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International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Green Synthesis of Cr_2O_3 NPs Using the Aervalanata Plant Demonstrates Significant Photophysical and Antibacterial Properties

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ABSTRACT:

This research focuses on the eco-friendly synthesis of chromium oxide (Cr_2O_3) nanoparticles utilizing a plant extract from Aervalanata as both a reducing and stabilizing agent. Various characterization methods, including ultraviolet-visible (UV-VIS) spectroscopy and scanning electron microscopy (SEM), were employed to analyze the produced nanoparticles. The nanoparticle sizes averaged between 27 and 40 nm. The antibacterial effectiveness of the green synthesized nanoparticles was assessed against six bacterial strains: Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), E. coli, and Klebsiella pneumoniae (KP), using agar well diffusion and a live/dead staining assay. The results demonstrated that a concentration of 9 µg/ml of the green Cr_2O_3 NPs displayed significant efficacy against these bacterial strains, which can be attributed to the presence of heterocyclic compounds derived from the plant. The findings indicated that the green synthesized Cr_2O_3 nanoparticles exhibited enhanced antibacterial properties, evidenced by the zones of inhibition (ZOIs) against both Gram-positive and Gram-negative bacteria when compared to the standard antibiotic streptomycin. These observations imply that the enhanced biological activity of the green synthesized Cr_2O_3 nanoparticles may result from a synergistic effect. Therefore, these environmentally friendly Cr_2O_3 nanoparticles could serve as promising candidates for prospective biomedical applications. The findings imply that the enhanced biological activity of the green synthesized Cr_2O_3 nanoparticles may result from a synergistic effect. Consequently, green synthesized Cr_2O_3 nanoparticles could serve as promising candidates for future biomedical applications.

Keywords: Green synthesis, Cr_2O_3, Aervalanata, antibacterial, Nanoparticle, biocompatibility

1. Introduction :

Medicinal plants have long been a cornerstone in the treatment of human ailments, dating back to ancient civilizations. Herbal medicines stand out as a highly effective alternative to modern synthetic drugs, typically exhibiting minimal or no side effects while being regarded as safe options [1-5]. The pursuit of substances with strong antimicrobial properties has become a critical area of research, aimed at significantly reducing the risk of infectious diseases caused by pathogenic bacteria, fungi, viruses, and parasites [6-9]. Plant extracts remain vital sources of numerous therapeutic agents, including powerful antimicrobials for infection treatment. Globally, the application of medicinal plants in managing both acute and chronic wounds is a well-established practice in traditional medicine. One notable example is Aervalanata, a common weed that flourishes throughout the plains of India and is distinguished by its camphor-like aroma [10-12]. The dried flowers, resembling soft spikes, are marketed under the names Buikallan and Boor. Virtually the entire plant is edible, with the leaves commonly incorporated into soups or consumed as spinach or a vegetable. Moreover, Aervalanata is firmly established in traditional medicine for treating snakebites, and the juice extracted from crushed Aervalanata roots is effectively used in the therapy for jaundice. The versatility and efficacy of this plant underscore the value of herbal remedies in contemporary healthcare [13-17].

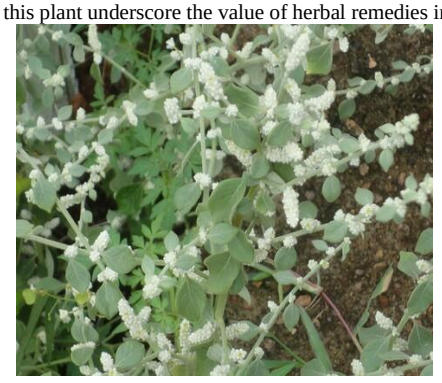


Figure 1. Image showing the Aervalanata plant

Transition metal complex and or their nanoparticles are recognized for their wide range of applications, primarily due to their ability to exist in multiple oxidation states and their large surface areas [18-24]. These characteristics enhance their reactivity compared to bulk materials, making them a significant area of research. One notable compound in this context is chromium trioxide, which has the chemical formula Cr_2O_3. This red, odorless powder is commonly used alongside additives that influence the plating process without reacting with the chromium trioxide itself [25,26]. In aqueous solutions, chromium trioxide can form chromic acid and various anhydrides. Recently, chromium oxides have garnered substantial interest due to their relevance in both scientific and technological advancements. With chromium's capability to adopt different stable oxidation states, it can generate various types of oxides. Notably, chromium nanoparticles have found numerous applications in the biomedical field, particularly in antibody-related therapies for various diseases [27]. Research indicates that biogenic nanoparticles, which are derived from natural sources, exhibit superior antimicrobial activity compared to their chemically synthesized counterparts. This enhanced property is often attributed to the action of proteins that act as capping agents during the synthesis process [28-33]. For instance, nanoparticles synthesized from the Aervalanata plant have proven effective against several bacterial strains, including Bacillus subtilis, Enterococcus faecalis, Escherichia coli, Salmonella typhimurium, as well as certain pathogenic yeasts.

The pursuit of substances with significant antimicrobial properties has emerged as one of the most active areas of research aimed at reducing the risk of infectious diseases caused by bacteria, fungi, viruses, and parasites that are pathogenic to humans. Plant extracts continue to serve as principal sources for a variety of therapeutic agents, including those utilized in the treatment of infectious diseases [34-38]. The application of medicinal plants in the synthesis of MRI contrast agents for both acute and chronic wounds is prevalent in numerous traditional medicine practices worldwide [39-41]. In this context, numerous plants from tropical and subtropical regions have been assessed for their wound-healing capabilities. Consequently, plants exhibiting antimicrobial activity against multidrug-resistant (MDR) pathogens represent valuable resources [42]. This study focused on the evaluation of the aqueous extract of the medicinal plant Aervalanata, followed by the synthesis of metal oxide nanoparticles, examining their absorption characteristics and antimicrobial efficacy against Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), Escherichia coli, and Klebsiella pneumoniae (KP). Given the bioactive properties of the selected plants and metals, the green-mediated nanoparticles demonstrate potential medicinal value in treating various infections, particularly within traditional medicine frameworks.

2. Materials :

Chromium(III) nitrate nonahydrate [$Cr(NO_3)_3 \cdot 9H_2O$] and sodium hydroxide (NaOH) were acquired from Sigma Aldrich. A variety of solvents—including acetone, acetonitrile, chloroform, dichloromethane, diethyl ether, ethanol, hexane, toluene, and *N, N*-dimethylformamide—as well as hydrochloric acid and acetic acid, were sourced from Merck India and utilized as received. Double distilled water was produced by distilling distilled water over alkaline potassium permanganate.

3. Methods :

3.1 Selection and Collection of Plants

The Indian herbal plant Aervalanata was collected from the campus of our institution. The dried and waste parts of the plant were meticulously separated. Subsequently, the collected specimens were washed with tap water and cut into smaller pieces. To prevent the degradation of phytoconstituents due to sunlight exposure, the plant materials were air-dried completely under shade at room temperature over seven days. Once adequately dried, the materials were processed into a powder using a pulverizer and were then sieved to a mesh size of 120. The resultant fine powder was homogenized and stored in an air-tight container for subsequent analysis.

3.2 Preparation of water extracts of Aervalanata plants

The preparation of plant extracts involves a constructive approach, starting with the careful mixing of 10 g of freshly dried plant powder with 200 ml of distilled water in separate batches. This mixture is then heated at 80°C for 2 hours with continuous stirring, facilitating optimal extraction. Following this process, the resulting residue is effectively filtered out using Whatman No. 42 filter paper. The extracts are stored at 4°C, providing a stable solution for the subsequent synthesis of chromium oxide nanoparticles.

3.3 Solubility test

Approximately 0.1 grams of the substance was placed in a clean 10 ml test tube, and 1 ml of a low-polarity solvent, such as benzene or petroleum ether, was added before shaking the mixture thoroughly. If the substance remained insoluble, the procedure was repeated using solvents with increasing polarity, including acetone, acetonitrile, toluene, ethanol, and others. The solubility of the substance was then assessed with high-polarity double-distilled water. Once solubility was confirmed, an additional 0.1 grams of the non-polar substance was introduced until the saturation limit was reached. This process allowed us to determine the saturation or solubility limit of our nanoparticles.

3.4 UV-visible Absorption Spectrum

The electronic spectra were recorded in the 200-900 nm range using a Deep Vision UV/VIS spectrophotometer and a cuvette with a 1 cm path length. The concentrations of the ligand and metal complexes were consistently maintained at 1.00×10^{-5} mol/L at a temperature of 310 K.

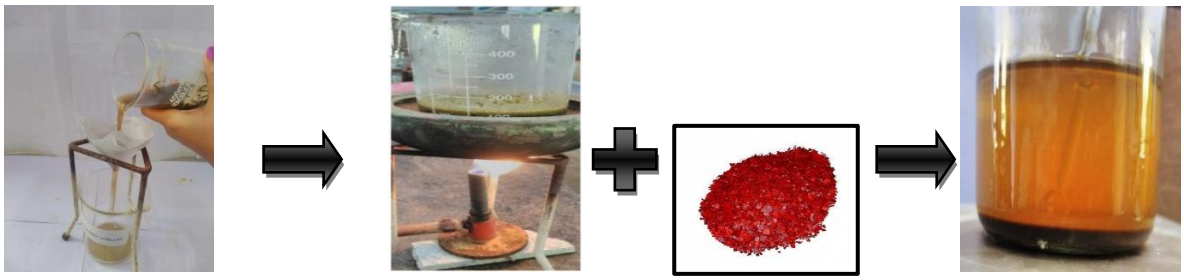
3.5 Antibacterial activity

The disc diffusion method was employed to assess the antibacterial capabilities of plant-derived metal nanoparticles (NPs) against several bacterial strains, including Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), E. coli, and Klebsiella pneumoniae (KP). Before conducting the experiments, the bacterial strains were incubated overnight in nutrient broth and maintained at 37 °C for 24 hours. To verify the antibacterial efficacy of the NPs, an overnight bacterial culture was spread onto prepared agar plates and allowed to dry for 5 minutes. Additionally, filter discs that contained varying concentrations of NPs (ranging from 1 to 10 µg/ml) were dried and placed on the surface of the agar. The plates were then placed in an incubator and monitored for zones of inhibition (ZOI). Streptomycin was utilized as the positive control, while DMSO served as the negative control.

4. Result and Discussion :

4.1. Green Synthesis of Chromium Oxide nanoparticle

A salt solution was prepared by dissolving 1 g of $[Cr(NO_3)_3 \cdot 9H_2O]$ in deionized water, which was subsequently combined with 30 mL of green extract from Aervalanata. This mixture was stirred at a temperature of 80°C for 2 hours. To achieve and maintain a pH level of 14, a dilute solution of sodium hydroxide (0.01 mM) was added incrementally. Following this, the resultant mixture was concentrated and left in a dark environment for 48 hours. The resulting crystals were then dried in a hot air oven at 90°C for 2 hours. The dried crystals were subjected to calcination at 400°C in a muffle furnace for 3 hours, leading to the formation of a dark greenish-orange crystalline powder of Cr_2O_3NP, achieved at a yield of 97%. The reaction process is illustrated in Scheme 1.



Scheme 1. Synthesis of Aervalanata extract-based Chromium Oxide nanoparticle

4.2 Saturation limit analysis

Approximately 0.1 grams of chromium(III) oxide nanoparticles (Cr_2O_3 NPs) were placed in a clean 10 ml test tube, followed by the addition of 1 ml of double-distilled water. The mixture was stirred until a clear solution was obtained, confirming the compound's solubility in the aqueous solvent. While maintaining stirring, an additional portion of 0.1 grams of Cr_2O_3 nanoparticles was introduced until the saturation limit was reached. This procedure established that the saturation limit of the nanoparticles in water is 0.7 grams per 1 ml.

4.3 UV-Visible spectroscopy

The synthesis of chromium oxide nanoparticles was validated using UV-VIS spectrophotometry. As illustrated in Figure 2, the UV-Vis absorption spectrum for the chromium oxide nanoparticle sample was obtained over a wavelength range of 200–800 nm. The spectrum exhibited a prominent absorbance band at 318 nm, along with a shoulder band at 351 nm, which are indicative of the characteristic optical transitions associated with chromium oxide nanoparticles.

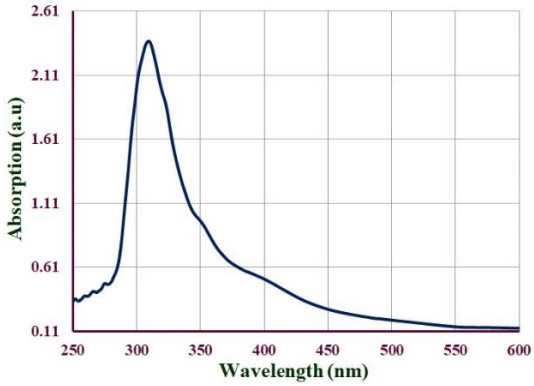


Figure 2. UV-visible spectrum of Chromium oxide nanoparticle

4.4. Surface morphological study

The investigation into the synthesized Cr_2O_3 nanoparticles derived from Aervalanata extracts has yielded impressive results, showcasing their remarkable characteristics. Through the use of Scanning Electron Microscopy (SEM), we conducted a thorough analysis of the surface morphology, and the findings were compelling. The SEM images demonstrate that the nanoparticles predominantly adopt spherical shapes, with an average diameter of 33 nanometers. This distinctly highlights the significant influence of Aervalanata extract in the synthesis process, producing nanoparticles with sizes ranging from 27 to 40 nanometers. Moreover, the outstanding dispersibility of these Cr_2O_3 nanoparticles is a crucial feature that enhances their utility across various applications. The presence of a distinct coating layer observed in the SEM images strongly indicates that the phytochemicals from Aervalanata serve as effective capping agents. This is a critical finding, as these phytochemicals play a vital role in stabilizing the nanoparticles during synthesis and preventing agglomeration. Overall, these compelling attributes position Cr_2O_3 nanoparticles as a highly promising material for advancing various technological innovations.

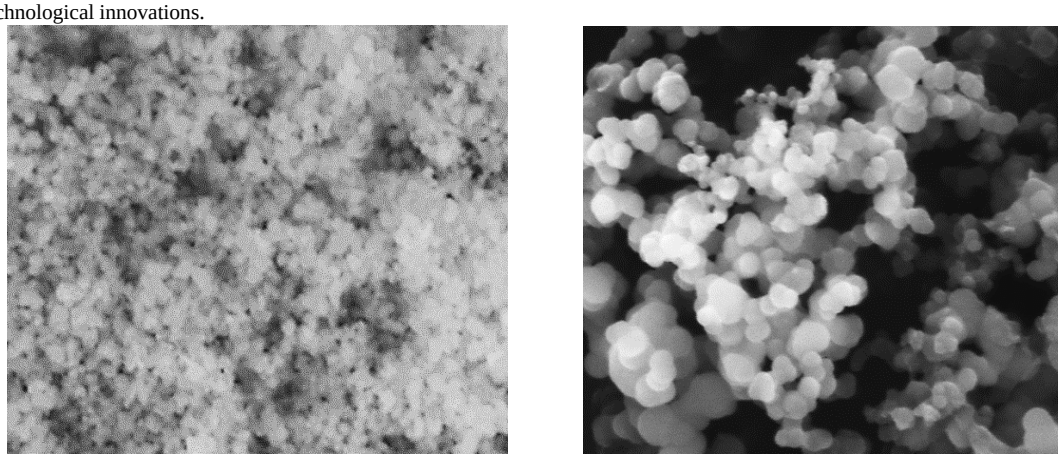


Figure 3. SEM image of Chromium oxide nanoparticle

4.5 Antibacterial activity

The antibacterial activity of Chromium oxide nanoparticles was evaluated against Gram-negative and Gram-positive bacteria at various concentrations of the samples. The study involved the determination of the minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), and assessment of the zone of inhibition. A specified volume of bacterial strains, including Bacillus subtilis (BS), Bacillus cereus (BC), Staphylococcus albus (SA), Pseudomonas aeruginosa (PA), Escherichia coli (E. coli), and Klebsiella pneumoniae (KP), was added to each sample in physiological serum to achieve a target concentration of 100,000 bacteria per mL. The samples were then incubated at 37 °C. Control groups, both positive and negative, were also established for comparative purposes. The disk diffusion method was employed to quantify the zone of inhibition, utilizing various sample concentrations placed at designated distances within the agar medium. Subsequently, the disks were incubated at 37 °C for 24 hours. The diameter of the zone of inhibition was measured accurately using a ruler. The results indicated that Bacillus subtilis (BS), Pseudomonas aeruginosa (PA), Escherichia coli (E. coli), and Klebsiella pneumoniae (KP) are viable candidates for exhibiting the antibacterial activity of Chromium oxide nanoparticles, as illustrated in Figure 4 and Table 1. The results demonstrated that a concentration of 9 µg/ml of the green Cr_2O_3 NPs displayed significant efficacy against these bacterial strains, which can be attributed to the presence of heterocyclic compounds derived from the plant.

Table 1. Showing the results of zone inhibition of chromium oxide with Bacteria's

S. No.	Bacteria	Chromium oxide nanoparticles @ 9 µg/ml	Control (STREPTOMYCIN)
1.	**BS**	19	22
2.	**BC**	5	20
3.	**PA**	13	12
4.	**SA**	3	12
5.	**KP**	15	13
6.	**E.coli**	16	11

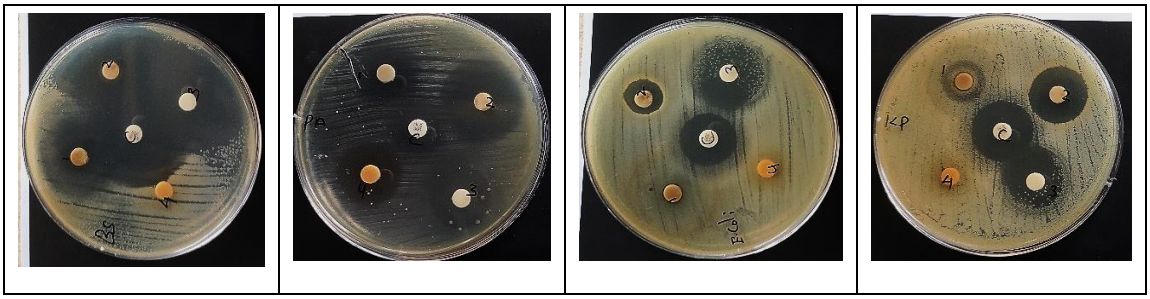


Figure 4. Antibacterial activity of chromium oxide nanoparticle

5. Summary and future scope :

Chromium oxide (Cr_2O_3) nanoparticles were synthesized using a green extract from Aervalanata, achieving a synthesis yield of 92%. The characterization of the nanoparticles was confirmed via UV-Vis spectroscopy, which displayed a distinct absorbance peak at 318 nm, indicative of chromium oxide. Scanning Electron Microscopy (SEM) imaging revealed that the nanoparticles predominantly exhibited spherical morphologies with an average diameter of approximately 34 nanometers. The size distribution of the Cr_2O_3 nanoparticles ranged from 27 to 40 nanometers, highlighting the effective influence of the Aervalanata extract on the synthesis process. In terms of dispersibility, the green-synthesized Cr_2O_3 nanoparticles demonstrated excellent characteristics, enhancing their potential application across various fields. Their antibacterial efficacy was assessed against six pathogenic bacterial strains, inclusive of both Gram-positive and Gram-negative species, in comparison to a standard antibiotic. Results indicated that all tested concentrations exhibited concentration-dependent antibacterial activity, with significant bacterial growth inhibition noted at 9 µg/mL. Notably, the green-synthesized Cr_2O_3 nanoparticles exhibited superior zones of inhibition (ZOIs) against both bacterial classes compared to the standard drug.

The study revealed effective antibacterial activity against several strains, including Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, and Klebsiella pneumoniae. This differential susceptibility observed among the bacterial strains may be attributed to variances in the chemical composition and structural characteristics of their cell walls. For instance, Gram-negative bacteria possess a cell wall comprised of lipopolysaccharides, lipoproteins, and phospholipids, while Gram-positive bacteria contain a more straightforward structure of peptidoglycan and teichoic acid, featuring larger pore sizes. The small dimensions of the nanoparticles facilitate their penetration through these cell walls, allowing for disruption and subsequent bacterial lysis. Further examination revealed that treated bacterial cells exhibited a red coloration, indicating a compromise in membrane permeability and integrity catalyzed by the synthesized Cr_2O_3 nanoparticles. Consequently, this interaction leads to the cell's ultimate demise, underscoring the potential of green-synthesized metal oxide nanoparticles in antibacterial applications.

6. Conclusions :

We successfully synthesized green plant-mediated Cr_2O_3 nanoparticles using a calcination method, which is simple, cost-effective, and environmentally friendly. The nanoparticles were characterized by UV-visible spectroscopy and SEM, revealing spherical shapes with an average diameter of 33 nanometers, influenced by Aervalanata extract, which produced sizes ranging from 27 to 40 nanometers. These nanoparticles have excellent dispersibility and antimicrobial efficacy against standard bacterial strains, with improved antibacterial activities due to their smaller size and increased surface area. The Aervalanata extract also shows strong antibacterial properties which enhances the biological activities of the nanoparticles. Our findings indicate that these green synthesized Cr_2O_3 nanoparticles have potential for various biomedical applications, including antifungal and larvicidal uses. This method is efficient and cost-effective for producing biocompatible nanoparticles with reduced toxicity and improved safety for human health. To ensure consistent therapeutic outcomes, standardization through pharmacokinetic studies should be conducted to maintain the appropriate dosage for effectiveness.

7. REFERENCE :

[1]. Paul, T., & Kumar, K. J. (2024). Standardization of Herbal Medicines for Lifestyle Diseases. In Role of Herbal Medicines: Management of Lifestyle Diseases (pp. 545-557). Singapore: Springer Nature Singapore.

[2]. Balasubramanian, S., Kala, S. M. J., & Pushparaj, T. L. (2020). Biogenic synthesis of gold nanoparticles using Jasminum auriculatum leaf extract and their catalytic, antimicrobial, and anticancer activities. Journal of Drug Delivery Science and Technology, 57, 101620.

[3]. Pushparaj, T. L., Raj, E. F. I., Rani, E. F. I., & Darwin, S. (2023). Hybrid metal complex with TiO2/SiO2 composite-doped polymer for the enhancement of photo energy conversion in silicon solar panels. Journal of Materials Science: Materials in Electronics, 34(23), 1665.

[4]. Hassan, L., & Fathi, A. (2024). The Convergence of Nanotechnology and Biotechnology: Small-Scale Solutions for Big Challenges in Medicine, Energy, and Environment. Journal of Academic Sciences, 6(1), 1-8.

[5]. Pushparaj, T. L., Raj, E. F. I., Rani, E. F. I., & Thanu, M. C. (2023). Synthesis of nickel oxide nanoparticles from Enicostemma littorale plant extract and investigation of their photocatalytic and antimicrobial properties. Applied Organometallic Chemistry, 37(12), e7285.

[6]. Angelini, P. (2024). Plant-Derived Antimicrobials and Their Crucial Role in Combating Antimicrobial Resistance. Antibiotics, 13(8), 746.

[7]. Pushparaj, T. L., Raj, E. F. I., Rani, E. F. I., & Appadurai, M. (2023). Synthesis of biogenic cerium oxide-supported osmium oxide nanoalloy from Oldenlandia umbellata L. plant extract for pharmacological applications. Biomass Conversion and Biorefinery, 1-15.

[8]. Lurthu Pushparaj, T., Fantin Irudaya Raj, E., Francy Irudaya Rani, E., & Appadurai, M. (2023). Biosynthesis of a tri-metallic nanoalloy for magnetic and biomedical applications. Applied Organometallic Chemistry, 37(10), e7178.
[9]. Balasubramanian, S., Kala, S. M. J., Pushparaj, T. L., & Kumar, P. V. (2019). Biofabrication of gold nanoparticles using Cressa cretica leaf extract and evaluation of catalytic and antibacterial efficacy. Nano Biomed Eng, 11(1), 58-66.
[10]. Boobalan, S., Srinivasan, R., Keerthanaa, T., Karunakaran, G., Srinivasan, R., Prasanna Rajeshkumar, M., & Kamalanathan, D. (2024). Enhancing the aervine and methylaervine production in in vitro cultures of Aerva javanica (Burm. F.) Schult via elicitors and Agrobacterium rhizogenes-mediated hairy root cultures. Journal of Plant Biochemistry and Biotechnology, 1-14.
[11]. Pushparaj, T. L., Raj, E. F. I., Rani, E. F. I., Darwin, S., & Appadurai, M. (2022). Employing novel Si-over-Si technology to optimize PV effect in a solar array. Silicon, 14(18), 12823-12835.
[12]. Appadurai, M., Irudaya Raj, E. F., Thanu, M. C., & Pushparaj, T. L. (2023). Finite element analysis and computational fluid dynamic study of hybrid composite-based offshore wind turbines. Materialwissenschaft und Werkstofftechnik, 54(11), 1362-1377.
[13]. Shanmuganathan, R., Devanesan, S., Oza, G., & Sharma, A. (2024). Assessment of antimicrobial, antidiabetic, and anti-inflammatory properties of acetone extract of Aerva lanata (L.) by in-vitro approach and bioactive compounds characterization. Environmental Research, 248, 118348.
[14]. Pushparaj, T. L., Irudaya Raj, E. F., & Irudaya Rani, E. F. (2023). A detailed review of contrast-enhanced fluorescence magnetic resonance imaging techniques for earlier prediction and easy detection of COVID-19. Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 11(4), 1450-1462.
[15]. Pushparaj, T. L., Rani, E. F. I., Raj, E. F. I., & Appadurai, M. (2022). Machine-based drug design to inhibit SARS-CoV-2 virus. Smart Health Technologies for the COVID-19 Pandemic: Internet of Medical Things Perspectives, 42, 295.
[16]. Raj, F. I., Appadurai, Pushparaj, L., & Thanu, C. (2023). Mechanical characterization of randomly oriented short Sansevieria Trifasciata natural fiber composites. International Polymer Processing, 38(5), 564-581.
[17]. Rani, E. F. I., Pushparaj, T. L., & Raj, E. F. I. (2024). Computer-aided Bio-medical Tools for Disease Identification. Disease Prediction using Machine Learning, Deep Learning and Data Analytics, 52.
[18]. Appadurai, M., Fantin Irudaya Raj, E., & LurthuPushparaj, T. (2022). Sisal fiber-reinforced polymer composite-based small horizontal axis wind turbine suited for urban applications—a numerical study. Emergent Materials, 5(2), 565-578.
[19]. Thanu, C., Raj, F. I., Appadurai, & Pushparaj, L. (2023). Mechanical strength enhancement of natural fiber composites via localized hybridization with stitch reinforcement. International Polymer Processing, 38(5), 539-550.
[20]. Pushparaj, L. P., & Sathya, S. (2021). Novel Designing of Ir (III)(Tris-Coumarin) Cored Gd (III) Complex as Targeted MRI CAs for Ovarian Cancer Treatment. Irish Interdisciplinary Journal of Science & Research (IIJSR), 5(1), 07-17.
[21]. Fantin Irudaya Raj, E., Appadurai, M., Lurthu Pushparaj, T., & Chithambara Thanu, M. (2023). Wind turbines with aramid fiber composite wind blades for smart cities like urban environments: Numerical simulation study. MRS Energy & Sustainability, 10(1), 139-156.
[22]. Raj, E. F. I., Appadurai, M., Thiyaharajan, D., & Pushparaj, T. L. (2024). State-of-the-art technologies for Crop Health Monitoring in the Modern Precision Agriculture. In Precision Agriculture for Sustainability (pp. 21-39). Apple Academic Press.
[23]. Santhiya, M., & Pushparaj, L. P. (2021). Insilico Anti-COVID Study of New-fangled High Polar Zr (IV) Complexes Functionalized with Resacetophenone and NMP Ligands. Available at SSRN 3879875.
[24]. Santhiya, M., & Pushparaj, L. P. (2021). Insilico and Invitro Evaluation of Dy (III) Complex on Serum Albumin as well as Amino Acid Loops in M-Protease of SARS-Coronavirus-2. Asian Journal of Applied Science and Technology (AJAST).
[25]. Hamza, R. S. A., & Habeeb, M. A. (2024). Reinforcement of morphological, structural, optical, and antibacterial characteristics of PVA/CMC bio blend filled with SiO2/Cr2O3 hybrid nanoparticles for optical nanodevices and food packing industries. Polymer Bulletin, 81(5), 4427-4448.
[26]. Pushparaj, L. T., & Alexander, V. (2016). Synthesis, pH, and HSA binding study of novel dinuclear [Gd (III) DO3VA] complex as magnetic resonance imaging contrast agent. International Journal of Scientific Engineering and Research, 7, 1600-1605.
[27]. Liu, B., Zhou, H., Tan, L., Siu, K. T. H., & Guan, X. Y. (2024). Exploring treatment options in cancer: tumor treatment strategies. Signal Transduction and Targeted Therapy, 9(1), 175.
[28]. Adetunji, T. L., Padi, P. M., Olatunde, A., Akuru, E. A., Adegbaju, O. D., Adetunji, A. E., & Siebert, F. (2023). Ethnomedicinal uses, phytochemistry, pharmacological activities, and toxicology of Enicostema axillare (Lam.) A. Raynal: a review. South African Journal of Botany, 159, 252-262.
[29]. Francy Irudaya Rani, E., Lurthu Pushparaj, T., & Fantin Irudaya Raj, E. (2023). Adopting a Fusion Approach for Optical Amplification. Modeling and Optimization of Optical Communication Networks, 11-34.
[30]. Pushparaj, L. P., & Rani, E. (2021). Therapeutic Properties of Gd (III)-Ir (III) Complex for Non-invasive Detection of Ovarian Cancer through M-MR Imaging. Irish Interdisciplinary Journal of Science & Research (IIJSR), 5(1), 23-33.
[31]. Pushparaj, T. L., & Alexander, V. (2017). Trinuclear Gd (III) metal complex with amide core displays remarkable enhancement in relaxivity. Applied Magnetic Resonance, 48, 813-825.
[32]. Rani, E. F. I., Pushparaj, T. L., Raj, E. F. I., & Appadurai, M. (2022). New approaches in machine-based image analysis for medical oncology. In Machine Learning and Deep Learning Techniques for Medical Science (pp. 333-359). CRC Press.
[33]. Santhiya, M., & Pushparaj, L. P. (2021). Insilico and Invitro Evaluation of Dy (III) Complex on Serum Albumin as well as Amino Acid Loops in M-Protease of SARS-Coronavirus-2. Asian Journal of Applied Science and Technology (AJAST).
[34]. Pathak, D., & Mazumder, A. (2024). A critical overview of challenging roles of medicinal plants in the improvement of wound healing technology. DARU Journal of Pharmaceutical Sciences, 32(1), 379-419.
[35]. Raj, E. F. I., Manimala, K., Pushparaj, T. L., & Thanu, M. C. (2024). Modern-Day Healthcare With Cloud-Enhanced Robotics. In Shaping the Future of Automation With Cloud-Enhanced Robotics (pp. 226-248).IGI Global.

[36]. Pushparaj, T. L., & Alexander, V. (2022). High rigid Gd (DO3VA) shows remarkable relaxivity: A novel class of MMI agent engineered for MR analysis. Applied Chemical Engineering, 5(1), 51-58.
[37]. Chithambara Thanu, M., Appadurai, M., Fantin Irudaya Raj, E., & Lurthu Pushparaj, T. (2023). Experimental analysis of localized hybridization using adding woven polyester strip. International Polymer Processing, 38(4), 505-517.
[38]. Pushparaj, L. T., & Alexander, V. (2014). Synthesis and relaxivity measurements of novel Gd (III) complex of DOTVA as MRA contrast agents. International Journal of Applied Biomedical Engineering, 8, 1-8.
[39]. Gang, R., Okello, D., & Kang, Y. (2024). Medicinal plants used for cutaneous wound healing in Uganda; ethnomedicinal reports and pharmacological evidence. Heliyon, 10(9).
[40]. Pushparaj, L. T., & Alexander, V. (2016). Development of novel dinuclear [Gd (III) DO3VA] complexes decorated with isovaleric acid as MRI contrast agents for tumor diagnosis. International Journal of Applied Biomedical Engineering, 10, 11-17.
[41]. Pushparaj, L. P., & Devi, U. (2021). Developing A Novel Coumarone-Phenyl Amide Functionalized [Gd (III)-Pt (IV)] Complex as High T1, T2 Relaxive M-MRI Contrast Agent for Cancer Diagnosis. T2 Relaxive M-MRI Contrast Agent for Cancer Diagnosis (March 28, 2021).
[42]. Jayram, J., Kondaveeti, S. S., Gnanaraj Johnson, C., Sampath, P. J., & Kalachaveedu, M. (2024). Challenges and Prospects of Development of Herbal Biomaterial Based Ethical Wound Care Products—A Scoping Review. The International Journal of Lower Extremity Wounds, 23(2), 291-305.