Review:
Manufacture of Activated Carbon Adsorbents from Jackfruit Waste for Removal of Heavy Metals and Dyes from Wastewater: A Review

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Abstract: Jackfruit is a fruit tree species distributed mainly in Southeast Asia and Brazil. The pulp and skin of jackfruit are widely used in various fields such as food, medicine, and interior decoration. However, the jackfruit processing into edible and usable products generates a large quantity of agricultural waste. In this review, we focused on summarizing the environmental applications of jackfruit waste in wastewater treatment. Specifically, the potential and application of activated carbon synthesized from jackfruit waste were assessed concerning the adsorption of organic dyes and metals from wastewater. In practical water treatment applications, the adsorption kinetic and isothermal models have been evaluated for activated carbon’s suitability and adsorption capacity. This study acts as the basis for further development of the by-product materials to environmental treatment application and to reduce the negative impact of agricultural by-products on the environment.

Keywords: jackfruit; activated carbon; agricultural by-products; potential application

INTRODUCTION

Jackfruit is a fruit plant species called Artocarpus heterophyllus, family: Moraceae, Genus: Artocarpus, distributed and grown mainly in Southeast Asia and Brazil [1-2]. Jackfruit properties were provided from the authors’ Center for Agriculture and Biosciences International (CABI) data [3]. A jackfruit tree is a tree with a height of 8–25 m to bear fruit after 3 years of age and the complex oval fruit in size from 30–60 to 20–30 cm [1,4]. Jackfruit is a fruit not only rich in nutrition but also good medicine [4–5]. Shamsudin et al. [6] applied jackfruit to make juice, while the Shinde group [7] used jackfruit seeds in ice cream products. In the study of Rengasamy [8], biodiesel oil products were studied and prepared from jackfruit seeds. In addition, starch from jackfruit is used to make bread or a snack [9-10]. Except for the thorny skin and pulp, the rest of the jackfruit is edible. Therefore, they are widely used in the food processing industry (Fig. 1). Then wood, pulp, peel, and leaves jackfruit will be discarded as agricultural by-products (Fig. 1).

Although the jackfruit tree has many economic benefits, large amounts of agricultural by-products have been discharged into the environment. As is known, agricultural by-products of agricultural solid waste are products discarded after harvesting and processing agricultural products [11]. Agricultural by-products are
often products such as bark, leaves, seeds non-used and discarded into the environment. The main components of agricultural by-products have contained many nutrients (phosphorus and nitrogen), biodegradable organic carbon, pesticide residues, and coliform bacteria in the feces [12-13]. Agricultural waste in the decomposition process of organic compounds will produce many pollutants [14]. Pollution from agricultural waste will affect the soil, water, air environment, living things, and human life [12,14].

Currently, there are many technologies to treat waste by-products. For example, the processing into agricultural fertilizer is often used. However, researchers around the world have been seen another huge potential in agricultural by-products. Therefore, the world has studied the application of agricultural by-products into new products such as animal feed, fertilizer, biological substrates, environmental treatment materials, biogas, and biopolymer [15-20]. Furthermore, the by-products of jackfruit are also applied in many production fields such as bioethanol, biogas, bio-oil, biofuel, biosorption, and activated carbon [21-24].

Animal feed and fertilizer have been researched and commercialized in countries with developed agriculture [17]. However, the nutritional substrate or environmental treatment materials are still quite limited [16]. It can be seen that the application of environmental treatment materials from waste by-products creates the potential to help reduce the amount of waste from the environment and treat other pollutants existing in the living environment. Environmental treatment technology is very diverse, but the high cost of treatment materials [25-26] may indicate that by-products’ utilization is a very potent treatment material [13-15,17,27]. The contribution to environmental protection, researchers have proposed to turn them into activated carbon. The material was used to treat pollutants in the environment. Many researchers have researched, synthesized, evaluated the materials from agricultural by-products such as rice husk ash, rice straw, sawdust, cellulose, corn cobs, date seeds, bean pods, coffee grounds, seed pods of fruits. [28-35]. In particular, jackfruit was evaluated for the habilitation to handle colorants, antibiotics, heavy metals, CO, or some other organic pollutants [36-39]. In this study, the adsorption capacity of activated carbon from the jackfruit tree was summarized to see potential practical applications that helped orient the benefits of jackfruit trees.

**POTENTIAL OF ACTIVATED CARBON FROM JACKFRUIT BY-PRODUCTS**

According to the Association of Agricultural Research Institutes of Asia - Pacific (APAARI) report, the world production of jackfruit was about 3.143 million tons in 2012 [40]. The amount of by-products after harvesting and production accounts is 10% of the harvested output. Therefore, it can be seen that about 0.314 million tons of by-products are generated. The products from jackfruit by-products include bio-activated carbon, biological substrates, membrane adsorbent materials, and superconducting materials (Fig. 2).
The peel and pulp of the jackfruit are of interest to researchers worldwide due to its porous structure. In addition, Foo et al. [41] studied the preparation of activated carbon (JPAC) from the jackfruit peel through NaOH activation with microwave support. Tengku Hasbullah's research [42] used jackfruit peel to prepare activated carbon (AC) using chemical activation. The activators NaOH, HNO₃, ethylene diamine tetra-acetic acid (EDTA), and sodium dodecyl sulfate (SDS) modify the surface to increase the adsorption capacity of jackfruit peel by Ranasinghe et al. [39]. Prahas et al. [43] used jackfruit peel to synthesize activated carbon. Activated carbon derived from jackfruit peel was studied with a chemical activation method using phosphoric acid as an activator. Activated carbon with a well-developed pore size is generated at the activation temperature of 450 °C and 550 °C. It can be seen that the method of synthesizing activated carbon from jackfruit is used by physicochemical methods combined with microwaves [3,24,39,44-48]. The AC was synthesized by chemical activation process using H₃PO₄ followed by the heating process with surface area values (1585 m² g⁻¹) [3]. The material's BET surface area and total pore volume range from 907–1260 m² g⁻¹ and 0.525–0.733 cm³ g⁻¹, respectively [43]. The methods and activators were all tested by the researchers (Table 1). It can be seen that activated carbon from jackfruit is potential material. Their application in adsorption is excellent potential. In which activated carbon is studied to treat heavy metal ions, color treatment in water.

### Potential of Activated Carbon from Jackfruit By-products in Wastewater Treatment

#### Removal of Harmful Organic Dyes

The production of AC from agricultural waste can be easily accomplished by finding easy raw materials and low cost. The utilization and reuse of waste have been benefits not only economically, socially but also environmental protection. The factors affecting the adsorption process, the kinetic and isothermal models are presented in Table 2.

In 2012, a study by Foo's team [41] on the investigation of the regeneration of carbon-activated durian and jackfruit-peels impregnated with methylene blue (MB) dye. Research has focused on the reused process of materials. The adsorption capacity and carbon yield of regenerated activated carbons can be maintained at 181.43–207.57 mg g⁻¹ and 80.51–81.63%, even after five consecutive adsorption cycles. Kinetic models were also evaluated in accordance with Langmuir. In addition, author Foo et al. [51] studied the preparation of activated carbon (JPAC) from the jackfruit peel. The adsorption capacity reached 400.06 mg g⁻¹ with a carbon efficiency of 80.82%. The adsorption data are consistent with the pseudo-second-order kinetic model.

<table>
<thead>
<tr>
<th>Jackfruit part</th>
<th>Activation methods</th>
<th>Activator</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>peel</td>
<td>Chemical</td>
<td>EDTA, SDS, NaOH, and HNO₃</td>
<td>[39]</td>
</tr>
<tr>
<td>rind and pulp</td>
<td>Physicochemical</td>
<td>K₂CO₃</td>
<td>[46]</td>
</tr>
<tr>
<td>wood sawdust</td>
<td>Chemical</td>
<td>H₃PO₄</td>
<td>[49]</td>
</tr>
<tr>
<td>peel</td>
<td>Physicochemical</td>
<td>H₃PO₄ (600–90 °C)</td>
<td>[3]</td>
</tr>
<tr>
<td>seeds</td>
<td>Physical</td>
<td>400 °C</td>
<td>[47]</td>
</tr>
<tr>
<td>rind</td>
<td>Physical</td>
<td>N₂ (400 °C)</td>
<td>[44]</td>
</tr>
<tr>
<td>peel</td>
<td>Microwave-assisted</td>
<td>KOH</td>
<td>[24]</td>
</tr>
<tr>
<td>peel</td>
<td>Microwave-assisted</td>
<td>N₂</td>
<td>[45]</td>
</tr>
<tr>
<td>peel</td>
<td>Physicochemical</td>
<td>K₂CO₃ (700 °C)</td>
<td>[46]</td>
</tr>
<tr>
<td>peel</td>
<td>Chemical</td>
<td>H₃PO₄</td>
<td>[43]</td>
</tr>
<tr>
<td>peel</td>
<td>Physicochemical</td>
<td>NaOH and N₂ (700 °C)</td>
<td>[41]</td>
</tr>
<tr>
<td>peel</td>
<td>Physicochemical</td>
<td>K₂CO₃ (700 °C)</td>
<td>[50]</td>
</tr>
<tr>
<td>seed</td>
<td>Physicochemical</td>
<td>ZnCl₂ and N₂ (600–1000 °C)</td>
<td>[48]</td>
</tr>
</tbody>
</table>
In 2014, Tengku Hasbullah’s research [42] used jackfruit peel to prepare activated carbon (AC) and assess the affecting factors. CAC showed an adsorption capacity of 10.43 mg g⁻¹ as a potential adsorbent that can treat dyeing wastewater by adsorption. In 2015, Karmaker’s [52] study investigated the adsorption of Reactive Orange 13 (RO13) onto activated carbon from jackfruit seeds. The results show that the adsorption of RO13 follows a pseudo-second-order kinetic model. The best fit to the data was collected from the Langmuir model. The adsorption capacity of jackfruit seeds was found to be 64.1 μmol g⁻¹ at pH 2. Ojha’s research work [53] used JLP (jackfruit leaf powder) synthesized into activated carbon, capable of adsorbing Amido Black 10 B dye and Crystal violet dye. The experimental data indicate that the optimal values are the JLP dose found to be 10 g L⁻¹, the adsorption time of 6 h, and the stirrer speed of 275 rpm for the black Amido and the dose, respectively. The amount of JLP was found to be 10 g L⁻¹, 4 h adsorption time, and 200 rpm stirrer speed, respectively, for Purple Crystal. Dye removal efficiency > 80%. Finally, the data is evaluated against different equilibrium and kinetic models. The experimental data are in good agreement with the Freundlich isotherm model.

In 2016, jackfruit seed (JS) was used to investigate potential adsorbents to remove Rhodamine B (RhB) dye from an aqueous solution in Kooh’s study [54]. The most suitable is a pseudo-quadratic kinetic model. Thermodynamic studies show that the adsorption process is endothermic. The Sips and Langmuir model...
were the best models that described the adsorption process with the predicted adsorption capacity of 26.4 and 37.9 mg g⁻¹, respectively.

In 2018, the study by Srivastava et al. [55] focused on jackfruit seeds’ adsorption characteristics to remove Malachite Blue (MG) from an aqueous solution. The Freundlich model was the best fit for the experimental data with an adsorption capacity of 66 mg g⁻¹. The kinetic mechanism follows a pseudo-second-order kinetic model. In addition, the artificial neural network tissue is used to predict the adsorption process with a high R-value of 0.966 and 0.981. In the study of Kooh’s group [56], activated carbon was prepared from jackfruit waste at 600 °C and named JC600. Experiments were conducted to evaluate the adsorption capacity of JC 600 removing Disperse Blue 14 (DB14). The isotherm equations were used to represent the adsorption process with the best model (Langmuir). The kinetic models were in agreement with the adsorption process by selecting the best model (the pseudo-second-order kinetic model).

In 2019, Das et al. [57] used the dried leaf powder of jackfruit (Artocarpus heterophyllus) to prepare activated carbon removing malachite blue from aqueous solution. The Freundlich isotherm model with the correlation coefficient (R²) value of 0.9880 was considered the suitable adsorption model for the dye adsorption.

**Removal of Heavy Metal Ions**

Agricultural residues can adsorb heavy metals thanks to their porous structure and composition of active functional groups [58]. Functional groups in biomass include acetamido, carbonyl, phenolic, polysaccharide framework, amine, hydroxyl sulfide, carboxyl, alcohol, and ester [59]. These groups form an affinity and complex with heavy metal ions. Some adsorbents bind non-selectively, which can bind to many heavy metal ions. While other materials selectively bind heavy metal ions depending on their chemical composition.

Waste products such as coir, rice husk, bagasse, tea leaves, chamomile, papaya stalks, banana stalks, rice husks, corn stalks were studied to separate heavy metals in water [60-62]. In general, the mechanism of heavy metal ion adsorption by agricultural waste is based on the chemical reaction between functional groups on the surface of the adsorbent and metal ions. Thus, the cation exchange reaction and the complexation reaction with metal ions are predominant. In addition, the accompanying mechanisms include surface adsorption, diffusion, and precipitation. The results show that the adsorbents can be used effectively to remove heavy metals with a concentration of about 10–60 mg L⁻¹ [63].

In 2017, Premachandra et al. [64] compared bio-adsorbent materials from jackfruit leaf powder modified with acetic acid and unmodified to evaluate the adsorption capacity of lead (Pb) from synthetic wastewater. The process of optimizing the influencing parameters is performed based on the contact time (120 and 150 min), pH 5, adsorbent dosage (30 g L⁻¹), and initial concentration of wastewater (90 mg L⁻¹). The obtained results show that the absorbent of modified jackfruit leaf powder has a higher ability to remove lead from wastewater than unmodified jackfruit leaf powder; more than 90% of Pb(II) is removed.

In 2018, The utilization of agricultural by-products was studied by Ranasinghe et al. [39]. The low-cost, effective bio-adsorbent from jackfruit peel (JFP) was used to remove Ni(II) and Cr(III) from the aqueous solution. According to the Langmuir adsorption isotherm model, the results after activation at optimal conditions are 41.67 with Cr(III) and 52.08 with Ni(II). The undenatured JFP has adsorption capacity Cr(III) 13.50 mg g⁻¹ and Ni(II) 12.03 mg g⁻¹. The pseudo-quadratic kinetic model is suitable for all Cr(III) and Ni(II) adsorption systems. Besides, the adsorbed metal ions can be recovered under an acidic solution. Thereby, the surface exchange material from by-products was creating a development direction for future studies on improving the adsorption capacity of heavy metals.

Another study in 2019, Banu et al. [65], was conducted using agricultural waste such as corn husks (CHQ) and jackfruit skins (JPQ) to remove nitrate and phosphate ions. The adsorption efficiency of agricultural waste to treat nitrate and phosphate ions was established through the conditions of initial concentration of 100 mg L⁻¹ solutions, contact time (40 and 60 min), dose 0.1 g, solution pH (6 and 7) for nitrate and phosphate.
Table 3. Activated carbon from jackfruit wastes to removal organic dyes and heavy metals

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Pollutants</th>
<th>Adsorption conditions</th>
<th>Adsorption capacity (mg g⁻¹)</th>
<th>Adsorption efficiency (%)</th>
<th>Adsorption model</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackfruit leaf</td>
<td>Pd(II)</td>
<td>Unmodified and modified: time 120 and 150 min, pH 4.08 and 5.2, adsorbent dosage 3 g/100mL.</td>
<td>-</td>
<td>&gt;90%</td>
<td>-</td>
<td>[64]</td>
</tr>
<tr>
<td>Jackfruit leaf</td>
<td>Cr(III) and Ni(II)</td>
<td>0.100 g of JFP, 0.400 g dosage, time 60.0 min, pH 5-6 (Ni II) and pH 4-5 (Cr III)</td>
<td>13.50 (Cr III) and 12.03 (Ni II)</td>
<td>-</td>
<td>Langmuir and Freundlich, Temkin and Dubinin-Radushkevich, Flory-Huggins and PFO, PSO</td>
<td>[39]</td>
</tr>
<tr>
<td>Jackfruit Peel</td>
<td>Nitrate and phosphate ions</td>
<td>Nitrate and phosphate: pH 6 and 7, dosage 0.1 g, time 40 and 60 min, initial concentration 100 mg L⁻¹ at 30 °C</td>
<td>62.91 (Nitrate) and 72.39 (phosphate)</td>
<td>-</td>
<td>Langmuir and Freundlich, Dubinin-Radushkevich and PFO, PSO and intraparticle diffusion</td>
<td>[65]</td>
</tr>
<tr>
<td>Jackfruit Peel</td>
<td>Cadmium</td>
<td>pH 7.6, 60 mg adsorbent dose, contact time for 1 h and 120 rpm</td>
<td>-</td>
<td>97.12%</td>
<td>-</td>
<td>[47]</td>
</tr>
<tr>
<td>Jackfruit seed</td>
<td>Cu²⁺, Cd²⁺ và Pb²⁺</td>
<td>pH 4.2 to 6.4, time 20 min. Agitation speed of 150 rpm. dosage 15 mg, 13 mg and 15 mg for Cu²⁺, Cd²⁺ and Pb²⁺ ions and optimal concentration of 30 ppm.</td>
<td>32.97 (Pb²⁺), 30.99 (Cu²⁺) and 24.75 (Cd²⁺)</td>
<td>-</td>
<td>Langmuir and Freundlich</td>
<td>[66]</td>
</tr>
<tr>
<td>Jackfruit seed</td>
<td>Pd(II)</td>
<td>Pb²⁺ concentration 2 μg mL⁻¹, pH 5.8 and biodsorbent dose 60 mg</td>
<td>-</td>
<td>96%</td>
<td>Langmuir and Freundlich, Temkin, PFO, PSO, Elovich and intraparticle diffusion</td>
<td>[67]</td>
</tr>
</tbody>
</table>

The adsorption capacity of JPQ is 72.39 and 62.91 mg g⁻¹ at 30 °C by The Langmuir isotherms. The adsorption mechanism mainly involved electrostatic attraction and validated ion exchange.

In 2020, Prasad et al. [47] have used by-products from jackfruit peel to produce activated carbon material to remove cadmium from aqueous solution. The adsorption efficiency was about 97.12% under optimal conditions such as pH 7.6, speed 120 rpm, contact time of 1 h, and adsorbent dosage 60 mg. The Flynn-Wall-Ozawa method was used to evaluate the activation energy of the jackfruit bio-adsorbent with an observed result of 130.69 kJ mol⁻¹. Simultaneously, the research team performed statistical analyzes and optimized using Design-Expert software. The validity of the model was expressed through the value of the correlation coefficient R² was found to be 0.92.

In 2020, jackfruit seeds were used by Ndung’u et al. [67] to remove Cu²⁺, Cd²⁺, and Pb²⁺ metal ions from an aqueous solution. The Langmuir isotherm model was showed a higher adsorption capacity of 30.99 mg g⁻¹ (Cu²⁺), 24.75 mg g⁻¹ (Cd²⁺) and 32.97 mg g⁻¹ (Pb²⁺) compared with crude adsorbents 21.3220 mg g⁻¹ (Cu²⁺), 19.6850 mg g⁻¹ (Cd²⁺) and 21.8818 mg g⁻¹ (Pb²⁺). The optimal conditions were achieved at the contact time from 15 to 20 min, pH from 4.2 to 6.4, excitation speed from 150 rpm to 175 rpm, and adsorbent doses from 10 mg to 15 mg [66].

In the latest study in 2021, Giri et al. evaluated the adsorption capacity between particles of Artocarpus...
Fig 2. Application of Activated carbon from jackfruit by-products

*Artocarpus heterophyllus* (SBAh) to remove lead ions (Pb\(^{2+}\)) from wastewater. Pb\(^{2+}\) removal efficiency ~96% for SBAh through optimized conditions (pH 5.8, 60 mg bioabsorbable dose and 2 μg mL\(^{-1}\) Pb\(^{2+}\) concentration) by the method surface response method. The intergranular diffusion model gives SBAh (R\(^2\) = 0.99). Besides, the Temkin adsorption isotherm model is said to be suitable for biosorbent. The detected adsorption capacity was 4.93 mg g\(^{-1}\) for SBAh after 70 min. It was found that the removal of organic and inorganic pollutants in wastewater from jackfruit seed by-products shows promise in the field of adsorption as a new, cheap, reusable, and environmentally friendly adsorbent [67]. The summary of the application of activated carbon from jackfruit wastes for organic dyes and heavy metals removal is listed in Table 3.

■ CONCLUSION

This report highlights the potential of biomass waste accruing from the jackfruit processing industry. Although different synthesis methods could be applied to convert jackfruit by-products to activated carbon, the physicochemical method and microwave-assisted are the activation method that achieved high specific surface area. The as-synthesized adsorbents generally showed outstanding results with pollutants from nonferrous, heavy metal ions and organic dyes. The treatment efficiency of AC from jackfruit is about > 80% suitable for Langmuir, PSO model. Several adsorption mechanisms have been proposed in the removal of pollutants. The review shows the great potential of adsorbents synthesized from agricultural by-products.

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