SRI VENKATESWARA INTERNSHIP PROGRAM
FOR RESEARCH IN ACADEMICS
(SRI-VIPRA)

SRI-VIPRA

Project Report of 2023: SVP-2323

"Natural polysaccharide-based nanomaterials as potential candidates for sensing applications"

IQAC

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<u>**SRIVIPRA PROJECT 2023**</u>

Title : Natural polysaccharide based nanomaterials as potential candidates for sensing applications

Name of Mentor: Laishram Saya Devi **Name of Department: Chemistry** **Designation: Assistant Professor**	**Photo** 

List of students under the SRIVIPRA Project

S.No	**Photo**	**Name of the student**	**Roll number**	**Course**	**Signature**
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Signature of Mentor

Certificate of Originality

This is to certify that the aforementioned students from Sri Venkateswara College have participated in the summer project SVP-2323 titled "**-Natural polysaccharide-based nanomaterials as potential candidates for sensing applications"**. The participants have carried out the research project work under my guidance and supervision from 15 June, 2023 to 15th September 2023. The work carried out is original and carried out in an online/offline/hybrid mode.

Signature of Mentor

Acknowledgements

I am grateful to the Principal, Sri Venkateswara College, University of Delhi, for his continuous encouragement and support in the field of research. I also would like to thank the SRI VIPRA team for giving me the opportunity and a platform to guide undergraduate students for research in the college as a mentor through the internship programme.

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Objectives:

- The main objective of the research project is to impart students the basic skills of research, to widen their horizon of scientific thought and aptitude along with application of their skill in constructive research.
- To give a hands-on practice of various tools and softwares which are required in doing research subsequently making its way to its publication.
- To inculcate in students the role of natural polysaccharides in present day research and particularly their applications as sensors.

Abstract:

Rapid industrialisation and urbanisation have led to tremendous release of hazardous chemicals into water bodies. Moreover, industrial waste emissions into the atmosphere posing a serious threat to the global environment. Innovative techniques along with the development of materials for the detection and remediation of these harmful materials have been constantly taking place. However, taking into consideration the global ecological condition, design and fabrication of sustainable materials with minimum toxicity as well as easy availability is the need of the hour. Natural polysaccharides stand out as promising candidates in this field due to its various beneficial properties and have the potential to be the next generation sustainable material which may serve multiple purposes. Numerous literatures have been reported wherein polysaccharides have been functionalised, tuned, doped or incorporated with several other materials to obtain useful materials which have wide range of sensing applications starting from hazardous gases like CO, NH_3, NO_2, etc. to heavy metals in water like Hg^{2+}, Cd^{2+} and Pb^{2+} Ag^{+} etc.

1. Introduction:

Due to the rising industrial waste emissions into the environment, there is now a serious problem with environmental contamination on a global scale (Lu et al., 2017). Environmentally hazardous gaseous pollutants include toxic gases such hydrogen sulphide (H2S), carbon monoxide (CO), and ammonia (NH3) (Kaur et al., 2008; Marszaek, Kowalski, & Makara, 2018; Ryu, Arifin, Ha, & Lee, 2015). New potential in healthcare and environmental monitoring have been made possible by the development of wearable electronics, such as smartwatches, smart fabrics, and smart eyewear that allow for chemical, physical, and biological detection and monitoring. Notably, real-time monitoring of gaseous pollutant concentrations in

people's immediate surroundings, such as nitric oxide, amine, and volatile organic compounds, is a dynamic and alluring strategy to enhance health and safety at work or at home (Pavon et al., 2018). However, the use of such a platform necessitates the use of inexpensive, lightweight, flexible sensing devices that can be attached to a variety of surfaces (such as skin and clothing) and have a high mechanical strength to withstand external pressures and strains. According to Park et al. (2019), wearable sensors must be able to function at room temperature, have good sensing performance (with improved sensitivity, detection limit, and reaction time), and alert users in real-time when exposed to a target gas at a dangerous concentration. Additionally, the development of more environmentally friendly technologies has been spurred by the desire to lessen human influence on the environment. Due to their direct conversion of chemical stimuli into quantifiable electrical signals, simplicity of manufacture, and minimal design requirements for signal collecting and interpretation, chemiresistive materials show promise for the development of wearable sensors.

Renewable natural biopolymers, polysaccharides in particular, have shown great promise for the design and fabrication of nanomaterials that are excellent for a variety of sensing applications. Polysaccharide-Based Nanomaterials have several associated benefits which make them a good choice for use in biosensors and environmentally friendly sensors since. They are biocompatible, non-toxic, and ecologically sustainable. Through a simple functionalization, it is possible to improve sensor performance and adaptability. Moreover, they have excellent tunability as well as adaptable for usage in optical, electrochemical, and piezoelectric sensors, which brings us to point. Moreover, they can be used for biological (like the detection of biomarkers) and environmental (like the monitoring of pollutants) sensing.

2. Types of sensors:

(i) **Chemiresistive Gas Sensors:** Conducting Polymer Sensors: These sensors employ organic polymers that change their electrical conductivity when exposed to gases. They are suitable for detecting a range of gases and are used in environmental monitoring and indoor air quality applications.Metal Oxide Sensors (MOS): These sensors consist of metal oxide materials like tin dioxide (SnO_2) or zinc oxide (ZnO). They change their electrical resistance in the presence of specific gases, making them widely used for detecting gases like carbon monoxide (CO) and methane (CH_4).

(ii) **Catalytic Gas Sensors:** Catalytic Bead Sensors: These sensors contain a bead made of materials such as platinum or palladium, which catalyze the combustion of gases like methane and hydrogen. The change in temperature due to combustion is measured and used to determine gas concentration.

(iii) **Electrochemical Gas Sensors:** Gas-Selective Electrochemical Sensors: These sensors consist of an electrolyte and electrodes. Gas molecules interact with the electrode's surface, causing a chemical reaction that generates a current. They are highly selective and are commonly used in applications like breathalyzers for alcohol detection and carbon monoxide detectors.

(iv) **Non-Dispersive Infrared (NDIR) Sensors:** These sensors use the absorption of infrared light at specific wavelengths by gases like carbon dioxide (CO2) and methane. The amount of absorbed light is proportional to the gas concentration, allowing for accurate measurements.

(v) **Photoionization Detectors (PID):** PID sensors use ultraviolet (UV) light to ionize gas molecules, producing a measurable electrical current. They are particularly effective in detecting volatile organic compounds (VOCs) and are used in environmental monitoring and industrial safety applications.

(vi) **Tunable Diode Laser Absorption Spectroscopy (TDLAS):** TDLAS sensors use a tunable diode laser to measure the absorption of specific wavelengths of light by gases. They offer high sensitivity and selectivity, making them suitable for trace gas analysis in research and industrial settings.

(vii) **Surface Acoustic Wave (SAW) Sensors:** SAW sensors rely on the changes in the propagation velocity of acoustic waves on the surface of a piezoelectric material when exposed to gas. These sensors are used for various applications, including gas chromatography and chemical warfare agent detection.

(viii) **Semiconductor Gas Sensors:** These sensors use semiconductors like silicon or organic semiconductors to detect gas molecules through changes in electrical conductivity. They are suitable for detecting a wide range of gases and are commonly used in industrial applications.

(ix) **Acoustic Wave Gas Sensors:** These sensors rely on the changes in the resonant frequency of acoustic wave devices when exposed to gas. They are sensitive to changes in mass and viscosity caused by gas absorption, making them suitable for gas detection.

3. Recent Developments:

Recent research has concentrated on innovative functionalization techniques to improve the selectivity and sensitivity of polysaccharide-based sensors. Efforts have also been made toward fusing natural polysaccharides with nanoparticles or other substances, to enhance their sensing properties. Apart from this, the use of polysaccharide-based nanomaterials in real-time and in-situ sensing devices have beeb tried upon which might lead to advancements in monitoring applications. However, several potential challenges have been faced in this field. Most importantly, to enable commercial applications, the scalability of these nanomaterials' production processes has to be improved. It is still difficult to improve the selectivity and sensitivity of polysaccharide-based sensors. One potential area for future study is the integration of several sensing functions onto a single platform. More investigation is required to make sure that these materials are completely biodegradable and recyclable.

4. Characterization:

(i) **X-Ray Diffraction (XRD) Method:** X-ray diffraction technique, that work on the Bragg's Rule, is a very useful characterization tool to study, non-destructively, the crystallographic structure, chemical composition and physical properties of materials and thin films. It can also be used to measure various structural properties of these crystalline phases such as strain, grain size, phase composition, and defect structure. The intensities measured with XRD can provide quantitative, accurate information on the atomic arrangements at interfaces.

(ii) **Raman Spectroscopy:** Raman spectroscopy represents another non-destructive method for the analysis of the symmetry and structure of a molecule. It offers structural information for both fundamental and practical study. Mainly for carbon-based materials, a careful observation of the G bands and D bands gives information about the nature of hybridisation of the carbon atoms in the graphene sheets. Moreover, information regarding whether the graphene sheets are single layered or multi layered as well the impregnation of the Fe_3O_4 nanoparticles are also predicted Raman spectrum.

(iii) **Fourier Transform Infrared (FTIR) spectroscopy:** Fourier transform Infrared Spectroscopy is one of the most important tools for surface characterisation of materials. Based on the molecular vibrations of the material, this particular spectroscopic technique results in a molecular fingerprint of these materials in the form of FTIR spectrum. It reveals the chemical composition of the nanoparticle surface as well as the reactive moieties/functional groups on the surface that are responsible for surface reactivity and chemical bonding. For obtaining the final FTIR spectrum, this method focuses on computing interferograms and applying Fourier transforms to them. FTIR is a time-saving approach which can analyse a wide range of samples including liquids, solids, gases and thin films for a variety of compounds in a short time span.

(iv) **Scanning Electron Microscopy (SEM):** pictures are crucial to many scientific fields because they offer insightful knowledge into the surface morphology, chemical makeup, and structural properties of materials. Visualising and analysing the surface morphology of materials requires the use of SEM images. High-resolution SEM imaging enable close examinations of surface characteristics including topography, texture, and roughness. Understanding surface characteristics and behaviour of materials, such as adhesion, friction, and contact interactions, requires the knowledge of this information. These surface features are visualised in SEM pictures, allowing researchers to assess and evaluate material performance.

(v) Energy-Dispersive X-Ray Analysis (EDAX):

The method of energy-dispersive X-ray analysis (EDAX) is utilized for the SEM assessment of nanoparticles. This method involves activating the nanoparticles using an EDS X-ray spectrophotometer, which is typically fitted together in current SEMs. The isolated individual nanoparticles are placed on a suitable substrate so that their characterization is unaffected. With regard to precise dimensions and elemental characterization, this technique has several drawbacks. EDAX works on the fundamental premise that an electron beam is used to generate X-rays from a specimen. The features and composition of the components present in the sample determine how the X-rays are produced.

(vi) **Transmission Electron Microscopy (TEM):** images play a crucial role in various scientific disciplines, offering valuable insights into the microscopic structure, composition, and morphology of materials. TEM images provide high-resolution imaging which allows researchers to visualize materials at an extremely fine scale, revealing intricate details at the atomic and nanoscale levels. is vital for understanding the arrangement of atoms, crystal defects, grain boundaries, and other structural features that govern the properties and behavior of materials.

(vii) **Vibrating Sample Magnetometry (VSM):** is a method used to analyse an adsorbent's or sample's saturation magnetization, hysteresis loop measurement, remanence curves, and other magnetic characteristics. The electronic configuration of the atoms in a sample, their ability to align in the presence of a magnetic field, and the alignment of domains (groups of metal ions) in a sample all affect the sample's magnetic characteristics.

(viii) **UV-Visible Spectrophotometry:** UV-Visible spectrophotometer is a simple, sensitive, reliable, low- cost technique that allows the determination of very less concentrations of compounds and the use of very small amounts of samples. This technique is based on attenuation of electromagnetic radiation measurement by an absorbing substance. Using Beer-Lambert's law, it can determine the concentration of the analyte quantitatively. We intend to employ a double beam Cary-100 UV-Visible spectrophotometer in this study.

4. Classification of polysaccharide-based materials and applications in gas sensing:

Sl.no.	polysaccharide-based materials	**Sensing applications**
1.	Cellulose-based materials	CO, NH_3 NO_2, H_2S gas sensors
2.	Chitosan- based materials	CO, NH_3 NO_2 and H_2 gas and acetone sensors
3.	Cyclodextrin- based materials	Formic acid vapor, humidity sensor, 2,4,6-trichlorophenol, H_2S, CO sensors
4.	Carrageenan- based materials	humidity, Hg^{2+}, Cd^{2+} and Pb^{2+} Ag^{+} and Lime Sulfur, e self-powered touch screen sensors
5.	Xanthan gum- based materials	NH_3, Cd^{2+}, pathogens, NO_2, Hg^{2+} sensors
6.	Inulin- based materials	Urea, glucose, cholesterol in food samples, creatinine sensors
7.	Guar-gum- based materials	Sensors for human motion detection, human motion monitoring

5. Conclusion and future perspectives:

Natural polysaccharide-based nanomaterials have emerged as promising candidates for sensing applications due to their biocompatibility, sustainability, and tunable properties. Recent developments and ongoing research efforts suggest a bright future for these materials in diverse sensing applications. However, addressing scalability and sensor performance challenges will be crucial to unlocking their full potential in the field of sensing. This comprehensive review highlights the substantial progress made in utilizing natural polysaccharides for sensing and provides a roadmap for future research and development in this exciting and dynamic field. Researchers are continually exploring innovative approaches to improve sensor performance, reduce costs, and expand their range of applications. For the most up-to-date information on recent developments in this field, consultation of scientific journals and publications from research institutions and conferences in nanotechnology and sensor technology is ~~recommended.~~