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Green Synthesis of Tin Oxide Nanoparticles from Plant Extracts: Characterization and Assessment of Photocatalytic, Antibacterial, and Antimicrobial Activities

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ABSTRACT: Green resource synthesis is a sustainable, economical, and environmentally benign process that produces no pollutants. Plantbased nanoparticles have a lower toxicity level. Because aloe vera contains bioactive chemicals such flavonoids, phenol, alkaloids, saponins, and others, it can operate as a reducing agent to reduce metal ions. As reducing agents, these substances are therefore essential to the formation of metal nanoparticles. When these nanoparticles are heated, they can transform into the corresponding metal oxides. This article describes the synthesis of tin (IV) oxide nanoparticles using aloe vera gel and their structural characteristics. The antibacterial ability of the produced nanoparticles was then evaluated by testing them against Gram-positive bacteria like Bacillus cereus and Staphylococcus aureus as well as Gram-negative bacteria like Shigella flexneri, Salmonella typhi, and Escherichia coli. This study shows the effectiveness and dependability of green synthesis techniques that use Aloe vera gel rather than the chemical-based approaches that have been used up to this point to create nanoparticles. It is less likely to fail and has a high biological activity. Thus, they are precious for applications in environmental and healthcare fields and industries. This highlights the advantages of developing sustainable materials through green synthesis routes and their wide range of applications.

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I. INTRODUCTION

Green synthesis has grown continuously prominent in recent years because of its simplicity, affordability, convenience of use, and cleanliness. It has several advantages over chemical synthesis. This type of synthesis is non-toxic, economical, and environmentally friendly. Nanoparticles of the appropriate sizes are synthesized using both top-down and bottom-up methods[1]. The top down method uses processes including ball-milling, etching, sputtering, thermal evaporation, and others to transform bulk material into microscopic nanoparticles. These are simple to use, but because they create tiny, irregularly shaped particles, they are useless. Nanoparticles are created from simple molecules using the bottom-up approach, which makes use of processes like the sol-gel process, laser process, molecular condensation, chemical vapour deposition, etc. These methods can be used to produce nanomaterials with precisely defined size, shape, and composition[2]. Bottom-up approaches use biological and chemical processes to turn smaller things, such as atoms and molecules, into nanoparticles[3]. Biological components such as bacteria, fungi, algae, and plant extract have been used to create metallic nanoparticles[4]. Phenols, flavonoids, terpenoids, ascorbic acids, aldehydes, ketones, and other phytochemicals included in plant extracts can transform metal salts into metal nanoparticles. Compared to bacteria and fungi, which take much longer, these phytochemicals are more effective at reducing metal salts[5]. Plants offer one-step methods for producing nanoparticles, but microbes such as bacteria, fungus, and algae require lengthy processes. It was discovered that plant extracts were perfect for creating nanoparticles due to their quick development, non-pathogenic reaction conditions, and environmental safety. The production of nanoparticles from plants requires plant elements such as leaves, flowers, seeds, and roots. Green chemistry principles, which include the use of environmentally

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friendly solvents, renewable resources, non-toxic chemicals, and the creation of biodegradable waste products during the development and design of nanoparticles, are upheld by this process for producing nanoparticles from plant extracts[6]. Using water as a solvent system and a natural source or extract as the main ingredient are two essential components of green synthesis[7]. The selection of wild plant species as an ingredient in this method also validates green synthesis, as water is regarded as a green solvent and has been used as a reaction medium throughout the reaction process[8]. Since metal oxide nanoparticles are being made utilizing an aqueous plant root extract, this paper discusses both of these factors. Metal oxide nanoparticles are used in food packaging, medicine delivery systems, environmental remediation, nanoelectronic components, and catalysis[9]. As a result of its application in solid state gas sensors, photoelectronic devices, light emitting diodes, and electrodes for lithium ion batteries, among other products[10].

Aloe vera has a rich phytochemical profile and is important for its involvement in a variety of applications, despite the fact that study has not found any traditional synthesis of Tin (IV) oxide nanoparticles in this plant. Anthraquinones, flavonoids, polysaccharides, vitamins, and enzymes are some of the main ingredients of aloe vera gel; these substances have all been shown to have anti-inflammatory, anti-bacterial, antioxidant, and restorative qualities[11]. Aloe vera is a medical and therapeutic plant that is frequently used for wound healing, skin care, and gastrointestinal disorders because of these bioactive components. Succulent plants like aloe vera are typically found in arid areas, particularly in the tropics and subtropics. During the warmer months, it is easily found and thrives on dry soil. The thick, fleshy, serrated leaves of this perennial, which reach a height of around 60 cm , contain a gel-like material. It is imposing by the small, tubular, yellow or orange flowers that grow on a tall stalk and by its rosette of leaves. Because of its many health benefits, the gel which is taken from the inner leaf tissue of aloe vera is utilized in a wide range of businesses, including food, medicines, cosmetics, and traditional medicine[12].The enhanced photocatalytic, antibacterial, and antimicrobial activities of SnO_2 nanoparticles made with aloe vera extract can be attributed to their improved surface and structural characteristics. When exposed to light it produce electronhole pairs that fuel the creation of reactive oxygen species, including superoxide and hydroxyl radicals, which efficiently break down organic contaminants and interface with microbial growth[13]. Because of high phytochemical makeup which is necessary for the development, stability and functional characteristics of nanoparticles, aloe vera was chosen for environmentally friendly synthesis of SnO_2 nanoparticle. A broad range of bioactive substance found in the plant, such as polyphenols, terpenoids and polysaccharides function as organic reducing and capping agent and help to transform tin precursors into SnO_2 nanoparticles without the need of hazardous chemicals. Aloe vera is less expensive and high antimicrobial and antioxidant qualities than other plant extracts. These qualities could enhance the antibacterial and photocatalytic activity of the produced SnO_2 nanoparticles[14]. The strong interaction with targeted pollutants and microbial cells, enhanced charge separation, and higher formation of reactive oxygen species are the main factors that affect the improved performance of SnO_2 nanoparticle made with aloe vera extract. aloe vera's bioactive substances create surface defects and oxygen vacancies, which reduce the electron-hole recombination as well as boost the effective photocatalytic reaction when irradiated to light.as a result oxidative processes cause organic containments to degrade quickly. Furthermore, SnO_2 ' reactivity is boosted by its small size and large surface area and phytochemicals are generated from aloe vera may also have antibacterial properties. Because of these complementary elements, green synthesized SnO_2[15].

Due to their capacity to produce reactive oxygen species and engage with target molecules or microbial cells, the produced SnO_2 nanoparticles demonstrate exceptional dual functionality in both photocatalytic and snit bacterial applications. Effective breakdown of organic containments is made possible by their photocatalytic effectiveness, which is mostly determined by surface characteristics, charge separation and light absorption. Their antibacterial efficiency on the other hand depends on oxidative stress and direct contacts between nanoparticles and bacteria which cause membrane rupture and cell death. Both process rely on the generation of Ros, but antibacterial activity targets the structure and activities of microorganisms directly, while photocatalysis concentrates on the breakdown of pollutants[16].

II. EXPERIMENTAL SECTION

A. RESOURCES AND TECHNIQUES

Tin chloride dihydrate ($SnCl_2 \cdot 2H_2O$), tin chloride ($SnCl_2$), distilled water, and methylene blue (MB) were used. These chemicals were purchased from Sigma-Aldrich and used without further purification. Alo vera were obtained and gel was prepared to be used as bio-template. Until methylene blue was required for photocatalytic activity, it was kept in a glass bottle in the refrigerator.

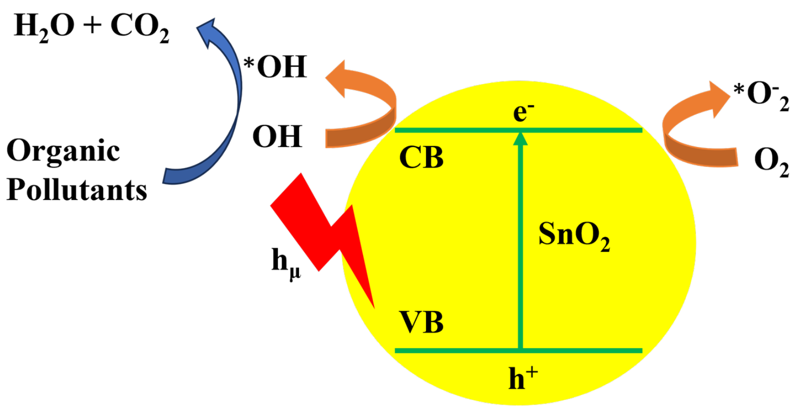

FIG. 1: Reaction mechanism of SnO_2.

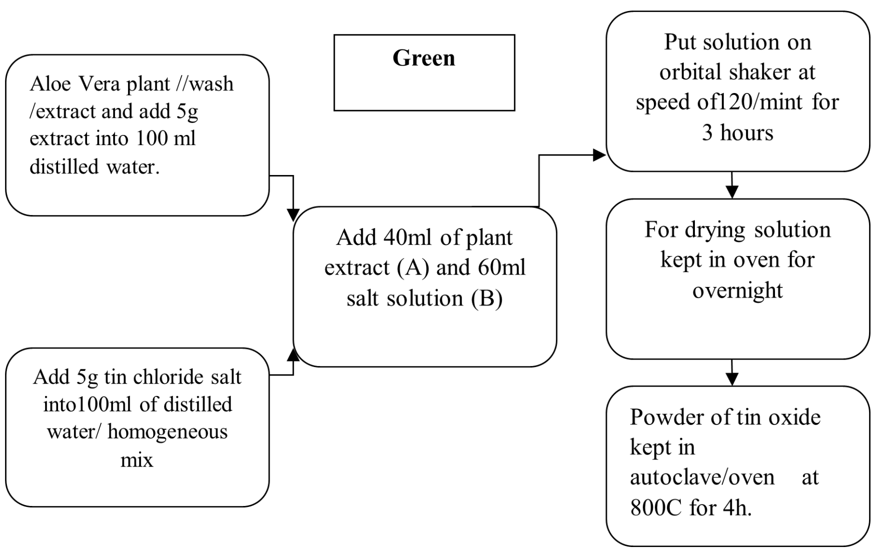

FIG. 2: Flow sheet diagram synthesis of tin oxide nanoparticles via Aloe Vera leaves.

B. Plant extracts preparation

For the preparation of tin oxide nanoparticles, fresh and clean leaves of Aloe Vera are washed with water and the gel is carefully extracted. After that, the extracted gel was ground into a fine consistency. A weight of 5 grams of the Aloe Vera gel was added in to 100 ml of distilled water followed by mixing for 20 minutes to ensure proper dispersion. To facilitate homogeneous mixing, the mixture is placed in a magnetic stirrer and a capsule-like magnetic stirrer is added for efficient agitation. The mixture is then stirred at 600 rpm for 2 hours at 60°C. After stirring, the solution is taken out from the magnetic stirrer and filtered to get the Aloe Vera extract. The process of filtration involves putting a funnel with filter paper over a beaker and pouring the prepared solution onto the filter paper. The solution is allowed to filter for 2-3 hours, after which a clear Aloe Vera extract is collected. The filtered extract is then kept in a refrigerator for further use.

C. SALT SOLUTION PREPARATION

The salt solution is prepared by weighing 5 grams of tin chloride salt using a balance. The measured salt is then added to 100 ml of distilled water. The mixture is stirred with a glass stirrer for 15 minutes to ensure proper dissolution. After that, the solution is placed on an orbital shaker to achieve a homogeneous mixture.

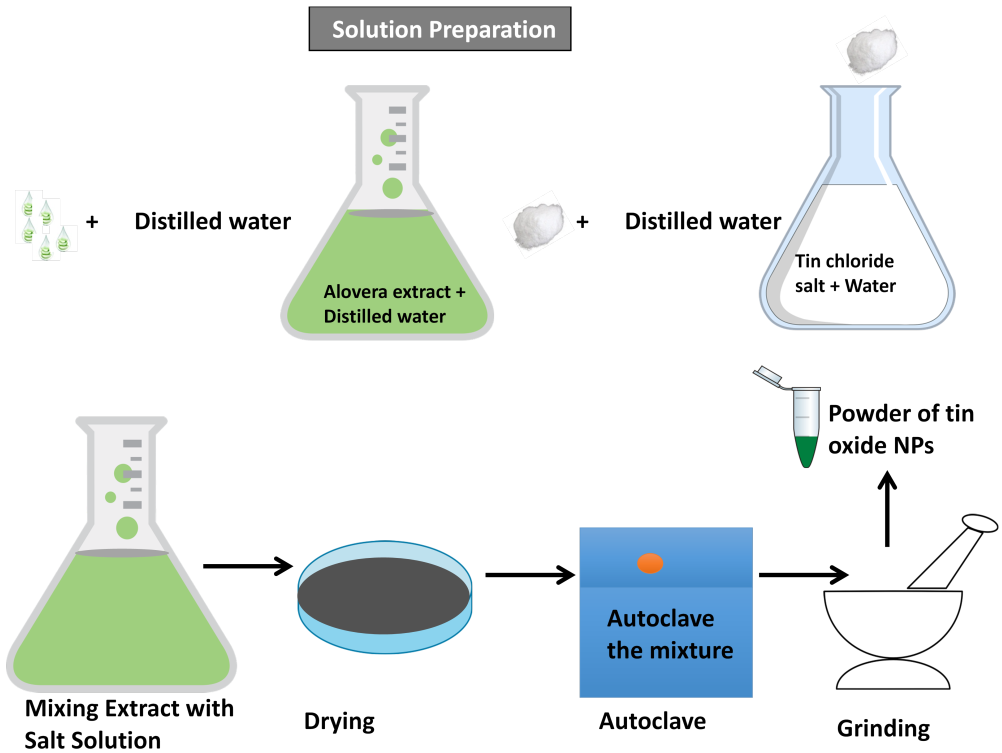

FIG. 3: Summary of green synthesis.

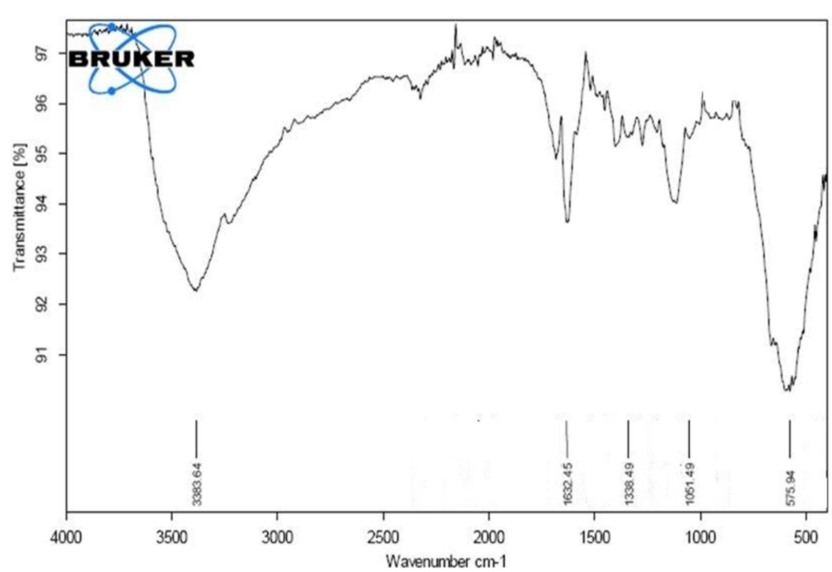

FIG. 4: FTIR spectra of SnO_2 NPs prepared by aloe Vera gel.

TABLE I: A comparison of the photocatalytic and antibacterial efficiency of SnO_2.

Research	Fabrication method	Photocatalytic capability	Antibacterial activity	References
Current study The green synthesis	Aloe vera assisted green synthesis.	Methylene blue degrades 90% in 120 minutes when irradiated to visible light.	At low amount, the strong inhibition against E. Coli and S. aureus.	This work
Chemical fabrication	Sol-gel method	Degradation of 85% under UV light in 150 minutes.	Moderate activity that inhibits microorganisms at enhanced amount.	17
Hydrothermal fabrication	Hydrothermal method	Degradation of 88% under UV radiations in 140 minutes.	Less efficient against gram negative and strong against gram positive.	18

D. PREPARATION OF TIN OXIDE NANOPARTICLES

Firstly 40 ml of the prepared aloe vera extract is added to 60 ml of the salt solution. Then, the mixture is kept on an orbital shaker for 3 hours at 120 rpm for uniform mixing. Then, the solution is transferred to an oven and left overnight to allow the formation of tin oxide nanoparticles. Once the powder is dried, it is put into an autoclave and heated at 800°C for 4 hours. Then tin oxide nanoparticles are ground using a mortar and pestle to obtain fine, white-colored tin oxide nanoparticles.

E. CHARACTERIZATIONS OF SAMPLE

The material was characterized using the FT-IR and XRD techniques. The solid's Fouriertransform infrared (FTIR) spectra was analyzed with a Perkin Elmer spectrophotometer (Model RZX). It shows that the alo vera extract contains functional groups and the changes that follow. The structural characteristics have been examined using the X-ray diffractometer system X'Pert PRO. With scan rates of 2 degrees per minute at 45 KV and 40 mA and 2 theta degrees every 2 minutes in the range of $10.0100 - 79.9900$, CuK alpha radiation = 1.54060 A0.

F. TEST FOR BACTERIAL ACTIVITY

Agar well diffusion was the technique used to test the antibacterial activity of environmentally generated Tin (IV) oxide nanoparticles against bacterial pathogens. The microbial biotechnology laboratory, Department of Biosciences, University of Agriculture Faisalabad (UAF) provided the bacteria pathogens that were utilised. Groups of clinically distinguished and pathogenic strains of bacteria which contained Escheria coli, Pseudomonas aureus, Staphylococcus aureus and Pseudomonas arignosa. These strains were analyzed for antibacterial activity by using tin oxide nanoparticles. The tin oxide nanoparticles were used to determine anti-fungal activity by using following fungal strains Cytospora *sp*, *C*. albicans, A . solani and B. cinereafor analysis. The bacterial culture was made using agar media, put into the sanitized petri dishes, and allowed to dry. Wells measuring 6 mm were made following solidification.

III. RESULTS AND DISCUSSION

Qualitative phytochemical analysis was carried out on a part of the aloe vera gel. It was observed that the gel consisted of a significant number of phenolic compounds. The second fraction of the gel extract turned light green with the addition of the solution of Tin (II) chloride salt. The appearance of a light green precipitate with heating and stirring indicated the formation of metallic tin nanoparticles. The calcined nanoparticles were obtained after separating them by centrifugation. The tin (IV) oxide nanoparticles, when tested against Grampositive and Gram-negative bacterial strains, showed good antibacterial activity. Fig. 2 represents the complete procedure.

A. FTIR ANALYSIS

Fourier transform infrared analysis was performed between 4000 and 400 cm^{-1}, and the findings demonstrated. There were organic species and the formation of tin (IV) oxide nanoparticles. For descriptation of various functional groups present in aloe Vera extract and SnO 2 NPs we performed FT-IR analysis. The obtain spectrum prove that deeply vibration stretch ranging from wave number of 450 to 500 cm^{-1}, H_2O band at 1623 cm^{-1}, SnOH at 1371 cm^{-1}, OH band at

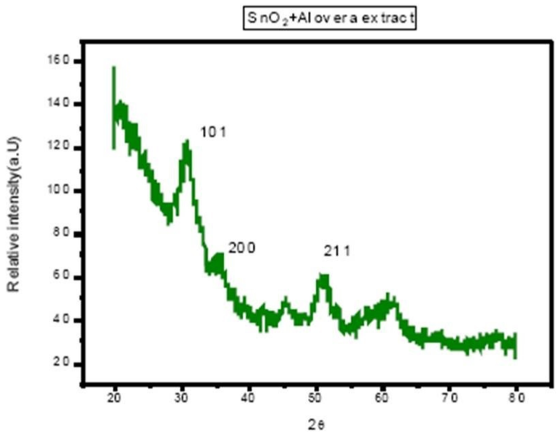

FIG. 5: XRD Spectrums of SnO_2 NPs via Aloe Vera plant.

3329 cm^{-1}, and SnO_2 peak at 1061 cm^{-1}. Fig. 3 shows more clearly the Fourier Transform Infrared Spectroscopy (FTIR) spectra of the prepared SnO_2Nps. The functional group and chemical composition present in mint plant can be examined by FTIR spectrum of the synthesized SnO_2 NPs. Due to the $Sn-O-Sn$ anti symmetric vibrations the sharp band at 575 cm^{-1} which are the characteristic band of SnO_2NP. Due to the stretching vibrations of -OH groups and the bending vibration of absorbed water molecule on the surface of the SnO_2 respectively the other two bands at 3308 cm^{-1} and 1338 cm^{-1} are originated. This is mostly due to the moisture adsorbed during sample preparation.

B. XRD ANALYSIS

XRD was use to investigate crystalline of the synthesized samples. Powder XRD data were recorded as a scanning rate of 1 s^{-1} using GNR, explorer x-ray diffraction at 40.0 KV and 30 Ma with the monochromatized CuKa($\lambda = 1.54187$ nm) radian. The range of 2θ was from $10-80$ degree. The XRD pattern of pure SnO_2 obtain by aloe Vera is show in the Fig. 4. Three main peaks observed at 2θ value of 34.3° for (100) planes. At 30° for 101 planes and at 35° for 200 and at 50° Plane attributed to the hexagonal structure of SnO_2. The sharp diffraction peaks confirm the high crystallinity of the SnO_2 sample. The particle size, SnO_2 catalyst and crystalline phase of SnO_2 NPs were analyzed by X-ray diffraction (XRD) All the standard diffraction pattern and prominent diffraction peaks goes well with of C (JCPDS 75-0444) and SnO_2 (JCPDS 41-1445).

C. SEM ANALYSIS

Scanning electron microscopic (SEM) was also employed to the study and size of pristine tin oxide nanoparticles. The SEM image of pristine SnO_2 sample show dense agglomeration of the spherical nanoparticles. From the SEM image (illustrated in Fig. 5) of the nano composite of SnO_2 synthesize in the presence of aloe Vera gel extract, it is found that the crystallites are found to be rod like shape with lesser crystalline which correlated with the PXRD results. Also the calculated crystalline size from PXRD matched with the SEM images. The morphology of green synthesized SnO_2 NPs was observed by SEM. It can be seen that the formed SnO_2 NPs illustrates the SEM images of SnO_2NPs at different resolutions from which a rough porous surface is observed. The individual size of the green synthesized SnO_2 cannot be measured visually due to the aggregation.

D. PHOTOCATALYTIC ACTIVITY

UV-visible spectrophotometer was used to study the spectra's which were recorded for study the photo catalytic degradation of methylene blue dye. Absorption spectrum was measured on a UV/Vis spectrophotometer in the wavelength range of $200-800$ nm. The UV-vis spectroscopy with various time intervals was controlled SnO_2 and extract solutions. This shows the clear Surface Plasmon Resonance (SPR) with the absorbance at the peak range of 668 nm . The conversion of $SnCl_2$ to SnO_2 NPs shows at highest absorbance peak of 668 nm in 90 min and estimated band gap is 3.51 eV . Fig. 6 shows the variation in absorption spectra of MB dye in the presence of SnO_2 photo catalyst. It can be seen from the absorption spectra of MB dye gradually decrease with increase irradiation time. With the passage of time degradation of methylene blue occurs and length of peak reduced. The lesser band gap values are favorable to photo catalytic activity. Therefore it is revealed that from all the above characterization the prepared SnO_2 NPs is pure without any significant impurity.

IV. CONCLUSION

Green solvent, a chemical-free reducing agent, ecologically friendly stabilizing agents, and biodegradable byproducts are used in the manufacturing process of nanoparticles from alo vera gel. The study's primary advantage is that alo vera gel was used as the primary ingradient, revealing a substantial amount of secondary metabolic products with different compositions that are in charge of reducing the metal salt Tin (II) chloride to Tin metal, which is then transformed into its oxides

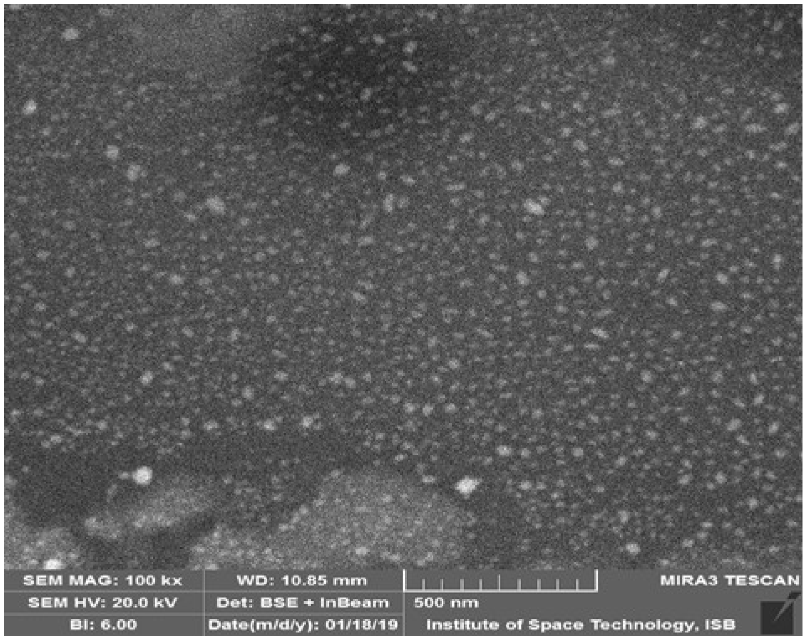

FIG. 6: XRD Spectrums of SnO_2 NPs via Aloe Vera plant.

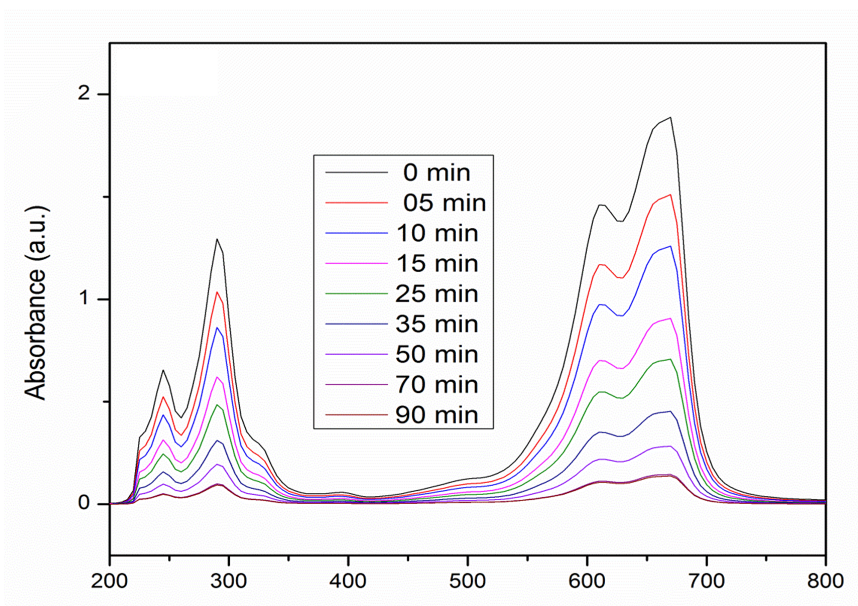

FIG. 7: UV- visible spectrum of tin oxide NPs by using aloe Vera.

adhering to nanoscale calcinations. The new study reveals that nanoparticles have outstanding antibacterial properties. Since tin (IV) oxide nanoparticles are used in practically every aspect of human existence, it is imperative to develop low-cost, environmentally friendly ways for producing nanoparticles. Additional nanotechnology research may be made possible by this kind of simple and safe preparation.

DECLARATION OF COMPETING INTEREST

The authors have no conflicts to disclose.

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