Activated date carbon: a sustainable solution for Pentachlorophenol adsorption in reused wastewater

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Abstract

Industrial wastewaters contain persistent and toxic organic compounds that pose a significant risk to public health and the environment upon release. Phenol and its derivatives are examples of such pollutants. Activated carbon, often sourced from unconventional materials like plant biomass, provides a sustainable solution for treating wastewater. This research focuses on creating activated carbon from date nuts through chemical activation with phosphoric acid. The effectiveness of this carbon in removing pentachlorophenol (PCP) from secondary wastewater (SWW) is evaluated. The analysis of the date nut activated carbon (DAC) includes studying its adsorption capacities for iodine and Methylene Blue, surface functional groups, and the point of zero charge (pHpzc) compared to a commercial activated carbon (CAC). The DAC demonstrates promising adsorption capacities, with values of 368.03 mg/g for iodine and 619.9 mg/g for Methylene Blue, which are close to those of the CAC (444.17 mg/g and 620.25 mg/g, respectively). Both DAC and CAC exhibit acidic surface functionalities, with pHpzc values below 10. The efficiency of PCP removal from SWW contaminated with PCP (100 mg/L) reaches 78% within 72 hours. This study indicates that using DAC for PCP removal from SWW is a sustainable approach for wastewater treatment, potentially allowing for the reuse of non-traditional water sources.

Keywords: biomass, chemical activation, activated carbon date, pentachlorophenol, wastewater.

1. INTRODUCTION

Using pesticides in modern agriculture plays a crucial role in pest control and ensuring food security (Wang et al., 2018). However, this practice can have unintended consequences. These chemicals have the potential to accumulate in the food chain and cause harm to various organisms (Sudaryanto et al., 2006; Wang et al., 2018). Another significant source of environmental contamination is industrial wastewater, which often contains harmful organic compounds such as phenols and their derivatives, including pentachlorophenol (PCP) (Busca et al., 2008). Pentachlorophenol (PCP, C6Cl5OH) is a chlorinated phenol derivative extensively used in wood preservation, pesticides, and herbicides (Werheni et al., 2022). The high chlorine content of PCP raises concerns due to its persistence in the environment and its widespread presence in industrial effluents, where it can reach concentrations as high as 150 mg/L (Zheng et al., 2011). Regulatory agencies like the World Health Organization (WHO, 1996) have established stricter limits for PCP in drinking water (0.001 mg/L) compared to aquatic environments (0.3 mg/L) due to the potential health risks associated with its presence (Choi et al., 2020).

Recent studies have indicated that the use of pesticides can have severe implications for human health, such as developing cancer, genetic mutations, compromised immune systems, hormonal imbalances, neurodegenerative disorders, respiratory problems, reproductive
difficulties, birth defects, and developmental issues (Chbib et al., 2018; Gao et al., 2017). This growing concern has prompted global efforts to eliminate pesticides from water sources, resulting in the development of various treatment methods including photocatalytic degradation, UV treatment, filtration, advanced oxidation processes, and aerobic degradation (Werheni et al., 2022). However, these techniques often encounter limitations such as high costs, complexity, and the potential generation of harmful byproducts (Srivastava et al., 2009). In search of a more sustainable and cost-effective solution, researchers have turned to adsorption, a process in which pollutant molecules are captured on the surface of solid materials known as adsorbents. Among these adsorbents, activated carbon (AC) has emerged as the most widely utilized due to its exceptional capacity and versatility (Foo and Hameed, 2010). Activated carbons (ACs) are highly desirable adsorbents because of their exceptional capacity to capture an array of organic and inorganic pollutants. These pollutants encompass organic compounds such as polycyclic aromatic hydrocarbons, polychlorobiphenyls, and pesticides, as well as inorganic heavy metals like hexavalent chromium (Bala et al., 2022; Shahnaz et al., 2020). However, commercially available ACs usually come with expensive price tags and necessitate intricate activation and regeneration processes (Crini, 2006; Gupta, 2009). Thankfully, researchers have discovered methods to produce cost-effective alternatives by utilizing agricultural waste materials such as coconut shells, almond shells, olive stones, and even date stones (Darweesh & Ahmed, 2017; Gebrekidan et al., 2015; González-García, 2018). Date stones from the Phoenix dactylifera palm are noteworthy due to their plentiful supply, minimal ash content, dense structure, and lignocellulosic composition. These characteristics make them an easily accessible source of valuable carbon content (Ahmed & Theydan, 2015; Ahmed, 2016). This encouraging method holds the potential for exceptionally effective adsorption of both small and large molecules (Ahmed, 2016).

This study creates an environmentally friendly approach to treating wastewater by producing activated carbon from date nuts. The main goals include: 1. Producing activated carbon (DAC) from date nuts through chemical activation with phosphoric acid. 2. Analyzing the characteristics of DAC compared to a commercial activated carbon (CAC). 3. Assessing the efficiency of DAC in eliminating pentachlorophenol (PCP), a harmful organic compound, from secondary wastewater (SWW) contaminated with PCP. This research explores the possibility of utilizing DAC as a sustainable method for PCP removal from wastewater, advocating for environmental conservation and potential water resource restoration.

2. MATERIAL AND METHODS

2.1. Preparation of activated carbon

The study utilized palm date stone activated carbon (AC) (Phoenix dactylifera) as adsorbents (Fig. 1). These were prepared through chemical activation with H3PO4 following the method outlined by Bouhamed et al. (2012) and further modified in the current research. Initially, palm date samples were sourced from a local market in the Gabès Tunisian region. The samples were cleaned by scraping off surface fibers with a knife. Subsequently, date stones of Ajwa, Anbari, and Khudri varieties, with mean sizes of 3.12 cm, 2.45 cm, and 1.8 cm, respectively, were washed and dried in an air oven at 70 °C for 48 hours. The combination of chemical activation using phosphoric acid and pyrolysis was employed to enhance the surface area yield, while also reducing energy costs by operating at lower temperatures. To activate, 50 grams of the crushed precursor underwent chemical activation with H3PO4 (60% H3PO4 by weight) in a stirred Pyrex reactor with a reflux condenser, at an impregnation ratio of 1.75 (weight of impregnate (H3PO4)/weight of date stones). The reaction liquid/solid was maintained at 104 °C for 2 hours. Following activation, the date stones were dried in an oven at 80 °C for 3 hours. The impregnated material was then pyrolyzed in a cylindrical stainless-steel reactor at 450 °C for 2 hours. Subsequently, the activated carbon was washed with hot distilled water until reaching a neutral pH, under a nitrogen flow at room temperature. The sample was dried at 105 °C for 2 hours, crushed, sieved to < 1.5 mm particle size, and stored in a hermetic bottle for future use.

2.2. Caracterisation of activated carbon:

Porosity: Porosity measurement involves placing a mass of activated carbon equivalent to a volume of 1 ml in a test tube. Methanol is then added until a total volume of 2 ml is reached, corresponding to a total mass (Siragi et al., 2017). The porosity is calculated using the following equation:*
Density of methanol; \(Z\): La porosity.

Apparent density \(\rho_a\) (g/cm\(^3\)): This value is measured by placing a mass of activated carbon \(m_c\) (g) in a graduated cylinder until it occupies a volume \(V_t\) (cm\(^3\)) (Siragi et al., 2017). Once weighed, the apparent density is calculated using the following equation:

\[ \rho_a = \frac{m_c}{V_t} \]

The real density \(\rho_R\) (g/cm\(^3\)): Knowing the bulk density and porosity, the true density is calculated as follows:

\[ \rho_R = \frac{\rho_a}{(1 - Z)} \]

Moisture content: Represents the quantity of water physically bound to the activated carbon. The classic value for water content varies between 1 and 5% by mass. A mass (5g) of carbon and crude were placed in the oven at 105 °C for one hour (Siragi et al., 2017). On leaving the oven, it was placed in a desiccator for 30 minutes and reweighed. The moisture content (H in % by mass) is then given by the following formula:

\[ H(\%) = \left( \frac{m_0 - m_f}{m_0} \right) \times 100 \]

\(m_0\): initial mass; \(m_f\): sample sec

Level of content: The Level content was determined by weighing a mass \(m_1\) of 1 g of biomass into a porcelain crucible. The mixture was heated in an oven at 550°C for 6 hours until ash was obtained. Finally, the mass \(m_r\) was recorded after cooling. The ash content is given by the equation:

\[ C(\%) = \left( \frac{m_r}{m_1} \right) \times 100 \]

\(m_r\): mass of residue after calcination; \(m_1\): sample mass.

Iodine value: The iodine index (in mg/g) is the quantity in milligrams of iodine adsorbed per gram of carbon in an aqueous solution with an iodine normality of 0.02 N (2.54 g of I\(_2\) are dissolved with 5.1 g of potassium iodide in one litre of distilled water) (Siragi et al., 2017). It characterises the zones accessible to any particle larger than or equal to the size of the iodine molecule, in particular the mini-micropores accessible to the small particles responsible for tastes and odours. The procedure used is that of the Centre d’Etude de Duchet, which is an adaptation of the CEFIC 1989 method and the AWWA B 600 -78 standard. Approximately \(m = 0.2\) g of carbon is weighed into a 100 ml beaker and steam at 110 °C for 24 hours. Pipette in 20 ml of 0.02 N iodine solution and shake for 4 to 5 min. Filter the mixture on filter paper and take 10 ml of the filtrate and place in an Erlenmeyer flask. From the burette, sodium thiosulphate is poured into the Erlenmeyer containing the filtrate until the solution is completely discoloured; \(V_n\) is the volume in ml of thiosulphate just required.

The quantity of iodine adsorbed (mg/g) is given by the following relationship:

\[ Q_{I_2} = \frac{C_v - C_i \times V_n \times M_{I_2} \times V_{ads}}{m_{CA}} \]

\(V_n\): The volume of sodium thiosulphate (in ml)
\(C_v\): The concentration of sodium thiosulphate (0.1mol/l)
\(C_i\): The concentration of the initial iodine solution (0.02mol/l)
\(V_{I_2}\): The volume of iodine measured (10ml)
\(M_{I_2}\): The molar mass of the iodine (253.81 g/mol)
\(V_{ads}\): Adsorption volume (20 ml)
\(m_{CA}\): Mass of activated carbon (g).

The formula for Relative Standard Deviation (RSD) is:

\[ \text{RSD} = \left( \frac{\text{Standard deviation}}{\text{Mean}} \right) \times 100\% \]

Methylene blue index: The methylene blue (MB) index, expressed in mg.g\(^{-1}\), represents the adsorption capacity of medium-sized molecules in order to evaluate mesopores and macropores (Siragi et al., 2017). The procedure used is that of the method of the European Chemical Industry Council (CEFIC, 1989). 0.007 g of methylene blue is introduced into a 1 L flask. In a 250 mL Erlenmeyer flask, 0.1 g of previously dried activated carbon and 100 mL of \(1.944 \times 10^{-5}\) M methylene blue solution were introduced. The mixture was stirred for 20 minutes and then filtered. The residual methylene blue concentration was determined using a UV-visible spectrophotometer at a wavelength of 620 nm. The methylene blue index was given by the following relationship

\[ Q_{BM} = \frac{(C_i - C_e) \times V \times M_{BM}}{m_{CA}} \]

\(Q_{BM}\): adsorption capacity of CA (in mg/g)
\(C_i\): initial concentration of BM solution (in mol/L)
C_r: residual concentration of the BM solution (in mol/L)
V: volume of BM solution (in mL);
M_BM: molar mass of BM
m_CA: mass of CA used (in g).

**Determination of pH at the Point of Zero Charge (pHPCZ)**

Activated carbon may display a net surface charge in solution, which can be influenced by the pH of the surrounding environment. The pH at which the surface charge becomes zero is called the point of zero charge (pHPCZ). Determining the pHPCZ of activated carbon can be achieved through the first bisector method (Siragi et al., 2017). This study employed a batch adsorption technique to evaluate the point of zero charge (pHPCZ). Subsequently, 0.1 g of activated carbon was introduced to 20 mL of each solution. The mixtures were then stirred for 72 hours on a magnetic stirrer. After stirring, the suspensions were filtered using filter paper, and the pH of the filtrates was measured using a pH meter. Finally, a graph was constructed plotting the final pH (pHf) of the filtrate against the initial pH (pHi) of the solutions. The pHPCZ was determined as the point of intersection between the plotted curve and the first bisector (y = x line).

**2.3. Wastewater Sample Collection and Characterization**

Secondary wastewater (SWW) samples were collected from a treatment plant El Manzah Tunis in March 2022. This wastewater had only undergone sand filtration prior to release, resulting in an average temperature of 32°C. Standard methods for wastewater and soil analysis (APHA, 1998) were used to measure suspended solids, pH, electrical conductivity (EC), COD, BOD5, total Kjeldahl nitrogen (N), phosphates, ammonium, and nitrates. Additionally, all samples were screened and enumerated for pathogenic bacteria (total coliforms, fecal coliforms, E. coli, and fecal streptococci) within 24 hours using the 5 dilution MPN method with 3 replicates (werheni et al., 2022).

**2.4. PCP adsorption in Secondary wastewater**

In this study we tested the adsorption efficiency of PCP by our date activated carbon in secondary wastewater. The SWW used was autoclaved 3 successive times to avoid the intervention of microbial activity in the remediation process. The concentration of PCP added was 100 mg/L SWW. PCP (MW=266,337. 99% purity) was purchased from Sigma-Aldrich (USA) and high-performance liquid chromatography (HPLC) grade solvents were purchased from Merck, Germany. All chemicals used for the culture media preparation and other reagents used were purchased from Sigma-Aldrich or Fluka. The system was incubated at 25°C. The plastic column used is 40 cm long and 20 cm wide (werheni et al., 2022).

**2.5. PCP content determination**

The investigation utilized high-performance liquid chromatography (HPLC) to measure the elimination of pentachlorophenol (PCP) (Rao et al., 2017; Werheni et al., 2022). After a 24-hour period of incubation, 1 mL samples from different treatments were extracted using a methanol solution. The resulting mixtures were subjected to 5 minutes of vortexing, followed by settling at 20°C for 10 minutes. After an additional 5-minute vortexing step, the samples were centrifuged at 8,000 rpm for 5 minutes. The supernatant obtained was then filtered through a sterile 0.22 µm filter. Subsequently, PCP analysis was carried out using a Perkin Elmer Series YL9100 HPLC, following the procedure described by Karn et al. (2010). All analyses were performed in triplicate to ensure accuracy.

**3. RESULTS & DISCUSSION**

**3.1. Physicochemical parameters determination Activated date carbon material**

The physico-chemical properties of activated carbon derived from date cores were investigated in this research to enhance the biotransformation of PCP. The results of the analysis of raw materials and activated carbon are presented in table 1. The activated carbon exhibited a higher porosity compared to the raw material, with values of 31.80% and 17.93% respectively. This is attributed to the highly porous nature of activated carbon, providing a larger surface area. Furthermore, the apparent density of the activated carbon was lower than that of the raw material, with values of 0.61 g/cm3 and 0.36 g/cm3 respectively. This is due to the activated carbon being less dense and
having numerous pores. The real density of the activated carbon was also lower at 0.74 g/cm³, again highlighting its less dense nature with a high pore volume. The moisture content of the raw material and activated carbon was similar, while the ash content of the activated carbon was higher. This results from the production process involving burning the raw material, leaving behind ash residue. The elimination of hydrogen, carbon monoxide, carbon dioxide, and specific light hydrocarbons like methane from the precursor mass occurs through carbonization at a temperature of 550°C for a duration of two hours. Additionally, the use of an impregnating agent minimizes the formation of tarry substances and liquids that could block the pores and impede the growth of the activated carbon’s porous structure. Because of carbonization and chemical activation, the bulk density decreases while the porosity increases.

**Iodine index of activated carbon:**
Both activated carbons were tested using the same amount of carbon (0.2 g). The activated date carbon required a higher volume of thiosulfate (1.1 ml) compared to the commercially available activated carbon (0.5 ml) (Table 2). This difference could be attributed to variations in testing protocols or initial iodine concentrations. The commercially available activated carbon exhibited a higher iodine index (444.17 mg/g) in contrast to the activated date carbon (368.03 mg/g), suggesting a potentially greater adsorption capacity. The iodine index indicates the areas accessible to particles equal to or larger than the iodine molecule. The iodine index of the commercially produced activated carbon surpasses that of the date pulp-derived activated carbon. The findings align with existing literature (Haimour, 2006).

### Table 1. Physicochemical parameters determination of raw materials and activated carbon

<table>
<thead>
<tr>
<th></th>
<th>Raw date material</th>
<th>Activated date carbon</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Porosity</strong></td>
<td>17.93 ± 0.98 b</td>
<td>31.80 ± 0.87</td>
<td>%</td>
</tr>
<tr>
<td><strong>Apparent density</strong></td>
<td>0.61 ± 0.01 bc</td>
<td>0.36 ± 0.325</td>
<td>g/cm³</td>
</tr>
<tr>
<td><strong>Real density</strong></td>
<td>0.74 ± 0.02 c</td>
<td>0.53 ± 0.21</td>
<td>g/cm³</td>
</tr>
<tr>
<td><strong>Humidity</strong></td>
<td>3.23 ± 0.032 c</td>
<td>3.43 ± 0.0025</td>
<td>%</td>
</tr>
<tr>
<td><strong>Cinder</strong></td>
<td>ND</td>
<td>9 ± 0.325</td>
<td>%</td>
</tr>
</tbody>
</table>

Different lower letters indicate significant differences among treatments at the same sampling time at Duncan post-hoc test (p < 0.05).

### Table 2. Iodine index of activated carbon from date pulp and commercial activated carbon

<table>
<thead>
<tr>
<th></th>
<th>Volume of thiosulphate</th>
<th>Mass of carbon</th>
<th>Iodine Index</th>
<th>RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit ml</td>
<td>g</td>
<td>mg.g⁻¹</td>
<td>%</td>
</tr>
<tr>
<td>Activated date carbon</td>
<td>1.1 ± 0.01 b</td>
<td>0.2 ± 0.01 c</td>
<td>368.03 ± 21.23 ac</td>
<td>5.76 c</td>
</tr>
<tr>
<td>Marked activated carbon</td>
<td>0.5 ± 0.012 ab</td>
<td>0.2 ±0.001 b</td>
<td>444.17 ± 32.3 c</td>
<td>7.27 ac</td>
</tr>
</tbody>
</table>

RSD: Relative Standard Deviation. Different lower letters indicate significant differences among treatments at the same sampling time at Duncan post-hoc test (p < 0.05).
Methylene blue index Table 3 presents a summary of the findings obtained from the Methylene Blue index of activated carbon derived from date stones and commercial activated carbon. In order to examine the macroporosity, we conducted the Methylene Blue test. Some observed that our CA, which is based on date pits, exhibited strong adsorption of BM, with an index of 619.90 ml/g, which is very similar to that of commercial activated carbon. This similarity is likely attributed to many macropores, as suggested by Fissinger (1981). Our research aligns with the findings of Belhachemi and Addoun (2011), indicating that date stone activated carbons possess a high adsorption capacity of 460 mg/g of Methylene Blue, with the best outcome achieved by the sample with a higher burn-off. Furthermore, the utilization of Date Stones and Palm-Trees Waste shows promising potential for biosorption in the removal of Methylene Blue from aqueous solutions, providing a cost-effective alternative to more expensive adsorbents (Belala et al., 2011).

Table 3. Methylene blue index of activated carbon from date pulp and commercial activated carbon

<table>
<thead>
<tr>
<th>Unit</th>
<th>Methylene blue index mg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated date carbon</td>
<td>619.9 ± 10.01 a</td>
</tr>
<tr>
<td>Marketer activated carbon</td>
<td>620.25 ± 12.012 ab</td>
</tr>
</tbody>
</table>

Different lower letters indicate significant differences among treatments at the same sampling time at Duncan post-hoc test (p < 0.05).

Determination of pH at zero charge point (pHPCN)
Activated carbon may display a net surface charge in solution, which can be influenced by the pH of the surrounding environment. The point at which the surface charge becomes zero is called the point of zero charge (pHPCZ). This pHPCZ plays a role in the adsorption of various pollutants onto activated carbon. When the pH is below the pHPCZ, the surface becomes positively charged and attracts negatively charged ions. Conversely, when the pH is above the pHPCZ, the surface becomes negatively charged and attracts positively charged ions. Understanding the pHPCZ can assist in determining the optimal pH for specific adsorption purposes. The pH values at the zero charge point for commercial DACs and CACs are all below pH < 10, ranging from 2 to 10 for activated carbons (Fig. 2). Interestingly, the values obtained for sophisticated activated carbons differ significantly from those reported by Rabilou (2015), which could be attributed to the post-elaboration washing method. The difference in values for commercial activated carbon is not as pronounced.

![Fig. 2. Determination of pH PCN of activated carbons produced (DAC) and marketed (CAC) from date nuts](image)

3.2. Wastewater Sample Collection and Characterization
Physicochemical parameters: In this study, we examined the effectiveness of DAC in adsorbing pollutant PCP using a secondary wastewater sample. The pH of the sample is 7.06, indicating a slightly acidic nature. A pH below 6 or above 9 could suggest the presence of toxic substances. The conductivity of the sample is 1827 µS/cm, which is significantly high. This high conductivity may indicate the presence of dissolved salts, minerals, or contaminants. The Chemical Oxygen Demand (COD) of the sample is 0.4 g/L, which falls within the acceptable range for secondary wastewater. A high COD value suggests the presence of non-biodegradable organic matter. The total nitrogen concentration in the sample is 3.255 g/L, which is considered high. It is crucial to determine the proportion of organic nitrogen and inorganic nitrogen. The Total Organic Carbon (TOC) level in the sample is 1.035 g/L, which is relatively high. This could indicate the presence of dissolved organic matter. The chloride concentration in the sample is 3.125 g/L, which is extremely high. This may suggest contamination from industrial wastewater or seawater. The dry matter concentration in the sample is 1.46 g/L, which is acceptable. The concentration of suspended solids (SS) in the sample is 0.605 g/L, slightly higher than normal. This could indicate the presence of suspended particles, algae, or organic matter. The Biological Oxygen Demand
over 5 days (BOD5) of the sample is 0.645 g/L, which is within the acceptable range. BOD5 measures the amount of oxygen required for the biological degradation of organic matter.

Microbiological parameters (Table 4): The examination of the secondary wastewater sample obtained from an arid region reveals that the coliform concentration is 24.57 \cdot 10^4 MPN/100 mL, indicating a significant level of fecal contamination (Table 4). Similarly, the streptococcus concentration is 20.24 \cdot 10^4 MPN/100 mL, also showing a high level of fecal contamination. Additionally, the E. coli concentration is 9.52 \cdot 10^4 MPN/100 mL, further indicating significant fecal contamination. The assessment of the secondary wastewater from the treatment facility highlights the need for improvement in water quality.

Microbial analysis plays a crucial role in ensuring environmental and human safety, as secondary treated wastewater (STWW) can serve as a safe alternative for irrigating root and leafy crops, with minimal microbial contamination and absence of pathogenic bacteria in soil or crops (Farhadkhani et al, 2018).

3.3. Wastewater Sample characterization after treatment

The efficacy of DAC as an adsorbent was examined in this study by introducing it into a plastic column containing 100 mg/L SWW for a duration of 72 hours. The experiment aimed to assess the impact of date palm activated carbon (DAC) on the physico-chemical properties of secondary wastewater. The findings indicate that DAC effectively eliminates TOC, P, COD, and TSS from secondary wastewater (Table 5). The removal efficiency is directly proportional to the quantity of DAC utilized. Additionally, the results demonstrate that DAC raises the pH level (from 4 to 8) and EC (from 2.01 to 2.35) of secondary wastewater. This is attributed to the release of ions by DAC into the wastewater, thereby enhancing its conductivity and alkalinity. Based on the outcomes of this experiment, it can be inferred that DAC holds potential to treat secondary wastewater. However, the optimal dosage of DAC would vary depending on the specific characteristics of the wastewater. Based on the obtained results, the elimination percentage of the tested pollutant, PCP, increases gradually from 1.23 to 78.21% over time (Table 5). These findings clearly demonstrate the effectiveness of DAC in reducing the concentration of PCP in the SWW. The activated carbon used as adsorbents in this study played a significant role in the adsorption and fixation of the pollutant PCP. To improve the efficiency of pollutant removal in a sub-surface flow wetland, various studies have explored the use of combined processes such as adsorption by activated carbon, phytoremediation, and bioaugmentation (Saeed and Sun, 2012). Additionally, the adsorption process has proven to efficiently remove contaminants even at low concentrations, producing no toxic intermediates or by-products (Nalaya et al., 2020). With the advancement of socio-economic development, the global production of waste is increasing. Waste management remains a major challenge, particularly in developing countries. The quantity of municipal waste continues to rise due to population growth and urbanization (Clément et al., 2015). Therefore, the utilization of CACs in SWW treatment is emerging as a promising solution. Furthermore, adsorbents derived from date palm have shown great potential in removing various unwanted substances from wastewater, including acid and basic dyes, heavy metals, and phenolic compounds (v et al., 2012). In another study, it was found that date stones and palm-tree waste effectively remove copper from aqueous solutions, with the highest sorption capacity achieved within 20 minutes (Belala et al., 2011).

### Table 4. Main physico-chemical parameters of secondary wastewater (SWW) samples used

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH&lt;sub&gt;H₂O&lt;/sub&gt;</td>
<td></td>
<td>7.06 ± 0.13 ab</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µs</td>
<td>1827.07 ± 0.13 a</td>
</tr>
<tr>
<td>COD</td>
<td>g L⁻¹</td>
<td>0.4 ± 0.08 a</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>g L⁻¹</td>
<td>3.255 ± 0.12 ab</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>g L⁻¹</td>
<td>1.035 ± 0.015 b</td>
</tr>
<tr>
<td>Chlorides</td>
<td>g Cl L⁻¹</td>
<td>3.125 ± 1.76 ac</td>
</tr>
<tr>
<td>Dry matter</td>
<td>g L⁻¹</td>
<td>1.46 ± 0.15 c</td>
</tr>
<tr>
<td>SS</td>
<td>g L⁻¹</td>
<td>0.605 ± 0.01 ac</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;₅&lt;/sub&gt;</td>
<td>g L⁻¹</td>
<td>0.645 ± 0.012 b</td>
</tr>
<tr>
<td>Coliforms</td>
<td>MPN/100 mL</td>
<td>24.57 · 10⁴ ± 3.25 ab</td>
</tr>
<tr>
<td>Streptococci</td>
<td>MPN/100 mL</td>
<td>20.24 · 10⁴ ± 2.36 b</td>
</tr>
<tr>
<td>E. coli</td>
<td>MPN/100 mL</td>
<td>9.52 · 10⁴ ± 2.51 a</td>
</tr>
</tbody>
</table>

COD: Chemical oxygen demand; BOD<sub>₅</sub>: Biological oxygen demand in five days; SS: Suspended Solids. Different lower letters indicate significant differences among treatments at the same sampling time at Duncan post-hoc test (p < 0.05).
4. CONCLUSION

In today’s world, finding sustainable solutions to manage waste and clean up the environment poses a significant challenge. One promising approach is the conversion of agri-food waste into functional materials. Through our date-pit activation process, we successfully produced high-quality activated carbon with excellent porosity. Utilizing these activated carbons, in addition to commercial ones, we treated secondary wastewater (SWW) contaminated with PCP. The removal tests demonstrated a 78% removal rate of PCP in aqueous solution. These positive outcomes highlight the potential of this technology in repurposing agri-food waste and addressing environmental concerns related to persistent pollutants like PCP.

Acknowledgments

This research was funded by the Water Treatment and Recycling Laboratory (CERT) member laboratory, Eremology and Combating Desertification, the Arid Regions Institute of Mednine, Therefore, this research was partially funded by the Tunisian Ministry of Higher Education and Scientific Research under the program contract 2020-2022 (CERTE). We thank all co-authors for their technical support and editing of the manuscript.

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