Research Article

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Carbon-based Materials from *Borassus flabellifer* and their Applications

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ABSTRACT

Plant-based carbon materials are a high-demand source nowadays, as they are of low-cost, eco-friendly, easily available and sustainable. *Borassus flabellifer* (Palmyra palm) is a gift of nature, offering numerous benefits, as all parts of the tree can be used for various purposes. Palmyra-culture is the practice of cultivating Palmyra palms and utilizing them to live a self-reliant life in working towards sustainable development. Due to the advancement in technology, *Borassus flabellifer* is used to synthesize carbon materials, including hard carbon, carbon nanodots, charcoal and activated carbon. These carbon materials can be used in electrochemistry as anode materials and catalysts; also, they can be used in biosensing, bioimaging and water purification. This review mainly focuses on the carbon materials derived from the *Borassus flabellifer*, their applications in various fields and other significant aspects to be considered.

Keywords: Asian palm; *Borassus flabellifer*; Carbon; Carbon dots; Materials.

1. INTRODUCTION

Carbon materials have been synthesized and used for various applications for more than 3000 years. Carbon Material Science, which was started after the discovery of fullerenes and carbon nanotubes, has become a widely explored field of study nowadays. In this modern era, due to factors such as energy crisis, global warming and environmental crisis, there is a high demand for simple, low-cost, eco-friendly, non-toxic, sustainable materials. Carbon materials are found to be fulfilling the demand (Hu *et al.* 2010). Carbon is a vital element in all living things, especially in plants (Sharon *et al.* 2006). Hence, deriving carbon materials from plant-based materials is less costly. The raw materials are easily accessible and environment-friendly.

Palmyra palm, *Borassus flabellifer*, is a palm that belongs to the family of *Arecaceae.* This tree is very abundant in South Asian regions such as Tamilnadu, Northern regions of Srilanka, Bangladesh, Myanmar, Thailand, Cambodia, etc. (Morton *et al.* 1988). According to ancient Tamil literature, the tree is used for 801 applications. Numerous polymeric structures are present in the Palmyra palm, including pectin, cellulose, hemicellulose, pentosane polysulfate, polyphenols and lignin, which add medicinal and nutritional values to the tree (Selvakumar *et al.* 2020). Palmyra palm paves the way for achieving sustainability environmentally, socially and economically, by providing numerous eco-friendly products. Palmyra-culture is the plantation and utilization of the Palmyra palm trees for self-reliant community-living, which contributes to sustainable development. The uses of Palmyra trees are still being explored in multiple aspects, such as the development of a fluorescent sensor for Fe^{2+} and Cd^{2+} ions from Palmyra fruit pulp extract, using its leaf extract as a wound-healing material, making nanomedicines from different parts of the tree (Mariselvam *et al.* 2021; Monichan *et al.* 2021; Varadaraju *et al.* 2021). One such application is the synthesis of carbon materials from different tree parts. This review mainly focuses on the carbon materials derived from the Palmyra palm and their various applications (Fig. 1).

2. CARBON MATERIALS AND THEIR APPLICATIONS

2.1 Hard Carbons

Hard carbons with wide inter-layer spacing, disordered architectures and linked porosity have been identified as possible sodium-ion battery anode materials. Research revealed the production of hard carbon from palm fruit calyx sepals, which are not edible and are usually a waste material. They are synthesized by carbonization at a moderate temperature (500 ºC-900 ºC). These plant-derived hard carbons can be used as anode materials, and are highly porous with interconnected porous networks and have a disordered structure with large inter-layer spacing (0.37 nm). Thus, the Palmyra palm sepals of fruit calyx (Fig. 2) show its electrochemical performance as an anode material for sodium-ion batteries (Damodar *et al.* 2019).

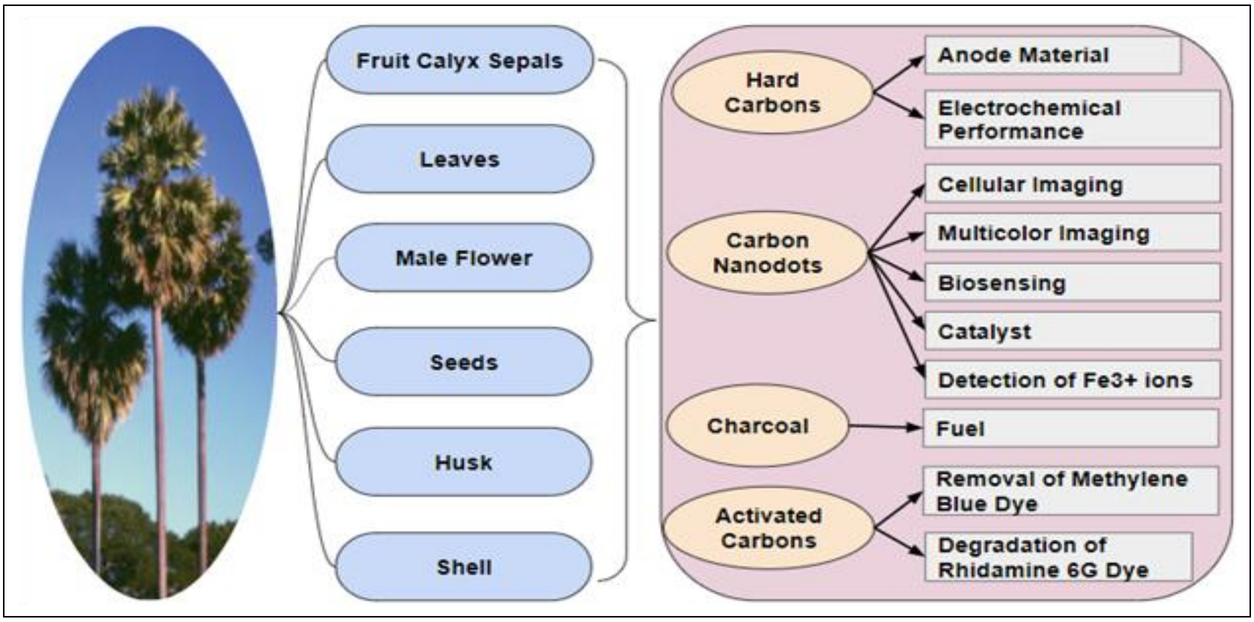

Fig. 1: Carbon materials synthesized from different parts of Palmyra and their applications

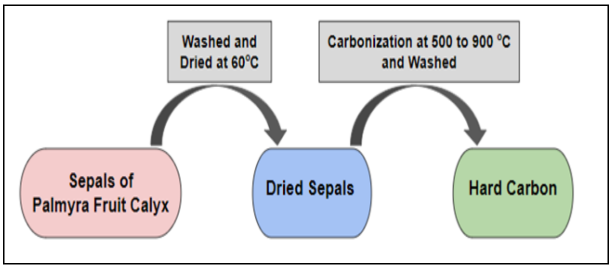

Fig. 2: Synthesis of hard carbon using the sepals of palmyra fruit calyx

2.2 Carbon Nanodots

Carbon nanodots are a group of quasi-spherical florescent nanostructured materials studied in recent times. These carbon nanomaterials have some distinct physicochemical properties, which include resistance to photobleaching, high-fluorescence characteristics, high water solubility, better cell penetrability and biocompatibility (Baker *et al.*, 2010; Lim *et al.* 2015; Athinarayanan *et al.* 2020b).

A recent study has been conducted in synthesizing carbon nanodots using Palmyra leaves by hydrothermal method. These nanodots are found to possess good compatibility with cells, can be used as versatile fluorescent probes for cellular imaging and has the potential for multi-color imaging by entering and gathering in the cytoplasmic region of the cell. Also, carbon nanodots have an extensive variety of medicinal applications, such as biosensing and catalysts (Athinarayanan *et al.* 2020a) (Fig 3).

Another study has reported the green synthesis of fluorescent carbon nanodots using the male flowers of Palmyra palm. Thermal pyrolysis synthesized these nanomaterials and showed excellent fluorescence quenching activity for Fe^{3+} ions. The carbon nanodots from the Palmyra flower are found to have the potential for detecting Fe^{3+} ions from 0 to 30 nm and the detection limit is 10 nm (Murugan and Sundaramoorthy, 2018).

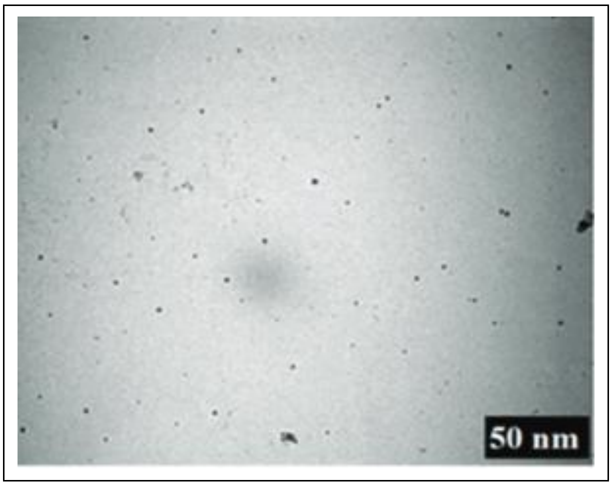

Fig. 3: Transmission Electron Microscope images of carbon nanodots derived from palmyra male flower

2.3 Carbon Derived from Palmyra Fruit Seed

The carbon derived from the seeds of the palmyra fruit has been reported to absorb Lead (II) on Palmyra palm fruit, which can be applicable in removing lead from synthetic wastewater, and it has been compared to the ability of commercial activated carbon in removing lead (Kannan and Thambidurai, 2007) (Fig 4). The Palmyra fruit seed carbon has been studied to absorb cadmium from aqueous solutions and commercial activated carbon. These derived carbons are being examined for metal plating industry wastewater treatment (Kannan and Malairajan *et al.*, 2014). Also, the carbon from Palmyra fruit seed is found to be removing chromium (VI) from aqueous solutions. The adsorption rate increases with the increase of adsorbent dosage and contact time. Moreover, it has the potential to be used for tannery wastewater treatment (Kannan *et al.* 2008).

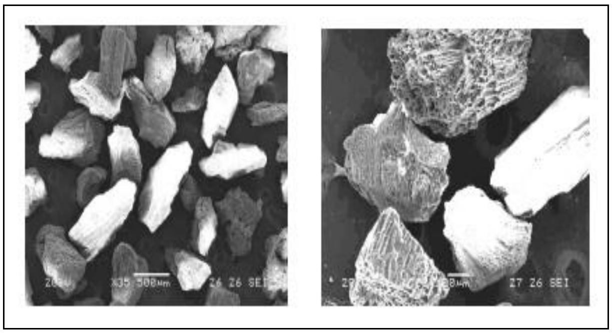

Fig. 4: Scanning Electron Microscope image of palmyra fruit seed carbon

2.4 Charcoal

Palmyra palm husks, fruit calyx and shells are used to make compressed charcoal briquettes in Thailand. These charcoal briquettes produced low quantity of crackling, smell, smoke emissions and drop shatter. The briquettes are found to be suitable for storage and transport. The study's findings have shown that these Palmyra briquettes can be used as an alternative to fuels such as wood charcoal and LPG (Chumsang *et al.*, 2014). The charcoal from Palmyra palm nuts shells has a calorific value of 26.111 MJ/kg, moisture content of 5.24 %, bulk density of 0.492 g/cm^3 and heat per volume unit of 12 846.610 J/cm^3 (Ma ni Kongnine *et al.* 2021).

2.5 Activated Carbon

The Palmyra shell-activated carbon has been used in removing Methylene blue dye from aqueous solutions using the batch adsorption technique. The activated carbon is observed to have mesopores and micropores in order to remove methylene blue dye. The removal rate increases with the increase of contact time (optimum contact time is 50 min) and adsorbent dose rate (optimum dose rate is 5 g/L). The Palmyra Shell Activated Carbon can be the alternative for removing Methylene blue Dye from the contaminated wastewater from the textile industries (Muniyandi *et al.* 2021). Study findings show that the activated carbon from the Palmyra tuber peel and Anatase TiO_2 nanotube-based nanocomposites increase the photocatalytic performance in the rhodamine 6G dye degradation. The tubular morphology, synergic effect and increased adsorption are found to be responsible for this property (Sivakumar Natarajan *et al.* 2016) (Fig. 5).

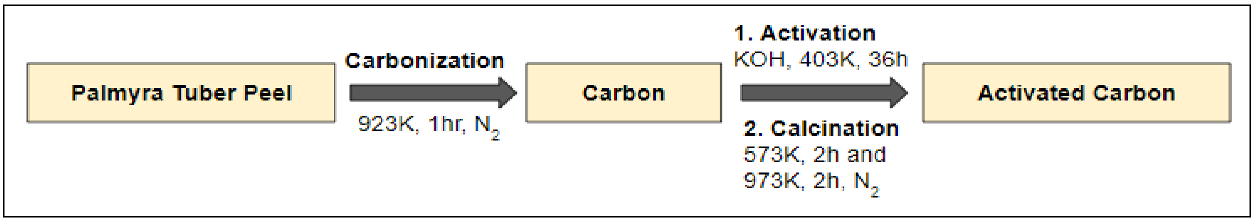

Fig. 5: The Synthesis of activated carbon using palmyra tuber peel

3. SCOPES AND CHALLENGES

The carbon materials from palmyra palm are potential alternatives to overcome the energy shortage and the environmental crisis - a major issue in the present context. The sustainability, abundance and cost-effectiveness of these materials derived from Palmyra are added advantages. The application of carbon materials has already been studied and is further explored in the purification of water, removal of harmful metals, alternative fuel production, nanotechnology and many more. Palmyra palm can be a potential source of synthesizing nanotubes and can be used for biomedical fields, enhancing the optical and thermal properties, renewable energy source, environmental monitoring and aerospace applications. Apart from the carbon materials discussed in this review, other carbon nanomaterials can be synthesized from plants, such as graphene, carbon nano-horns, nanocarbon sol, carbon nanofibers, etc. (Verma *et al.* 2019). Thus, further research is needed to extend knowledge of synthesizing more carbon-based nanomaterials from Palmyra palm and their applications in different fields.

4. CONCLUSION

Palmyra trees are very popular among the Asian Region for their numerous benefits. The tree provides both edible and non-edible products. With the advancement of research, carbon materials such as hard carbons, carbon nanodots, activated carbon and charcoal are derived from the Palmyra tree and have been used for multiple purposes. These materials are becoming promising alternatives in fighting against the scarcity of energy and environmental issues such as global warming and pollution. Other than carbon-based materials, Palmyra palm is a potential source for eco-friendly community living.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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