Review Article

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Comprehensive review on synthesis, physicochemical properties, and application of activated carbon from the Arecaceae plants for enhanced wastewater treatment

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Abstract: Arecaceae presents one of the plant families distributed mainly in the equatorial and subequatorial regions. Arecaceae are widely applied in many fields such as food, cosmetics, fuel, and chemical industries. However, a large amount of agricultural waste from the Arecaceae trees has been released into the environment. The objective of this report is to gain more insights into the potentials and applications of activated carbon (AC) from the Arecaceae trees in wastewater treatment, in which, the ability to handle organic pigments, metals, and antibiotics is focused. The physical properties and processability of AC are statistically evaluated. With a uniform structure, large specific surface area, processing ability according to Langmuir and pseudo-second-order models, we showed that ACs from Arecaceae trees are promising materials for water treatment applications. This is the basis for the development and reduction of by-products that affect the environment.

Keywords: Arecaceae family, activated carbon, wastewater treatment

1 Introduction

The palm family (Arecaceae) of the perennial flowering plant family including five subfamilies, 28 tribes, 181 genera, about 2600 species are known and distributed mainly in equatorial and subequatorial regions [1]. Among, the popular trees including the date palm (Phoenix dactylifera) [2,3], coconut palm (Cocos nucifera) [4], oil palm (Elaeis guineensis) [5–7], areca palm (Areca catechu) [8,9], nipa palm (Nypa fruticans) [10,11], palmyra palm (Borassus flabelifer) [8,12], and rattan palm (Calamus) [8,13] have been widely cultivated to meet human necessities. According to the Food and Agriculture Organization (FAO), the cultivated area and production yield of Arecaceae plants (coconut, oil palm, date palm, and areca palm) have increased annually (Figure 1a). Besides, the oil palm is known to meet the requirement ability of food, cosmetics, animal feed, and fuel production [14]. Next is the coconut tree (13.35 and 27.91%), the second source of production after the palm tree (84.47 and 66.27%) in terms of total production and area worldwide (Figure 1b) [14]. To meet the decoration and construction necessities, the rattan is one of the trees associated with bamboo in projects according to the announcement of the International Bamboo and Rattan Organisation [15]. Besides, trees such as date palm, nypa palm, areca palm, and palmyra palm are also species to meet the food and pharmaceutical [3,8,11,16–19] requirement.

Apart from economic applications, the Arecaceae family is helping to assess the impact of climate change. The study by Aboubacar Oumar Zion has highlighted the effects of climate change on the growth, reproduction, and productivity of the Arecaceae family in West Africa [20]. Although the Arecaceae family tree brings many socioeconomic and environmental benefits, the agricultural by-products were released in large quantities into the environment [21]. They even cause numerous environmental problems such as the transmission of toxic fumes, the pollution of ground water, and the creation of a breeding ground for most microbial
pathogens and mosquito vectors [22]. To benefit from agricultural by-products and contribute to environmental protection, the researchers have been focusing to convert them into activated carbon (AC) for application in environmental treatment. In this study, the physicochemical properties and the adsorption capacity of AC from the Arecaceae plants are summarized, revealing the potential for practical applications. The prospects for the future will be generalized and directed toward future studies to realize the benefits provided by the Arecaceae family.

2 Potential materials from the Arecaceae plants

Numerous plant species of the Arecaceae family are used for oil extraction, and their worldwide production amounts to millions of tons per year. Nevertheless, the agricultural waste of the Arecaceae family is generated in large quantities during the cultivation process. In the Arecaceae family, the palm tree has an output of 410.69 Mt in 2019 as announced by FAO. In the study of Muthanna J. Ahmed published in 2016, there is 10% of agricultural by-products for every ton of palm [23], which shows it is about 41 Mt as of 2019. The amount of waste is a potential for use as a precursor for AC. Over the past decade, by-products from Arecaceae have attracted the attention of researchers (Table 1). Applied research for AC materials from Arecaceae including CO₂, NaCl, dye, heavy metals, and some other toxic substances have been studied in recent years [24–38], in which palm trees, coconut trees, and date palm have more scientific publications than other types of trees. The potential for by-products of the Arecaceae family has not been fully exploited.

3 Techniques of AC from the Arecaceae plants

The method of synthesizing AC through activation process includes physical, chemical, and physicochemical
activation [54,55]. Physical activation method is to use heat with inert gases, such as nitrogen and carbon dioxide, and water. Chemical activation method is to use activators such as NaOH, KOH, H₃PO₄, and ZnCl₂. The physicochemical activation method is a combination of two physical and chemical methods. In addition, the microwave-assisted activation method is currently a method using microwaves to heat the activation process (Figure 2). Looking at Table 2, AC from the Arecaceae family was synthesized mainly by chemical or physicochemical methods, in which, activators such as NaOH, KOH, and H₃PO₄ are often used. After the activation process, the solvent washing and removing the residue of the activator is usually with acids or distilled water. The material was accepted until the pH of the wash solution reached neutral. The iodine index is an important indicator that characterizes the pore surface area and the adsorption capacity of AC. The higher the value of the iodine index in AC, the higher the activation level of the charcoal.

### Table 1: Research statistics on Arecaceae family trees

| Common name                  | AC material from | Adsorption application | Year | Ref. |
|------------------------------|------------------|------------------------|------|------|
| Nipa palm                    | Nut              | Lead(II)               | 2011 | [39] |
| Date palm                    | Leaflets         | Ciprofloxacin          | 2012 | [40] |
| Conoon                       | Husk             | Methylen blue (MB)     | 2012 | [41] |
| Coconut and oil palm         | Shell and kernel shell | Six metal ions    | 2012 | [42] |
| Oil palm                     | Fronds           | Pesticides             | 2014 | [43] |
| Nipa palm                    | Leaves           | Azo-benzene carboxylic acid | 2014 | [44] |
| Date palm                    | Fronds, seeds, and fiber | Bismarck brown G, Reactive yellow dye 145 | 2015 | [45] |
| Date palm                    | Seeds            | MB                     | 2015 | [46] |
| Oil palm                     | Shell            | Reactive black 5 dye   | 2016 | [47] |
| Palmyra                      | Tuber peel       | Rhodamine 6 G dye      | 2016 | [48] |
| Areca                        | Nut              | Hg(II) and phenol      | 2017 | [49] |
| Coconut                      | Shell            | MB                     | 2017 | [50] |
| Rattan                       | Stalks           | MB                     | 2017 | [51] |
| Areca                        | Nut              | Fluoride               | 2017 | [52] |
| Coconut                      | Fiber            | MB, Congo red (CR), and Neutral red dyes | 2018 | [53] |
| Oil palm                     | Shell            | MB                     | 2019 | [36] |
| Date palm                    | Seed             | NaCl                   | 2019 | [35] |
| Nipa palm                    | Fiber            | MB                     | 2020 | [34] |
| Date palm                    | Leaflets and rachis | Methyl-thioninium chloride | 2020 | [33] |
| Oil palm                     | Empty fruit bunch fiber | Cibacron blue 3G-A   | 2020 | [32] |
| Oil palm                     | Kernel shell     | CO₂                    | 2020 | [31] |
| Oil palm                     | Trunk            | Chromium (Cr(III))     | 2020 | [30] |
| Oil palm                     | Shell            | CO₂                    | 2021 | [29] |
| Date palm                    | Seeds            | Organochlorine pesticides | 2021 | [28] |
| Coconut                      | Shell            | Heavy metals           | 2021 | [27] |
| Coconut and palm             | Kernel shell     | MB and iodine          | 2021 | [26] |
| Palmyra                      | Shell            | MB                     | 2021 | [25] |
| Coconut                      | Shell            | Diclofenac (DCF) and amoxicillin (AMX) | 2021 | [24] |
| Rattan                       | Trunk            | Uranium(III)           | 2021 | [38] |
| Palmyra                      | Male inflorescence | Cd(II) ions           | 2021 | [37] |

### 4 Physicochemical properties of AC from the Arecaceae plants

The physical properties of AC were analyzed using scanning electron microscope, Brunauer–Emmett–Teller (BET), X-ray diffraction (XRD), and fourier-transform infrared spectroscopy (FTIR). In Figure 3, it can be seen that the material of the Arecaceae family gives a structure similar to the honeycomb network [33,34,36,49,56–60]. This shows that the Arecaceae family has its own characteristic structure, the surface area of the plants is also almost the same. The surface area of the material depends on the activation method. For the chemical method, the surface area is about 4–12 m² g⁻¹ [26]. Physical methods give a surface area of about 800 m² g⁻¹ [31]. Physicochemical methods give a surface area about 300–1,200 m² g⁻¹ [28,32], and with the microwave-assisted method, the surface area is about 500 m² g⁻¹ [36]. This shows that the average surface area
of AC from the Arecaceae family is about 300–1,200 m² g⁻¹. With a large specific surface area, the structure of AC was analyzed through XRD and FTIR methods. In recent studies, the structure of AC is semiamorphous [24,26,28,38]. This similarity was found when analyzing the crystal structure of activated carbon from jackfruit and coffee (2θ = 20–25°, 40–45°) [61,62]. The functional groups OH, CO, CH, C=O, and C=C are recognized as functional groups that characterize the structure of AC (Figure 3). Besides, AC from jackfruit, bamboo, citrus, and coffee

![Activation methods of AC from Arecaceae.](image)

**Table 2 : Method for synthesizing AC from the Arecaceae family**

| Tree name               | Activation methods         | Activator                           | Ref. |
|-------------------------|----------------------------|-------------------------------------|------|
| Oil palm                | Microwave-assisted activation | Microwave radiation                 | [36] |
| Date palm               | Physicochemical activation  | KOH + 1,173 K                       | [35] |
| Nipa palm               | Physicochemical activation  | KOH + 973 K                         | [34] |
| Date palm               | Physical activation        | 873 K                               | [33] |
| Oil palm                | Physicochemical activation  | H₂SO₄ + 873 K                       | [32] |
| Date palm               | Chemical activation        | H₃PO₄                               | [28] |
| Coconut                 | Chemical activation        | NaOH, HNO₃, KMnO₄, and FeSO₄        | [27] |
| Coconut and oil palm    | Chemical activation        | Distilled water, H₃PO₄, and NaOH    | [26] |
| Palmyra                 | Physical activation        | 773 K                               | [25] |
| Coconut                 | Chemical activation        | H₃PO₄                               | [24] |
| Rattan                  | Physicochemical activation  | ZnCl₂ + 873 K                       | [38] |
| Palmyra                 | Physical activation        | 673 K                               | [37] |
had the same structure as OH, CH, C=O, C=C, and CO [63–66]. The functional groups of Arecaaceae ACs did not differ when compared with commercial ACs [67]. The characteristic structure of AC of the Arecaaceae to nondifference from other types of AC [26,33,53,68] can be seen. The results from the analysis of structural and physicochemical properties have shown the uniformity of pore structure, surface area, and surface functional groups. The structural homogeneity shows a very high potential for the commercialization of the material (Table 3).

5 Potential of AC from Arecaaceae in wastewater treatment

5.1 Removal of heavy metal ions

Heavy metals are those that have a density greater and are generally only those associated with pollution and toxicity. Heavy metals are divided into three main groups: highly toxic metals (Hg, Cr, Pb, Ni, Cd, As, Sn, etc.), precious
metals (Pd, Pt, Au, Ag, Ru, etc.), and radioactive metals (U, Th, Ra, Am, etc.) [70]. Most of the heavy metal elements such as mercury, nickel, lead, arsenic, cadmium, and platinum are highly toxic and have almost no nutritional role in living things; when entering the organism and accumulating in the cell, they will be highly toxic. For humans, heavy metals are potentially toxic not only at high concentrations but even at low concentrations for a long time due to the bioaccumulation process reaching toxic concentrations. The toxicity of these elements can be at very low concentrations around 0.1–10 mg L\(^{-1}\) [71]. The toxicity and nontoxicity of heavy metals depend not only on the metal itself, but also on its content in soil, water, and chemical, physical, and biological factors. The reuse of agricultural by-products in the preparation of AC is also an effective way of removing metal ions from wastewater and reducing the use of raw materials, minimizing waste, and protecting water resources [72,72–74]. It can be seen that the application of AC from Arecaceae to remove metals studied in a variety of ways. Kinetic, isothermal models, and influencing factors are shown in Table 4.

In 2010, *A. catechu* was selected and collected from Bakhrapara village in Bongaigaon district of Assam in India. Because of its soft and porous nature, the heartwood of the tree has been used as an adsorbent in the treatment of polluted water. Chakravarty et al. conducted an experiment to investigate the factors of time, pH, and adsorption dose to remove Pb\(\text{II}\) ions. The study results also showed that the adsorbent heartwood of *A. catechu* powder removal of Pb\(\text{II}\) follows the Langmuir isotherm model and the pseudo-second-order kinetic model [75].

In 2014, the study of Alagesan Kannan showed the efficiency of cadmium removal from aqueous solution by palmyra palm fruit seed carbon (PPFSC). The results show that the treatment efficiency is 92.5%. In addition, PPFSC was also tested and compared with commercial AC in electroplating wastewater treatment. During the 5 h period, 86% of cadmium was removed by 1 g of PPFSC and only 58% for 1.6 g of commercial AC [76].

In 2017, the removal of fluoride from the water was performed by the group Sahira Joshi et al. (2016) by AC from areca nut seeds in the presence of Fe\(_2\)O\(_3\). The maximum adsorption capacity to remove fluoride of Fe\(_2\)O\(_3\)/areca nut AC (4.8 mg g\(^{-1}\)) is higher than commercial AC (1.2 mg g\(^{-1}\)) and groundnut shell AC Zr-Imp (2.3 mg g\(^{-1}\)) [52]. Lalmunsiana et al. used microwave irradiation with succinic anhydride to functionalize AC from areca nut waste. The Langmuir adsorption isotherm was suitable for Hg\(\text{II}\) with the maximum adsorption capacity found to be 11,235 mg g\(^{-1}\). Besides, the nonlinear Thomas equation is used to calculate the column load capacity when removing Hg(\(\text{II}\)) of areca nut AC functionalized at 2.49 mg g\(^{-1}\) [49].

In addition, the studied Arecaceae plants have been treated with other ions such as chromium, copper, iron, and zinc as shown in Table 4. It can be seen that AC from the Arecaceae family all following the Langmuir isotherm model when applying heavy metal removal. The best metal treatment concentration is 20 mg g\(^{-1}\) in acidic medium (pH < 5) and room temperature.

### 5.2 Removal of antibiotics

The problems associated with antibiotics are similar to heavy metal pollution. Similar to heavy metals, antibiotics are natural compounds found in different ecosystems. Synthetic antibiotics (e.g., quinolones) are difficult to biodegrade. However, they are still degraded to varying degrees in the natural environment. Studies have demonstrated that ciprofloxacin present in river water samples is completely

**Table 3**: Physical properties of activated carbon from Arecaceae

| AC name                                      | Activator       | BET              | Surface area (m\(^2\) g\(^{-1}\)) | Pore volume (cm\(^3\) g\(^{-1}\)) | Ref. |
|----------------------------------------------|-----------------|------------------|----------------------------------|-----------------------------------|------|
| Coconut shell (CS)                           | H\(_3\)PO\(_4\) |                  | 11.62                            | 0.29                              | [26] |
| Palm kernel shell (PKS)                      | H\(_3\)PO\(_4\) |                  | 8.76                             | 0.27                              | [26] |
| Fibre-rich Palmyra palm tree biomass derived carbon (PP-C) | 1,573 K |                  | 190                              | —                                 | [69] |
| Palm date stone AC                           | H\(_3\)PO\(_4\) |                  | 1,262                            | —                                 | [28] |
| Oil palm trunk activated carbon Fibers (ACFs) | H\(_2\)SO\(_4\) |                  | 1,800                            | 0.7                               | [30] |
| PKS                                          | 1,273 K         |                  | 803                              | —                                 | [31] |
| Oil palm empty fruit                         | H\(_2\)SO\(_4\) |                  | 362.84                           | —                                 | [32] |
| Date seed porous activated carbon            | 1,273 K         |                  | 1020.85                          | 0.2                               | [35] |
| Waste palm shell                             | Microwave steam  |                  | 570.8                            | 0.262                             | [36] |
Table 4: Optimum conditions and treatment efficiency of AC produced from Arecaceae species

| Adsorbent | Pollutants | \( C_0 \) (mg L\(^{-1}\)) | Dose (gL\(^{-1}\)) | Temp. (K) | Time (min) | pH | Adsorption capacity (mg g\(^{-1}\)) | Adsorption efficiency (%) | Adsorption model | Ref. |
|-----------|------------|-----------------|----------------|----------|-----------|----|-----------------------------------|--------------------------|----------------|------|
| Palmyra palm fruit seed | Cadmium | 20 | — | 303 | 300 | 3–5 | — | 92.5 | PFO and Langmuir | [76] |
| Areca nut seeds | Fluoride | 20 | 20 | — | 180 | 2 | — | 4.8 | — | Langmuir | [52] |
| Areca nut waste | Hg\((\text{II})\) | 10 | 2 | 298 | 720 | 2–8 | — | 11.235 | — | Langmuir | [49] |
| Areca catechu | Pb(II) | 20 | — | 304 | 25 | 5 | — | — | 97 | Langmuir and PSO | [75] |
| Coconut husk | 2,4,6-Trichlorophenol | 100 | — | 303 | 1,440 | 2 | — | 716.10 | 92.93 | Langmuir and PSO | [96] |
| CS | Ammonium ion | 500 | 40 | 283 | 120 | 9 | — | — | 93 | Freundlich and PSO | [97] |
| Chitosan-treated banana and areca fiber | Chromium(VI) | 40 | 1.2 | 300 | 120 | 3 | — | 92.5 | Langmuir | [76] |
| CS | Cu\(^{2+}\), Fe\(^{3+}\), Zn\(^{2+}\), and Pb\(^{2+}\) | — | 1 | 305 | 80 | 6 | — | <90 | PSO | [99] |
| Date palm leaflets | Ciprofloxacine | 200 | 0.5 | 298 | 2,880 | 6 | 100 | 83 | — | Langmuir and PSO | [40] |
| Palm oil | CPX | 20 | 1.6 | 298 | 60 | 4–5 | 57.47 | <90 | — | Langmuir and PSO | [85] |
| Date palm fiber | Tylosin | 15–150 | 1 | 303 | 120 | 5.8 | 147 | 99 | — | PSO and Langmuir | [100] |
| Palm tree male | MB | 200 | — | 303 | 60 | 6 | 56.93 | — | — | Langmuir and PSO | [87] |
| Cocos nucifera | MB | 19.01 | 1.26 | 300 | 5 | 8.65 | 112.35 | 86.38 | — | Langmuir and PSO | [88] |
| B. aethiopum | MG | 25–100 | 0.1 | 300 | 1,440 | 6.78 | 48.48 | <98 | — | Langmuir and PSO | [86] |
| PTF | CR and RhB | 25 | 5 | 298 | 120 | 2 | — | — | 98 | — | Langmuir and PSO | [91] |
| Palmyra shell | MB | 55 | 5 | — | 50 | 10 | — | — | 100 | — | Langmuir and intraparticle diffusion | [25] |
| CS | Basic yellow13 and basic red14 | 100 | — | — | — | 11 | — | 20–50 | — | Langmuir | [101] |
| Coconut frond | Carboburan insecticide | 250 | 0.2 | 303 | 240 | Not dependent on pH | — | 80 | — | Langmuir and PSO | [102] |
| Date palm seeds | Acid dye Eosin yellow | 200 | 0.05 | 303 | 240 | 2 | — | 99.78 | — | — | Langmuir, PSO, and intraparticle diffusion | [103] |
| Coir pith | CR | — | 4 | 308 | 40 | 2 | 6.72 | — | — | — | Langmuir and PSO | [103] |
| Date palm waste | Methylthioninium chloride | 2,000 | — | 296 | 1,440 | 7 | — | 83 | — | — | Langmuir, PSO, and intraparticle diffusion | [33] |
| B. flabellifer shell | Naphthalene | 200 | — | 313 | 720 | 7 | — | 76 | — | — | Langmuir and PSO | [59] |
degraded after 3 months, whereas only 20% of oxolinic acid in samples is degraded after 5 months [77]. Concentrations of several antibiotics were found in wastewater in several Asian countries [78]. In addition, wastewater is another important source of antibiotic contamination in the aquatic environment. The presence of antibiotics in surface water, groundwater, seawater, soil, and sludge has also been investigated [79–81]. AC can be used to remove hydrophobic and charged particles from wastewater [82]. AC is also used in the drug manufacturing industries to purify antibiotics [83]. Kinetic, isothermal models, and influencing factors are shown in Table 4.

In 2008, Hameed et al. used locally available coir materials to prepare AC to eliminate the harmful effects of 2,4,6-Trichlorophenol (TCP) in the country. The highest adsorption efficiency removes TCP up to 92.93% at pH 2 and an initial TCP concentration of 100 mg L\(^{-1}\). The Langmuir isotherm model (716.10 mg g\(^{-1}\) at 303 K) and pseudo-second-order kinetics were found to be suitable for TCP adsorption, and the adsorption mechanism was determined through the intraparticle diffusion model [84].

In 2012, Said Ibrahim and coworkers used date palm leaflets to adsorb the antibiotic ciprofloxacin through sulfuric acid carbonization at 433 K. After 48 h of adsorption equilibrium, the activation energy was 17 kJ mol\(^{-1}\) at pH 6. The adsorption of the positively charged antibiotic ciprofloxacin is described by cation exchange and hydrogen bonding, along with electrostatic interactions with the charges on the AC surface [40].

In 2021, Daouda et al. optimized the removal of DCF and AMX using the response surface methodology through the use of CS by-products as adsorbents. The pseudo-quadratic kinetic model and Langmuir isotherm are said to be suitable for kinetic and isothermal research. Results showed that AMX adsorbed more slowly than DCF, removing more than 98% in 15 min (DCF) and 90 min (AMX) [24]. The activity of removing the antibiotic cephalaxin (CPX) in an aqueous solution by AC from palm oil fiber residues was reported by Acelas et al. conducted survey. Experimental results show that AC is the best adsorbent for CPX in wastewater, and this process is consistent with the pseudo-second-order kinetic model and Langmuir isotherm (57.47 mg g\(^{-1}\)). However, pH is one of the factors affecting the removal of CPX, with the removal efficiency of about 90% (acidic pH), and 20% (pH >6.5). The interaction between adsorbent and antibiotic is shown specifically through hydrogen bonding, π–π interaction, and electrostatic interaction representing the CPX adsorption mechanism [85].

It can be seen that at a temperature of 25, pH < 6 gives more than 80% treatment efficiency. The ability to handle antibiotics of negative origin is better than that of positive ones. This shows the uniformity in the adsorption process of AC from Arecaaceae when following the kinetic (PSO) and adsorption isotherm model (Langmuir).

### 5.3 Removal of organic dyes

To contribute to the study of utilizing waste materials in water pollution treatment, in this study, Arecaaceae by-products were used to fabricate color adsorbents for application in color treatment of dyeing wastewater. The recycling and utilization of waste not only brings economic and social benefits but also plays an important role in environmental protection. Kinetic, isothermal models and influencing factors are shown in Table 4.

In 2010, AC derived from Borassus aethiopum flower was prepared and applied as a malachite green (MG) dye adsorbent by Nethaji et al. The adsorption efficiency was evaluated through influencing parameters at three different particle sizes 100, 600, and 1,000 μm, adsorbent dosage of 10 g L\(^{-1}\), pH 6.78, and temperature 300 K. The Langmuir equilibrium isotherm model is evaluated to be effective for the actual adsorption process compared to the Temkin and Freundlich models. The research team also investigated the adsorption mechanism and determined the adsorption rate constant through intraparticle diffusion models, Elovich model, pseudo-first-order model, and pseudo-second-order model [86].

In 2014, Kini et al. have been used palm tree male flower (PTMF) as a MB adsorbent from an aqueous solution. Medium PTMF powder particles with a size of 150 μm were used for biosorption experiments. When increasing the adsorbent content from 0.05 to 0.30 g, the MB dye adsorption efficiency increased from 40.75 to 91.65% at equilibrium. Besides, the pseudo-second-order kinetics model is evaluated as suitable with a very good correlation coefficient for MB adsorption rate. The adsorption isotherm of MB onto PTMF was described by Langmuir isotherm with an adsorption capacity of 157.3 mg g\(^{-1}\) at 323 K [87].

In 2015, Jawad et al. used an available source of agricultural waste, which is fallen coconut leaves as an adsorbent for cationic dye (MB) from an aqueous solution. The leaf material will be processed into a powder with a particle size of 150–212 μm. MB adsorption efficiency was up to 86.38% under the optimal conditions of stirring time, initial MB concentration, adsorbent dosage, and initial solution pH of 5.00 min, 19.01 mg L\(^{-1}\), 1.26 g L\(^{-1}\), and 8.65, respectively. The correlation coefficient of the pseudo-quadratic model was better than that of the pseudo-first-order model under optimal experimental conditions [88].
In 2016, one of the popular materials for the production of AC, which is still used the most by its adsorption capacity, is CSs. Therefore, Islam et al. conducted the preparation of AC from CSs through the activation process with potassium hydroxide. In addition, 100% of the methyl orange dye was adsorbed for 12 min and followed the pseudo-second-order adsorption model mechanism \( (R^2 > 0.995) \) [89].

In 2019, Youssef et al. used by-products from date palm pits at the pastry factory in (Shubra Al Khaimah) to prepare AC. Optimal conditions for MB removal were confirmed at 24 h equilibration time, pH 7, and increasing with temperature. The correlation coefficient reached 0.9943 for the MB adsorption of AC according to the pseudo-second-order kinetic model. Three adsorbents (CP212, CP214, and CP124) investigated MB adsorption according to the Langmuir isotherm model to obtain a maximum adsorption capacity of 19.2, 20, and 80 mg g\(^{-1}\), respectively [90].

In 2021, the date palm tree remains an irreplaceable symbol for the natives, numbering about 23 million trees in Saudi Arabia. Therefore, Alhogbi et al. have been used palm tree fiber (PTF) to test AC production. Since then, AC is applied to remove cationic dyes (Rhodamine B [RhB]) and anionic dyes (CR) in polluted water. The pseudo-second-order reaction and the suitable Langmuir model are considered suitable for the studies of adsorption kinetics and isotherms. PTFAC results in a relatively high dye removal from contaminated water with RHb (99.86%) and CR (98.24%), along with the ability to reuse up to five uses [91]. The adsorption efficiency of MB dye from textile wastewater from Palmyra shell activated carbon (palm) was investigated by Muniyandi et al. The experimental process obtained optimal conditions such as time of 50 min, initial concentration of 55 mg L\(^{-1}\), pH 10, and adsorbent dosage of 5 g L\(^{-1}\). With the characteristics of large surface area and pore volume, dye adsorption is almost 100% based on the electrostatic repulsion mechanism between the surface of the adsorbent and the cationic MB dye [25].

This indicates temperature, concentration, time, and content significantly unaffected with adsorption ability. For the positive dye, the pH >6 conditions give the treatment efficiency about 80%. For negative dye, pH <6 gives about 90% treatment efficiency. The adsorption process has been dominated by the pH of the medium. With the porous structure and large surface area, the processing efficiency does not change significantly.

### 5.4 Removal of harmful organics

In 2017, Research by Rebecca Manesco Paixão’s team was using AC from Babassu coconut to remove nitrate from water. The adsorption capacity was recorded as 10.13 mg g\(^{-1}\) at 45°C. The best conditions for adsorption were recorded at pH 2, the mass of material (0.2 g), time (90 min), and concentration of nitrate (100 mg L\(^{-1}\)) [92]. Mohammad Hassan’s research was using AC-based membrane materials from the date for removal of *Escherichia coli* bacteria from water. The membrane filter showed a high ability to remove *E. coli* bacteria (removal of ~96–99%) [93].

In 2019, AC from date seeds was used to remove NaCl in saline solution by the author group Abdul Hai. The adsorption capacity was recorded as 22.5 mg g\(^{-1}\), with conditions such as time (20–60 min), concentration (250 mg L\(^{-1}\)), dosage (2 g L\(^{-1}\)). Adsorption takes place in a continuous device with flow rate of 10 mL min\(^{-1}\) [35].

In 2020, The group of Adeline Lim was using AC from oil palm trunk to remove the tannin in aqueous solution. The processability of the material was evaluated based on its suitability with the kinetic and isothermal models of adsorption. The AC sample was showed a good fit for the Freundlich and pseudo-first-order models. Maximum adsorption capacities were recorded at 1047.47 mg g\(^{-1}\) (pH 2) and 1087.28 mg g\(^{-1}\) (pH 4). It can be seen that the material performs well in acidic environments [94].

In 2021, a continuous adsorption system was used to treat organochlorine pesticides from contaminated water by using date AC in Sahmarani Rayane’s study. The selected conditions for the adsorption process include 50 g of adsorbent, natural pH, low rate of 2.5 mL min\(^{-1}\), and inlet concentration of 57 µg L\(^{-1}\). The optimum adsorption capacity was 70–100% [95].

### 6 Conclusion

The focus of this review is on the biomass potential of plants in the Arecaceae family in wastewater treatment. Generally, plants in the Arecaceae are often manufactured by the physicochemical method to afford ACs with high specific surface area. The combination of activator and high temperature has been helped to stabilize the structure of the resulting AC. The surface functional groups were considerably increased by physical and chemical activators. For wastewater treatment, AC from Arecaceae has shown outstanding results for a wide range of pollutants from heavy metal ions, antibiotics/anti-inflammatory drugs, organic dyes to pollutants, and nonbiodegradable organic matter. Several plausible therapeutic mechanisms have been proposed with the main role of functional groups. Although there are many perspectives on Arecaceae family
ACs for emerging applications, some new directions are raised for better visibility in further studies.

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