generally involves the careful combination of an aqueous extract derived from a specific plant source with a solution containing the desired metal salt. This reaction typically occurs at room temperature, allowing for a more controlled and gentle synthesis environment. Once the two components are mixed, the reduction process unfolds rapidly, often culminating within just a few minutes. During this brief period, the phytochemicals present in the plant extract facilitate the conversion of metal ions from the salt into elemental nanoparticles, resulting in the formation of a stable colloidal suspension rich in the synthesized nanoparticles. This method highlights the efficiency and effectiveness of using natural materials in nanomaterial fabrication.

2.1 UV-Vis Absorption Spectrum.

The electronic spectra were recorded in the 200-900 nm regions using a Deep Vision UV/VIS spectrophotometer. A cuvette with a 1 cm path length was utilized. The concentration of the ligand and metal complexes was maintained at 1.00 x 10-5 mol L-1 at a temperature of 310 K [23].

2.2 Selection and collection of plants.

We began our process by carefully collecting the Spermacoce Hispida plant from various locations within our college campus, ensuring we selected healthy specimens. After bringing the plants back to our lab, we meticulously separated the dry and waste parts to ensure only the usable portions were retained.

Figure 1. Image showing the structure of *Spermacoce Hispida* plant

The collected plants were then thoroughly rinsed with tap water to remove any dirt, debris, or contaminants that could interfere with our analysis. After cleaning, we proceeded to cut the plants into smaller, more manageable pieces to facilitate the drying process. To prevent the degradation of valuable phytoconstituents due to exposure to sunlight, we air-dried the cut pieces under shade at room temperature for 14 days. This method was chosen to preserve the integrity of the compounds present in the plant. Once the drying process was complete, we used a pulverizer to grind the shade-dried plant material into a fine powder. To achieve a uniform particle size, we then sieved the powdered material through an 80-mesh screen. The final step involved homogenizing the powder to ensure a consistent texture throughout. The finely powdered material was subsequently stored in an airtight container to prevent moisture absorption and preserve its phytochemical properties for further analysis.

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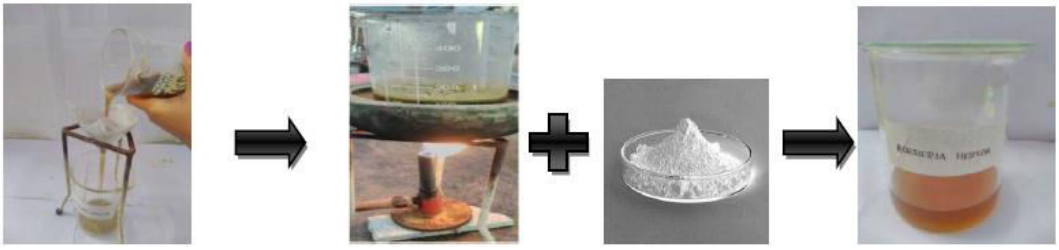
2.3 Preparation of plant extract.

To prepare the plant extract, we began by measuring out 10 grams of freshly dried plant powder. This powder was then combined with 200 milliliters of distilled water in a separate container. The mixture of plant powder and water was heated to a steady temperature of 80°C, allowing it to simmer gently for 2 hours. Throughout this process, we ensured continuous stirring to promote the extraction of the plant's beneficial compounds. Once the heating period was complete, we allowed the solution to cool down to room temperature. After cooling, we carefully filtered the mixture through Whatman filter paper to separate the liquid extract from any remaining solid particles. The resulting filtered extract was then stored in a clean container at 4°C, ready for future use.

2.4 Green synthesis of Vanadium nanoparticles.

The synthesis of V_2O_5 nanoparticles (VONPs) can be accomplished through a straightforward and efficient method involving the reaction of 0.4 grams of sodium metavanadate with a green extract from Spermacoce hispida in an aqueous medium. By continuously stirring the reaction mixture for 90 minutes at room temperature, we observe a significant color change from pale yellow to reddish brown, indicating the reduction of the metal. After the reaction, the VONPs are separated from the mixture through a calcination process, resulting in red-brown crystals with an impressive yield of 96%. To assess their solubility, 0.1 grams of VONPs is mixed with 1 milliliter of double-distilled water in a clean 10-milliliter test tube. The mixture is stirred until a clear solution forms, confirming the nanoparticles' solubility in water. Subsequently, an additional 0.1 grams of VONPs is gradually added while stirring until saturation is reached. This procedure reveals that the water solubility limit of the nanoparticles is 0.8 grams per ml of water. Overall, this synthesis and solubility evaluation highlights the promising characteristics and potential applications of VONPs in various fields.



Scheme 1. Synthesis of *Spermacoce Hispidain* extract based vanadium oxide Nanoparticle

2.5. Solubility cum saturation test.

Approximately 0.1 g of vanadium oxide nanoparticles (VONPs) were placed into a clean 10 mL test tube. Next, 1 mL of double-distilled water was added and stirred until a clear solution was achieved, confirming the compound's solubility in water. While continuing to stir, an additional 0.1 g of VONPs was gradually added until the saturation point was reached. This process allowed us to determine that the solubility limit of our nanoparticles in water was 0.8 g per 1 mL.

III. RESULT AND DISCUSSION

In this section, the findings of our study and engage in a thorough discussion of their implications and significance.

3.1 Characterization of synthesized Vanadium nanoparticles

The absorption spectra of vanadium oxide nanoparticles, synthesized using environmentally friendly methods, were measured in water as the solvent across a wavelength range of 200 to 800 nm. As shown in Figure 2, the UV-visible absorption spectrum of these synthesized nanoparticles revealed distinct absorption peaks at 373 nm. This specific peak is indicative of the successful formation of vanadium oxide nanoparticles, highlighting the efficiency and effectiveness of the green synthesis approach utilized in this study. The presence of this peak not only confirms the formation of the nanoparticles but also suggests their potential applicability in various fields such as catalysis and materials science due to their unique optical properties [24].

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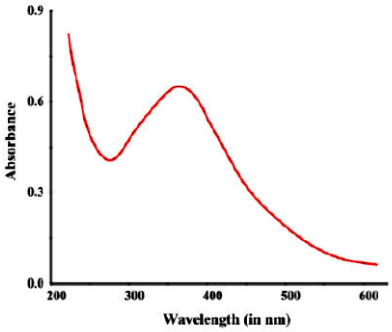

Figure 2. UV-VIS spectrum of vanadium oxide nanoparticle

3.2 Surface morphological study

The surface morphology of the synthesized V_2O_5 nanoparticles was analyzed in detail using Scanning Electron Microscopy (SEM), a technique well-suited for observing the microstructure of materials. The SEM images reveal that the nanoparticles predominantly exhibit spherical and oval shapes, with a size distribution ranging from 30 to 42 nanometers. In addition to their distinct morphology, the V_2O_5 nanoparticles demonstrate outstanding colloidal dispersibility, which is crucial for their potential applications in various fields. The presence of a distinct coating layer, visible in the SEM imagery, strongly suggests that the phytochemicals obtained from Spermacoce hispidain juice act as effective capping agents. These phytochemicals likely play a significant role in stabilizing the nanoparticles during synthesis and limiting their agglomeration. Moreover, the stability of these nanoparticles during the drying process indicates that their size and shape are preserved, contributing to their functional properties. This is further corroborated by the observed hydrodynamic diameter (Dh) of the V_2O_5 nanoparticles, which averages 38 nanometers in aqueous dispersion (Figure 3). This small diameter suggests a high surface-to-volume ratio, enhancing their reactivity and potential for incorporation into various applications, such as catalysis, electronics, or drug delivery.

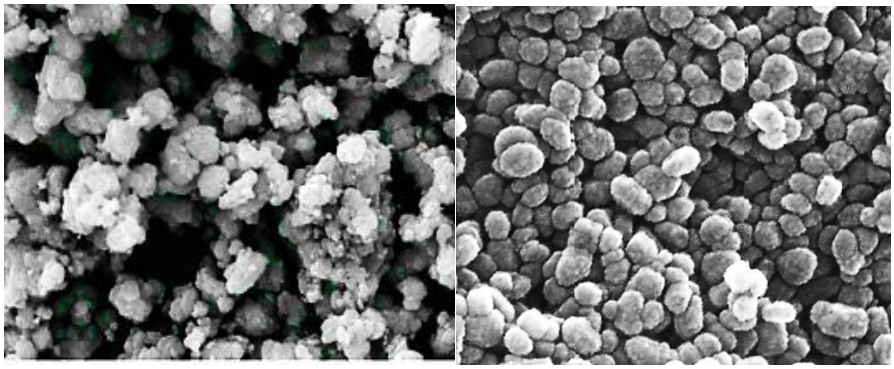

Figure 3. SEM images of Vanadium oxide nanoparticle

3.1 Antibacterial activity

The antibacterial efficacy of V_2O_5 nanoparticles was rigorously assessed against both Gram-negative and Gram-positive bacteria. This evaluation involved a series of tests aimed at determining the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC), as well as observing the zone of inhibition produced by the nanoparticles. During the experiment, vanadium oxide nanoparticles were blended with a specified volume of bacterial cultures. The bacterial strains used in this study included Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), Escherichia coli (E. coli), and Klebsiella pneumoniae (KP). Aiming for a standardized bacterial count of 100,000 cells per milliliter, the mixtures were prepared in physiological serum and then incubated at a controlled temperature of 37°C to encourage optimal bacterial growth. To ensure the reliability of the

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results, positive and negative control groups were incorporated into the experimental design. The assessment of antibacterial activity was carried out using the disk diffusion method [25-28]. Different concentrations of the vanadium oxide nanoparticles were strategically applied at set distances on an agar medium. After inoculating the discs, they were incubated in a 37°C environment for a full 24 hours. Following the incubation period, the zones of inhibition surrounding the discs were meticulously measured using a ruler. The findings revealed that Pseudomonas aeruginosa (PA), Escherichia coli (E. coli), and Klebsiella pneumoniae (KP) displayed notable antibacterial activity in response to the vanadium oxide nanoparticles, confirming their potential as effective antimicrobial agents (refer to Figure 4, 5 and Table 1 for detailed results).

Table 1 shows the results of zone inhibition of vanadium oxide with Bacteria

S.No.	Bacteria	V_2O_5 NPs 8 µg/mL	Control (STREPTOMYCIN)
1	BS	11.7	22
2	BC	13.5	20
3	PA	14	12
4	SA	10.5	12
5	KP	12.5	13
6	E.coli	16	11

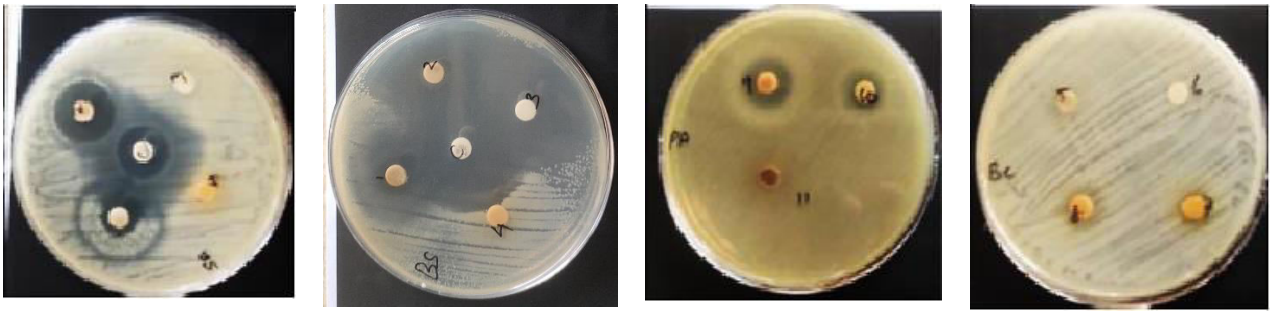

Figure 4. Antibacterial activity of vanadium oxide nanoparticle

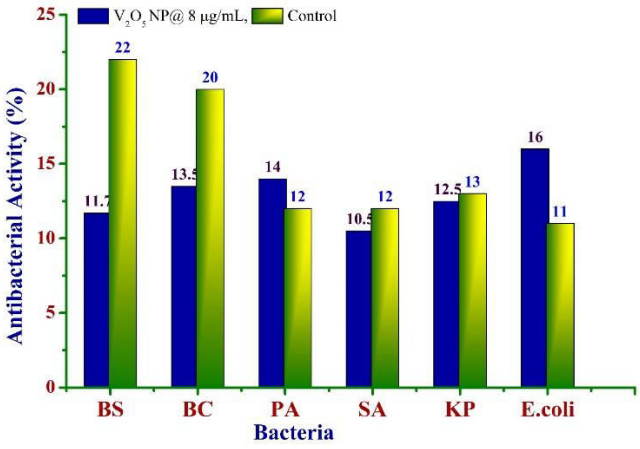

Figure 5. Antibacterial activity of V_2O_5NP on Gram-negative and Gram-positive bacteria

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IV. DISCUSSION

Vanadium oxide plays a crucial role as a catalyst in a wide range of industrial chemical reactions, showcasing its versatility. Its applications are particularly notable in optics, where it contributes to the creation of laser crystals, as well as in the development of nanofibers and nanowires. Furthermore, vanadium nanoparticles have emerged as a promising area of research due to their distinctive properties and potential uses in various fields, including sensor technology, electrode materials for electrochemical capacitors, electrochromic and optical switching devices, MRI Contrast agents, and solar cell windows [29-33]. Recent advancements have made it possible to synthesize vanadium oxide nanoparticles (V_2O_5NPs) through conventional approaches, which utilize chemical compounds as base sources and capping agents. However, there is a growing shift towards biosynthesis, employing safe and effective green chemistry methods that leverage the capabilities of microorganisms and plants [34-37]. The plant Spermacoce hispidain stands out for its medicinal properties and contributes significantly to the treatment of conditions such as eczema, bacterial infections, and cardiovascular disorders. Remarkably, vanadium nanoparticles derived from this plant have demonstrated antibacterial activities. The interaction between metals, ligands, and various stages of a pathogen's life cycle presents valuable opportunities for creating innovative therapeutic agents [38-41]. This research direction holds promise for addressing the growing need for more effective treatments.

V. CONCLUSION

In our research, we made V_2O_5 nanoparticles from Spermacoce hispidain plants using a simple and eco-friendly method. We confirmed the structure of these nanoparticles with SEM analysis, and UV-visible spectroscopy and tested their ability to fight against bacteria. The results indicated that our synthesis method enhanced antibacterial activity due to factors such as reduced particle size, the production of reactive oxygen species (ROS), and an increased surface area. These properties present numerous potential benefits in the future, with reduced harm and toxicity to human health, while promoting greater safety. To use them effectively in modern medicine, we need to standardize their properties. This will help ensure proper applications that benefit more people. More studies involving animals and humans are needed to determine how effective these compounds are and whether they are safe. V_2O_5 NPs can target different stages of harmful pathogens, providing new options for treatment. However, the process of making these nanoparticles from plants often leads to inconsistent sizes and shapes, which can make them less effective than those made with chemicals.

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