Himalayan Physics

# Synthesis and electrochemical performance of activated carbon from lapsi (*choerospondias axillaris*) seed biomass for supercapacitor application

https://doi.org/10.3126/hp.v12i1.66158

**Kaushal Pyakurel[1, 2], Dipak Oli[1, 3], Ravi Kiran Neupane[1], Sandip Dangi[1], Pitamber Shrestha[1], Shriram Sharma[1], Leela Pradhan Joshi[1]***

1 Department of Physics, Amrit Campus, Tribhuvan University, Lainchaur, Kathmandu, Nepal

2 Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal

3 Department of Physics, University of Idaho, Moscow, USA, 83844

**Abstract:** The conversion of biomass waste into porous carbon for supercapacitor electrode application represents a promising approach due to the low cost, abundance of raw materials, and environmental advantages. In this study, activated carbon (AC) was synthesized from Lapsi (*Choerospondias axillaris*) seed biomass by the chemical activation method with zinc chloride ($ZnCl_2$) followed by carbonization in the tubular furnace at 850 °C under continuous nitrogen flow of 100 cc/min for 4 hours. Electrochemical characteristics of the AC electrode were studied in a three-electrode system with a potentiostat device through cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS). The electrochemical parameters, such as specific capacitance, stability, and impedance were evaluated. The electrode exhibited a specific capacitance of 71.95 F/g at a current density of 1 A/g and maintained 95.71% capacitance retention over 5000 cycles, demonstrating good electrochemical stability.

**Keywords:** Activated carbon • Biomass • Chemical activation • Choerospondias axillaris • Supercapacitor

**Recieved: 2025-03-30** **Revised: 2025-05-28** **Published: 2025-06-21**

## I. Introduction

To fulfill the rapidly increasing global energy demands, the use of nonrenewable energy resources is increasing continuously. The environmental degradation issues caused by using nonrenewable resources have forced humankind to think of suitable alternatives. Therefore, renewable energy sources like solar, wind, biomass, and geothermal are being used to create a sustainable future for upcoming generations and reduce reliance on fossil fuels [1, 2]. Supercapacitors (SCs) have been considered promising energy storage devices compared to others because they have fast charging-discharging rates, longer lifetimes, and high

* *Corresponding Author: leela.pradhanjoshi@ac.tu.edu.np*

power density [3, 4]. It has a larger electrode surface area than typical capacitors, so it can produce enormous energy storage capacity or high capacitance values [5, 6]. Various carbon-based materials likes activated carbon, graphene, and carbon black [7] are widely used in supercapacitors (SCs) due to their properties such as high electrochemical stability, high conductivity, lightweight, adjustable porosity, and large surface area [8–16].

Activated carbon (AC) is commonly used as a potential electrode material for supercapacitors and undergoes processes such as slurry preparation, coating, drying, and electrolyte filling for fabrication [17]. Activated carbon electrodes made from biomass are most commonly used in supercapacitors due to their exceptional porous structure, which permits ion absorption and desorption without requiring any chemical reactions [18]. During the chemical activation process, several activating agents, including bases, acids, and salts, are used to activate biomass powder chemically. After this, a carbonization process occurs at temperatures ranging from 450 to 900 °C [19]. Biomass-derived materials including coconut shell, bamboo, wood [18, 20], orange peel [21], banana peel, corn cob, rice husk, sawdust [22] are widely used as primary precursors for synthesis of activated carbon due to their characteristics that make them suitable for use in effective energy storage device like supercapacitors [23].

The biomass of Lapsi seed is a naturally abundant, environmentally friendly, and inexpensive material found mainly in Nepal and South Asian countries. In this study, Lapsi seed was used as a starting material to produce activated carbon for a supercapacitor electrode. Cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), electrochemical impedance spectroscopy (EIS), and electrode stability techniques were used to analyze the electrochemical performance of the AC electrode in a 6 M KOH alkaline electrolyte.

# II. Experimental Method

## Synthesis of Activated Carbon

Using the chemical activation method, activated carbon was prepared from the bio-waste of Lapsi seed at a carbonization temperature of 850 °C. First, Lapsi seeds gathered from the field of Amrit Campus were washed with distilled water and dried for 24 hours at 100 °C in a hot air oven. The dry seeds were ground using a grinder, and the resulting powder precursor was sieved to obtain a fine powder with a particle size of 80 µm. 20 g of Lapsi seed powder and 20 g of Zinc chloride ($ZnCl_2$), which acts as an activating agent, are mixed. $ZnCl_2$ is used to make the powder of the lapsi seed more porous. When the carbon becomes more porous, the material can absorb more charges. After that, the preactivated carbon was mixed with 20 ml of distilled water. Then, the mixture was shaken in a magnetic stirrer with a hot plate until excess water evaporated. The obtained mixture was then dried in an electric oven at 110 °C for 24 hours and then placed in the middle of the quartz tube. The tube was moved to a horizontal

tubular electric furnace and carbonized at 850 °C under a continuous flow of nitrogen gas at a flow rate of 100 cc/min, for 4 hrs. Following carbonization, the resultant sample was rinsed with 1 M HCl and then distilled water to neutralize the precursors. After that, it was dried at 110 °C for 3 hours. Following the synthesis of activated carbon, an electrochemical analysis was carried out. A demonstrative illustration of the inclusive process of synthesis of AC is presented in Fig. 1.

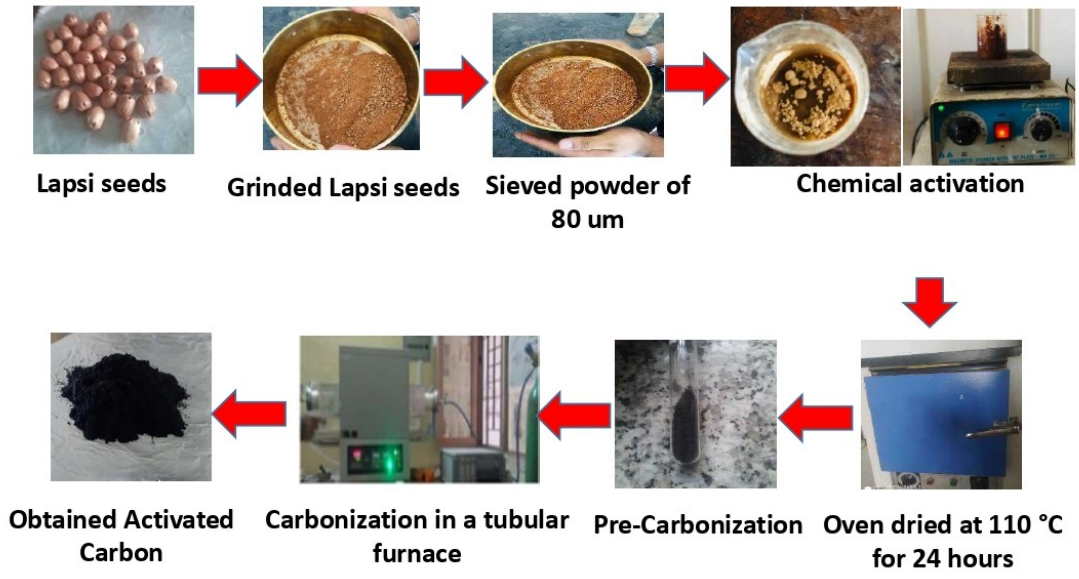


Figure 1. Overall synthesis process of activated carbon

## Electrode Fabrication

First, nickel foam was cut into square pieces measuring 1 cm x 1 cm, treated with ethanol, and then cleaned with distilled water, and placed in a sonicator for 15 minutes with 10 ml of diluted HCl solution until the impurities present were removed. The cleaned foam was then dried in an electric oven at 70 °C to eliminate any remaining moisture. This foam acts as a working electrode substrate. For the preparation of the working electrode, AC, carbon black, and Polyvinylidene Fluoride (PVDF), which acts as a binder, were mixed in a weight ratio of 10:1:1 using an agate mortar and made into a slurry using isopropyl alcohol, so that a homogeneous mixture is achieved. The slurry was then deposited dropwise onto the nickel foam substrate in multiple layers and subsequently dried overnight at 70°C. There was 5 mg of active mass in the AC electrode.

## Electrochemical Performance

The electrochemical performance of the activated carbon (AC) electrode was measured using a Corrtest CS 300M Potentiostat/Galvanostat system configured with a three-electrode cell in a 6 M KOH

aqueous solution. In this setup, a platinum wire acted as the counter electrode, a saturated calomel ($Hg/Hg_2Cl_2$) electrode served as the reference, and the AC electrode was used as the working electrode. Cyclic voltammetry (CV) tests were performed over a potential range from –1 to 0 V at scan rates between 5 mV/s and 100 mV/s. In comparison galvanostatic charge-discharge (GCD) tests were conducted within a 1 V window at current densities of 0.25 A/g, 0.5 A/g, 0.75 A/g and 1 A/g. Additionally, electrochemical impedance spectroscopy (EIS) was carried out by applying a 10 mV AC voltage at open-circuit potential over a frequency range from 0.01 Hz to 50 kHz. The specific capacitance ($C_{sp}$) was calculated from the charge-discharge curves, as detailed in [24].

$$C_{sp} = \frac{I \cdot \Delta t}{m \cdot \Delta V} \tag{1}$$

Where $C_{sp}$ represents the specific capacitance (F/g), I for the charge-discharge current (A), $\Delta t$ for discharge time (s), m for the mass of the active material (g), and $\Delta V$ represents the potential window of the working electrode (V)

# III. Results and Discussion

## Electrochemical performance of the activated carbon electrode

The prepared AC electrode's cyclic voltammetry (CV) curves were measured at different scan rates (5, 10, 20, 30, 50, 80, and 100 mV/s) within a potential window of 1 V, as illustrated in Fig. 2(a). It showed a quasi-rectangular shape without any noticeable redox peaks, which confirms the capacitive behavior of the Electric Double-Layer Capacitor (EDLC) [25]. Fig. 2(b) shows the AC electrode's galvanostatic charge-discharge (GCD) curves at different current densities of 0.25, 0.5, 0.75, and 1 A/g within a potential window of 1 V. The symmetric triangular shape of the charge-discharge curves further indicates the capacitive behavior of EDLC [26, 27]. The specific capacitance of the AC electrodes is calculated from GCD curves using equation (1) and is found to be 101.93, 88.19, 81.86, and 71.95 F/g at the current densities of 0.25, 0.5, 0.75, and 1 A/g, respectively. It is seen that the AC electrode at a lower discharge current takes a longer time to discharge due to sufficient time for the electrolyte ions to diffuse out of the inner pores of the AC electrode, showing a higher charge storage capacity [28].

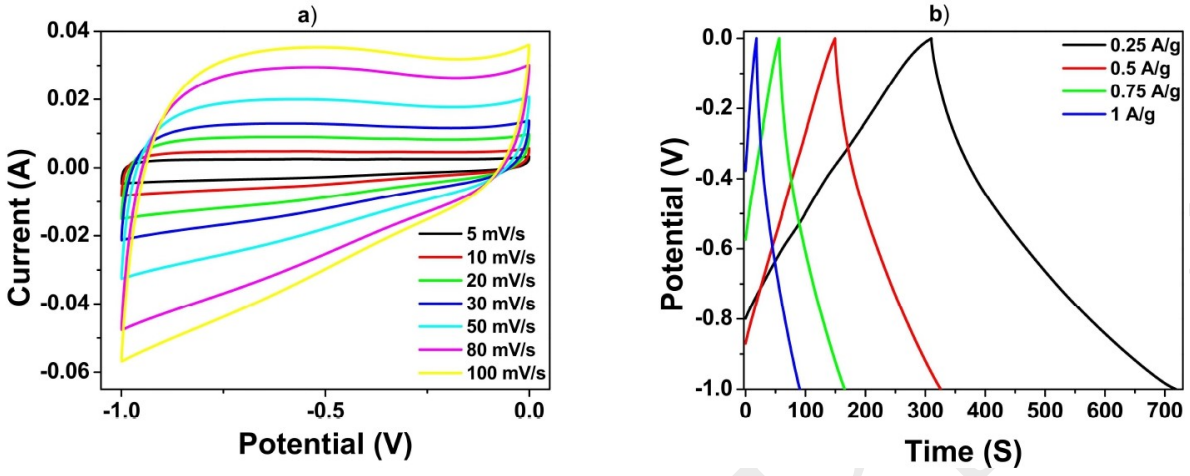


Figure 2. (a) CV curves at various scan rates, (b) GCD curves at various current densities

Fig. 3(a) illustrates the specific capacitance values of the AC electrode at current densities of 0.25, 0.5, 0.75, and 1 A/g. It shows that the specific capacitance decreases from 101.93 F/g to 71.95 F/g as the current density increases from 0.25 A/g to 1 A/g due to kinetic resistance and insufficient charge transfer onto or across the electrode/ electrolyte interface [29, 30]. To evaluate cycling stability, the electrode underwent 5000 consecutive charge-discharge cycles at a constant current density of 1 A/g, as shown in Fig. 3(b). The specific capacitance gradually decreased from an initial value of 71.96 F/g to 68.8 F/g, resulting in a retention rate of 95.71%, which is an excellent cyclic stability for supercapacitor applications. This high retention indicates the long-term stability of the prepared AC and further confirms its suitability as an electrode material for supercapacitors. This value surpasses the retention rates reported for other biomass waste-derived activated carbons such as bamboo (91%) [18], cotonier strobili fibers (84.21%) [31].

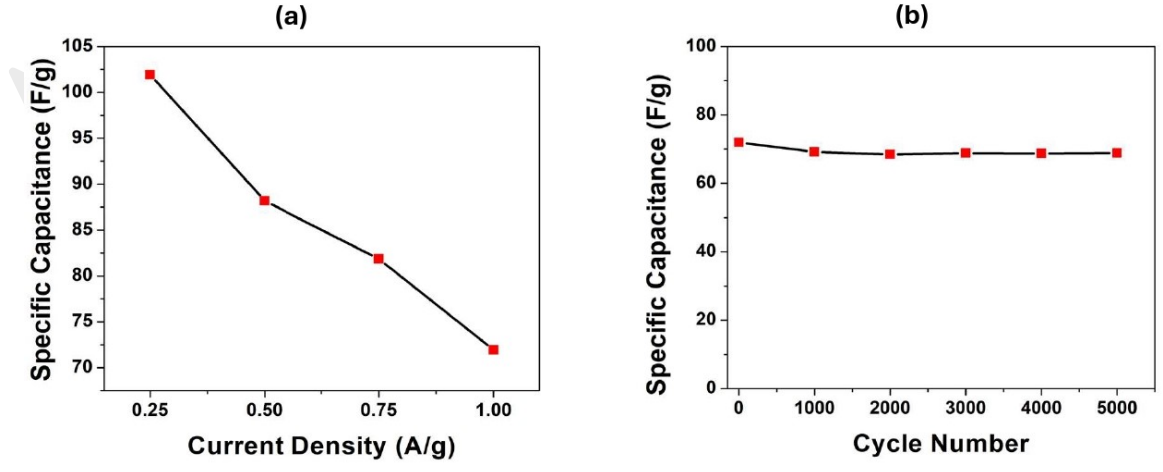


Figure 3. (a) Specific capacitance of the AC as a function of current density (0.25-1 A/g), (b) Specific capacitance vs cyclic stability of AC, across various cycles.

Electrochemical impedance spectroscopy (EIS) analysis of the AC electrode was performed at open-circuit potential using an AC voltage of 10 mV over a frequency range from 0.01 Hz to 50 kHz. Fig. 4 illustrates the Nyquist plot for EIS measurements, which includes both the experimental data and the results from the fitted equivalent circuit model. An incomplete semicircle in the high-frequency region indicates EDLC behavior. In contrast a linear section with an approximate 45° slope in the low-frequency region is an indication of Warburg impedance due to ion diffusion. The solution resistance (Rs) and charge transfer resistance (Rp) were measured to be 0.67 Ω and 1.87 Ω, respectively, indicating the high electrochemical performance of the AC electrode. In the equivalent circuit model, Rs, CPE, Rp, and Wo represent the solution resistance, constant phase element, charge transfer resistance, and Warburg impedance, respectively.

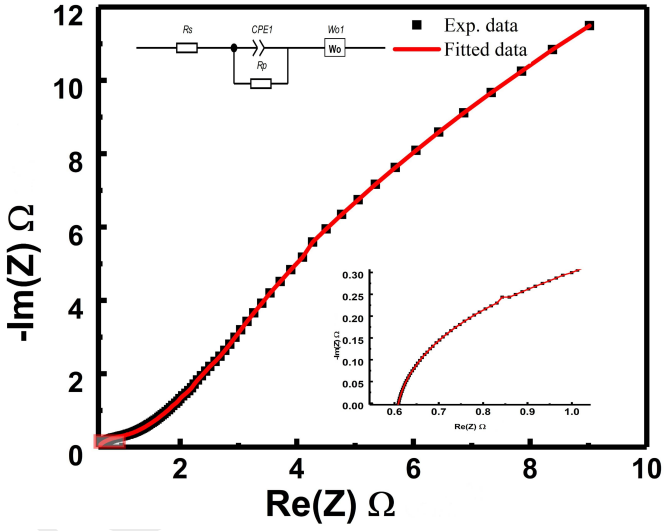


Figure 4. Nyquist plot for EIS measurement

## IV. Conclusions

Lapsi seed biomass was used as the raw material for the synthesis of activated carbon for supercapacitor application. The activated carbon was synthesized using a chemical activation method with $ZnCl_2$ as an activating agent, followed by carbonization in a tubular furnace at 850 °C under a continuous nitrogen flow (100 cc/min) for 4 hours. The electrode's electrochemical performance was tested using cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS) in a three-electrode configuration with a 6 M KOH electrolyte. The CV curves demonstrated a quasi-rectangular shape with no redox peaks, indicating typical EDLC behavior. GCD tests revealed that as the current density decreased from 1 A/g to 0.25 A/g, the specific capacitance increased from 71.95 F/g to 101.93 F/g. At 1 A/g, the specific capacitance dropped slightly from 71.95 F/g to 68.8 F/g

after 5000 cycles, meaning the electrode retained 95.71% of its capacitance. The EIS results, showing an incomplete semicircle in the high-frequency region, confirm the EDLC behavior. Additionally, the low values of solution resistance (Rs) and charge transfer resistance (Rp), i.e., 0.67 Ω and 1.87 Ω further confirm the high electrochemical performance. All these findings suggest that activated carbon from Lapsi seeds is a strong candidate for supercapacitor electrodes.

## V. Acknowledgments

The authors acknowledge the International Science Program (ISP), Uppsala University, Sweden, for supporting the Atmospheric and Material Science Research Center (AMSRC) at Amrit Campus under grant NEP:01, where the overall project was conducted. The authors would also like to thank the Department of Applied Science and Chemical Engineering at the Institute of Engineering (IOE), Tribhuvan University, Nepal, for facilitating the carbonization process.

### References

[1] Wu Y, Zhang T, Gao R, Wu C. Portfolio planning of renewable energy with energy storage technologies for different applications from electricity grid. Applied Energy. 2021;287:116562.

[2] Oli D, Rijal OS, Neupane RK, Shrestha P, Sharma S, Joshi LP, et al. Study of adsorption behavior of HCN and H2S molecules over unlopped and Al-doped zinc oxide monolayer: A DFT approach. Results in Surfaces and Interfaces. 2025:100439.

[3] Li X, Sun C, Cai Z, Ge F. High-performance all-solid-state supercapacitor derived from PPy coated carbonized silk fabric. Applied Surface Science. 2019;473:967-75.

[4] Abbas Q, Mirzaeian M, Ogwu AA, Mazur M, Gibson D. Effect of physical activation/surface functional groups on wettability and electrochemical performance of carbon/activated carbon aerogels based electrode materials for electrochemical capacitors. International Journal of Hydrogen Energy. 2020;45(25):13586-95.

[5] Adhikari SP, Awasthi GP, Kim KS, Park CH, Kim CS. Synthesis of three-dimensional mesoporous Cu–Al layered double hydroxide/gC 3 N 4 nanocomposites on Ni-foam for enhanced supercapacitors with excellent long-term cycling stability. Dalton Transactions. 2018;47(13):4455-66.

[6] Basri NH, Deraman M, Kanwal S, Talib I, Manjunatha J, Aziz A, et al. Supercapacitors using binderless composite monolith electrodes from carbon nanotubes and pre-carbonized biomass residues. biomass and bioenergy. 2013;59:370-9.

[7] Krause A, Kossyrev P, Oljaca M, Passerini S, Winter M, Balducci A. Electrochemical double layer capacitor and lithium-ion capacitor based on carbon black. Journal of Power Sources.

2011;196(20):8836-42.

[8] Zhan C, Lian C, Zhang Y, Thompson MW, Xie Y, Wu J, et al. Computational insights into materials and interfaces for capacitive energy storage. Advanced Science. 2017;4(7):1700059.

[9] Brandiele R, Picelli L, Pilot R, Causin V, Martucci A, Rizzi GA, et al. Nitrogen and Sulfur Doped Mesoporous Carbons, Prepared from Templating Silica, as Interesting Material for Supercapacitors. ChemistrySelect. 2017 Aug;2(24):7082–7090. Available from: http://dx.doi.org/10.1002/slct.201701404.

[10] An Y, Yang Y, Hu Z, Guo B, Wang X, Yang X, et al. High-performance symmetric supercapacitors based on carbon nanosheets framework with graphene hydrogel architecture derived from cellulose acetate. Journal of Power Sources. 2017;337:45-53.

[11] Di Lecce D, Andreotti P, Boni M, Gasparro G, Rizzati G, Hwang JY, et al. Multiwalled carbon nanotubes anode in lithium-ion battery with LiCoO2, Li [Ni1/3Co1/3Mn1/3] O2, and LiFe1/4Mn1/2Co1/4PO4 cathodes. ACS Sustainable Chemistry & Engineering. 2018;6(3):3225-32.

[12] Zeigler DF, Candelaria SL, Mazzio KA, Martin TR, Uchaker E, Suraru SL, et al. N-Type hyperbranched polymers for supercapacitor cathodes with variable porosity and excellent electrochemical stability. Macromolecules. 2015;48(15):5196-203.

[13] Oli D, Neupane HK, Neupane RK, Rijal OS, Shrestha P, Sharma S, et al. Comprehensive Study of Structural, Mechanical, Dynamical, Electronic, Magnetic, and Optical Properties of Ti3GeC2 and Ti3SiC2 Compounds via DFT Approach. Physica B: Condensed Matter. 2025:417009.

[14] Shoaib M, Al-Swaidan HM. Optimization and characterization of sliced activated carbon prepared from date palm tree fronds by physical activation. Biomass and bioenergy. 2015;73:124-34.

[15] Oli D, Neupane RK, Rijal OS, Shrestha P, Sharma S, Joshi LP, et al. First Principles Study of Undoped and Halogen Doped ZnO Monolayer. Journal of Nepal Physical Society. 2024;10(1):1-7.

[16] Pant B, Park M, Ojha GP, Park J, Kuk YS, Lee EJ, et al. Carbon nanofibers wrapped with zinc oxide nano-flakes as promising electrode material for supercapacitors. Journal of colloid and interface science. 2018;522:40-7.

[17] Hwang JY, Li M, El-Kady MF, Kaner RB. Next-generation activated carbon supercapacitors: a simple step in electrode processing leads to remarkable gains in energy density. Advanced Functional Materials. 2017;27(15):1605745.

[18] Yang CS, Jang YS, Jeong HK. Bamboo-based activated carbon for supercapacitor applications. Current Applied Physics. 2014;14(12):1616-20.

[19] Divyashree A, Hegde G. Activated carbon nanospheres derived from bio-waste materials for supercapacitor applications–a review. Rsc Advances. 2015;5(107):88339-52.

[20] Yang J, Yue L, Hu X, Wang L, Zhao Y, Lin Y, et al. Efficient CO2 capture by porous carbons derived from coconut shell. Energy & Fuels. 2017;31(4):4287-93.

[21] Xie Z, Wang X, Chi S. Simultaneous calibration of the intrinsic and extrinsic parameters of structured-light sensors. Optics and Lasers in Engineering. 2014;58:9-18.

[22] Taer E, Taslim R, Aini Z, Hartati S, Mustika W. Activated carbon electrode from banana-peel waste for supercapacitor applications. In: AIP Conference Proceedings. vol. 1801. AIP Publishing; 2017. .

[23] Yahya MA, Al-Qodah Z, Ngah CZ. Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: A review. Renewable and sustainable energy reviews. 2015;46:218-35.

[24] Ghimire J, Jha MK, Shah D, Pant HR, Joshi S. Synthesis and Characterizations of Activated Carbon from Bayer (Ziziphus Mauritiana) Seeds and its Possibility in Energy Storage Application. Carbon. 2021;2:1.

[25] Wang H, Pilon L. Physical interpretation of cyclic voltammetry for measuring electric double layer capacitances. Electrochimica Acta. 2012;64:130-9.

[26] Senthilkumar S, Selvan RK, Melo J. The biomass derived activated carbon for supercapacitor. In: AIP Conference Proceedings. vol. 1538. American Institute of Physics; 2013. p. 124-7.

[27] Rufford TE, Hulicova-Jurcakova D, Zhu Z, Lu GQ. Nanoporous carbon electrode from waste coffee beans for high performance supercapacitors. Electrochemistry Communications. 2008;10(10):1594-7.

[28] Gouda MS, Shehab M, Soliman MM, Helmy S, Salama R, et al. Preparation and characterization of supercapacitor electrodes utilizing catkin plant as an activated carbon source. Delta University Scientific Journal. 2023;6(1):255-65.

[29] Owusu KA, Qu L, Li J, Wang Z, Zhao K, Yang C, et al. Low-crystalline iron oxide hydroxide nanoparticle anode for high-performance supercapacitors. Nature communications. 2017;8(1):14264.

[30] Yuksel R, Cevher SC, Cirpan A, Toppare L, Unalan HE. All-organic electrochromic supercapacitor electrodes. Journal of The Electrochemical Society. 2015;162(14):A2805.

[31] Su XL, Li SH, Jiang S, Peng ZK, Guan XX, Zheng XC. Superior capacitive behavior of porous activated carbon tubes derived from biomass waste-cotonier strobili fibers. Advanced Powder Technology. 2018;29(9):2097-107.