5 SUMMARY AND CONCLUSION

The development of high-performance supercapacitors relies on electrode materials with high surface area, excellent electronic conductivity, and electrochemical stability. A new approach aims to produce functional carbon materials using a time-efficient, cost-effective, and environmentally friendly method. The study focuses on synthesizing electrode materials from *Spathodea campanulata* and *Tecoma capensis* leaves. The summary of the key findings of the investigation entitled **"Investigation of Biomass Derived Functional Carbon Electrodes from leaves of *Spathodea campanulata* and *Tecoma capensis* for Supercapacitor applications"** are listed below

5.1. PHASE I

Carbon materials and nitrogen-doped carbon materials were synthesized following the methodology detailed in the respective section and were designated as SPL-700, SPL-800, SPL-900, TCL-700, TCL-800, TCL-900, SN-700, SN-800, SN-900, TN-700, TN-800, TN-900.

5.2. PHASE II

Advanced analytical techniques were employed to comprehensively analyze the physicochemical properties of the synthesized pyrolyzed and functionalized carbon materials, providing detailed insights into their structural characteristics and functional groups.

- X-ray diffraction (XRD) analysis revealed the amorphous nature of SPL-700, SPL-800, SPL-900, SN-700, SN-800, SN-900, TN-700, and TN-800, whereas TCL-700, TCL-800, TCL-900, and TN-900 exhibited a crystalline structure.
- Fourier-transform infrared (FT-IR) spectroscopy indicated the presence of functional groups such as OH, C=O, and C-O on the surface of all synthesized carbon materials.
- Raman spectroscopy confirmed the presence of characteristic D and G bands at approximately 1350 cm^{-1} and 1590 cm^{-1}, respectively. The observed I_D/I_G ratio nearly 1 indicating a high degree of graphitization in the prepared carbon materials.

- Energy-dispersive X-ray spectroscopy (EDS) analysis validated the predominant presence of carbon and oxygen, consistent with FT-IR findings.
- Field emission scanning electron microscopy (FESEM) images showed a microporous structure, confirming the development of micro and mesopores on the surface.
- Transmission electron microscopy (TEM) images of SPL-900, TCL-900, SN-900, and TN-900 samples illustrated an interconnected porous spherical morphology, indicating efficient ion transport and charge storage potential.
- BET adsorption-desorption isotherm studies highlighted the presence of micropores and mesopores in the carbon materials.

5.3. PHASE III

- Cyclic voltammetry (CV) profiles demonstrated significant electrical double-layer capacitance (EDLC) behavior with a low pseudocapacitive nature.

- Galvanostatic charge/discharge (GCD) measurements showed a decrease in specific capacitance as current density increased from 75 µA/g to 250 µA/g, attributed to rapid electrode charging. Lower current densities yielded higher specific capacitance due to the retention of electrolyte ions in micropores.

- The maximum specific capacitance values from GCD were recorded as 338 F/g for SPL-900, 122 F/g for TCL-900, 450 F/g for SN-900, and 470 F/g for TN-900.

- Electrochemical impedance spectroscopy (EIS) analysis revealed low charge transfer resistance and semi-circle patterns in the high-frequency region, indicating low ionic conductivity.

- Functionalized carbon materials including SPL, TCL, TN, and SN-derived carbon materials were found to be very probable for energy storage applications as per the Ragone plot.

- These comprehensive analyses offered great perspectives concerning both functional carbon electrode materials' electrochemical responses and surface morphology with respect to their applicability for energy storage technologies.

5.4. Conclusion

Functionalized carbon materials, including SPL-700, SPL-800, SPL-900, TCL-700, TCL-800, TCL-900, SN-700, SN-800, SN-900, TN-700, TN-800 and TN-900, were prepared by using dried leaves of *Spathodea campanulata* (SPL) and *Tecoma capensis* (TCL) using direct pyrolysis. The results show that the nitrogen-doped carbon material TN-900, show superior ionic conductivity, high specific capacitance (Csp), high energy (E) and power density (P) could be achieved. These properties suggest that the materials are suitable for energy storing devices like supercapacitors or batteries. All synthesized carbon materials were characterised revealing that *Spathodea campanulata* and *Tecoma capensis* leaves possess potential candidate for supercapacitor applications.

5.5. Suggestions for future work

- Attempts to be carried out to evaluate the electrochemical performance of the prepared carbon materials with different binder ratio and doping agent ratio
- Attempts to be made to consider different electrolytes and different temperature conditions to synthesize carbon with an aim to determine their applicability in energy storage systems.
- Attempts to be made to enhance the electrochemical stability window using ionic liquids etc.
- Cyclic stability of the prepared carbon to be made with more than 10,000 cycles to evaluate the stability of the materials
- Additionally, it is important to develop real-time supercapacitor devices using the synthesized carbon materials to assess their effectiveness in energy storage applications.