Synthesis and Characterization of Nanostructures with Functional Properties for the Novel Applications

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Chapter-1: Introduction

Nanotechnology is concerned with the design and application of materials with nanoscale dimensions in numerous fields of human civilisation. Due to their nano dimensions, nanoparticles have significant surface-to-volume ratios and consequently extremely specialised characteristics.Nanotechnology connects multiple fields of science and technology with its various novel applications.Nanomaterials have numerous functional properties that encourage the feasible advantages and sustainable development of society.Functional nanomaterials unveil diverse aspects to resolve the rising complicacy of technical developments. Nanocomposite materials are classified mainly in two groups as per their structural configurations, such as microcrystal and nanocrystal matrices. Microcrystal matrix consists of micro-nano composition, where nanoparticles are distributed in inter/intragranular region matrix grains. Nanocrystal matrix consists of nano-nano compositions, which generally indicate the nanocrystalline phases or the incorporation of the amorphous systems in the nanocrystal matrix.Metal oxide nanomaterials such as TiO_2, ZnO, SnO_2, Fe_2O_3, Al_2O_3, SiO_2, etc. are popularly used materials in the field of research and industry. Ti is one of the most recognizable materials for its stable chemical configuration, biocompatibility, physical and optoelectronic properties. Anatase TiO_2 is most significant due to its higher specific surface area, non-hazardous nature, cost-effective, photochemically stable structure, and hence exhibiting higher photocatalytic activities. The composite of TiO_2 and SnO_2 attain a stable band structure. The hybrid nanostructure that consists of both the anatase and rutile phases shows excellent catalytic behaviour. At present, ZnO nanostructures retain great interest due to their easy production and assemblage processes. ZnO nanoparticle is a biocompatible element that can control the photo-oxidization process and influence biological systems. Coupling of different phases like anatase or rutile TiO_2 and wurtziteZnO in the TiO_2-ZnO nanocomposite promote the enhanced catalytic activities under visible light radiation. The concentration of ZnO in the TiO_2-ZnO composite regulates the phases of that compound nanostructure.The hetero-structures in the nanocompositepromote rapid mobility of charge carriers, causing the enhancement of electrochemical activities. Bismuth is an environment-friendly material (often called green metal), which has a wide range of functional applications, from organic synthesis to engineering. The ferromagnetic substances mainly made of iron oxide are known as ferrite. Ferrite is a promising material for many advanced applications due to its cost-effectiveness, greater thermal resistance, and efficient operation ability over a higher-frequency range, and low corrosion potential. Bismuth ferrite (BFO) is one of the most significant ferrite materials due to its extensive polarization and immense ferromagnetic behaviour. A co-occurrence of ferro-electricity and magnetism are seen in bismuth ferrite. The conductivity in BFO depends on the translocation of oxygen vacancies and exhibits conductivity above room temperature.It has novel electrochemical applications.

Nanomaterial synthesis is one of the vital targets in nanotechnology, becoming a quickly developing area of research due to the controlling ability of unique shape, composition, and particle size distributions. There are several techniques for synthesizing nanoparticles. Among them, green synthesis is a very fabulous approach. Nature is an enormous resource of biomolecules from plants, algae, fungi, yeast, etc. Biomolecules play significant roles in the green synthesis of nanomaterials with different morphologies. This type of clean, secure and eco-friendly approach has gained a lot of attention for synthesizing various nanomaterials. The utilization of bio-elements for synthesizing nanomaterials is cost-effective and non-toxic and more compatible relative to other chemical processes.

Solvent cast technique is used to prepare polymeric membranes in membrane technology. Depending on the type of applications tocontrol the membrane's properties, various additives such as, co-solvents, nonsolvents, and fillers are used with low concentrations in the solvent casting method.The polymer-nanocomposite membrane is prepared by adding different nanofiller with lower concentrations in the polymeric system, using the solvent casting technique.

Various nano and nanocomposite materials exhibit efficient applications inphotocatalysis, solid-state electrolytes, humidity sensing devices,novel agronomic techniques, etc., for the sustainable development of human society.Photocatalysis is a photo-induced process that has been investigated in the last decades for diverse industrial applications.In this process, semiconductor materials are excited by solar radiation, have energy greater than the energy bandgap of that material, causing the generation of electron-hole pairs.In the photocatalysis process, the benefit of sunlight is achieved by the evolution of efficient reactor designs usingnanostructured materials. Various hazardous contaminants like dyes can be removedfrom industrial wastewater by photocatalytic degradation.

In electrochemistry, nanomaterials can have significant applications due to biocompatibility, higher conductivity, larger surface area, etc. The evolution of nanostructured materials enhances the possibilities of diverse electrochemical applications. Recently, inclusions of nanomaterials in various polymer matrices to construct polymer-nanocomposite membranes have fetched greater attention.Polymer-based nanocomposite electrolytes are ionically conductive in nature, which play a significant role in solid-state electrochemical appliances such as charge storage cells, capacitors, etc.

The application of nano-fertilizer is deemed to be one of the sustainable and advantageous strategies for enhancing crop production with the up-growing population in the world. Engineered nanomaterials can be conceived for targeted delivery in the plant body systems.They can transfer various agronomical usable chemical components like fertilizers, insecticides, or herbicides to the plant system as per requirement for nutrient transport and pest prevention purposes. Although, from the point of view related to the application of nanomaterials, agriculture was a less developed field than energy, medicine, etc.Yet, recent research is going to devote towards agricultural applications gradually.Nanotechnology in crop cultivation has several future research scopes like enhancing the yielding rate, lowering the output waste, proper uses of resources, etc.

Chapter- 2: Characterization techniques

Nanotechnology is predominantly associated with various organic and inorganic nanostructured materials that exhibit different shapes and structures, having diverse applications. Precise characterization methods of synthesized nanomaterials are crucial for achieving appropriate functional activities. Characterization techniques help to find new types of materials by estimating their unique features and inspire to improve their properties like surface area, structures, compositions, etc. Various characterization techniques such as X-ray diffraction (XRD), Scanning electron microscopy (SEM), Field emission scanning electron microscopy (FE-SEM), Energy-dispersive X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS), Transmission electron microscopy (TEM), Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), Ultraviolet-visible spectroscopy, Brunauer–Emmett–Teller (BET) & Barrett-Joyner-Halenda (BJH) techniques, Impedance spectroscopy, etc., are used to define several functional characteristics of the nanostructured materials.

Chapter- 3: Green Synthesized TiO_2-SnO_2 Nanocomposite for the Photocatalytic Degradation of Methylene Blue Dye

TiO_2-SnO_2 nanocomposite was prepared by green synthesis method with the help of *Allium sativum*extract obtained from garlic cloves. The green synthesized TiO_2-SnO_2 nanocomposite was characterized by XRD, SEM, EDS, Raman, ATR-FTIR, and UV-Visible spectroscopy. The XRD pattern indicates the polycrystalline nature of the synthesized nanocomposite, where anatase and rutile TiO_2 present simultaneously along with SnO_2. The calculated average crystallite size is 11.79 nm. The SEM images give the concept of surface morphologies of the synthesized nanocomposite.EDS spectrum detects the presence of Ti, Sn, and O in the synthesized nanocomposite material. The Raman spectrum confirms the chemical compositions. ATR-FTIR spectrum shows the presence of organic components of garlic as functional groups in the synthesized nanocomposite. The Tauc plot obtained from the UV-Visible spectral data displays the direct and indirect bandgap values. The present study investigates the effect of the synthesized nanocomposite's concentration on the photocatalytic degradation of methylene blue (MB) dye. The aqueous suspension of TiO_2-SnO_2 nanocompositephotocatalystfor a particular concentration exhibitsmaximum photocatalytic activity.Wastewater contains various organic pollutants, which have numerous negative environmental issues. Mostly, wastewater is generated from industrial resources such as textile, food, furniture, paint, etc., containing various organic dyes like methylene blue as impurities. Photocatalysis is a remarkable process of ecological cleanupfacility, which can effectively degrade methylene blue dye.

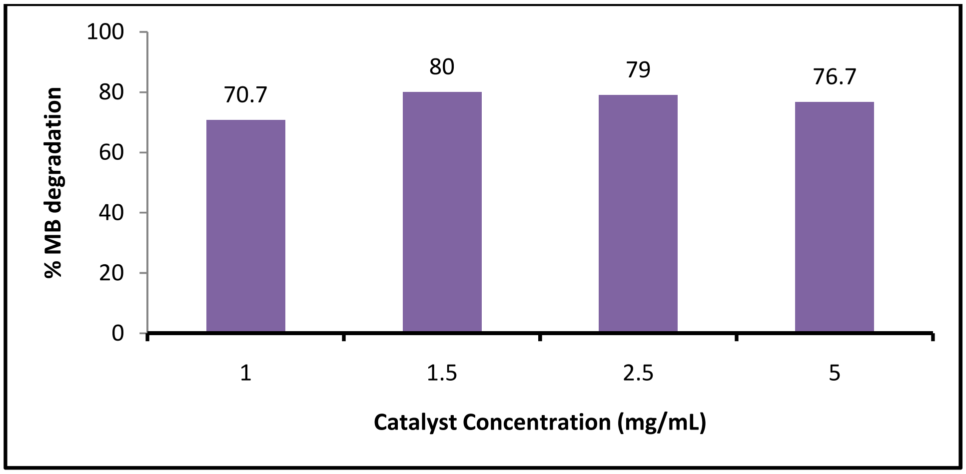

Fig. 1: Photodegradation percentage of MB dye for different concentrations of synthesized TiO_2-SnO_2 nanocomposite photocatalyst

Table 1:A comparison between green synthesized TiO_2-SnO_2nanocomposite material and other previously reported composite materials for the photocatalytic degradation of MB dye is given below.

S. No.	Photocatalyst	Concentration of MB dye (mg/L)	Irradiation source	% of degradation	Degradation time	Ref.
1	$Cu_2O/BiVO_4$	25	Visible light	72.9	160 min	[1]
2	CeO_2/V_2O_5	10	Visible light	76.9	300 min	[2]
3	α-$Fe_2O_3/SiO_2/SnO_2/TiO_2$	25	UV light	-	120 min	[3]
4	Ni-Cu-Zn ferrite@SiO_2@TiO_2	20	35 W-Xe arc lamp	69	360 min	[4]
5	Fe_3O_4@MIL-100 (Fe)	40	500 W-Xe lamp	99	200 min	[5]
6	SnO_2@TiO_2nanopillers	3.2	UV light	~90	480 min	[6]
7	Green TiO_2-SnO_2nanocomposite	20	Direct sun light	80	120 min	Present work [7]

Chapter-4: Leaf Extract Mediated Synthesis of Bismuth Ferrite for PVA-PANI-BFO Polymer-Nanocomposite Membrane: Impacts on Ionic Conductivity with Variation of Relative Humidity

Bismuth ferrite (BFO) nanoparticles were synthesized by an environment-friendly process using the *Moringaoleifera* leaf extract. The synthesized BFO nanoparticles were used as nanofiller to synthesize PVA-PANI-BFO polymer-nanocomposite membrane. Also, the PVA-PANI polymer membrane was synthesized for a comparative study purpose between PVA-PANI and PVA-PANI-BFO membranes. Both the polymer and polymer-nanocomposite membranes were synthesized by the solution cast technique. The Green synthesized BFO nanoparticles and the synthesized membranes were characterized by spectroscopic techniques such as XRD, RAMAN, and FTIR. XRD patterns confirm the $BiFeO_3$ phase of the synthesized BFO nanoparticles, as well as the existence of PVA, PANI, and BFO in the membrane. The Raman spectrum for the synthesized nanoparticles exhibits $BiFeO_3$ characteristic bands. The bands of PVA and PANI are also seen for the membranes. FTIR spectrum indicates some phytochemicals as the functional groups in the synthesized BFO nanoparticles. The surface structures of the synthesized membranes were characterized by FESEM. Ionic conductivities of the synthesized membranes were calculated by estimating bulk resistance of them from Cole-Cole plots that were obtained with the help of an impedance spectrometer. The conductivities of the membranes change with the relative humidity (RH).

Table 2: The variations in bulk resistances and ionic conductivities of PVA-PANI and PVA-PANI-BFO membranes estimated at different relative humidity are represented below.

Relative humidity (RH) (%)	**PVA-PANI membrane**		**PVA-PANI-BFO membrane**	
	Bulk resistance (R in KΩ)	**Ionic conductivity (σ in S/cm)**	**Bulk resistance (R in KΩ)**	**Ionic conductivity (σ in S/cm)**
28%	69.109	3.646×10^{-7}	111.392	1.795×10^{-7}
55%	100.555	2.506×10^{-7}	120.808	1.655×10^{-7}
95%	81.723	3.083×10^{-7}	100.555	1.988×10^{-7}

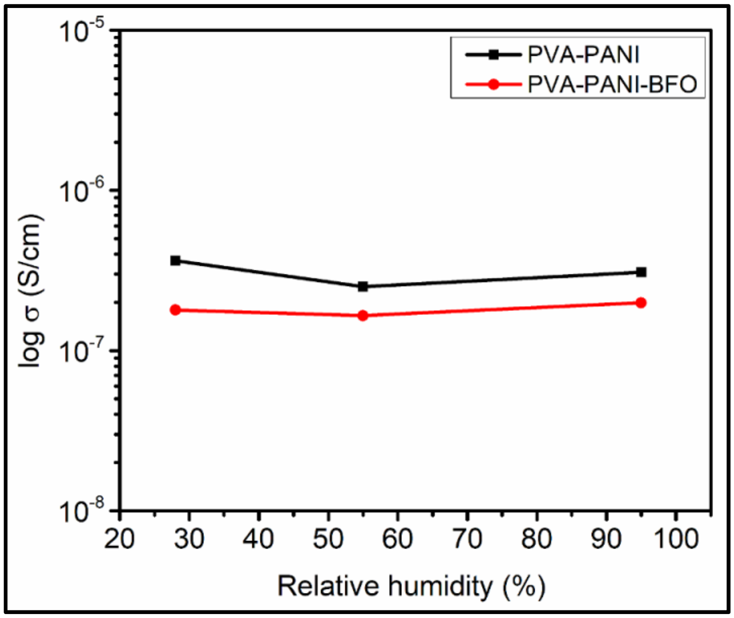

Fig. 2: Variation of ionic conductivity with relative humidity for PVA-PANI and PVA-PANI-BFO membranes.

Chapter-5: Biosynthesized TiO_2 Nano-Stimulator for Aquaculture Growth of *Oryzasativa* L.

The present investigation is associated with the biosynthesis of TiO_2 nanoparticles using *Dilleniaindica* fruit extract as a reducing and capping and agent. It represents a rare application of green synthesized TiO_2 nanoparticles in the soil-free aquaculture system that exhibits a significant effect on the germination and growth of *Oryzasativa L.*, in comparison to the previously reported commercially produced TiO_2 nanoparticles and other metal oxide nanoparticles. In the experiment, the Hoagland nutrient solution, as alternative to the soil, was used as the nutrient medium. Different concentrations of synthesized TiO_2 nanoparticles relative to the control system were used to study the development of *Oryzasativa* L. The synthesized nanoparticles were characterized using various spectroscopic and microscopic techniques such as XRD, EDS, FTIR, Raman, UV-Visible spectroscopy, SEM, and TEM microscopy, and also the surface properties using BET analysis. The XRD spectrum confirms the anatase phase of TiO_2 nanoparticleswith an average crystallite size of 6.34 nm, and the EDS spectrum indicates the elemental purity. The TEM analysis shows the particle sizes of TiO_2 below 10 nm. The BET surface analysis indicates the mesoporous nature of the synthesized nanoparticles. From the experimental study, it is noticed that a particular concentration of the green synthesized TiO_2 nanoparticles (10 mg/L) in the nutrient solution exhibits efficient germination and growth for *Oryzasativa*L. The overall process from the synthesis to the application of the biosynthesized TiO_2 nanoparticles is entirely environment-friendly.

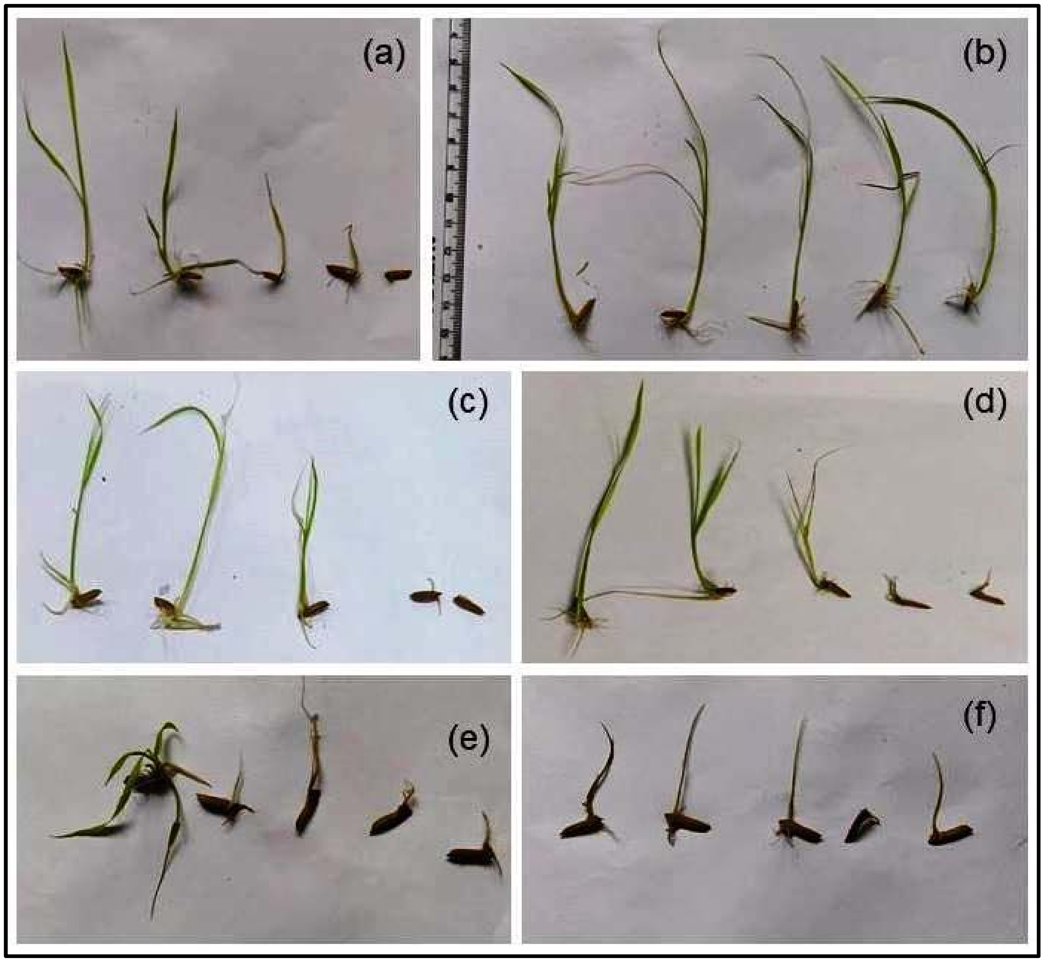

Fig. 3: Effect of biosynthesized TiO_2 nanoparticles (with different concentrations in Hoagland nutrient solution: **(a)** control, **(b)** 10 mg/L, **(c)** 30 mg/L, **(d)** 50 mg/L, **(e)** 100 mg/L, **(f)** 200 mg/L) in the aquaculture system for the growth of *Oryzasativa* L., on the 10th day of the observations

Table 3: A comparative study between the previously reported numerous metal oxide nanoparticles and the biosynthesized TiO_2 for the growth of *O. sativa L.*

Name of nanoparticles	Concentrations of nanoparticles applied to the plant	Effects of nanoparticles on the plant's growth	Ref.
CuO (Purchased from Sigma Aldrich Chemical Co.)	62.5, 125, 250 mg/L, with respect to the control	No growth, phytotoxic effect on roots and leaves with increasing concentration.	[8]
γ-Fe_2O_3 nanoparticles (Purchased from Nano-Oxides, INC, USA)	500, 1000, 2000 mg/L, with respect to the control	Higher Root elongation above the concentration of 500 mg/L, and maximum at 1000 mg/L.	[9]
SiO_2 (Purchased from Sigma-Aldrich Co.)	10, 20, 40, 60, 80, 100 mg/L, with respect to the control	Increase of germination percentage than control; the concentration 40 mg/L exhibits the maximum shoot and root elongation, and highest dry weight.	[10]
ZnO (Purchased from Sigma-AldrichChemical Co., USA)	25, 50, 100 mg/L, with respect to the control	Phytotoxic effect, reduce the fresh and dry weights of roots and shoots with increasing nanoparticle concentration relative to the control.	[11]
Y_2O_3 (Purchased fromNanjingHongde Nano Material Co Ltd., China)	1, 5, 10, 20, 50, 100 mg/L, with respect to the control	No significant role in seed germination rate at lower concentrations (1 and 5 mg/L), but decrease the rate at higher concentrations (50 and 100 mg/L) relative to the control; lower concentrations (1, 5, 10 mg/L) enhance the rot elongation, higher concentrations (20, 50, 100 mg/L) notably oppose the root elongation; negative impacts on root and shoot biomass.	[12]
TiO_2 (Purchased from Sigma-Aldrich Inc., USA)	5, 10, 30, 50, 100, 150 mg/L, with respect to the control	Enhance the shoot growth at higher concentration 150 mg/L; very little increment of fresh weight at the concentrations 5 and 10 mg/L, but lower the germination ratio than the control.	[13]
TiO_2 (Purchased frome Aladdin® Chemical	100, 250, 500 mg/L, with respect to the control	Reduction of root biomass and seedling leaves biomass.	[14]

Reagent Co., Ltd., China)			
Green synthesized TiO_2 (Synthesized using *Dilleniaindica* fruit extract)	10, 30, 50, 100, 200 mg/L, with respect to the control	Higher germination percentage at the minimum concentration 10 mg/L (lesser time consuming for germination) also at higher concentrations 50, 100 mg/L (longer time consuming for germination); Advancement in root and seedling growth with greater seedling vigor indices at 10 mg/L than control and any other concentrations; the maximum increase of weight (both fresh and dry weight) and maximum water uptake percentage at 10 mg/L; The maximum nutrient transportability from the Hoagland nutrient solution to the plant body at the concentration of 10 mg/L.	The Present work

Chapter- 6: TiO_2-ZnO Nanocomposite-Stimulator for the Growth of *Solanumlycopersicum* in Aquaculture

The current study is focused on the green synthesis of TiO_2-ZnO nanocomposite using *Allium sativum* leaf extract as a capping and reducing agent. It describes a unique application of green synthesized TiO_2-ZnO nanocomposite in the soilless aquaculture system that exhibits a significant influence on the germination and growth of *Solanumlycopersicum*plant. Here, Hoagland nutrient solution was employed as a substitute for soil in the aquaculture system, which is used as the nutrient medium. Different concentrations of green synthesized TiO_2-ZnO nanocomposites (10, 20, 30, 50, 100, 200, and 300 mg/L) compared to the control system were applied to investigate the growth of *Solanumlycopersicum*. The experimental investigation shows that a particular minimum concentration of the TiO_2-ZnO Nanocomposites (20 mg/L) in the Hoagland nutrient solution shows the overall effective germination and growth for the *Solanumlycopersicum*. The synthesized sample was characterized with several spectroscopic and microscopic techniques- XRD, FESEM, EDS, XPS, TEM, BET, Raman, FTIR, and UV-Visible spectroscopy. The XRD pattern ensures the composition of anatase TiO_2 and ZnO in the nanocomposite. The calculated average crystallite size is 4.58 nm comparable to the particle sizes (4-13 nm) as indicated by HR-TEM. FESEM displays the spherical shapes of nanostructures. EDS and XPS indicate the Ti, Zn, O as elemental compositions of the nanocomposite. The BET exhibits mesoporous nanostructures with a larger specific surface area of 133.824 m^2/g. A larger surface area indicates greater adsorption of nutrients, can act as nutrient carriers. Thus, stimulate nutrient transportation and influence plants' growth.

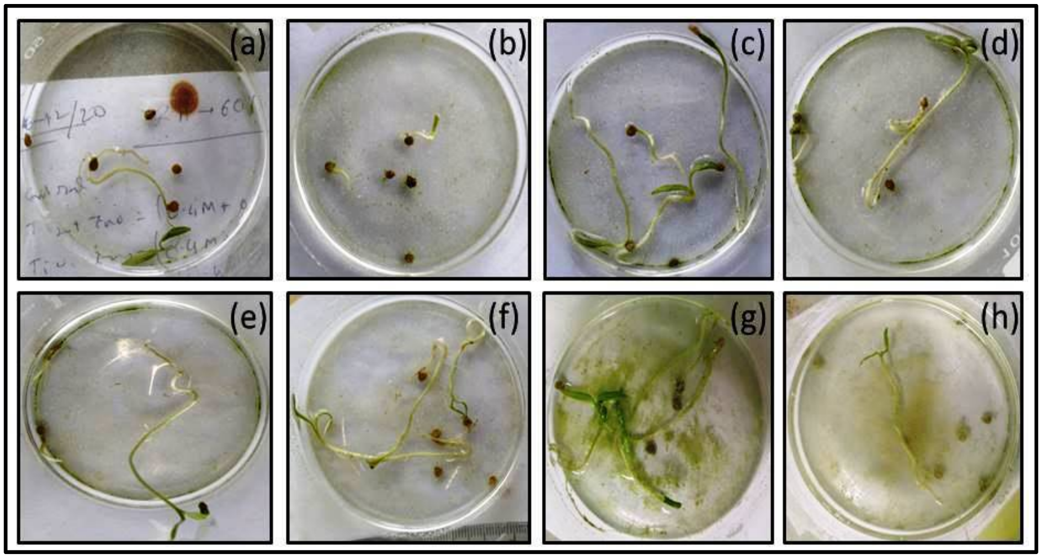

Fig. 4: Effect of TiO_2-ZnO nanocomposite with different concentrations in Hoagland nutrient solution: **(a)** control, **(b)** 10 mg/L, **(c)** 20 mg/L, **(d)** 30 mg/L, **(e)** 50 mg/L, **(f)** 100 mg/L, **(g)** 200 mg/L, **(h)** 300 mg/L in the water culture system for the growth of *Solanumlycopersicum* plants, on the 16^{th} day of the observations

Chapter-7: Conclusions and Future Prospects

7.1. Conclusions

In the present thesis, nanoparticles and nanocomposites were synthesized by utilizing extracts of plant components. The synthesized nanomaterials were characterized with X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Field Emission Scanning Electron Microscopy (FESEM), X-ray Energy Dispersive Spectroscopy (EDS), High Resolution Transmission Elecrton Microscopy (HRTEM), Fourier Transform Infrared (FT-IR), Raman Spectroscopy, UV-Visible spectrophotometer, spectroscopy, Brunauer-Emmett-Teller (BET) and Barret-Joyner-Halenda (BJH) analysis. Green synthesized nanomaterials were used for novel applications. Based on the results found throughout the research work, there are some key findings of this study which are briefly described below:

(1) Present study suggests that the plant mediated methods of synthesizing metal oxide nanoparticles have proved to be one of the best methods till date. This is due to its cost effective, simple, efficient and eco-friendly nature.

(2) Green synthesized TiO_2-SnO_2nanocomposite exhibit efficient photocalytic performance. The greensynthesizedTiO_2-SnO_2photocatalyst shows brilliant activity towards the degradation of methylene blue (MB) in the aqueous solution. As compared to the others nanomaterials including the chemically synthesized SnO_2@TiO_2nanopillers, the green synthesized TiO_2-SnO_2nanocomposite exhibits the better photocatalytic activity to degrade MB dye within the shortest time duration of just 120 minutes.

(3) Bismuth ferrite (BFO) nanoparticles using the leaf extract of *Moringaoleifera* L., is utilized as nanofiller to construct the PVA-PANI-BFO polymer-nanocomposite membrane.The inclusion of BFO nanoparticles as nanofiller in the membrane makes it more stable against the surrounding humidity, which may have some advanced applications for electrochemical devices in the future in an open environment to overcome the negative impacts of moisture.

(4) A simple, eco-friendly and green chemistry principles based approach is adopted to synthesize TiO_2 nanoparticles using *Dilleniaindica* fruit extract and its effectiveness is evaluated for the soil free water-culture system to cultivate *Oryzasativa*L. A particular concentration of synthesized TiO_2 nanoparticles in the nutrient solution (10 mg/L in nutrient solution) can be acted as the catalyst to enhance the metabolic rate of the plant *Oryzasativa* L. It is more effective for enhancing plant's growth, including the germination rate or percentage. At this particular concentration, the nutrition uptake rate by plant also increases.

(5) Biosynthesized TiO_2-ZnO nanocomposite in the modified Hoagland nutrient solution is used as the germination and growth medium of seeds and plants. It plays an important role in influencing the germination and growth of *Solanumlycopersicum*. A particular minimum concentration of TiO_2-ZnO nanocomposite (20 mg/L) in the nutrient medium, able to stimulate germination and growth of *Solanumlycopersicum*more efficiently in comparison to other nutrient mediums.

7.2. Future Prospects

The green synthesized nanostructured materials are biocompatible. Thus, they have gained innumerable possibilities in potential sustainable applications. Their various future prospects in the view of the current research works are briefly illustrated below.

(1) The photocatalytic activities of green synthesized nanomaterials may have a novel application for wastewater purification. Mostly, wastewater is generated from industrial resources such as textile, food, furniture, paint, etc., containing various organic dyes like methylene blue, rhodamine B, phenol, etc. as impurities. Photocatalysis is a remarkable process of ecological remediation and energy augmentation facilities, which can effectively degrade the contaminants in wastewater to purify it and make it reusable.

(2) The inclusion of green synthesized nanofiller in the conducting polymeric membrane system enhance it stability against ambient moisture that can have utilization in polymeric electrolyte system in electrochemical devices. Also property like the change in ionic conductivity in the conducting polymeric membrane with relative humidity by the insertion of green synthesized nanofiller can be useful for humidity sensing applications.

(3) The use of green synthesized nanomaterials in soil-free aquaculture methods has great potential prospect for the future. Due to the lack of sufficient agricultural lands with the up-growing human population and the increasing of urbanization, the soilless water culture process (hydroponic) has great prospects for cultivating and producing crops using minimum agricultural land, less water consumption, and cost-effectiveness.

(4) The green synthesis of nanomaterials, and their utilization in the soilless water-culture system, the overall experimental process is a completely environment-friendly process in favor of the ecological system. Thus in the sense of sustainability, green synthesized nanomaterials have great future prospects in agronomy.

(5) More understanding the fundamental reaction mechanisms in green synthesis process, and better characteristics analysis of the green synthesized nanomaterials will construct a solid foundation of an environment-friendly sustainable nanotechnology via green approach.

References:

[1] S. Min, F. Wang, Z. Jin, J. Xu, Cu_2O nanoparticles decorated $BiVO_4$ as an effective visible-light-driven p-nheterojunctionphotocatalyst for methylene blue degradation, *Superlatt. Microstruc.*74 (2014) 294-307. DOI: 10.1016/j.spmi.2014.07.003

[2] R. Saravanan, S. Joicy, V.K. Gupta, V. Narayanan, A.J.M.S. Stephen, Visible light induced degradation of methylene blue using CeO_2/V_2O_5 and CeO_2/CuO catalysts, *Mater. Sci. Eng. C,* 33 (2013) 4725-4731. DOI: 10.1016/j.msec.2013.07.034

[3] J.S. Chen, C. Chen, J. Liu, R. Xu, S.Z. Qiao, X.W. Lou, Ellipsoidal hollow nanostructures assembled from anatase TiO_2 nanosheets as a magnetically separable photocatalyst, *Chem. Communic.* 47 (2011) 2631-2633. DOI: 10.1039/C0CC04471G

[4] C.C. Chen, D. Jaihindh, S.H. Hu, Y.P. Fu, Magnetic recyclable photocatalysts of Ni-Cu-Zn ferrite@ SiO_2@ TiO_2@ Ag and their photocatalytic activities, *J. Photochem. Photobiol. A: Chem.* 334 (2017) 74-85. DOI: 10.1016/j.jphotochem.2016.11.005

[5] C.F. Zhang, L.G. Qiu, F. Ke, Y.J. Zhu, Y.P. Yuan, G.S. Xu, X. Jiang, A novel magnetic recyclable photocatalyst based on a core–shell metal–organic framework Fe_3O_4@ MIL-100 (Fe) for the decolorization of methylene blue dye, *J. Mater. Chem. A.* 1 (2013) 14329-14334. DOI: 10.1039/C3TA13030D

[6] H.E. Cheng, C.Y. Lin, C.M. Hsu, Fabrication of SnO_2-TiO_2 core-shell nanopillar-array films for enhanced photocatalytic activity, *Appl. Surf. Sci.* 396 (2017) 393-399. DOI: 10.1016/j.apsusc.2016.10.166

[7] D. Roy, A.K. Yadav, K.B. Singh, G. Pandey, Green synthesized TiO_2-SnO_2nanocomposite for the photocatalytic degradation of methylene blue dye, *Jordan J. Phys.* 16 (2023) Accepted article.

[8] Z. Yang, Y. Xiao, T. Jiao, Y. Zhang, J. Chen, Y. Gao, Effects of copper oxide nanoparticles on the growth of rice (OryzaSativa L.) seedlings and the relevant

physiological responses. *Int. J. Environ. Res. Public Health*.17 (2020) 1260. DOI: 10.3390/ijerph17041260

[9] D. Alidoust, A. Isoda, Phytotoxicity assessment of γ-Fe_2O_3 nanoparticles on root elongation and growth of rice plant. *Environ. Earth Sci*. 71 (2014) 5173–5182. DOI: 10.1007/s12665-013-2920-z

[10] T. Adhikari, S. Kundu, A.S. Rao, Impact of SiO_2 and Mo nano particles on seed germination of rice (*OryzaSativa* L.).*Int. J. Agriculture Food Sci. Technol*. 4 (2013) 809-816.

[11] J. Chen, R. Dou, Z. Yang, T. You, X. Gao, L. Wang, Phytotoxicity and bioaccumulation of zinc oxide nanoparticles in rice (*Oryzasativa* L.). *Plant Physiol. Biochem*. 130 (2018) 604–612. DOI: 10.1016/j.plaphy.2018.08.019

[12] X. Zhao, W. Zhang, Y. He, L. Wang, W. Li, L. Yang, G. Xing, Phytotoxicity of Y_2O_3 nanoparticles and Y^{3+} ions on rice seedlings under hydroponic culture.*Chemosphere*.263 (2021) 127943. DOI: 10.1016/j.chemosphere.2020.127943

[13] Y. Hao**,** Z. Zhang, Y. Rui, J. Ren, T. Hou, S. Wu, M. Rui, F. Jian, L. Liu, Effect of different nanoparticles on seed germination and seedling growth in rice, Proceedings of the 2nd Annual International Conference on Advanced Material Engineering (AME 2016). In: Bhatnagar, A.K., Dahai, R., Pandey, K.M., Haeri, H., Andrievskiy, R.A., Ziara, M., Feng, G. (eds.) Advances in Engineering Research, *Atlantis Press* (part of Springer Nature). 85 (2016) 166-173.

[14] B. Wu, L. Zhu, X.C. Le, Metabolomics analysis of TiO_2 nanoparticles induced toxicological effects on rice (*Oryzasativa* L.). *Environment.Pollut*.230 (2017) 302-310. DOI: 10.1016/j.envpol.2017.06.062

List of Publications

Published and Accepted Research papers:

1. **<u>Diptarka Roy</u>**, Anil Kumar Yadav, Green TiO_2-ZnO nanocomposite-stimulator for the growth of *Solanumlycopersicum* in aquaculture, *Applied Nanoscience*. **2022**, 12, 1403–1423, https://doi.org/10.1007/s13204-021-02329-x

2. **<u>Diptarka Roy</u>**, Anil Kumar Yadav, KijayBahadur Singh, GajananPandey, Green synthesized TiO_2-SnO_2nanocomposite for the photocatalytic degradation of methylene blue dye, Accepted on 31st October **2021** for publication in *Jordan Journal of Physics*. 2023, 16 (2).

3. **<u>Diptarka Roy</u>**, KamleshPandey, Anil Kumar Yadav, Green synthesized bismuth ferrite for PVA-PANI-BFO polymer-nanocomposite membrane: Impacts on ionic conductivity with variation of relative humidity, Accepted on 18th March, **2022** for publication in *Journal of Physical Science.*

4. Sachin Kumar Yadav, **<u>Diptarka Roy</u>**, Anil Kumar Yadav, PinkySagar, Sarvesh Kumar Avinashi, Synthesis and characterization of graphene oxide-based nanofluids& study of their thermal conductivity, *Journal of Thermal Analysis and Calorimetry*. Published 30th May, **2022**, https://doi.org/10.1007/s10973-022-11388-3

5. Surya PratapGoutam, Sarvesh Kumar Avinashi, ManjuYadav, **<u>Diptarka Roy</u>**, RajkamalShastri, Green synthesis and characterization of characterization of aluminium oxide nanoparticles using leaf extract of Rosa, *Advanced Science, Engineering and Medicine*. **2018**, 10, 719-722. https://doi.org/10.1166/asem.2018.2236

6. RajkamalShastri, NidhiAwasthi, Devesh Kumar, Anil Kumar Yadav, **<u>Diptarka Roy</u>**, Surya PratapGoutam, AnweshPandey, A Density Functional Theory Study on Structural Stability and Electronic Properties of Co_xO_y (x + y = 4–12) Nanoclusters, *Advanced Science, Engineering and Medicine*. **2018**, 10, 814-818. https://doi.org/10.1166/asem.2018.2242

Communicated Research Papers:

1. **<u>Diptarka Roy</u>**, Surya PratapGoutam, Anil Kumar Yadav, Green synthesized TiO_2 nano-stimulator for aquaculture growth of *Oryzasativa* L. (Communicated in *Materials Today Communications*)

2. KamleshPandey, MrigankMauliDwibedi, NidhiAsthana, **<u>Diptarka Roy</u>**, Narinder Kumar, Anil Kumar Yadav, Devesh Kumar, Finding the Shadowy Facts behind PVA Membrane Development in different Solvent: A Spectroscopic Study from DFT and Experimental Aspects. (Communicated in *European Physical Journal Plus*)

Book Chapter and Review Article:

1. Surya PratapGoutam, GauravSaxena, **<u>Diptarka Roy</u>**, Anil Kumar Yadav, Ram NareshBharagava, Green Synthesis of Nanoparticles and Their Applications in Water and Wastewater Treatment, Chapter-16, In: Bioremediation of Industrial Waste for Environmental Safety, Volume I: Industrial Waste and Its Management", *Springer Singapore*, **2020**, https://doi.org/10.1007/978-981-13-1891-7_16

2. BananiKar, **<u>Diptarka Roy</u>**, Surya PratapGoutam, Anil Kumar Yadav, Perovskite Structured Nanomaterials: An Advanced Key for Global Development of Nanotechnology, *Sensor Letters*. **2019**, 17, 787-791, https://doi.org/10.1166/sl.2019.4156