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 flabellifer*) [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

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Figure 1: (a) Cultivated area and production yield and (b) percentage of production and area of Arecaceae 2019, data sources are reproduced from FAO at <https://www.fao.org> under an open access Creative Commons CC BY license.

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

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]
Coconut	Husk	Methylene 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	CO ₂	2020	[31]
Oil palm	Trunk	Chromium (Cr(VI))	2020	[30]
Oil palm	Shell	CO ₂	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(VI)	2021	[38]
Palmyra	Male inflorescence	Cd(II) ions	2021	[37]

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.

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 m²g^{−1} [26]. Physical methods give a surface area of about 800 m²g^{−1} [31]. Physicochemical methods give a surface area about 300–1,200 m²g^{−1} [28,32], and with the microwave-assisted method, the surface area is about 500 m²g^{−1} [36]. This shows that the average surface area

Figure 2: Activation methods of AC from Arecaceae.

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

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	H ₂ SO ₄ + 873 K	[32]
Date palm	Chemical activation	H ₃ PO ₄	[28]
Coconut	Chemical activation	NaOH, HNO ₃ , KMnO ₄ , and FeSO ₄	[27]
Coconut and oil palm	Chemical activation	Distilled water, H ₃ PO ₄ , and NaOH	[26]
Palmyra	Physical activation	773 K	[25]
Coconut	Chemical activation	H ₃ PO ₄	[24]
Rattan	Physicochemical activation	ZnCl ₂ + 873 K	[38]
Palmyra	Physical activation	673 K	[37]

Figure 3: AC structure from Arecaceae.

had the same structure as OH, CH, C=O, C=C, and CO [63–66]. The functional groups of Arecaceae ACs did not differ when compared with commercial ACs [67]. The characteristic structure of AC of the Arecaceae 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 Arecaceae 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 but for a long time due to the bioaccumulation process reaching toxic concentrations. The toxicity of these elements can be at very low concentrations around $0.1\text{--}10\text{ mg L}^{-1}$ [71]. The toxicity and nontoxicity of heavy metals depends 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(II) ions. The study results also showed that the adsorbent heartwood of *A. catechu* powder removal of Pb(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_2O_3 . The maximum adsorption capacity to remove fluoride of Fe_2O_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]. Lalhmunsiam et al. used microwave irradiation with succinic anhydride to functionalize AC from areca nut waste. The Langmuir adsorption isotherm was suitable for Hg(II) with the maximum adsorption capacity found to be $11,235\text{ mg g}^{-1}$. Besides, the nonlinear Thomas equation is used to calculate the column load capacity when removing Hg(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 ($\text{pH} < 5$) 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		Ref.
		Surface area ($\text{m}^2\text{ g}^{-1}$)	Pore volume ($\text{cm}^3\text{ g}^{-1}$)	
Coconut shell (CS)	H_3PO_4	11.62	0.29	[26]
Palm kernel shell (PKS)	H_3PO_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_3PO_4	1,262	—	[28]
Oil palm trunk activated carbon Fibers (ACFs)	H_2SO_4	1,800	0.7	[30]
PKS	1,273 K	803	—	[31]
Oil palm empty fruit	H_2SO_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 (g L ⁻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	75	Langmuir	[52]
Areca nut waste	Hg(II)	10	2	298	720	2–8	11.235	—	Langmuir	[49]
<i>Areca catechu</i>	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	—	85.42	Langmuir	[98]
CS	Cu ²⁺ , Fe ²⁺ , Zn ²⁺ , and Pb ²⁺	—	1	305	80	6	—	<90	PSO	[99]
Date palm leaflets	Ciprofloxacin	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]
<i>Cocos nucifera</i>	MB	19.01	1.26	300	5	8.65	112.35	86.38	Langmuir and PSO	[88]
<i>B. aethiopum</i>	MG	25–100	0.1	300	1,440	6.78	48.48	—	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	Carbofuran 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]
<i>B. flabellifer</i> 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 cephalixin (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 Arecaceae 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, Arecaceae 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 $\mu\text{g L}^{-1}$. 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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