Activated carbon material derived from *Millingtonia hortensis* leaves as a biomass source by simple carbonization and Microwave - assisted synthesis method

S.RAMYA
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Thesis submitted to
Avinashilingam Institute for Home Science and Higher Education for Women,
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In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Chemistry

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LIST OF ABBREVIATIONS

MHL	*Millingtonia hortensis* leaves
AC	Activated Carbon
PC	Precarbonized Carbon
UV	Ultra Violet Spectroscopy
FT-IR	Fourier Transform Infrared Spectroscopy
TGA	Thermo gravimetric analysis
XRD	X-Ray Diffraction

1. INTRODUCTION

The rising energy consumption, depletion of natural energy resources, drastic climate change and environmental concerns dictate moving toward sustainable energy sources with green energy storage. Energy storage devices such as batteries and supercapacitors play a significant role in the development of renewable and sustainable energy sources such as solar, geothermal and wind energy. **(Sudhan Nagarajan *et al* ., 2016).** Supercapacitors have received extensive attention due to their high power density, fast charge and discharge rates, long-term cycling stability, etc.

Supercapacitors are an electrical energy storage technology that stores and releases energy by nanoscopic charge separation at the electrochemical interface between the electrode and the electrolyte. Although the energy density of supercapacitors is very high compared to conventional capacitors, this energy density is still significantly lower than that of batteries. Furthermore, supercapacitors with their performance are considered necessary to supply energy for a longer period. This has prompted a strong interest in researchers to enhance the energy density of supercapacitors to get closer to batteries. The electrode material is the main key component that determines the high performance of the supercapacitor.

Supercapacitors are mainly classified into three types:

- Double-layer capacitors,
- Pseudo-capacitors,
- Hybrid capacitors.

Compared with the pseudo-capacitors based on quick and reversible faradaic redox reaction on the surface and bulk structure of metal oxides, the electrical double-layer capacitors (EDLCs) are dependent on the electrostatic interaction between the ions on the surface area of the electrode materials and electrolytes are a more common mode for energy storage. However, the intrinsic low energy density limits the practical application in energy-efficient industrial equipment. **(Xiao -Li Su *et al.*, 2018).**

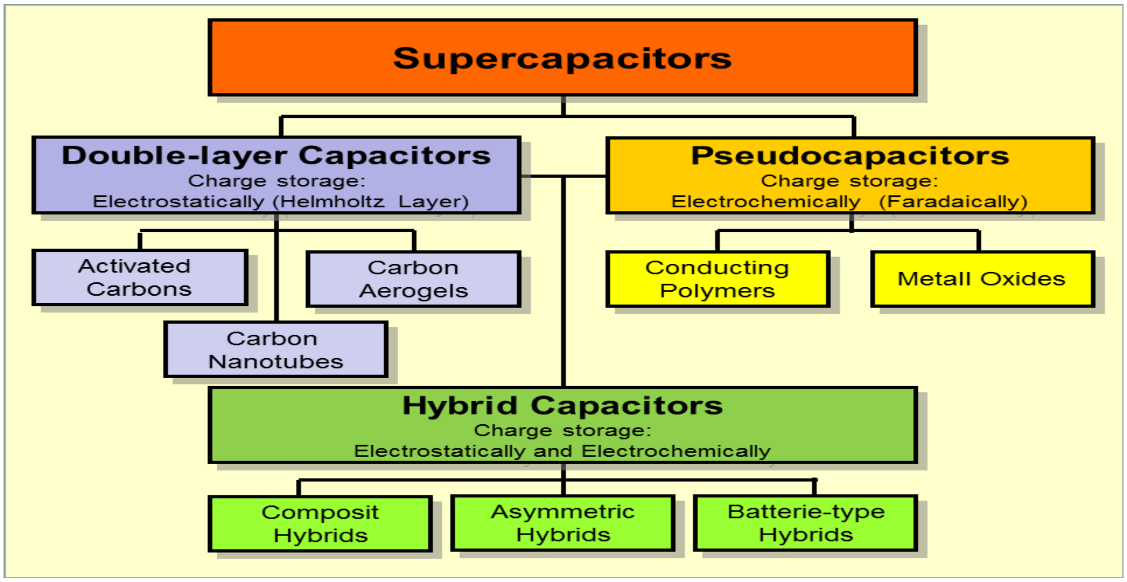


Fig 1.1 Types of Supercapacitors (Fisher *et al.*, 2000)

Carbon based electrode materials

The carbon based nano materials like graphene, carbon nano sheets, nonporous carbon, carbon nanotubes, activated carbon, carbon aerogels, metal oxides, conducting polymers and polymer composites have played significant role in the highly efficient supercapacitors. **(Richa Dubey *et al.*, 2019).**

It can exhibit many advantages such as high specific surface area, meso - micro porosity and high electrical conductivity, so they have been considered useful for various applications. In contrast to graphene oxide and carbon nanotubes which require complicated synthetic processes and instrumental activated carbons (ACs) can be prepared from various types of biomass (coconut shell, dead mango leaves, guava leaves, water bamboo, pumpkin stems, eggplants, etc.).

In addition, the synthesized ACs have been employed in various applications such as supercapacitors Li-ion batteries, removal of organic dyes and toxic metal ions,4 electrochemical and biomedical sensors and electro-catalysts owing to their high surface area with modulated pore size, low cost, self-doping of hetero atoms and natural abundance.

The most commonly used electrode materials for double-layer capacitors or super capacitors are activated carbon, carbon aerogel, and carbon fiber-cloth and carbon nanotubes. **(Vediyappan Veeramani *et al.*, 2017)**.

Carbon aerogel:

Carbon aerogel is a highly porous synthetic, ultra- light material derived from an organic gel in which the liquid component of the gel has been replaced with a gas. Aerogel electrodes are made via pyrolysis of resorcinol-formaldehyde aerogels and are more conductive than most activated carbons. Aerogel electrodes also provide mechanical and vibration stability for supercapacitors used in high-vibration environments**. (Fisher *et al.*, 2000).**

Carbide derived carbon:

Carbide-derived carbon (CDC) also known as tunable nano porous carbon, is a family of carbon materials derived from carbide precursors, such as binary silicon carbide and titanium carbide, that are transformed into pure carbon via physical, e.g., thermal decomposition or chemical, halogenation processes. **(Presser *et al.*, 2011)**

Graphene:

Graphene, as one of the advanced carbon nano-materials, has received tremendous attention since its discovery in 2004 as a two-dimensional (2D) monolayer carbon nanomaterial consisting of sp^2 -hybridized carbon atoms arranged in a hexagonal crystalline structure. They have gained significant attention as novel materials for environmental applications due to their high specific surface area (theoretically ~ 2630 m^2 /g), high thermal conductivity and rapid heterogeneous electron transfer. **(Jilani *et al.*, 2018)**

Carbon nanotubes:

Carbon nanotubes (CNTs) also called bulky tubes, are carbon molecules with a cylindrical nanostructure. They have a hollow structure with walls formed by one-atom thick sheets of graphite. These sheets are rolled at specific and discrete ("chiral") angles and the combination of chiral angle and radius controls properties such as electrical conductivity, electrolyte wettability and ion access. Nanotubes are categorized as single walled nanotubes (SWNTs) or multi-walled nanotubes (MWNTs).

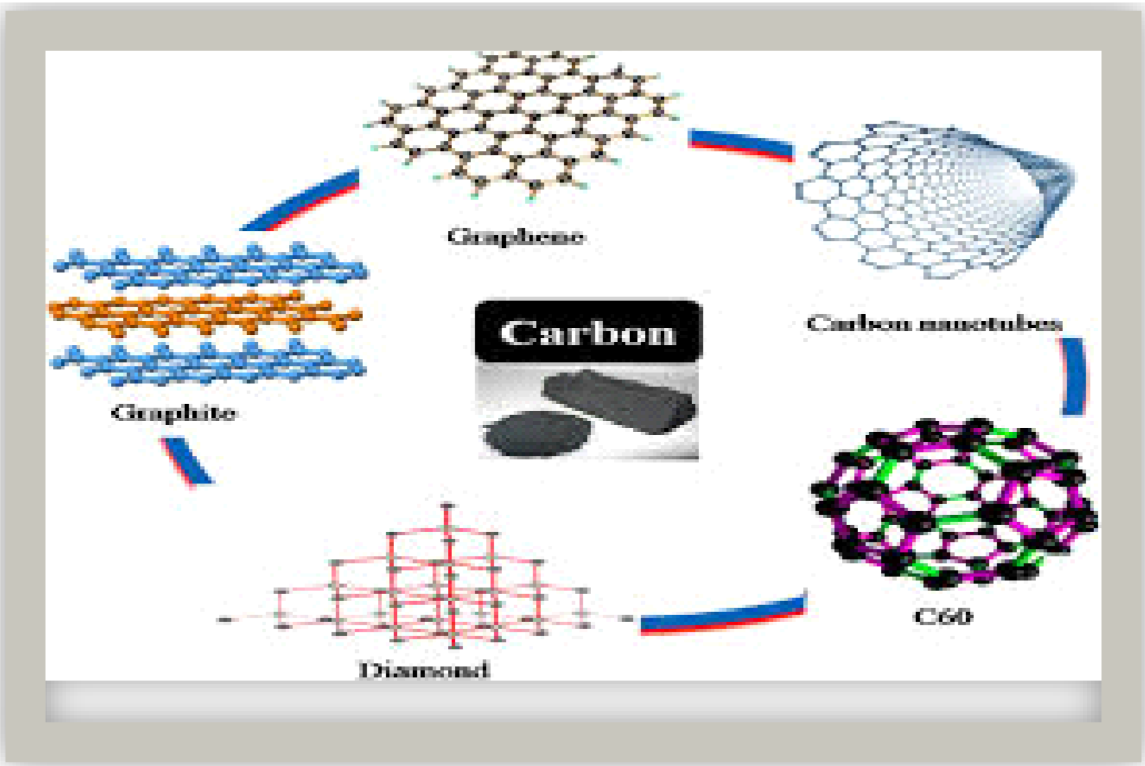


Fig no 1.2 Types of Carbon materials (Jilani *et al.*, 2018)

Activated carbon:

Activated carbons are produced largely from coal and petroleum and their derived products. Due to environmental pollution and a limited reserve of fossil fuels, researchers are exploring biomass waste as a potential resource for the preparation of activated carbon. By-products and residues obtained from agriculture and industries can be converted into activated carbon. Significant research has been carried out in recent years to prepare activated carbon from different biological products such as seaweed, dried neem leaves, coconut shell, coffee endocarp, sawdust, rice bran, pinecone, chestnut shell, rice husk, oil to be converted to AC via physical activation and chemical activation process.

In the physical activation process, an activation gas, e.g., CO_2, steam or a mixture of gasses is used to prepare the AC.

In the chemical activation process, the biomass-derived carbon precursor is mixed with chemical reagents such as H_3PO_4, $FeCl_3$, KOH, H_2SO_4, NaOH and $ZnCl_2$. **(Sofia Jennifer Rajasekaran *et al* ., 2020)**.

Preparation of activated carbon:

The preparation and production of activated carbon usually consist of carbonization and activation that can be done either separately in a two-stage process or combined in a single stage process.

The carbonization of a precursor takes place at a low temperature usually between 400 ̊C-850 ̊C and in the absence of oxygen. Activation is a process of converting carbonaceous materials into activated carbon by thermal decomposition in a furnace (convectional heating) or a microwave using a controlled atmosphere and heat. Physical activation, chemical activation and microwave-induced activation are the methods being employed for the preparation of activated carbon. **(Adekunle Moshood Abioye *et al*.,2015)**

Physical and Chemical activation:

Activated carbons (AC) serve as adsorbents in various applications requiring specific functionalities. In this study, the effects of biomass type, pre-carbonization process and activation method on the properties of ACs were investigated.

Chemical (KOH and H_3PO_4) and physical (CO) activations were performed on slow pyrolyzed and hydrothermally carbonized (HTC) bio chars produced from two feeds tocks, willow and Scots pine bark (SPB). KOH activation produced highly micro porous ACs from all bio chars, whereas with H_3PO_4 and CO_2 there was also an increase in the meso - and macro porosity with the HTC bio chars. The adsorption capacity for dyes was dependent on the surface area, while for zinc it depended on AC's pH. The results provide interesting insights into tailoring ACs for specific applications. **(Sipola *et al.*,2018)**

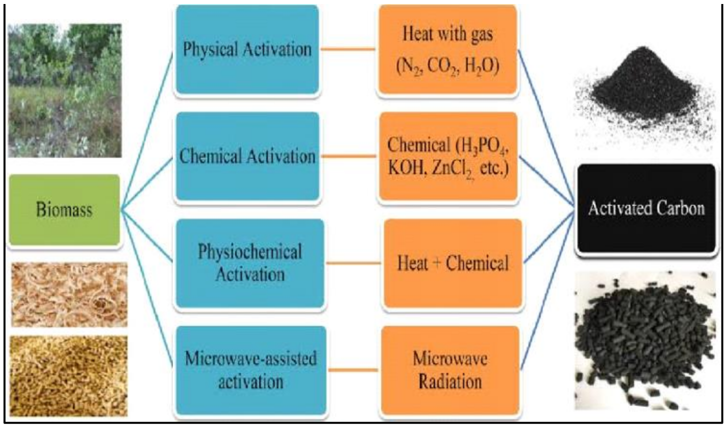


Fig no 1.3 Physical and Chemical activation (Sipola *et al.*,2018)

Carbonization process:

Carbonization is a slow pyrolysis process in which biomass is converted into a highly carbonaceous, charcoal-like material. Typically, carbonization consists of heating the biomass in an oxygen-free or oxygen-limited environment and reaction conditions are tailored to maximize the production of char. **(Frederik Ronsse *et al.*, 2015)**.

Carbon based electrode materials:

The carbon based nanomaterials like graphene, carbon nanosheets, nonporous carbon, carbon nanotubes, activated carbon, carbon aerogels, metal oxides, conducting polymers and polymer composites have played significant role in the highly efficient supercapacitors. **(Richa Dubey *et al.*, 2019).**

Porous carbon:

Porous carbon is the main strategy to enhance the capacitance of EDLC-type SC. According to the classification of the International Union of Pure and Applied Chemistry (IUPAC), the pores in porous materials are classified into macropore (>50 nm), mesopore (2–50 nm) and micro pore (<2 nm). **(Jian Yin *et al.*, 2020)**.

Porous carbon materials with various pore sizes and pore structures shave been synthesized using several different routes. Micro-porous activated carbons have been synthesized through the activation process. Ordered micro-porous carbon materials have been synthesized using zeolites as templates. Mesoporous carbons with a disordered pore structure have been synthesized using various methods, including catalytic activation using metal species, carbonization of polymer/polymer blends, carbonization of organic aerogels and template synthesis using silica nanoparticles**. (Lee *et al.*, 2006).**

Hydrothermal Carbonization:

Hydrothermal carbonization is a thermo chemical conversion process for biomass to yield a solid, coal like product. It has been used for almost a century in different sciences, mainly to simulate in the laboratory. Due to the need for efficient biomass conversion technologies, hydrothermal carbonization has attracted some interest as a possible application for biomass in recent years and projects have been launched to assess its feasibility and discover additional possibilities for applications. **(Axel Funke., *et al.*, 2010)**.

Applications of activated carbon:

The main application of AC is in the purification processes that consumed about 80% of the world production, especially for liquid-phase applications. In advanced technology, AC now is used in a wide range of applications in gas-phase and liquid-phase adsorption processes.

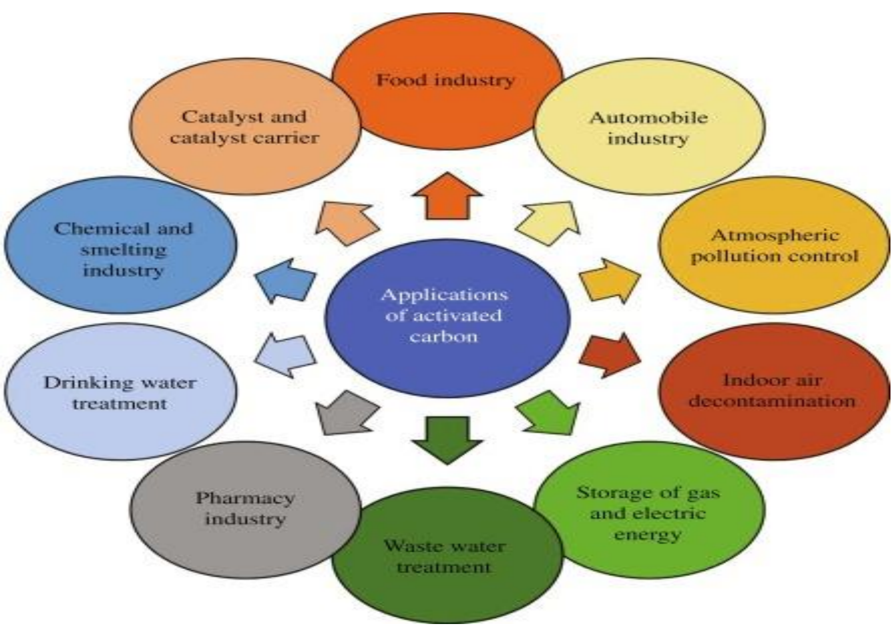


Fig 1.4 Applications of activated carbon (Ahmad Fariz Nicholas *et al.*, 2019)

Plant description:

Millington hortensis Linn. (Bignoniaceae) commonly known as the Cork tree, Akash neem, Neem chameli. It is an important medicinal plant in Southern Asia ranging from India, Burma, Thailand and Southern China. Cultivated in various parts of India in gardens and avenues. It can grow up to 25 meters tall. Flowers have very rich and pleasant scent, used in the treatment of asthma, sinusitis, cholagogue, tonic and rituals. The stem roots of the cork tree are used for anti-asthmatic and antimicrobial activity. Fruit is very long and narrow, pointed at both ends and contains thin, flat seeds. Trees do not seed very easily in India.

This gives information about the plant's medicinal aspects, pharmacognosy, phytochemistry and pharmacological activities of the plant. The tree flowers twice a year and the white flowers come as large panicles which emit a pleasant fragrance. Flowers are white, waxy, trumpet-shaped and two-lipped with five. The flowers are in corymbose, long tubular, white and delightfully fragrant bark is used traditionally as mainly lung tonic, anti-asthmatic and antimicrobial properties.

(Aruna kumari *et al.*, 2013) .

Fig 1.5: *Millingtonia hortensis* leaves

Scientific classification of *Millingtonia hortensis*:

Botanical Name	*Millingtonia hortensis*
Synonyms	Bignonia suberosa Robx
Family	Bignoniaceae

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Liamiales
Genus	*Millingtonia*
Species	*Hortensis*

Table1: Taxonomic classification of *Millingtonia hortensis*

Phytochemical constituents of *Millingtonia hortensis*:

The roots containing Lapachol, β-sitosterol, and paulownia were isolated from the roots of *Millingtonia hortensis*. The leaves of *Millingtonia hortensis* contain hispidulin Rutinoside19. And the fresh flowers of *Millingtonia hortensis* isolate from a new glycoside (scutellarein-5-galactoside) and scutellarein. The flowers of *Millingtonia hortensis* contain flavonoids scutellarein, hispidulin and scutellarein-5-glucuronide.

Uses:

1) The tree is considered as ornamental and the pleasant fragrance of the flowers renders it ideal as a garden tree.

2) The wood and bark is used as timber and inferior substitute for cork respectively.

3) The leaves are used as a cheap substitute for tobacco in cigarettes.

4) Leaves and roots of cork trees used for anti-asthmatic and antimicrobial activity.

5) Extract of the leaves of *Millingtonia hortensis* has good antimicrobial activity**.**

6) The leaves of *Millingtonia hortensis* are used as antipyretic, sinusitis, cholagogue, and

tonic in folklore medicine. **(Mansfield's *et al.*, 2001).**

Objectives:

1) To synthesize carbon from Biomass.

2) To activate the synthesized carbon by using KOH as activating agent.

3) To characterize synthesized carbon materials using FT-IR, Raman Spectroscopy, TGA, UV-Visible Spectroscopy and XRD.

2. REVIEW OF LITERATURE

Literature relevant to the present study entitled "Activated carbon material derived from *Millingtonia hortensis* leaves as a biomass source by simple carbonization and Microwave-assisted activated synthesis method" is reviewed and summarized in this chapter.

- Supercapacitor electrode material carbon was prepared from ***Metaplexis japonica*** shell using NH_3 and $ZnCl_2$ as an activation agent. The obtained sample was characterized by XRD, Raman spectra and XRD. According to the authors the combination of N-doping and layered porous improves the energy density of carbon based on supercapacitors. **(Li Zhi Sheng *et al* ., 2021).**

- The ***Walnut shell*** is used as a biomass precursor for preparing activated carbon using KOH as an activation agent. The obtained sample is characterized using N_2 Adsorption desorption, scanning electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy and FTIR spectra. These results conclude that the prepared sample has high specific capacitance and it is a promising electrode material for supercapacitors. **(Dawei lan *et al* ., 2020)**.

- Ever-increasing energy demand and consumption of fossil fuels, combined with growing environmental degradation, need the creation and development of novel, ecologically friendly and renewable high-performance energy devices. The supercapacitor as well as other electrode materials and polymer electrolytes, have gotten a lot of interest. Carbon-based electrodes and electrolytes made from biomass are highly regarded as potential options for use in electric vehicles. Because of their appealing structure, abundance, low cost, renewability and environmental friendliness supercapacitors are becoming increasingly popular. This will emphasize the existing material properties, synthetic methodologies and biomass-derived material enhancement method electrodes and electrolytes for supercapacitor applications. **(Shiying Lin *et al.*, 2020).**

- Agro-waste-derived porous carbon had gotten increased attention as an electrode material for high-performance supercapacitor applications. Using a twin crucible process, hierarchically porous carbon was effectively synthesized from the most abundant biomass

onion peel. It was also looked into as a low-cost carbon source for energy storage devices. The electrode of the supercapacitor has a high specific capacitance of $127Fg^{-1}$ at 0.75 Ag^{-1}current densities with 109 percent capacitance retention. In a three-electrode system, 2000 cycles were performed. More crucially, its symmetric supercapacitor device has an energy density at the power density with electrochemical stability of 200W kg^{-1}, exhibiting capacitance. **(Manohar D. Mehare *et al.*, 2019).**

- Method of "Thermal dissolution carbon enrichment" has been shown to effectively separate biomass wastes into carbon-rich target products (extracts) and a byproduct (the residue). The residue has a lot of potential for high-performance activated carbon preparation and supercapacitor application because of its increased gasification reactivity and concentrated minerals. As a result, the residue was first activated into porous carbon and then used as a supercapacitor electrode in this investigation. In the meantime, for comparison, activated carbons made from raw biomass with or without thermal pretreatment were made. The activated carbon made from residue had the largest specific surface area of 2764 m^2 /g with a hierarchical structure and the supercapacitor derived from it had good capacitive performance, with a specific capacitance of 228 F/g and low charge transfer and diffusional resistance. **(Zhenzhong Hua *et al* ., 2020)** .

- N-doped porous carbon using a one-pot $MgCl_2$ activation of ***lotus root flour*** with urea was carried out by modifying precursors, a variety of lotus root carbons with various physical/chemical properties were produced as well as pyrolysis temperatures. Activation of $MgCl_2$ in nano carbons could result in a large number of micro-porous and meso-porous channels which are advantageous to ion adsorption and diffusion. Addition of urea increased the porosity, specific surface area and nitrogen content of the soil. Carbon content rose, increasing the double-layer capacitance and pseudo-capacitance. MgCl-142-800 with the best performance was made from a 1:4:2 mixtures of lotus root flour, $MgCl_2$, and urea at 800°C, exhibiting high specific capacitance (331 and 267F g^{-1} in the three- and two-electrode systems respectively), excellent rate capability and good durability. Additionally, porous carbons generated from corn and black soybeans are made using the same techniques and showed outstanding capacitive performance. As a result, biomass-derived nano carbons activated with $MgCl_2$ have a potential future for use as a supercapacitor. Porous carbons produced from corn and black soybeans were also successfully prepared using this technique. **(Guoyu Zhong *et al.*, 2020)** .

- Biomass is an appealing source of carbon materials for energy conversion and storage applications because it offers a low-cost and long-term solution for the large-scale manufacturing of carbon-based electrode materials. Using a chemical degradation process followed by two simple carbonization stages in the presence of argon gas, demonstrate the fabrication of three-dimensional and hierarchical carbon foam (3DCF) from bio-renewable ***Pinus nigra*** pine. The 3DCF in the supercapacitor electrode as constructed, has a high scan rate capability of up to 10 VS^{-1} .In a three-electrode cell arrangement, it has a specific capacitance of 165 F g^{-1} at a specific current of 3.3 A g^{-1} in 6 M KOH electrolyte and retains 69.6% of its original capacitance when the particular current is increased to 13.3 A g^{-1}. Furthermore, an asymmetrical two-electrode cell based on 3DCF has been developed. These findings demonstrate a long-term and low-cost electrode fabrication method for making high-performance supercapacitors using both KOH and Li-ion-based electrolytes in large quantities. **(Mohd. Khalid *et al.*, 2020)**.

- Carbon compounds generated from biomass that have unique electrical, chemical and surface properties have become a hot topic in energy storage research. However, in the recent age, these activated carbon materials are unable to match the rising need for high energy/power densities. Heteroatom doped materials on the other hands; carbon materials have shown improved conductivity, surface wet ability and stability as supercapacitor electrodes. As a result of the produced pseudo capacitance effect, increased energy/power densities with flexible properties are achieved. Self-doping of heteroatoms, unlike external doping procedures, does not necessitate additional processing steps and/or equipment. The usage of hazardous compounds. While there is the post- doping of biomass carbon using external dopants in the literature, there are few complete reports on self-doped carbon for supercapacitors. This focuses on a state-of-the-art update on recent discoveries in the field of supercapacitor electrodes made from self-doped biomass-derived carbon materials. Progressive development in single-/dual-/multi-heteroatom doped porous carbon and its electrochemical performance including specific capacitance, cyclic life and energy/power densities is investigated with the discussion on the effect of heteroatom doping species. Finally, the problems of self-doped carbon materials and their prospects are discussed to provide critical insight into the prospective variables for future supercapacitor electrode improvements. **(Arthi Gopalakrishnan *et al.*, 2020)** .

- Liquefaction, half-curing and one-step activation procedures were used to create activated carbon hollow fibers (ACHF) with a high surface area of 1873 m^2g^{-1} from wood waste. The shape, structure and content of ACHF were studied using scanning electron microscopy; nitrogen gas findings suggest that the application of supercapacitors, the current technology, is promising for the synthesis of biomass-derived activated carbon hollow fibers from agricultural and forestry waste. **(Xiaojun Ma *et al.*, 2018).**

- Activated biomass carbons are carbonized and activated ***bamboo carbons*** with large specific surface areas and meso porous architectures. The activation temperature is adjusted from 700 to 1000°C to manage the specific surface area, total pore volume and average pore size of the activated biomass carbon. Carbon materials that have been activated at 900°C give the best results. Powder X-ray diffraction radiation was used to study the crystal structures of activated biomass carbon compounds. SEM photos were acquired using a Quanta FEG-250 scanning electron microscope. The pore size distribution and specific surface area were calculated. The mesoporous ABCs' outstanding electrochemical performance indicates that, with further tuning, they could be very attractive for energy-storage applications. **(Guoxiong Zhang *et al.*, 2018)** .

- Activated carbon from tree bark (***A.auriculiformis* tree**) was made using a simple and environmentally friendly activation and carbonization process at various temperatures using potassium hydroxide (KOH) pellets as a source of heat (between 700 and 800°C). The material displayed a network of microporous / mesoporous architecture with an ever-increasing tendency in surface area as the temperature of carbonization rises. SEM and TEM micrographs revealed a porous structure with a variable distribution of pore sizes, which was required for ion transport. The presence of a high-quality carbon was confirmed by the EDX, XPS and Raman spectroscopy data including carbon-functionalized material. When used as supercapacitor electrodes, the Na_2SO_4 electrolyte, porous activated carbons showed the best potential electrochemical characteristics, working in both positive and negative potential ranges. These findings advance the field of energy storage by investigating a low-cost plant biomass raw material as a green (environmentally friendly) and non-toxic carbon source for future energy storage EDLC materials. **(Damilola Momodu *et al.*, 2016).**

- The ongoing energy demand, combined with environmental concerns and fossil fuel depletion, has driven research into electrochemical energy storage, such as the supercapacitor. Activated carbon, particularly from biomass sources, has gained a lot of interest in electrode development because of its renewability, low cost and excellent electrochemical performance. Utilization of biomass in conjunction with various reactors. For the manufacture of activated carbon, various technologies (including reactor/furnace, microwave and hydrothermal) have been evaluated. Hydrothermal and microwave technology are emerging technologies on a commercial and industrial scale. Furthermore, the electrochemical performance of the activated carbon electrode is influenced by both physical-chemical and surface functionalities. Finally, This work that can be incorporated while producing superior activated carbon supercapacitors. This study is intended to serve as a guide for researchers interested in investigating cost-effective and simple methods for manufacturing activated carbons for electrochemical supercapacitor applications**. (Nor Adilla Rashidi *et al.*, 2022).**

- Supercapacitors with prestigious electrochemical performance have attained outstanding value. For electrode materials with high charge storage capacity, a simple and environmentally benign solution is still sought-after. The established the simple synthesis of activated carbon (AC) and strontium phosphate in this study for energy storage applications. Surface morphology and crystal structure X-ray diffraction (XRD) and scanning electron microscopy (SEM) are used to analyze the structure of the produced materials. The highest specific capacity, whereas the AC has the highest specific capacitance. The synthesized material was then used in a hybrid design to create a real-world device. The positive electrode and the negative electrode are AC. The kinetics of the charge storage mechanism for the device are also analyzed using Dunn's model, as well as the diffusive and capacitive contributions to overall device capacity. Furthermore, by computing the b values, the power law is used to prove the device's hybrid nature. As a result of the proposed approach, electrode materials with potential energy storage performance have been developed. **(Meshal Al Zaid *et al.*, 2021)**.

- Graphene-like activated and non-activated carbon nanostructures were produced from sugar, rice husk and jute, among other natural sources. SEM, FTIR and Raman spectroscopy, as well as surface area and thermo gravimetric analysis, were used to describe these carbon nanostructures. These carbon materials electrochemical tests validate their potential properties for supercapacitor applications. When compared to non-activated carbon nanostructures, activated carbon nanostructures have a higher specific capacitance and a current density activated carbon (Ac-jute) has a maximum specific capacitance of 476 F/g, which is substantially greater than graphene oxide (GO). Instead of having more functions than activated carbon nanostructures, it has been discovered that activated carbon has a far greater specific capacitance than graphene oxide. **(Kasinath Ojha *et al.*, 2017).**

- Natural biomass-derived active carbon from recycled jute was manufactured using a straight forward hydrothermal method, then chemically activated with KOH to improve electrochemical properties. The jute carbon, structural, chemical composition, morphological and electrochemical measurements are detailed with a specific capacitance of 346.00 F/g in 6 M KOH at a current density of 1.0 A/g, the prepared active jute carbon exhibits a high surface area and high charge storage capacity, as well as excellent cyclic stability (capacity retention of 96 percent) over 10,000 cycles, demonstrating excellent charge storage capacity of electrode material. Jute carbon was used as both the positive and negative electrode materials in a supercapacitor device. As a result of the findings, it can be inferred that biomass-derived active jute carbon could be employed as a new and sustainable electrode material for supercapacitors and batteries. **(Pantrangi Manasa *et al.*, 2020).**

- Synthesis of biomass waste-based activated carbon monolith from the ***Tectoma grandis*** leaf for supercapacitor electrode materials. This research was carried out using a mix of chemical and CO_2 activation techniques KOH was employed in the chemical activation process as an activating agent. Integrated systems were used to conduct the pyrolysis process, which included carbonization and CO_2 activation, at a temperature of 600°C in an N_2 gas environment; temperatures of 750, 800, 850, and 900°C were used to activate the enzyme. Activated carbon samples made from *Tectona grandis* leaves show a variety of results. The TL-AC samples' optimum-specific capacitance was using a two-electrode arrangement measured in 1 M sulphuric acid solution. The study gives an economic approach to the preparation of electrical power systems. **(Erman Taera *et al.*, 2021)** .

- Oxidation polymerization, freeze-drying and carbonization/activation of aniline and sodium alginate were used to create three-dimensional (3D) O, N-codoped activated carbon aerogels with ultra microres. Field emission spectroscopy was used to examine the morphologies and microstructures of the prepared samples. The accelerating voltage scanning electron microscopy and high-resolution transmission electron microscopy. When ACA700 was used as the electrode material for a supercapacitor, the greatest specific capacitance and current density. As a result, the (3D) O, N-doped activated carbon aerogels were long-lasting. Ultra micro pores had been shown to have a lot of potential for energy storage devices. Advanced 3D hierarchical ultra-micro and mesoporous O, N-doped activated carbon aerogels will have a wide range of applications, including energy storage, catalysis and many others. **(Zhengqing Ye *et al.*, 2018) .**

- ***Rice straw*** was carbonized and then activated with KOH at 600̊C in an argon environment to produce biomass-derived activated carbon materials. N_2 adsorption-desorption validated the creation of disordered micro and mesopores on carbon as a result of KOH chemical activation, as well as the high specific surface area in an aqueous electrolyte, the three-electrode cell has a high specific capacitance of 99 percent specific capacitance retention after 5000 cycles. The electrochemical performance of activated Carbon generated from rice straw strongly suggests that it could be used as a promising electrode material in a supercapacitor for electrochemical energy storage. The produced carbon material is suitable for commercial applications in supercapacitors due to the cheaper and readily available rice-straw raw materials, simple chemical activation procedure and high performance. **(Sudhana *et al* ., 2016)** .

- Porous carbon was prepared from rotting **potato wastes**, a novel self-catalytic activation technique was proposed. Metals that were already present in the decaying potatoes were used as the catalyst. As activating reagents, catalysts and gasses generated during pyrolysis were employed, resulting in the creation of hierarchically porous carbon compounds with fewer reagents. The activated carbon as-made has a large BET surface area of optimum hierarchically porous and conductivity. When made into a symmetrical supercapacitor, it has a comparatively high specific capacitance. More importantly, the method described herein presents a promising strategy for producing advanced activated carbon from other biomass wastes in a cleaner manner. **(Wang *et al.*, 2020).**

- Porous carbon derived from ***cattail biomass*** was a potentially useful material for a variety of applications. The carbon was then activated with CO_2 without the use of any other chemical reagents. The results revealed that the activated carbon, as prepared had a large specific surface area. Following CO_2 activation in a 6 M KOH solution, the activated carbon also performed exceptionally well electrochemically as supercapacitors with specific capacitance reaching a current density within a potential range of 1.0–0V. The resulting activated carbon's superior adsorption capabilities and electrochemical performance showed that it could be a good contender as an adsorbent and supercapacitor. **(Miao Yuan *et al.*, 2017).**

- Scientific and technological community was very interested in the sustainable conversion of biomass waste into a cost-effective and high-performance electrical energy storage system. The supercapacitor electrode developed has a high volumetric capacitance and gives a higher volumetric energy density. Even under high current loads, a linked porous network of activated carbon fibers can improve the quick electrolyte ion transfer. Good capacitance retention at high current and high voltage reflects the presence of the optimal carbon electrode pore size, which may match the electrolyte ion size for a rapid capacitive response. A solar-powered supercapacitor was also built as a self-powering energy harvesting and energy storage device and it was used to power a commercial solar lantern. This research presents a simple and practical synthetic technique for transforming renewable biomass waste into cost-effective and high-performance supercapacitor electrodes for real-time supercapacitor applications. **(Manavalan Vijayakumar *et al.*, 2019).**

- Hybrid Nano composite material and biomass-derived N-doped activated carbon with variable shape, composition and topologies are used to make highly efficient supercapacitor devices. Surfactants are used to synthesize $NiCo_2O_4$ materials with various morphologies, such as spherical, urchin, rod and granular. Rigaku Ultima III was used to examine and confirm structural formation and the existence of functional groups in the material. Fourier transform infrared spectrometer (FTIR) and powder X-ray diffractometer (XRD). The electrode surface underwent morphological modifications. Analyzed with a ZEISS EVO-18 scanning electron microscope (SEM). Honeycomb porous structured N-doped activated carbon is created with the ***Ricinus communis*** seed to make the hybrid supercapacitor device. These findings corroborated a successful demonstration of a highly efficient hybrid supercapacitor device based on NZC2/NACC that can be employed in a variety of real-time applications that are suitable. **(Juliet Christina Mary *et al.*, 2020)** .

- A typical lignocellulosic biomass was the ***Amygdalus pedunculata*** shell was utilized to make ethanol and activated carbon, yielding a maximum ethanol output and activated carbon with a maximum BET surface. Furthermore, porous carbon was comprehensively studied and used as an electrode material for a supercapacitor with a high specific capacitance at a current density. After 1000 iterations, at a current density, the capacitor still performed well, retaining 86.3 percent of its capacitance. *Amygdalus pedunculata* shells were converted to bioethanol and activated carbon was used. The use of lignocellulosic biomass as electrode material in a high-performance supercapacitor has significant implications for lignocellulosic biomass utilization. **(Wenchao Li *et al.*, 2016).**

- Carbonization and KOH activation methods were used to create biomass-derived activated carbon electrode materials from a ***Rice husk***, which was made up of organic compounds and silica. Due to the template effect of silica in rice husk, activated carbon primarily consists of mesopores and macropores. Due to the presence of a perfect electrical double layer in the KOH electrolyte, fast rate performance was achieved. High voltage (2.5 V) was attained in organic electrolytes. The capacity of an activated carbon electrode for the Li-ion capacitor was also a high voltage range of 2.5 V. The capacities of sulfur-activated carbon in Li-S batteries were 1230 and 970mAh/g, respectively. According to the preliminary findings, activated carbon materials containing mesopores were a good host for immobilizing polysulfides. **(Kunfeng Chen *et al.*, 2017).**

- Ability to supply sufficient energy for all scientific applications is the most crucial aspect of modern research and technology. Because fossil fuel reserves are rapidly depleting, an alternative is constantly necessary to meet the needs of the future world. Limited resources also encourage people to come up with new ways to make better use. This research examines the prospect of employing biomass-derived hard carbon as electrochemical supercapacitors using a straightforward synthesis technique. For electrochemical energy storage, a cheap, environmentally friendly, and easily synthesized carbon material is used as an electrode. KOH activated banana stem, a phosphoric acid-treated banana stem derived carbons (PHC), corn-cob derived hard carbon (CHC) and potato starch was used to make four different hard carbons. The results with the material property, a rigorous analysis are performed. Overall, this study gives a thorough examination of the physics behind the components of an electrochemical energy storage system and they work various characterization procedures necessary to assess the material's quality and reliability. **(Sourav Ghosh *et al.*, 2019).**

- ***Green monoliths*** (GMs) were made using oil palm empty fruit bunch fibers and a mixture of KOH carbon nanotubes and self-adhesive carbon The GMs were carbonized at 600, 700, and 800 ̊C in an N_2 gas atmosphere and then activated with CO_2 gas at 800 degrees Celsius. The X-ray diffraction (XRD) patterns were recorded using a model D8 Advance at a wavelength of 1.5406 nm. ACMs are acronyms for the carbonization temperature that had a significant effect on the structure, microstructure, electrical conductivity and porosity of the ACMs, according to the characterization. As a result, three independent methods for electrochemical characterization of supercapacitor cells fabricated using ACMs as electrodes, galvanostatic charge-discharge, cyclic volt ammetry and electrochemical impedance spectroscopy, consistently found that the ACM7 and ACM8 cells have higher specific capacitance and specific power. When compared to the ACM6 cell, they produce 161 W kg^{-1} and respectively. These findings show that when making supercapacitor electrodes out of biomass precursors, carbonization should be done at temperatures near or equivalent to the activation temperature. **(Deraman *et al.*, 2013)**.

- Biomass waste-***Cotonier strobili*** fibers are used to prepare hierarchical porous carbon tubes activated by KOH. For the first time, the biomass waste- Cordonnier strobili fibers were used to make activated carbon tubes. The materials that arise have a very accessible surface. Vast ion storage and high-rate ion transfer are aided by large regions and many micro-mesopores. The PTAC-6 material, which has been optimized has a high specific capacity in supercapacitors with three electrodes. In addition, with capacitance retention of the symmetric supercapacitor has outstanding cycling stability. After 10,000 cycles, the efficiency of the coulombic system was 84.21 percent, with a coulombic efficiency of over 100 percent. The Porous activated carbon tubes, as described, provide a green and low-cost electrode material for high-power applications. supercapacitors with high performance. These porous carbon tube materials, which are made from low-cost, sustainable and abundant Cordonnier strobili fiber bio-waste, show promise. Supercapacitors and even Li-ion batteries have a lot of potential as energy storage devices. **(Xiao-Li Su *et al.*, 2018).**

- Biomass ***Rice straw*** was converted into porous carbon (PC). X-ray diffraction, scanning electron microscopy, surface area and porosity investigations using the BET (Brunauer, Emmett and Teller) nitrogen adsorption method and Fourier transform infrared spectroscopy were used to evaluate the morphological and chemical features of PC. PC's specific surface area and pore size grow as a result of the alteration process. The temperature of carbonization was discovered to play a role. Porous carbons play a critical role in the evolution of structural and electrochemical characteristics. Porous carbon tube materials made from low-cost, sustainable and abundant Cordonnier strobili fiber bio-wastes show promise. Supercapacitors and even Li-ion batteries have a lot of potential as energy storage devices. **(Adinaveen *et al.*, 2015).**

- A low-cost and straight forward activation approach using $ZnCl_2$ as an activating agent was used carbon obtained from ***Saccharum bengalense*** (S. Bengalese) leaf biomass. The use of S. Bengalese-derived activated carbon (SbAC) as an electrode material in Electric Double Layer Capacitors (EDLCs) has been described. X-ray diffraction (XRD), Field Emission Scanning Electron Microscopy (FE-SEM), Fourier Transform Infrared Spectroscopy (FTIR), Raman spectroscopy and Brunauer-Emmett-Teller (BET) surface area were used to characterize the structure, surface morphological research and vibrational response of the SbAC. According to electrochemical tests, the SbAC has a maximum specific capacitance. The findings suggest that SbAC has good electrochemical characteristics and could be employed for energy storage in the future. **(Sangeeta Rawala *et al.*, 2017).**

- Activated carbon was made from ***Eichhornia crassipes*** biowaste using a chemical activation process with KOH as the activating agent at different carbonization temperatures (600, 700, and 800°C). XRD, SEM and FT-IR were used to investigate the disordered nature, morphology and surface functional groups of ACs. Using cyclic voltammetry (CV), galvanostatic charge-discharge and electrochemical impedance spectroscopy (EIS) techniques in a three-electrode system. The constructed supercapacitor with an AC electrode gave a greater specific capacitance and energy density. The activated carbon from the new precursor *Eichhornia crassipes* can be concluded to be a viable electrode material for electric double-layer capacitors based on the foregoing finding. **(Senthil Kumaran *et al.*, 2013)**.

- Nitrogen-doped hierarchically porous carbon was fabricated by using **Pig nail** as a protein-rich carbon source by the facile process of pre-carbonization and KOH high-temperature activation. To introduce the pseudo capacitance and increase conductivity and surface wet ability in the existence of a nitrogen functional group. The obtained sample was characterized by XRD, Raman spectrometer. The result shows that the micro morphology and structure can effectively be tailored by changing activation temperature. **(Lin Tang *et al.*, 2019).**

- Biomass-based energy conversion and storage applications have shown to be the most cost-effective and environmentally friendly technology. A simple method for producing activated carbon-based electrode materials generated from with a focus on supercapacitor applications, natural biomass was being used. The biomass waste that was chosen is made out of ***Longan leaves***. $ZnCl_2$ was used to transform the precursor into activated carbon. An excellent amorphous structure was confirmed by carbon. LF0.5 had good electro capacitive performance in asymmetric supercapacitor cell, with the maximum specific capacitance of 169.83 F g^{-1} at a constant current density of 1.0 Ag^{-1} in 1 M H_2SO_4 electrolyte solution. These findings suggest that the sustainable Longan leaves biomass base material had outstanding electrochemical performance, indicating that the precursor has a lot of potential for supercapacitor applications. **(Erman Taer *et al* ., 2021).**

- Biomass-derived activated carbon hollow fibers were prepared from **wood wash** by liquefaction, half-curing and one-step activation methods. The sample was characterized using scanning electron microscopy. The sustainable biomass-derived activated carbon hollow fibers from agricultural and forestry waste were promising and sustainable candidates as high-performance electrode materials for supercapacitors. **(Xiaojun Ma *et al* ., 2018)** .

- ***Syzygium cumini*** fruit shells were prepared from biomass-derived micro porous activated carbon materials. The results show that the biomass-activated carbon-based electrode materials the excellent EDLC in an aqueous electrolyte of solution. The capacitor exhibits outstanding cycling stability over the long term and high energy density. **(Murugan vinayagam *et al.*, 2020)**.

- ***Lemon Citrus Limon*** was prepared from biomass-derived activated carbon. The sample was characterized by using FTIR, SEM, EDX, BET and XRD methods. The results show that various types of economically valuable materials could be synthesized by the citrus waste like a lemon product and the bio-waste-derived new materials can be used in different applications such as wastewater treatment. **(Zehra Qruc *et al.*, 2019)**.

- Biomass-derived activated carbon was prepared from European deciduous trees, ***Birch, Fagaceae and Carpinus betulus*** commonly known as European born beams. The carbon sample was characterized using XRD, and Raman spectroscopy. The pyrolysis followed by the activation process can be considered the novel promising manufacturing of the biomass-derived activated carbon material. The synthesis was found to be a scalable and cost-effective method, suitable for commercial applications. **(Amrita Jain *et al.*, 2021)**.

- ***Pinecone*** was to prepare activated carbon by pyrolysis and chemical activation *process*. The sample was characterized using Field emission scanning electron microscopy and Raman spectrum. The pinecone biomass can be desirable electrode materials for various forms of supercapacitor devices. **(Won-Je. Cho *et al.*, 2020).**

- **Wheat husk** was used as biomass for preparing activated carbon using KOH as the activation agent. The obtained sample was characterized by XRD, SEM and FTIR. The electrochemical studies show low resistance and low frequency. The utilization of biomass waste as a potential electrode material for supercapacitors. This process was used to reduce the biomass waste from wheat husks and develop the porous carbon electrodes for energy storage devices. **(Mutawara Mahmood Biag *et al.*, 2021)**.

- Active electrode material carbon was generated from discarded ***Camellia oleifera*** shell (COS) using $ZnCl_2$ activation technique. For the first time, electric double-layer capacitors (EDLCs) were created. The activation temperature and $ZnCl_2$/COS impregnation ratio were found to be two important parameters that influence the surface area and pore structure of activated carbons, and thus their capacitive performance. Electrochemical tests demonstrate that activated carbon generated at 600°C activation temperature and impregnation ratio of 3 has a maximum specific capacitance of 374 and 266 Fg^{-1}, respectively. In both acid and alkaline electrolytes, activated carbon has strong cycle stability. All of these electrochemical findings show that biomass waste COS may be used to make high-performance electrode materials. **(Juntao Zhang *et al.*, 2012).**

- Biomass-derived activated carbons have gotten a lot of attention as supercapacitor electrode materials because of their low cost, abundance and undesired natural wastes. For the first time, a simple KOH activation process is used to make activated carbon tubes from biomass waste toner strobili fibers. The materials that arise have a very accessible surface. Vast ion storage and high-rate ion transfer are aided by large regions and many micro-mesopores. PTAC-6 was an improved material with a high specific capacity as well as a better rate of performance in supercapacitors with three electrodes. In addition, the symmetric supercapacitor has good cycling stability, with 84.21 percent capacitance retention and approximately 100 percent coulombic efficiency after 10,000 cycles. The porous activated carbon tubes, as proposed, provide a low-cost and environmentally friendly electrode material for high-performance supercapacitors. **(Xiao -Li Su *et al.*, 2018)**.

- Carbon that is porous in three dimensions with ***Sakura petals*** as raw materials, aqueous materials were created by combining pre-carbonization with KOH activation. The prepared porous sakura carbon (SAC-4) had large specific surface area, a good pore size distribution, a low proportion of oxygen-rich groups and N functional groups and a partially graphitized phase, all of which are favorable for the material's electrochemical performance as a supercapacitor electrode. When the current density is maximum and specific capacitance is 265.8 Fg^{-1}. The findings show that porous carbon made from cherry blossom as a raw material was an effective and environmentally acceptable electrode for energy storage. As a result, it can be concluded that SAC-4 has a lot of promise as an outstanding electrode material for future applications. **(Shaolan Ding *et al.*, 2018).**

- ***Tobacco*** is a renewable, abundant and low-cost biomass material and the current study used simple carbonization followed by KOH activation to successfully produce tobacco-derived activated carbon (TAC). Electrochemical cells using electrodes constructed from as-prepared TAC material showed high specific capacitance, high energy density and good cycling stability, with no visible capacitance reduction after 9000 cycles at 1 Ag^{-1} current density. The reported high capacitive performance had the potential to turn waste tobacco into a new source of activated carbon for use in high-performance supercapacitors. **(Hui Chen Yan *et al.*, 2017)**.

- Pyrolytic chemical activation technique was used to prepare activated carbon (AC) samples derived from ***Polyalthia longifolia*** seeds (PLS) at various temperatures (600, 700, 800 and 900°C). Spectral and analytical methods were used to characterize the PLS-ACs as they were created. Cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) and Impedance spectroscopy techniques were used to characterize the electrochemical properties. In 1M Na_2SO_4, a three-electrode system was created using the as-prepared PLS-AC samples coated with nickel foil (working electrode), Ag/AgCl (reference electrode) and Pt-wire (counter electrode). Furthermore, its capacitive character was supported by its significant electrochemical behavior within the specified potential window. The bio-waste-derived high-performance carbon materials showed increased super capacitance, making them suitable for power storage devices. As a result, the observations led to the conclusion that the as-prepared novel material has a lot of potential for low-cost energy applications. Applications for storage devices electrodes were identified as a good candidate for high-performance supercapacitors. **(Raj Kumar Srinivasan *et al.,* 2019).**

- Tubular carbon materials, such as carbon nanotubes (CNTs) and carbon micro tubes (CMTs), are thought to have an intriguing ability to function as miniature reactors for catalysis, 1 storage, 2 or micro-and Nano channels for ion or molecule transport. 3 For use in catalytic supports, batteries and supercapacitor electrodes, large inner-diameter CNTs or CMTs with a high specific surface area (SSA), adequate pores and an appropriate pore structure are critical. ACMTs-6, ACMTs-7, ACMTs-8 and ACMTs-9 are the active CMTs prepared at 600, 700, 800 and 900̊C respectively. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) pictures of ACMTs-7 reveal that the sample had tubular structure of the CMT precursor after chemical activation. The SAED pattern shows an inner halo ring for diffraction and a faint outer ring for diffraction, indicating that the activated CMTs are mostly made up of amorphous carbon. Because it provides a micro channel for ion movement, the microtubule structure is advantageous for electrochemical energy storage. Furthermore, because the inner tubes of the activated CMTs are available for the incorporation of metal oxide and polymer, as well as the growth of CNTs, the performance of the activated CMTs might be increased further. **(Yi Wei *et al.,* 2014).**

- A novel N, S -doped activated carbon was effectively produced from elm flowers for supercapacitors using a simple pre-hydrothermal process and KOH activation. Through altering the KOH-to-pre hydrothermal mass ratio N, S -doped activated carbon from carbonized elm blossoms Carbon has a large specific surface area and a moderate pore size. There are a lot of volumes and a lot of functional groups. In addition, the N, S -doped activated carbon electrodes were produced that showed a high specific capacitance. These excellent results show that N, S -doped activated carbon produced from elm blossoms is a promising material for energy conversion and storage applications. **(Hui Chen *et al* ., 2018)**.

- A simple hydrothermal process was used to generate activated carbon from ***Eucalyptus globulus*** seed (EGS), followed by chemical activation with potassium hydroxide as the activating agent at various carbonization temperatures. The carbon's amorphous and turbostratic disordered character was confirmed by X-ray diffraction and Raman spectroscopy investigation. The SEM/EDX investigations indicated the presence of tiny and large graphitic pores with random orientation. The material was also investigated as an electrode for supercapacitors to better understand the electro catalytic nature of the synthesizing carbon. Cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance (EIS) investigations were used to illustrate the electrochemical performance. The electrochemical properties of EGGS-derived activated carbon show that it might be used to manufacture energy storage devices as a high-performance, low-cost supercapacitor electrode material. **(Sofia Jeniffer Rajasekaran *et al.*, 2020)**.

- Activated carbon with excellent electrochemical performance environmentally hydrothermal treatment of rotting potatoes at 200 ̊C followed by KOH activation at 750 ̊ C successfully synthesized a specific area and micro-/meso-/macropore structure. The resulting AC has a high specific capacitance and current density, when the current density is increased 100 times and strong stability with just 5% capacitance degradation after 7000 cycles. Furthermore, at a current density of, the built symmetric capacitor based on the rotten potatoes-derived AC has a high specific capacitance and a significant energy density. As a result, a simple, low-cost and environmentally benign method for fabricating high-capacitive carbon materials for commercial EDLC applications has been developed. The findings point to a low-cost, simple method for high-performance AC based on waste biomass, signaling commercial potential in supercapacitor applications. **(Xueyang Chen *et al.*, 2015).**

- ***Wisteria Sinensis (WS)*** seeds biomass was used to create a novel activated carbon (AC) material. Field-emission scanning electron microscopy, transmission electron microscopy, X-ray diffraction, Raman spectroscopy, Fourier-transform infrared spectroscopy, X-ray photoelectron spectroscopy and Brunauer-Emmett-Teller specific surface area analysis were used to characterize the material. As a test, synthetic AC was used as an electrode material to be used in energy applications. In an acidic electrolyte, the results revealed improved capacitive performance. When compared to a neutral electrolyte with the same current density As a result, as-synthesized AC could be useful be a good choice for energy storage applications. This type of activated carbon material could offer a wide range of useful properties about a large surface area imparting its broad range of industrial applications such as energy storage, water purification, adsorption of organic pollutants and metal ions adsorptions in the future research perspective. **(Ganesh Prasad Awasthi *et al* ., 2018)** .

- ***Palm oil*** mills produced vast amounts of fibers from empty fruit bunches of oil palms, which were processed into self-adhesive carbon grains. Before N_2-carbonisation and CO_2-activation, untreated and KOH-treated SCG were converted into green monolith without binder to generate extremely porous binderless carbon monolith electrodes for supercapacitor applications. The pore structure of the intestine is being studied. Combining chemical and physical activation procedures yielded a major benefit in the form of electrodes. The electrochemical tests on the supercapacitor cells made with these electrodes, This approach also has an economic advantage because a small amount of KOH can considerably shorten activation time, and minimizing excessive heating that could potentially damage the electrodes' monolithic structure during activation. The current work presents a new approach for producing electrodes from biomass wastes that saves chemicals, time and energy. **(R. Farma *et al.*, 2013).**

- Simultaneous carbonization and KOH activation of chitosan biomass regenerated from **Prawn shells** at high temperatures resulted in nitrogen-doped activated carbons. They are extremely tempting for charge storage in supercapacitors due to their sufficient porosity and high nitrogen heteroatom content. Because of the optimum combination of electronic double-layer capacitance and pseudo capacitance, activated carbon produced at $700^{0}C$ demonstrates outstanding capacitive performance in both acidic and alkaline electrolytes. The activated carbons that result have a high specific area, nanoporosity with a limited pore size distribution and stable surface chemistries. The AC-700 sample was found to offer high specific capacitances, stable cycle life of 5000 cycles, a specific energy density of 10 Wh kg^{-1} and a specific power density of 1000 W kg^{-1} at a current density. The materials, which are made from low-cost, commonly available materials, present a viable method for the creation of innovative capacitive-based energy storage devices. **(Feng Gao Jiangying Qu *et al.*, 2016).**

- A simple technique for producing porosity in porous carbons was proposed, with a carton box as the starting point. The significant differences in capacitance behavior for the NaOH and KOH melt activated porous carbon and KOH activated samples at high current density emphasize that particular surface area is not the only factor that influences capacitive performance, especially at high charge-discharge rates. The simple activation method described here demonstrates how easy it is to control the pore structure of activated carbon materials, opening up new avenues for the preparation of various porous carbon-based functional materials for practical applications, including high-performance supercapacitors and other emerging devices. **(Dewei Wang *et al.*, 2016)**.

- Hazardous aquatic plant ***Alternanthera philoxeroides*** produced carbon material with a super high specific surface area consideration of cost and environmental protection. These carbon materials' structure and content were studied using SEM, EDS, XPS and BET measurements. The substance obtained had a maximum density 275 Fg^{-1} specific capacitance at a concentration of 0.5 Ag^{-1} and maintains a 210 Fg^{-1} capacitance. Furthermore, it has capacity retention of 5000 cycles at 10 Ag^{-1}. The large specific surface area, plentiful porosity and the limited number of oxygenic groups were responsible for the high supercapacitor performance. **(Jiangfeng Li *et al.*, 2017)** .

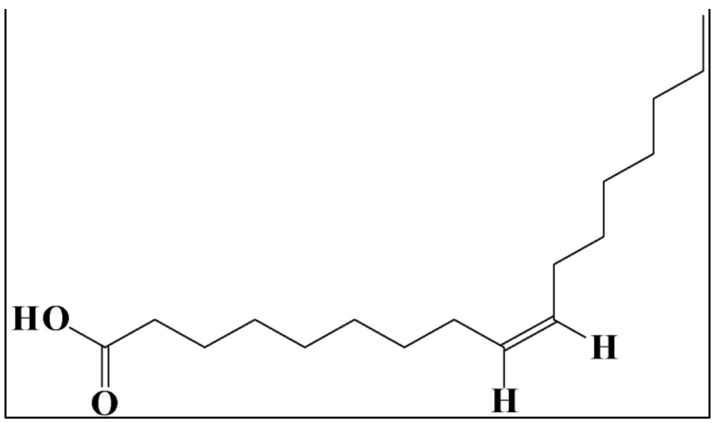
- Hydrothermal treatment followed by carbonization at 800°C for various periods yielded activated carbon (AC) from three different plant biomass waste sources (coconut shell, pine cones and rice husk). The altered carbon material exhibited a highly disordered graphitic carbon consisting of a porous network with energy storage capabilities based on its morphological and structural properties. In all sample combinations employing all three transformed activated carbon materials, the mixed assembly type cells built from the best samples based on specific capacitance from single electrode testing demonstrated electric double layer capacitance (EDLC) behavior. The findings revealed that adopting such a design has virtues and is not just dependent on the specific qualities of the materials, but also on the integrated functionality of the entire device. Although the AC-CO and AC-PC samples had higher specific capacitance values than the AC-RH samples. The PC RH device exhibited the best EDLC properties based on the textural, morphological and structural properties which collectively determine the electrochemical response and extensive stability of the mixed assembly device for developing efficient and stable electrochemical double-layer capacitor devices. **(Damilola Momodu *et al.*, 2017).**

- ***Cocoa (Theobroma cacao)*** pod waste was chosen as an activated carbon material for supercapacitor electrodes and studied as active material. At 700°C, the carbon electrode was produced with 0.3 M and 0.4 M potassium hydroxide (KOH) activators. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to assess physical qualities, while the Cyclic Voltammetry (CV) method was used to examine electrochemical parameters. A combination of chemical and physical activation processes was used to create activated carbon electrodes. The process of creating carbon electrodes began with pre-carbonization, milling, carbonization, physical activation, chemical activation and pellet production. The results of physical and electrochemical characterization on the supercapacitor electrodes demonstrate that activated carbon production from Cocoa-pods is consistent with the results of physical and electrochemical characterization on the supercapacitor electrodes. The most common shrinkage of mass results in a drop in the carbon electrode's value. density. In general, the following conclusions can be drawn: These findings point to the significant potential of activated carbon monoliths made from agricultural cocoa pods as supercapacitor electrodes. **(Yuli Yetri *et al.,* 2020)**.

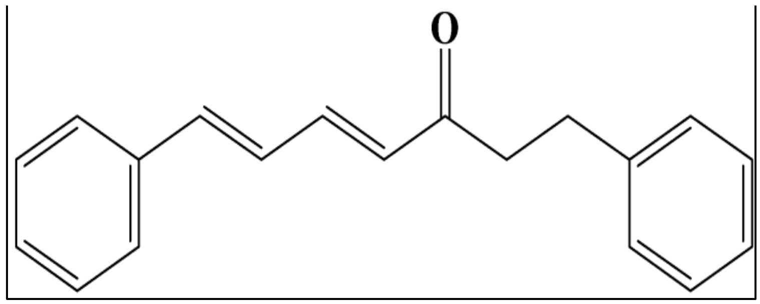
Phytochemical screening of leaf extracts of *Millingtonia hortensis*

The preliminary phytochemical screening is a means of evaluating the potential phyto compounds in the leaf extract of *Millingtonia hortensis*. Phytochemical characterizations of solvent extracts of *M. hortensis* are presented in (table 1). The phytochemical screening revealed the strong presence of carbohydrates, tannins, saponins, flavonoids, alkaloids, betacyanins, phenols and coumarins.**(Janaki A, *et al.,*2017).**

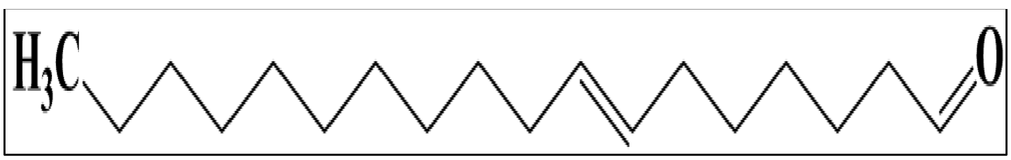
1. **Oleic acid.**



2. 4,6 Heptadien-3-0ne,1,7-diphenyl



3. 7-Octadecenal



4. Octadecanoic acid, 2(2-hydroxyl ethoxy) ethyl ester

5. Aspidofractinine-3-methanol(2a,3a,5a)

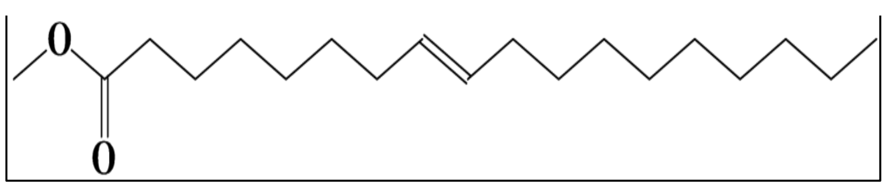


TABLE : 2.1

Synthesis of activated carbon materials using various biomasses.

S.No	Plant Biomass	Activated Method	Specific Surface area($m^2 g^{-1}$)	Average pore size (nm)	Specific Capacitance (Fg^{-1})	Electrolyte	Reference
1	Bamboo	KOH	2221	3.044 - 2.282	293	3M KOH	Guoxiong Zhang *et al* ., 2018
2	Tree bark*(Acaca auriculiformis tree)*	KOH	1018	2.0-3.8	114	1M Na_2SO_4	Damilola Momodu *et al.*, 2016
3	*Corchorus olitorius (Jute fiber)*	KOH	1903	2-11	346	6M KOH 1M Na_2SO_4	Pantrangi Manasa *et al.*,2020
4	*Tectona grandis leaf*	KOH	514	2.718-1.258	168	1M H_2SO_4	Erman Taera *et al.*,2021
5	*Rice straw*	KOH	1007	-	156	1M Na_2SO_4	Sudhana *et al.*,2016
6	*Rotten potato*	KOH	2201	1-4	54	6M KOH	Ao Wang *et al.*,2020
7	*Cattail*	CO2(or) KOH	441.12	2.1-4.0	125	6M KOH	Mio Yuan *et al.*,2017
8	*Syzygium oleana leaves*	KOH	216 - 1218	2-10	188	1M KOH	Jiangfeng Li *et al.*, 2017

9	*Amygdalus pedunculaa*	KOH	2059	1-20	358	H_2SO_4	Wnchao Li *etal.*,2016
10	*Saccharum bengalense*	ZnCl2	2090	2.05	102	1M $LiSO_4$	Sangeeta Rawala *et al.*, 2017
11	Peanut shells	KOH	1279	-	242.84 272	1 M KOH $LiSO_4$	NghiaTrongNguyen *et al.*,2021
12	*Prosopis Juliflora* wood	KOH	2943	1.3-90	588	6M KOH	Selvaraj *et al.*,2021
13	*Chenopodium Quinoa*	KOH	2597	-	330	6M KOH	Jianjun *et al.*,2020
14	*Borassus Flabel lifer flower*	KOH	474.99	-	275	KOH	MariaSundar *Raj et al.*,2020
15	Tea waste	KOH	1610	3.05-5.97	332 and 222	6M KOH	Khan *et al.*,2020
16	*Eucalyptus globulus* seeds	KOH	2388.	1.7	150	KOH	Rajasekaran *et al.*,2020
17	*Fungus bran*	KOH	1515	1.821-1.989	537	KOH	Houjuan *et al.*, 2020
18	Carrot	KOH	388	0.36-0.38	161	6.0 M KOH	Shixiong *et al.*,2020
19	*Pomelo peel*	ZnCl2	1582	-	180	6M KOH	Li,Jing *et al.*,2020
20	*Pinus nigra pine*	KOH	264	-	165	6 M KOH	Khalid *et al.*,2015

3. MATERIALS AND METHODS

The methodology pertaining to the title "Activated carbon materials derived from *Millingtonia hortensis* leaves as a biomass source by simple carbonization Microwave –assisted synthesis method " is presented in this chapter.

Materials:

The leaves of *Millingtonia hortensis* were collected from a garden located at north Coimbatore, Tamil Nadu, India. The identification of the leaves was confirmed by the taxonomist of the Botany department of our university. The collected Plant sample was firstly washed with distilled water and dried at 80°C for 12 h. The dried plant sample was ground into pieces and pre-carbonized at 300°C for 2 h to obtain the as- prepared char.

Then the char was soaked in 6.0 M KOH solution in the ratio of 1:3 to obtain the KOH/char composite. The KOH/char composite was transferred into a ceramic crucible and placed in the microwave oven to undergo a microwave treatment for 3 min at a power of 600 W. After microwave treatment, the obtained sample was washed with 1.0 M HCl solution and then thoroughly washed with deionized water.

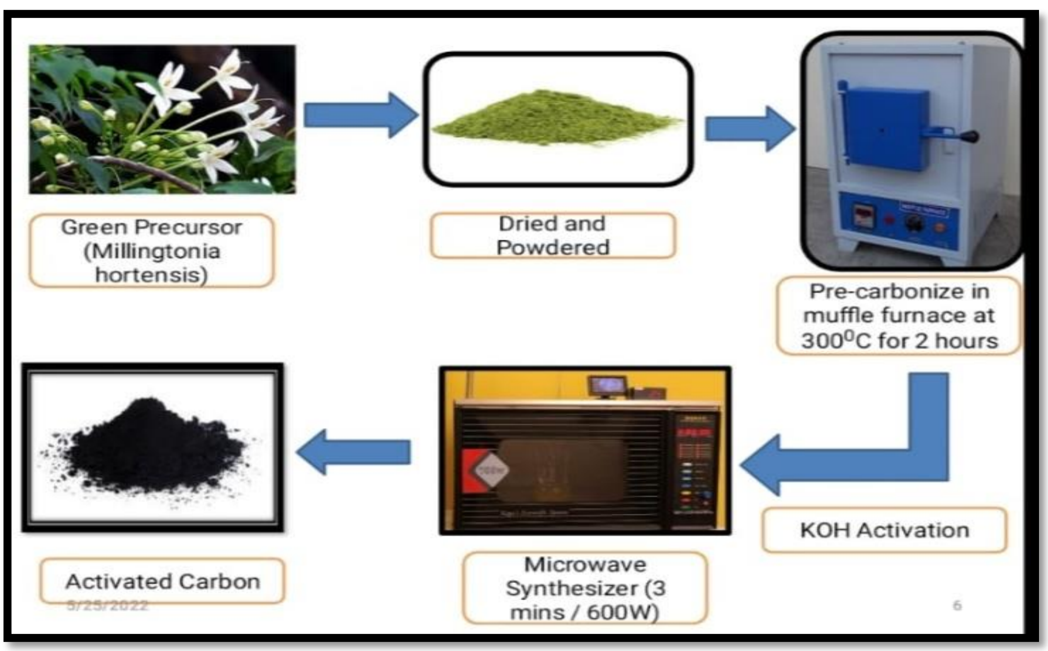


Fig 3.1 Systematic representation of prearation of carbon materials

Preparation of the plant leaf extract:

Fresh leaves of *Millingtonia hortensis* were thoroughly cleaned with running tap water to remove debris and other contaminants, followed by distilled water and air dried at room temperature. Leaves were finely chopped into small pieces. The aqueous extract of sample was prepared by boiling the freshly collected cut leaves (10g), with 100 ml of distilled water, at 60℃ for about 20 minutes, until the colour of the aqueous solution changes from watery to light brown. Then the extract was cooled to room temperature and filtered using Whatman filter paper. The extract was stored in a refrigerator in order to be used for further experiments.

3.3 Phytochemical screening :

Phytochemical examinations were carried out for the extract as per standard methods (Tiwari et al., 2011)

1. **Detection of alkaloids:** Extracts were dissolved individually in distilled water and filtered.

a) Mayer's Test: Filtrates were treated with Mayer's reagent (Potassium Mercuric Iodide).Formation of a yellow coloured precipitate indicates the presence of alkaloids.

b) Wagner's Test: Filtrates were treated with Wagner's reagent (Iodine in Potassium Iodide). Formation of brown/reddish precipitate indicates the presence of alkaloids.

c) Dragendroff's Test: Filtrates were treated with Dragendroff's reagent (solution of Potassium Bismuth Iodide). Formation of red precipitate indicates the presence of alkaloids.

d) Hager's Test: Filtrates were treated with Hager's reagent (saturated picric acid solution). Presence of alkaloids confirmed by the formation of yellow coloured precipitate.

2. Detection of carbohydrates: Extracts were dissolved individually in 5 ml distilled water and filtered. The filtrates were used to test for the presence of carbohydrates.

a) Molisch's Test: Filtrates were treated with 2 drops of alcoholic a-naphthol solution in a test tube. Formation of the violet ring at the junction indicates the presence of Carbohydrates.

b) Benedict's Test: Filtrates were treated with Benedict's reagent and heated gently. Orange red precipitate indicates the presence of reducing sugars.

c) Fehling's Test: Filtrates were hydrolyzed with dil. HCl, neutralized with alkali and heated with Fehling's A & B solutions. Formation of red precipitate indicates the presence of reducing sugars.

3. Detection of glycosides: Extracts were hydrolyzed with dil. HCl, and then subjected to test for glycosides.

a) Modified Borntrager's Test: Extracts were treated with Ferric Chloride solution and immersed in boiling water for about 5 minutes. The mixture was cooled and extracted with equal volumes of benzene. The benzene layer was separated and treated with ammonia solution. Formation of rose-pink colour in the ammoniacal layer indicates the presence of anthranol glycosides.

b) Legal's Test: Extracts were treated with sodium nitroprusside in pyridine and sodium hydroxide. Formation of pink to blood red colour indicates the presence of cardiac glycosides.

4. Detection of saponins

a) Froth Test: Extracts were diluted with distilled water to 20ml and this was shaken in a graduated cylinder for 15 minutes. Formation of 1 cm layer of foam indicates the presence of saponins.

b) Foam Test: 0.5 gm of extract was shaken with 2 ml of water. If foam produced persists for ten minutes it indicates the presence of saponins.

5. Detection of phytosterols

a) Salkowski's Test: Extracts were treated with chloroform and filtered. The filtrates were treated with few drops of Conc. Sulphuric acid, shaken and allowed to stand. Appearance of 2 golden yellow colour indicates the presence of triterpenes.

b) Libermann Burchard's test: Extracts were treated with chloroform and filtered. The filtrates were treated with few drops of acetic anhydride, boiled and cooled. Conc. Sulphuric acid was added. Formation of the brown ring at the junction indicates the presence of phytosterols.

6. Detection of phenols

Ferric Chloride Test: Extracts were treated with 3-4 drops of ferric chloride solution. Formation of bluish black colour indicates the presence of phenols.

7. Detection of tannins

Gelatin Test: To the extract, 1% gelatin solution containing sodium chloride was added. Formation of white precipitate indicates the presence of tannins.

8. Detection of flavonoids

a) Alkaline Reagent Test: Extracts were treated with few drops of sodium hydroxide solution. Formation of intense yellow colour, which becomes colourless on addition of dilute acid, indicates the presence of flavonoids.

b) Lead acetate Test: Extracts were treated with few drops of lead acetate solution. Formation of yellow colour precipitate indicates the presence of flavonoids.

9. Detection of proteins and amino acids

a) Xanthoproteic Test: The extracts were treated with few drops of conc. Nitric acid. Formation of yellow colour indicates the presence of proteins.

b) Ninhydrin Test: To the extract, 0.25% w/v Ninhydrin reagent was added and boiled for a few minutes. Formation of blue colour indicates the presence of amino acid.

3.2 Characterization of Carbon materials :

UV- visible analysis

UV-visible spectroscopy is usually conducted to confirm the synthesis of carbon materials peaks, which studied in the range of 200-800 nm? Different peaks are obtained in this range. Absorbance is also obtained through this analysis. ***(Santhosh Kumar et al., 2017)***

FT-IR analysis

Specific signals obtained by IR spectroscopy according to the vibrations of the molecule. FT-IR spectra and functional groups involved in Carbon materials synthesis illustrated peaks in the range of 400-4000 cm^{-1}.The sample pellet was placed into the sample holder and FT-IR spectra were recorded in FT-IR spectroscopy.

Thermo gravimetric analysis

TGA is a method of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing temperature or as a function of time with constant temperature. It is a temperature based study.

X –Ray Diffraction

Powder X-Ray Diffraction (XRD) analysis of activated carbon materials were performed at room temperature by a **X-PERT-PRO Pan analytical diffractometer** using Cu-kα(λ=1.5406 nm) as an X-ray source at a generator voltage of 45kV and current of 30mA. The scanning rate was 1^0/ min. From the XRD date, the interlayer spacing of carbon was calculated using **Bragg's law** as follows;

$$\mathbf{d = \lambda/2\sin\theta}$$

From XRD data we can easily calculate the size of particles. The particle size of decarbonized and activated carbon materials were calculated using **Scherrer formula** as follows:

$$\mathbf{D_P = (0.94 \times \lambda) / (\beta \times \cos\Theta)}$$

Where, D_P= Average Crystalline size, β = Line broadening in radians, Θ = Bragg angle, λ = X-ray wavelength.

XRD analysis is very useful to determine the crystallinity of the prepared carbon materials to determine the layer to layer distance **.(*Sadhukhan et al*.,2016)**

4. RESULT AND DISCUSSION

The present investigation entitled "Activated carbon material derived from *Millingtonia hortensis* leaves as a biomass source by simple carbonization and Microwave- assisted activated synthesis method" deals with the synthesis of carbon materials from *Millingtonia hortensis* leaves. Characterization studies were carried out with the synthesized carbon materials. The synthesis of carbon materials can be carried out using 2 different synthesis methods.

- Carbonization method
- Activation method

4.1 Qualitative Phytochemical Analysis

The phytochemical analysis of the plant extract of *Millingtonia hortensis* leaves is shown in table no 4.1

The analysis revealed the presence of several phytochemicals such as carbohydrates, alkaloids, glycoside, phenolic test, tannins, Saponins, flavonoids, phytosterols, proteins, and amino acids. The result + sign represents that positive, ++ indicates highly positive and – sign represents that absence of compounds.

S. No	**Chemical constituent**	**Phytochemicals Test**	**Result**
1	Carbohydrates	Fehling's test	+
		Molisch's test	+
2	Alkaloids	Drangendroff's test	+
3	Glycoside	Legal's test	-
4	Phenolic test	Ferric chloride test	+
5	Tannins	Gelatin test	-

6	Saponins	Foam test	-
7	Flavonoids	Alkaline reagent test	-
8	Phytosterols	Salkowski's test	-
9	Proteins	Xanthoproteic test	-
10	Amino acid	Ninhydrin test	-

Table 4.1 Phytochemical constituents of Millingtonia hortensis leaf extract

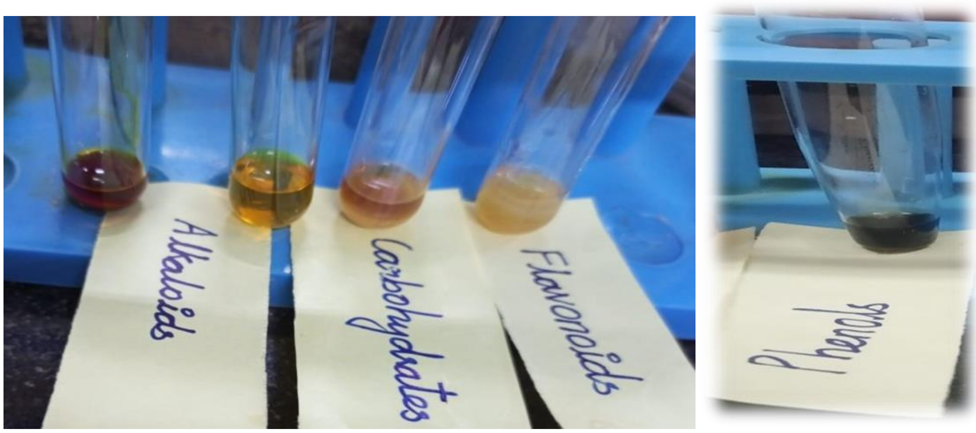


Figure :4.1.1 Confirmatory test for phytochemicals constituents

4.2 Characterization

The characterization of carbon materials was carried out using the methods

- UV - Visible analysis
- FT-IR analysis
- Raman spectroscopy analysis
- XRD analysis
- TGA analysis

4.2.1 UV -Visible spectroscopy

Ultraviolet (UV) visible spectroscopy is a type of absorption spectroscopy in which UV-Visible light is absorbed by the molecule. Molecules containing π-electrons or non-bonding electrons (n-electrons) can absorb ultraviolet or visible light energy and be excited to higher anti-bonding molecular orbital. Absorption of the UV-visible radiations results in the excitation of the electrons from lower to higher energy levels.

UV - Visible spectra of activated carbon and porous carbon were monitored in the spectral range of 200-800 nm. The two main absorption peaks can be observed. The maximum peak is observed at 250 nm in porous carbon which attributed to the π-π* transitions of aromatic C-C bonds from porous carbon. And the shoulder peak at 300 nm due to n-π* transitions of C=O Bonds from activated carbon. The band gap energy of carbon materials was calculated from UV-Visible spectra using the following equation. **(Mohammad Faraji *et al*., 2021).**

$$E = h\times c/\lambda$$

Where,

E is the Energy,

h is the Planks constant (6.626×10^{-34} J/ sec)

C is the speed of light (2.99×10^{8} m/sec)

λ is the wavelength

The band gap is obtained from the equation. The band gap of porous carbon and activated carbon are calculated to be 5.642 eV and 4.13 eV respectively. **(Liu *et al* ., 2008)** .

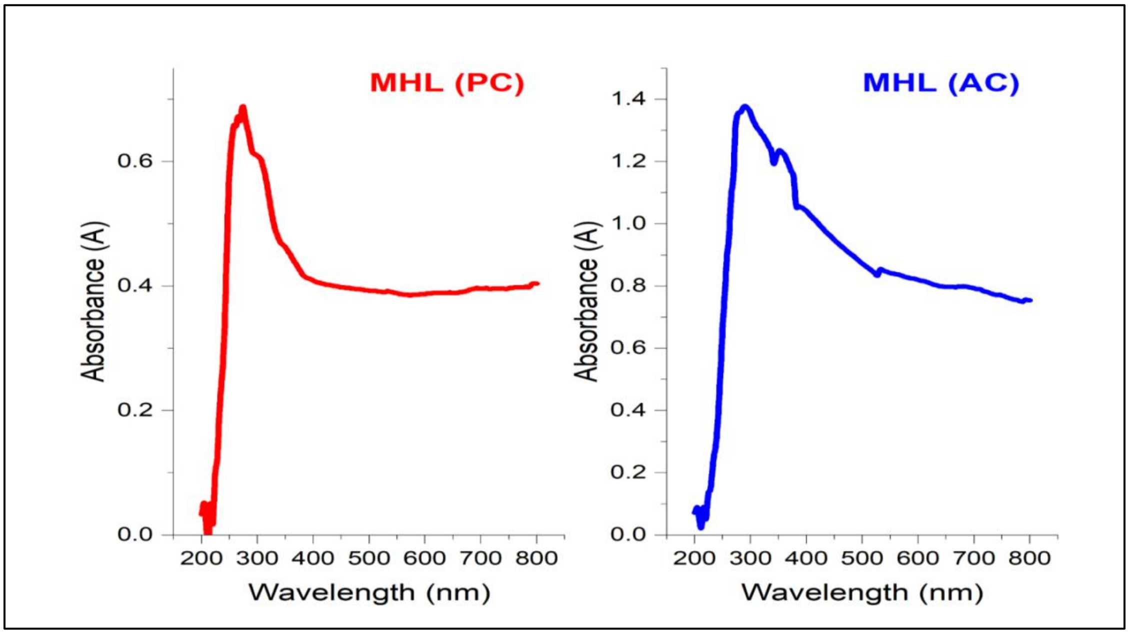


Fig 4.2.1 UV spectrum image of MHL (PC) and MHL(AC)

Sample	Absorbance spectra for carbon material in ethanol	Band gap	Transistion
MHL(AC)	300	4.13	π -π*
MHL(PC)	250	5.64	n-π*

Table - 4.2.1 UV Bands for PC and AC MHL

4.2.2 FT-IR

The functional groups were confirmed using the (500–4000) cm^{-1} FTIR spectrum. When KOH is added, the distinct different peaks disappear, indicating that K^{+} has absorbed into the hydro chars quinone, carboxylate and aromatic sites. The apparent effect of KOH on the aromatic ring was also indicated by the decrease in peak intensity of aromatic C=C stretching around 1589 cm^{-1}. The FTIR diagram obtained from the FTIR curve with different peaks could be seen. In 842cm^{-1}, 977cm^{-1}, 1589cm^{-1}, and 3302cm^{-1}, the intense bands were absorbed. The sharp absorption bands observed at 1440cm^{-1} demonstrate the stretching of (O-H) bending in a carboxylic acid. The vibrations caused by band bending or stretching were linked to the bands in a region 1589 cm^{-1}. The vibrations caused by (C=C) bending cyclic alkene were represented by the strong peak 977cm^{-1}. The presence of (C-Cl) stretching vibrations of the halo compound is associated with the peak appearing at approximately 842cm^{-1}. (Araujo et al. 2005) The peak at 1746 cm^{-1} indicates that oxygen is also present in the form C=O.

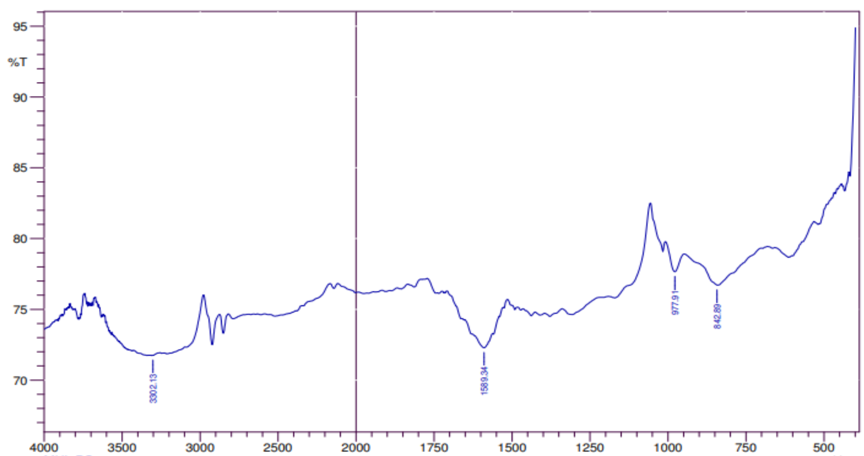


Fig 4.2.3 FTIR image of *Millingtonia hortensis* MHL(PC)

Vibrational frequency cm^{-1}	**Functional group**
842.89	C-Cl stretching
977.91	C=C bending
1589.34	C=C bending
3302.13	C-H stretching

Table 4.2.3 FT-IR range for MHL(PC)

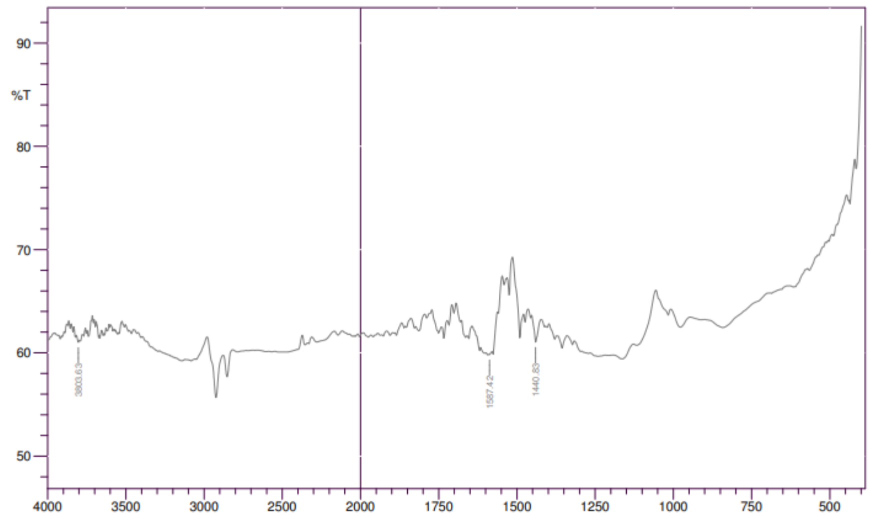


Fig 4.2.2 FTIR image of *Millingtonia hortensis* MHL(AC)

Vibrational frequency cm^{-1}	Functional group
1440	O-H bending
1587	C=C stretching

Table 4.2.2 –FT-IR values of MHL (AC)

RAMAN SPECTROSCOPY:

Raman spectroscopy is a non-destructive chemical analysis technique which provides detailed information about graphitization degrees and crystallinity of carbon materials.

The Raman spectra of two strong peaks are displayed in the Raman spectrum. One peak (D band) of 1650 cm^{-1} can be observed in the carbon materials. The appearance of this peaks indicates that the graphite bands (G bands) of 1700 cm^{-1}. Both samples show characteristic D and G bands at 1650 and 1700 cm^{-1} respectively. The I_D/I_G ratio of activated carbon is 0.87872791 and pre-carbonized carbon is 0.87999. And the results of the crystallite size of activated carbon are 21.88 nm and pre-carbonized carbon is 21.85 nm. The activated carbon is lower than that of pre-carbonized carbon.

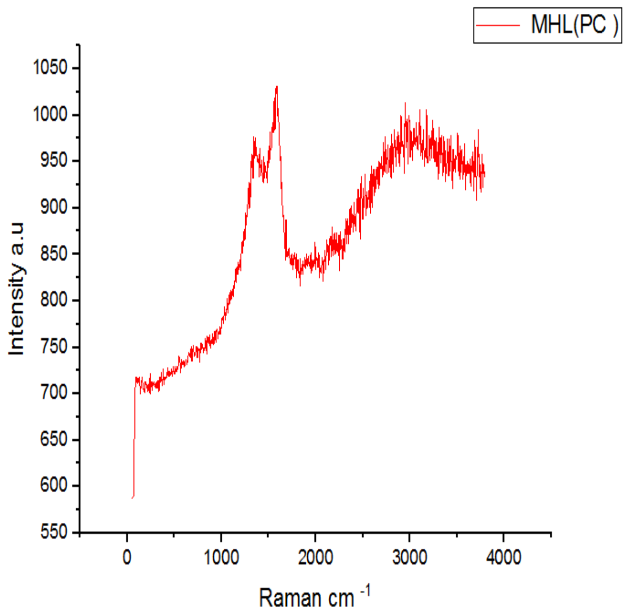


Figure 4.2.5 Raman spectra image MHL(PC)

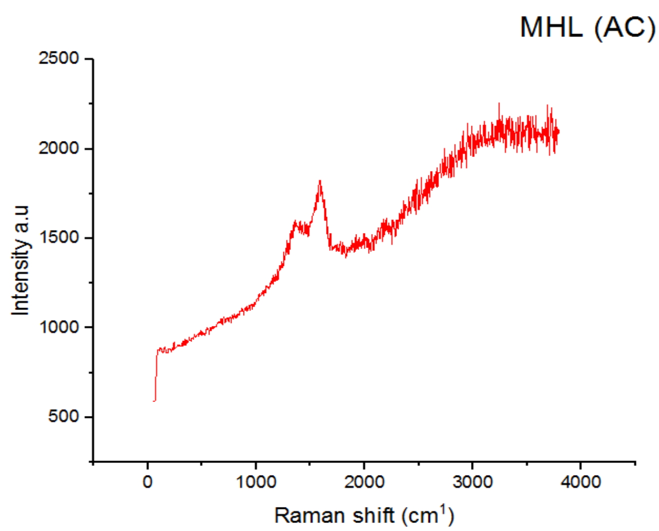


Figure 4.2.4 Raman spectra image for MHL(AC)

Sample	I_D	I_G	I_D/I_G	Crystalline size (nm)
MHL(AC)	1605.69	1827.30	0.87872	21.88
MHL(PC)	1503.90	1708.99	0.8799	21.85

Table 4.2.4 Raman Spectra Bands for MHL (PC) and MHL (AC)

THERMOGRAVIMETRIC ANALYSIS

The thermal stability of carbon materials is indicated by thermo gravimetric and differential thermal analysis. Thermo-gravimetric analysis is a technique for measuring a loss in relation to temperature. The TGA curves are taken in a N_2 atmosphere at a heating rate of 15 C/min. The raw material curve reveals that decomposition (carbonization) begins at 260°C. As a result, 300°C is retained as the standard for carbonization of the raw material. For 300°C carbon, activation occurred between 400 and 600°C, followed by a weight decrease. When comparing 800°C activated carbon samples, the decomposition appears linearly and is very stable. As a result, it suggests that the functional groups are better removed at 800°C. It demonstrates the weight loss of the powder sample as synthesized powder from room temperature to 1000°C. The primary weight loss in MHL was observed at 62°C (PC).

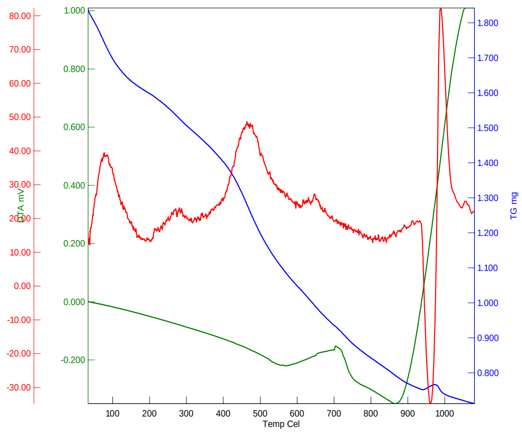


Figure 4.2.7 TGA image of MHL(PC)

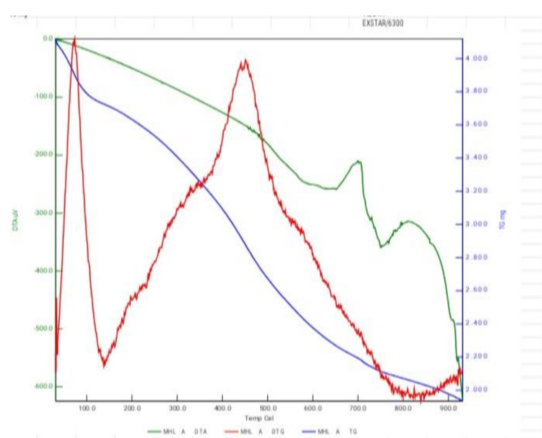


Figure 4.2.8,TGA image of MHL(AC)

Thermo-gravimetric analysis of porous carbon synthesized using an aqueous extract of *Millingtonia hortensis* leaves was carried out at temperature ranging from 0 to 1000 C. The primary weight loss was observed at 98^{0}C, and the secondary weight loss was observed at 90^{0}C, indicating water evaporation.

X-RAY DIFFRACTION

X-ray diffraction analysis was used for determining the crystalline/ amorphous nature of synthesized carbon materials.

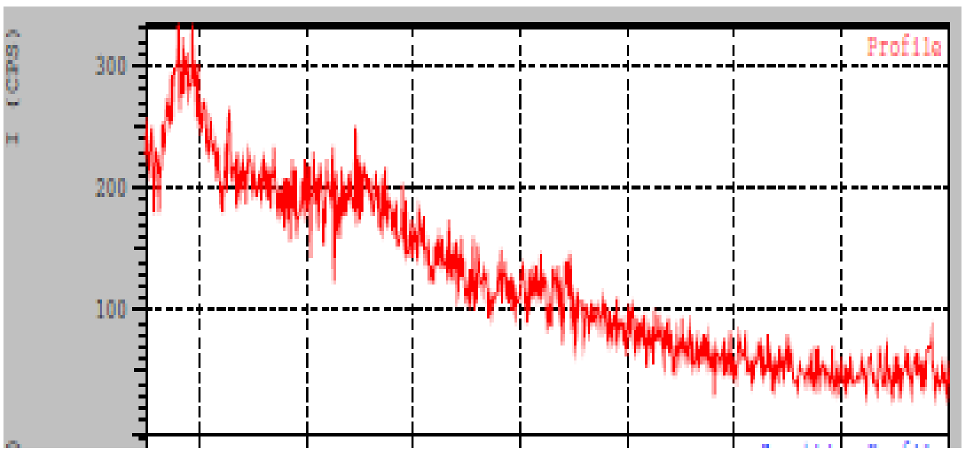


Figure 4.2.10 XRD image for MHL(PC)

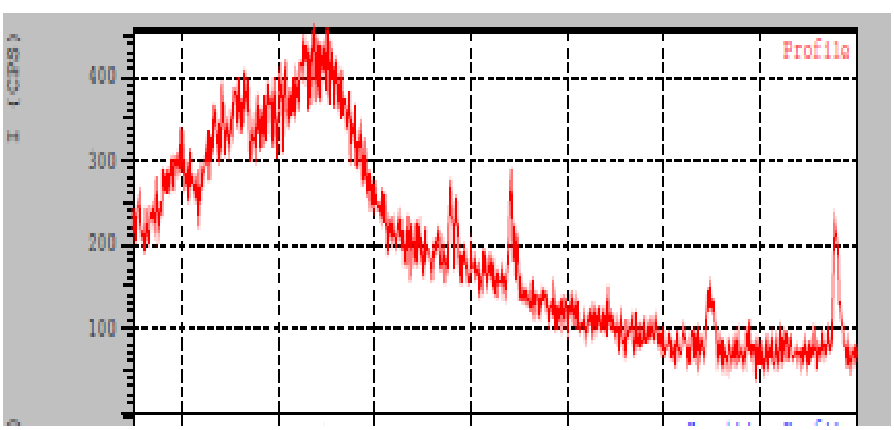


Figure 4.2.9 XRD spectra for MHL(AC)

Figure 4.2.9 depicts the XRD patterns of synthesized carbon samples MHL (PC) and MHL (AC). The sample exhibits two board diffraction peaks at approximately 20 and 44, which correspond to the (002) and (100) planes of amorphous carbon, respectively. The (002) peak of MHL (AC) was as weak and broad as that of MHL (PC), with a slight left shift to lower angles and a slight distortion on the meso-porous structure. The presence of C=C and C=O functional groups has been confirmed, with the C=O carbonyl group being more electrochemically active. The broad and sharps peaks indicate that the carbon samples was turbostratic in nature (Kumar et al.) (2018). During activation, the (002) peak intensity decreased as the KOH ratio increased from 1 to 3. This is most likely due to amorphization of the sample as the KOH etched out inorganic and accelerated extractive volatilization in the carbon precursor. Peak intensity increased as activation temperature and time increased (002). This increases the crystallinity of the samples due to the formation of carbon microstructures and crystallites during the graphitization process at high temperatures. **(Belenkov *et al*.,2001).** For both the samples the average crystallite size is determined from the XRD pattern parameters using Debye Scherrer equation,

$$\mathbf{D_P = (0.94 \times \lambda) / (\beta \times Cos\Theta)}$$

Where, D is the average crystallite size

k is Scherrer equation

β is the full-width at half-maximum (FWHM)

θ is the Braggs angle.**(Sharma *et al.*,2011)**

Sample	**2(θ)**	**FWHM (deg)**	**Crystalline size (nm)**
MHL(PC)	20.47	0.15000	56.23
MHL(AC)	44.80	0.28580	31.42

Table 4.2.9- XRD Spectra for MHL(AC) and (PC)

Comparison of crystalline size in Raman and XRD :

The comparison of crystalline size was obtained in Raman spectra MHL(PC) and MHL(AC) was 21.88 nm and 21.85nm . XRD spectra for crystalline size were 56.23 and 31.42 nm. MHL(PC) crystalline size was higher than that MHL(AC).

Carbon materials	**Crystalline size in Raman (nm)**	**Crystalline size in XRD (nm)**
MHL(AC)	21.88	56.23
MHL(PC)	21.85	31.42

5. SUMMARY AND CONCLUSION

This study focused on the green synthesis of activated carbon material using *Millingtonia hortensis* leaves.

In conclusion , *Millingtonia hortensis* leaf biomass has been confirmed through various characterization techniques including Fourier- transform infrared spectroscopy, X-Ray Diffraction, Raman spectroscopy, UV Visible spectroscopy , Thermo gravimetric analysis were used to characterize the material.

The FTIR results show an absorption peak at 1440 cm^{-1} in carboxylic acid and the functional group was thermally stable. The X-Ray Diffraction (XRD) patterns of the MHL (PC) and MHL (AC) sample demonstrates two board diffraction peaks at 20°and 44°. The planes of amorphous carbon crystalline length is 56.23nm and 31.42 nm.

The UV visible spectra of carbon materials were calculated by using band gap the value is 5.642 eV are π-π^* transitions and 4.23eV are n-π^* transitions.

Raman spectroscopy shows that the crystallite size of the activated carbon is lower than that of precarbonized carbon.

These finding shows that carbon materials derived from Millingtonia hortensis have a huge potential in supercapacitor device applications.

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