Review:

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

Kim Ngan Thi Tran[1,2], Bich Ngoc Hoang[1,2], Kim Oanh Thi Nguyen[1,2], Hong Tham Thi Nguyen[2,3], Sy Chi Phung[1,2], Huong Tra Do[4], and Cam Quyen Thi Ngo[1,2*]

[1]*Faculty of Food and Environmental Engineering, Nguyen Tat Thanh University, 298-300A Nguyen Tat Thanh, Ward 13, District 4, Ho Chi Minh City, 700000, Vietnam*

[2]*Institute of Environmental Technology and Sustainable Development, Nguyen Tat Thanh University, 298-300A Nguyen Tat Thanh, Ward 13, District 4, Ho Chi Minh City, 700000, Vietnam*

[3]*Da Vo Giu High School, Hoai An District, Binh Dinh Province, Vietnam*

[4]*Faculty of Chemistry, Thai Nguyen University of Education, Tan Thinh Ward, Thai Nguyen City, Thai Nguyen 250000, Vietnam*

** **Corresponding author:***

tel: +84-964240067
email: ntcquyen@ntt.edu.vn

Received: October 3, 2021
Accepted: October 26, 2021

DOI: 10.22146/ijc.69538

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

Fig 1. Application of the jackfruit

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 interested in researchers worldwide due to the porous structure. In addition, Foo et al. [41] studied the preparation 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, HNO_3, 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 into 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 synthetic by chemical activation process using H_3PO_4 followed by the heating process with surface area values (1585 $m^2\ g^{-1}$) [3]. The material's BET surface area and total pore volume range from 907–1260 $m^2\ g^{-1}$ and 0.525–0.733 $cm^3\ g^{-1}$, 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 will 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 an 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 to 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 1. Method for synthesizing activated carbon from jackfruit

Jackfruit part	Activation methods	Activator	Ref.
peel	Chemical	EDTA, SDS, NaOH, and HNO_3	[39]
rind and pulp	Physicochemical	K_2CO_3	[46]
wood sawdust	Chemical	H_3PO_4	[49]
peel	Physicochemical	H_3PO_4 (600–90 °C)	[3]
seeds	Physical	400 °C	[47]
rind	Physical	N_2 (400 °C)	[44]
peel	Microwave-assisted	KOH	[24]
peel	Microwave-assisted	N_2	[45]
peel	Physicochemical	K_2CO_3 (700 °C)	[46]
peel	Chemical	H_3PO_4	[43]
peel	Physicochemical	NaOH and N_2 (700 °C)	[41]
peel	Physicochemical	K_2CO_3 (700 °C)	[50]
seed	Physicochemical	$ZnCl_2$and N_2 (600–1000 °C)	[48]

Table 2. Summary of results of dye adsorption studies of activated carbon from jackfruit wastes

Adsorbent	Pollutants	Adsorption conditions	Adsorption capacity (mg g^{-1})	Adsorption efficiency (%)	Adsorption model	Ref.
Jackfruit Peel	MB	Temp 30 °C, Dose 0.2 g L^{-1} initial concentration 300 mg L^{-1}	207.57	81.63	Langmuir	[51]
Jackfruit Peel	MB	pH 6.28, temp 30 °C, initial concentration 500 mg L^{-1}	400.06	80.82	PSO	[41]
Jackfruit Peel	MB	initial concentration 2.0 mg L^{-1}, dose 7.5 g L^{-1}, time 24 h	10.43	-	-	[42]
Jackfruit seed	RO13	pH 2, temp 30 °C, initial concentration 100 μmol L^{-1}	64.1 μmol g^{-1}	-	Langmuir, PSO	[52]
Jackfruit leaf	AB	Dose 10 g L^{-1}, time 5 h, stirrer speed 200 rpm	-	> 80	Freundlich, PSO	[53]
Jackfruit seed	RhB	pH 4.3, time 2.5 h, initial concentration 300 mg L^{-1}	26.4	-	Langmuir	[54]
Jackfruit seed	MG	pH 4, Time 2 h, initial concentration 100 mg L^{-1}	66	-	Freundlich, PSO	[55]
Jackfruit Peel and jackfruit pulp	DB14	Adsorbent dose 0.07 g, time 50 min, pH 3	93	-	Langmuir, PSO	[56]
Jackfruit leaf	MG	Dose 0.5 g L^{-1}, time 150 min, pH 8	-	97.8	Freundlich	[57]

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 64.10 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 (R^2) 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

Adsorbent	Pollutants	Adsorption conditions	Adsorption capacity (mg g^{-1})	Adsorption efficiency (%)	Adsorption model	Ref.
Jackfruit leaf	Pd(II)	Unmodified and modified: time 120 and 150 min, pH 4.08 and 5.2, adsorbent dosage 3 g/100mL	-	>90%	-	[64]
Jackfruit leaf and Jackfruit Peel	Cr(III) and Ni(II)	0.100 g of JFP, 0.400 g dosage, time 60.0 min, pH 5-6 (Ni II) and pH 4-5 (Cr III)	13.50 (Cr III) and 12.03 (Ni II)	-	Langmuir and Freundlich, Temkin and Dubinin-Radushkevich, Flory-Huggins and PFO, PSO	[39]
Jackfruit Peel	Nitrate and phosphate ions	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	62.91 (Nitrate) and 72.39 (phosphate)	-	Langmuir and Freundlich, Dubinin-Radushkevich and PFO, PSO and intraparticle diffusion	[65]
Jackfruit Peel	Cadmium	pH 7.6, 60 mg adsorbent dose, contact time for 1 h and 120 rpm	-	97.12%	-	[47]
Jackfruit seed	Cu^{2+}, Cd^{2+} và Pb^{2+}	pH 4.2 to 6.4, time 20 min. Agitation speed of 150 rpm. dosage 15 mg, 13 mg and 15 mg for Cu^{2+}, Cd^{2+} and Pb^{2+} ions and optimal concentration of 30 ppm.	32.97 (Pb^{2+}), 30.99 (Cu^{2+}) and 24.75 (Cd^{2+})	-	Langmuir and Freundlich	[66]
Jackfruit seed	Pd(II)	Pb^{2+} concentration 2 μg mL^{-1}, pH 5.8 and bioadsorbent dose 60 mg	-	96%	Langmuir and Freundlich, Temkin, PFO, PSO, Elovich and intraparticle diffusion	[67]

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 R^2 was found to be 0.92.

In 2020, jackfruit seeds were used by Ndung'u et al. [67] to remove Cu^{2+}, Cd^{2+}, and Pb^{2+} metal ions from an aqueous solution. The Langmuir isotherm model was showed a higher adsorption capacity of 30.99 mg g^{-1} (Cu^{2+}), 24.75 mg g^{-1} (Cd^{2+}) and 32.97 mg g^{-1} (Pb^{2+}) compared with crude adsorbents 21.3220 mg g^{-1} (Cu^{2+}), 19.6850 mg g^{-1} (Cd^{2+}) and 21.8818 mg g^{-1} (Pb^{2+}). 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*

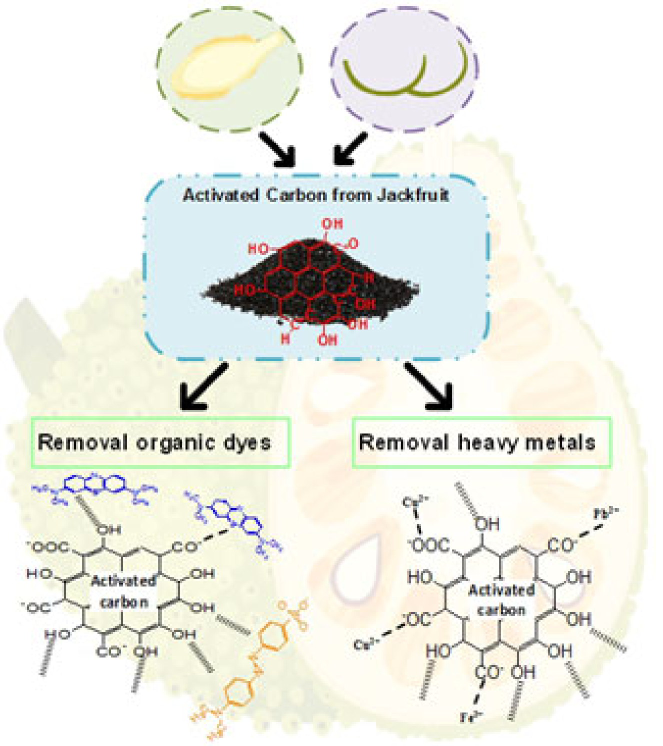

Fig 2. Application of Activated carbon from jackfruit by-products

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.

■ ACKNOWLEDGMENTS

This study was funded by the Science and Technology Development Fund, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam.

■ REFERENCES

[1] Elevitch, C.R., and Manner, H.I., 2006 "*Artocarpus heterophyllus* (jackfruit), ver. 1.1v." in *Species Profiles for Pacific Island Agroforestry*, Eds. Elevitch, C.R., Permanent Agriculture Resources (PAR), Hōlualoa, Hawaii, 1–17.

[2] Witt, A., and Luke, Q., 2017, *Guide to the Naturalized and Invasive Plants of Eastern Africa*, CABI, Wallingford, UK.

[3] Rajabathar, J.R., Manoharan, S., Vijaya, J.J., Al-Lohedan, H.A., and Arunachalam, P., 2020, Synthesis of porous carbon nanostructure formation from peel waste for low-cost flexible electrode fabrication towards energy storage applications, *J. Energy Storage*, 32, 101735.

[4] Prakash, O., Kumar, R., Mishra, A., and Gupta, R., 2009, *Artocarpus heterophyllus* (jackfruit): An overview, *Pharmacogn. Rev.*, 3 (6), 353.

[5] Baliga, M.S., Shivashankara, A.R., Haniadka, R., Dsouza, J., and Bhat, H.P., 2011, Phytochemistry, nutritional and pharmacological properties of *Artocarpus heterophyllus* Lam (jackfruit): A review, *Food Res. Int.*, 44 (7), 1800–1811.

[6] Shamsudin, R., Ling, C.S., Ling, C.N., Muda, N., and Hassan, O., 2009, Chemical compositions of the jackfruit juice (*Artocarpus*) cultivar J33 during

storage, *J. Appl. Sci.*, 9, 3202–3204.
[7] Shinde, V., Pawar, C., Warang, O., Dandekar, V., Kulkarni, M., Josiya, J., and Joshi, M., 2021, Studies on preparation of ice-cream from jackfruit (*Artocarpus heterophyllus*) seed powder, *Int. J. Chem. Stud.*, 9 (1), 2710–2712.
[8] Rengasamy, M., Raj, R.V., and Vedagiriswaran, N., 2017, Study on oil extraction from jackfruit seed and its application in biodiesel production, *Elix. Renewable Energy*, 102, 44269–44272.
[9] Felli, R., Yang, T.A., Wan Abdullah, W.N., and Zzaman, W., 2018, Effects of incorporation of jackfruit rind powder on chemical and functional properties of bread, *Trop. Life Sci. Res.*, 29 (1), 113–126.
[10] Meethal, S.M., Kaur, N., Singh, J., and Gat, Y., 2017, Effect of addition of jackfruit seed flour on nutrimental, phytochemical and sensory properties of snack bar, *Curr. Res. Nutr. Food Sci.*, 5 (2), 154–158.
[11] Duque-Acevedo, M., Belmonte-Ureña, L.J., Cortés-García, F.J., and Camacho-Ferre, F., 2020, Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses, *Global Ecol. Conserv.*, 22, e00902.
[12] Speight, J.G., 2020, "Sources of Water Pollution" in *Natural Water Remediation*, Butterworth–Heinemann, Oxford, UK, 165–198.
[13] Elbasiouny, H., Elbanna, B.A., Al-Najoli, E., Alsherief, A., Negm, S., Abou El-Nour, E., Nofal, A., and Sharabash, S., 2020, "Agricultural Waste Management for Climate Change Mitigation: Some Implications to Egypt" in *Waste Management in MENA Regions*, Eds. Negm, A., and Shareef, N., Springer Water. Springer, Cham, 149–169.
[14] Nagendran, R., 2011, "Agricultural Waste and Pollution" in *Waste, A Handbook for Management*, Eds. Letcher, T.M., and Vallero, D.A., Academic Press, Boston, 341–355.
[15] Xue, L., Zhang, P., Shu, H., Wang, R., and Zhang, S., 2016, Agricultural waste, *Water Environ. Res.*, 88 (10), 1334–1369.
[16] Sathiparan, N., and De Zoysa, H.T.S.M., 2018, The effects of using agricultural waste as partial substitute for sand in cement blocks, *J. Build. Eng.*, 19, 216–227.
[17] Obi, F., Ugwuishiwu, B., and Nwakaire, J., 2016, Agricultural waste concept, generation, utilization and management, *Niger. J. Technol.*, 35 (4), 957–964.
[18] Rao, R.A.K., and Khan, M.A., 2009, Biosorption of bivalent metal ions from aqueous solution by an agricultural waste: Kinetics, thermodynamics and environmental effects, *Colloids Surf., A*, 332 (2-3), 121–128.
[19] Gontard, N., Sonesson, U., Birkved, M., Majone, M., Bolzonella, D., Celli, A., Angellier-Coussy, H., Jang, G.W., Verniquet, A., Broeze, J., Schaer, B., Batista, A.P., and Sebok, A., 2018, A research challenge vision regarding management of agricultural waste in a circular bio-based economy, *Crit. Rev. Environ. Sci. Technol.*, 48 (6), 614–654.
[20] Abioye, A.M., and Ani, F.N., 2015, Recent development in the production of activated carbon electrodes from agricultural waste biomass for supercapacitors: A review, *Renewable Sustainable Energy Rev.*, 52, 1282–1293.
[21] Soetardji, J.P., Widjaja, C., Djojorahardjo, Y., Soetaredjo, F.E., and Ismadji, S., 2014, Bio-oil from jackfruit peel waste, *Procedia Chem.*, 9, 158–164.
[22] Ginting, M.H.S., Irvan, Misran, E., and Maulina, S., 2020, Potential of durian, avocado and jackfruit seed as raw material of bioethanol: a review, *IOP Conf. Ser.: Mater. Sci. Eng.*, 801, 012045.
[23] Nsubuga, D., Banadda, N., Kabenge, I., and Wydra, K.D., 2020, Potential of jackfruit waste for biogas, briquettes and as a carbondioxide sink-A review, *J. Sustainable Dev.*, 13 (4), 60–75.
[24] Bhushan, B., Nayak, A., and Kotnala, S., 2021, Green synthesis of highly porous activated carbon from jackfruit peel: Effect of operating factors on its physico-chemical characteristics, *Mater. Today: Proc.*, 44, 187–191.
[25] Yadav, D., Rangabhashiyam, S., Verma, P., Singh, P., Devi, P., Kumar, P., Hussain, C.M., Gaurav, G.K., and Kumar, K.S., 2021, Environmental and

health impacts of contaminants of emerging concerns: Recent treatment challenges and approaches, *Chemosphere*, 272, 129492.

[26] Manahan, S.E., 1997, *Environmental Science and Technology*, CRC Press, Boca Raton, Florida.

[27] Singh, S., Wasewar, K.L., and Kansal, S.K., 2020, "Low-Cost Adsorbents for Removal of Inorganic Impurities from Wastewater" in *Inorganic Pollutants in Water*, Eds. Devi, P., Singh, P., and Kansal, S.K., Elsevier, Amsterdam, Netherlands, 173–203.

[28] Menya, E., Olupot, P.W., Storz, H., Lubwama, M., and Kiros, Y., 2018, Production and performance of activated carbon from rice husks for removal of natural organic matter from water: A review, *Chem. Eng. Res. Des.*, 129, 271–296.

[29] Nam, H., Choi, W., Genuino, D.A., and Capareda, S.C., 2018, Development of rice straw activated carbon and its utilizations, *J. Environ. Chem. Eng.*, 6 (4), 5221–5229.

[30] Rattanapan, S., Srikram, J., and Kongsune, P., 2017, Adsorption of methyl orange on coffee grounds activated carbon, *Energy Procedia*, 138, 949–954.

[31] Bello, O.S., Adegoke, K.A., Sarumi, O.O., and Lameed, O.S., 2019, Functionalized locust bean pod (*Parkia biglobosa*) activated carbon for Rhodamine B dye removal, *Heliyon*, 5 (8), e02323.

[32] Yaseen, M., Ullah, S., Ahmad, W., Subhan, S., and Subhan, F., 2021, Fabrication of Zn and Mn loaded activated carbon derived from corn cobs for the adsorptive desulfurization of model and real fuel oils, *Fuel*, 284, 119102.

[33] Luo, X., and Zhang, L., 2009, High effective adsorption of organic dyes on magnetic cellulose beads entrapping activated carbon, *J. Hazard. Mater.*, 171 (1-3), 340–347.

[34] Kumar, A., and Gupta, H., 2020, Activated carbon from sawdust for naphthalene removal from contaminated water, *Environ. Technol. Innovation*, 20, 101080.

[35] Thi, T.T.L., and Van, K.L., 2016, Adsorption behavior of Pb(II) in aqueous solution using coffee husk-based activated carbon modified by nitric acid, *Am. J. Eng. Res.*, 5 (4), 120–129.

[36] Tran, V.A., Kadam, A.N., and Lee, S.W., 2020, Adsorption-assisted photocatalytic degradation of methyl orange dye by zeolite-imidazole-framework-derived nanoparticles, *J. Alloys Compd.*, 835, 155414.

[37] Tran, V.A., Vu, K.B., Thi Vo, T.T., Le, V.T., Do, H.H., Bach, L.G., and Lee, S.W., 2021, Experimental and computational investigation on interaction mechanism of Rhodamine B adsorption and photodegradation by zeolite imidazole frameworks-8, *Appl. Surf. Sci.*, 538, 148065.

[38] Hieu, V.Q., Phung, T.K., Nguyen, T.Q., Khan, A., Doan, V.D., Tran, V.A., and Le, V.T., 2021, Photocatalytic degradation of methyl orange dye by Ti_3C_2–TiO_2 heterojunction under solar light, *Chemosphere*, 276, 130154.

[39] Ranasinghe, S.H., Navaratne, A.N., and Priyantha, N., 2018, Enhancement of adsorption characteristics of Cr(III) and Ni(II) by surface modification of jackfruit peel biosorbent, *J. Environ. Chem. Eng.*, 6 (5), 5670–5682.

[40] Sidhu, A.S., 2012, *Jackfruit Improvement in the Asia-Pacific Region: A Status Report*, Regional Consultation on Collective Actions for Opening Access to Agricultural Information and Knowledge in the Asia-Pacific Region, 13-15 December 2012, Thimphu, Bhutan.

[41] Foo, K.Y., and Hameed, B.H., 2012, Potential of jackfruit peel as precursor for activated carbon prepared by microwave induced NaOH activation, *Bioresour. Technol.*, 112, 143–150.

[42] Tengku Hasbullah, T.N.A., Selaman, O.S., and Rosli, N.A., 2014, Removal of methylene blue from aqueous solutions using chemical activated carbon prepared from jackfruit (*Artocarpus heterophyllus*) peel waste, *J. Civ. Eng. Sci. Technol.*, 5 (1), 34–38.

[43] Prahas, D., Kartika, Y., Indraswati, N., and Ismadji, S., 2008, Activated carbon from jackfruit peel waste by H_3PO_4 chemical activation: Pore structure and surface chemistry characterization, *Chem. Eng. J.*, 140 (1-3), 32–42.

[44] Lee, K., Shabnam, L., Faisal, S.N., Hoang, V.C., and Gomes, V.G., 2020, Aerogel from fruit biowaste

produces ultracapacitors with high energy density and stability, *J. Energy Storage*, 27, 101152.

[45] Nayak, A., Bhushan, B., Gupta, V., and Kotnala, S., 2021, Fabrication of microwave assisted biogenic magnetite-biochar nanocomposite: A green adsorbent from jackfruit peel for removal and recovery of nutrients in water sample, *J. Ind. Eng. Chem.*, 100, 134–148.

[46] Nagalakshmi, T.V., Emmanuel, K.A., and Bhavani, P., 2019, Adsorption of disperse blue 14 onto activated carbon prepared from jackfruit-PPI-I waste, *Mater. Today: Proc.*, 18, 2036–2051.

[47] Prasad, N., Kumar, P., and Pal, D.B., 2020, Cadmium removal from aqueous solution by jackfruit seed bio-adsorbent, *SN Appl. Sci.*, 2 (6), 1018.

[48] Chaudhary, R., Maji, S., Shrestha, R.G., Shrestha, R.L., Shrestha, T., Ariga, K., and Shrestha, L.K., 2020, Jackfruit seed-derived nanoporous carbons as the electrode material for supercapacitors, *C*, 6 (4), 73.

[49] Mutiara, T., Rofiki, I., and Al Ghifari, M.A.D., 2018, Bio adsorbent from modified jackfruit wood sawdust for removal of lead ions, *Mater. Sci. Forum*, 934, 159–164.

[50] Nagalakshmi, T.V., Emmanuel, K.A., Suresh Babu, C., Chakrapani, C., and Divakar, P.P., 2015, Preparation of mesoporous activated carbon from jackfruit PPI-1 waste and development of different surface functional groups, *Int. Lett. Chem., Phys. Astron.*, 54, 189–200.

[51] Foo, K.Y., and Hameed, B.H., 2012, A cost effective method for regeneration of durian shell and jackfruit peel activated carbons by microwave irradiation, *Chem. Eng. J.*, 193-194, 404–409.

[52] Karmaker, S., Uddin, M.N., Ichikawa, H., Fukumori, Y., and Saha, T.K., 2015, Adsorption of reactive orange 13 onto jackfruit seed flakes in aqueous solution, *J. Environ. Chem. Eng.*, 3 (1), 583–592.

[53] Ojha, A.K., and Bulasara, V.K., 2015, Adsorption Characteristics of jackfruit leaf powder for the removal of Amido black 10B dye, *Environ. Prog. Sustainable Energy*, 34 (2), 461–470.

[54] Kooh, M.R.R., Dahri, M.K., and Lim, L.B.L., 2016, Jackfruit seed as a sustainable adsorbent for the removal of Rhodamine B dye, *J. Environ. Biotechnol. Res.*, 4 (1), 7–16.

[55] Saranya, N., Ajmani, A., Sivasubramanian, V., and Selvaraju, N., 2018, Hexavalent chromium removal from simulated and real effluents using *Artocarpus heterophyllus* peel biosorbent - Batch and continuous studies, *J. Mol. Liq.*, 265, 779–790.

[56] Kooh, M.R.R., Dahri, M.K., and Lim, L.B.L., 2018, Jackfruit seed as low-cost adsorbent for removal of malachite green: Artificial neural network and random forest approaches, *Environ. Earth Sci.*, 77 (12), 434.

[57] Das, M., and Mishra, C., 2019, Jackfruit leaf as an adsorbent of malachite green: Recovery and reuse of the dye, *SN Appl. Sci.*, 1 (5), 483.

[58] Afroze, S., and Sen, T.K., 2018, A review on heavy metal ions and dye adsorption from water by agricultural solid waste adsorbents, *Water Air Soil Pollut.*, 229 (7), 225.

[59] Sabir, A., Altaf, F., Batool, R., Shafiq, M., Khan, R.U., and Jacob, K.I., 2021, "Agricultural Waste Absorbents for Heavy Metal Removal" in *Green Adsorbents to Remove Metals, Dyes and Boron from Polluted Water*, vol. 49, Eds. Inamuddin, Ahamed, M.I., Lichtfouse, E., and Asiri, A.M., Springer, Cham, 195–228.

[60] Lu, X.G., and Guo, Y.T., 2019, Removal of Pb(II) from aqueous solution by sulfur-functionalized walnut shell, *Environ. Sci. Pollut. Res.*, 26 (13), 12776–12787.

[61] Cid, H., Ortiz, C., Pizarro, J., and Moreno-Piraján, J.C., 2020, Effect of copper(II) biosorption over light metal cation desorption in the surface of *Macrocystis pyrifera* biomass, *J. Environ. Chem. Eng.*, 8 (3) 103729.

[62] do Nascimento Júnior, W.J., da Silva, M.G.C., and Vieira, M.G.A., 2019, Environmental science and pollution research competitive biosorption of Cu^{2+} and Ag^{+} ions on brown macro-algae waste: Kinetic and ion-exchange studies, *Environ. Sci. Pollut. Res.*, 26 (23), 23416–23428.

[63] Bernard, E., Jimoh, A., and Odigure, J.O., 2013, Heavy metals removal from industrial wastewater

by activated carbon prepared from coconut shell, *Res. J. Chem. Sci.*, 3 (8), 3–9.

[64] Premachandra, J.K., Manoj, B.S., Aberathne, S.N.P.P.G.P.E., and Warnapura, L.H.P., 2017, Removal of lead from synthetic wastewater using chemically modified jackfruit leaves, *2017 Moratuwa Engineering Research Conference (MERCon)*, Moratuwa, Sri Lanka, 29–31 May 2017, 29–33.

[65] Banu, H.A.T., Karthikeyan, P., and Meenakshi, S., 2019, Comparative studies on revival of nitrate and phosphate ions using quaternized corn husk and jackfruit peel, *Bioresour. Technol. Rep.*, 8, 100331.

[66] Ndung'u, S.N., Wanjau, R.N., Nthiga, E.W., Ndiritu, J., and Mbugua, G.W., 2020, Complexation equilibrium studies of Cu^{2+}, Cd^{2+} and Pb^{2+} ions onto ethylenediamine quaternised *Artocarpus heterophyllus* L. seeds from aqueous solution, *IOSR J. Appl. Chem.*, 13 (12), 1–12.

[67] Giri, D.D., Alhazmi, A., Mohammad, A., Haque, S., Srivastava, N., Thakur, V.K., Gupta, V.K., and Pal, D.B., 2021, Lead removal from synthetic wastewater by biosorbents prepared from seeds of *Artocarpus heterophyllus* and *Syzygium cumini*, *Chemosphere*, 287, 132016.