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Utilization of *Nephelium lappaceum* (Rambutan) waste as biosorbent for heavy metals and dyes: a review

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ABSTRACT
Pollution of environmental streams and ecosystems is rising. One of the sources of water contamination is the wastewater from the textile, plastics, and mining sectors, which contains both organic and inorganic pollutants. Heavy metals and dyes in wastewater must be treated before disposal to protect the aquatic environment and human health. Due to its effectiveness, low cost, and simplicity of use, biosorption has emerged as a wastewater treatment option. Rambutan waste, in particular, is promising for commercial usage due to its extensive availability and efficiency. In this article, we review the usage of natural rambutan peels, seeds, leaves, and stems for the biosorption of water contaminants. We discuss the factors that influence pollutant removal. A pH of 6 to 12 is advantageous for cationic pollutant removal, whereas a pH of less than 5 is appropriate for anionic pollutant removal. More significant concentrations of pollutants generally result in lesser removal, whereas higher doses of biosorbent result in higher removal. The ideal adsorption contact time for rambutan peels and seeds was less than an hour. We also discuss the isotherms of the adsorption process

Keywords:
Biosorption; rambutan (*Nephelium lappaceum*); heavy metals; dyes.

Introduction

Nowadays, the industry's expansion is directly correlated with the quickening pace of the age. It is not practicable if the industrial activity does not generate waste. For instance, coal mining produces waste containing heavy metals like iron (Fe) and manganese (Mn). Additionally, waste from other sectors contains a variety of heavy metals, including lead (Pb), nickel (Ni), copper (Cu), zinc (Zn), and cadmium (Cd) (Adam et al., 2021). Heavy metals are categorized as pollutants because they are harmful at specific concentrations, non-degradable, and a source of well-known water issues (Mohd Salim et al., 2016). The industrial sector typically causes heavy metal water pollution. Some of them include the Way Umpu River in the Lampung region, which is contaminated by heavy metals (Cd, Fe, and Pb) as a result of industry and gold mining (Kiswandono et al., 2022), the Garang River and the West flood canal, which are contaminated by heavy metals (Cu, Fe, Mn, and Pb) as a result of nearby industry (Rahman, 2022), rivers and beaches contaminated by heavy metals (Ni and Fe) as a result of the nickel mining industry in the Konawe area (Ekawati et al., 2021), and rivers in the Ratai bay region that have been contaminated by Cr, Cu, and Fe metals as a result of the mining and industrial activities (Fitrianingsih & Widiastuti, 2021).

The growth of the textile sector has an impact on heavy metals and other issues as well. There is no denying that the waste produced by the textile sector poses a threat to the surrounding area's ecosystem if released into the environment without prior treatment. The water's pH, TDS (total dissolved solids), COD (chemical oxygen demand), and BOD (biological oxygen demand) could increase as a result of the dye waste (Badaruddin et al., 2018).

Based on PP.RI. No. 22 of 2021, heavy metal pollution in Way Ampu River was detected to exceed the predetermined quality standards, while the quality standards for Cd and Pb metals were 0.01 and 0.03 mg/L , respectively, while the analysis results showed that the concentration of Cd metal in this river was in the range of 0.011-0.020 ppm, and Pb metal 0.201-0.254 ppm (Kiswandono et al., 2022).

In other studies that investigated biota quality in sediments, referring to sediment quality guidelines for the protection of aquatic biota life Pb metal, the threshold of Pb metal is 35.0 mg/kg. While the average concentration of Pb in the Garang River ranged from 7.03 to 63.70 mg/kg. This result indicated that sediments in the Garang River were polluted with heavy metals, namely Pb (Rahman, 2022)

Based on IAEA-407 (2003), the quality standard of biota for Cr metal is 0.73 mg/kg, Cu 3.28 mg/kg, 146 mg/kg, and Mn 3.52 mg/kg. Based on the analysis of the highest Cr concentration found in crab biota (Episesarma sp.) with a value of 415.863 mg/kg. Cu content in almost all biotas was above the quality standard; the highest value was found in fish biota with a content of 163.312 mg/kg. The highest concentration of iron metal (Fe) was found in crabs (Episesarma sp), with a value of 3,339.89 mg/kg. The highest concentration of Mn was 26,392 mg/kg found in blood clam biota (Fitrianingsih & Widiastuti, 2021). These kinds of conditions hurt human health. The effects of heavy metals and dyes in water on human health are provided in table 1.

There are several methods for removing pollutants from water, including ion exchange (Abbasi et al., 2013), (Vardhan et al., 2019), (Lalmi et al., 2018) membrane separation (Roy Choudhury et al., 2018), (Abdi et al., 2018), (Jana et al., 2018), chemical precipitation (Xanthopoulos et al., 2017), coagulation(Tang et al., 2016), and photocatalytic degradation (Away et al., 2020). However, these methods have several disadvantages, requiring high costs and producing a large amount of sludge residue. Generally, the disadvantages of each pollutant removal method are cost, such as coagulation with high operational costs for chemicals, then for the chemical precipitation method sometimes requires the addition of chemicals to increase efficiency, as well as additional costs for maintenance and sludge disposal in the process carried out. The method of ion exchange also requires chemicals used to regenerate the resin. The photocatalytic method also requires a long process time as well as the use of a combination of techniques for other treatments. You conclusively stated that the above methods require considerable costs. Therefore, adsorption has become an option due to its efficiency, low cost and ease of application (Karnib et al., 2014)(Chen et al., 2015).

Adsorption is a separating method that separates a solid, typically a porous solid, based on variations in a compound's affinity or diffusivity. According to the mechanism, there are two types of adsorption: chemical adsorption, also called chemisorption, and physical adsorption, also called physisorption. In addition to the term "adsorption," other terminologies in adsorption include "adsorbent" and "adsorbate." Adsorbents are solid, typically porous materials used in adsorption to absorb adsorbate molecules (Astuti, 2018).

Various materials that are frequently thought of as useless have been used in numerous studies. These materials have been used as an adsorbent for the adsorption of heavy metals like iron (Fe), manganese (Mn), copper (Cu), nickel (Ni), lead (Pb), and others. For example, studies on adsorbents for lead (Pb) have been done with rambutan peels (Purwiandono & Haidar, 2022) (Almuchty et al., 2020), rambutan leaves (Mapiliandari & Herawati, 2020), corn cobs (Purnamawati et al., 2019), and bamboo charcoal (Widayatno et al., 2017).

On the other hand, rambutan peels (Normah et al., 2022) and bagasse (Imani et al., 2021) were used as Fe metal adsorbents. It is not only for lead and iron; studies on adsorbates Mn (Imani et al., 2021), Cu (Anggriawan et al., 2019), Cd (Kiswandono et al., 2022) has also been carried out. In case of dyes adsorption, several previous studies have been conducted utilizing organic materials including bagasse (M. F. P. Sari et al., 2017), tea pulp (Rahayu et al., 2022), pineapple leaf fibre (Suryani et al., 2018), *ketapang* leaves (Takwanto, 2022), corn cobs (Purnamawati et al., 2019), and *gelam* wood charcoal (Nopilda, 2019).

Table 1. Health Effects of Heavy Metals and Dyes

No	Adsorbate	Health Effect	Reference
1.	Iron (Fe)	Due to the high toxicity of this Fe ion, it will effect on both human health and the ecology of the environment. Health effects include abnormal behavior, convulsions, brain damage, and even death.	(Normah et al., 2022), (Imani et al., 2021), (Suliestyah et al., 2020), (Hidayah et al., 2012)
2.	Manganese (Mn)	Humans can become chronically poisoned by manganese ions, leading to other consequences such as dull faces and limb weakness.	(Imani et al., 2021), (Mohadi et al., 2022)
3.	Copper (Cu),	Dizziness, nausea, and stomach cramps are common side effects of copper ions, and long-term exposure can harm organ tissues and result in kidney and liver problems.	(Suliestyah et al., 2020), (Anggriawan et al., 2019), (T. K. Sari et al., n.d.), (Rinaldi et al., 2018)
4.	Lead (Pb)	Lead ions are carcinogenic and non-biodegradable; thus, this metal will affect the ecosystem and species in the waterways. Including Lead (Pb) can cause damage to brain tissue, causing children's intelligence to decline, anemia, stunted body growth, kidney damage, paralysis, and death.	(Purwiandono & Haidar, 2022), (Almuchty et al., 2020), (Bulut & Baysal, 2006), (Mapiliandari & Herawati, 2020), (Ningsih et al., 2017), (Widayatno et al., 2017), (Fashindyar & Kurniawati, 2020), (Huang et al., 2014)
5	Nickel (Ni)	Additionally, carcinogenic nickel ions are hazardous to human health. The most harmful thing about this metal is that it can kill people. It can affect systemic, immunological, neurological, reproductive, and developmental functions.	(Rinaldi et al., 2018), (Aris et al., 2020)
6	Zinc (Zn)	Zn ions can potentially harm sensory function and reduce sensitivity to taste and smell.	(Setiawan, 2018)
7	Cadmium (Cd)	Cadmium ion can build up in human organs, and it is highly poisonous and carcinogenic. Abdominal (stomach) diseases, bronchial (lung) disorders, digestive system disorders, damage to the bones (osteoporosis), kidney damage, cyanosis (bluish hue of the skin owing to lack of oxygen), and shock can all result from cadmium-heavy metal overdose.	(Kusumawardani et al., 2018), (Zhang et al., 2017)
8	Mercury (Hg)	Mercury metal ions are strongly associated with skin health. Thus, if contaminated with this metal, it will cause skin damage.	(Halid & Pauzan, 2023)
9	Chromium (Cr)	The adverse effects of chromium metal ions, such as nephritis liver and stomach diseases if they are contaminated, make them dangerous to human health as well.	(Hasdi, 2020)
10	Procion red	Skin irritating, dermatogenic, allergenic, and carcinogenic	(M. F. P. Sari et al., 2017)
11	Naphthol Yellow	Skin irritation and allergies, kidney, liver, and brain diseases, as well as neurological system and reproductive system issues	(Utoo1 et al., 2019)
12	Methylene Blue	Methylene blue can irritate the skin when touched, the digestive tract when consumed, and the lungs when inhaled, leading to cyanosis.	(Suryani et al., 2018), (Hamdaoui & Chiha, 2007)
13	Rhodamine B	Rhodamine B can harm the liver in high quantities and cause inflammation and cancer.	(Takwanto, 2022),

Indonesians are accustomed to the rambutan plant, known by its Latin name, Nephelium lappaceum (Ariany et al., 2016). This tropical fruit plant contains vitamins A, vitamin C, vitamin B6, vitamin B12, calcium, magnesium, and iron, which causes rambutan to become one of the favorite fruits of the community (Ariany et al., 2016). Unfortunately, the benefits of rambutan fruit are only known from the fruit's flesh, leaving the peels and seeds to be discarded. However, rambutan seeds and peels can be used again, specifically as an adsorbent (Rinaldi et al., 2018), (Purwiandono & Haidar, 2022), (Almuchty et al., 2020), (Winata et al., 2020), (Selvanathan et al., 2017), (Selvanathan et al., 2017), (Hasanah et al., 2022),(Lee & Ong, 2017), (Alrozi et al., 2012), (Krishnaiah et al., 2014). It turns out that rambutan, like coconut fruit, has a thousand benefits; aside from the peels and seeds, which may be reprocessed, other components of rambutan, such as leaves and stems, can also be reprocessed. Many studies have been conducted recently on using rambutan parts as adsorbents, including seeds, peels, stems, and leaves. These studies concentrated on one type of adsorbate, such as heavy metals or dyes, and used a variety of treatment variables, including pH, contact time, adsorbent mass and initial concentration. Table 2 show related study to this research.

Table 2. Related Studies

No	Adsorbent	Adsorbate	Results	Reference
1	**Rambutan peels**	Ni^{2+}, Cu^{2+}	Adsorption capacity Ni(II) 64.02 mg/g Cu(II) 41.12 mg/g	(Rinaldi et al., 2018)
		Zinc and copper ions	The amount of rambutan peel biocharcoal that could be absorbed most effectively was 40 mg, with adsorption percentages of 98.81% and 98.94%. According to this study, the ideal concentration of Zn metal ions was 40 ppm with a 98.32% adsorption percentage. In comparison, the ideal concentration of Cu metal ions was 60 ppm with a 98.25% adsorption percentage.	(Setiawan, 2018)
		Pb^{2+} ions	The non-activated biosorbent can lower the concentration of the solution from 10.88 ppm to 2.89 ppm, whereas the activated biosorbent can only reduce the concentration of the solution to 3.17 ppm.	(Purwiandono & Haidar, 2022)
		Pb^{2+} ions	The optimum contact time is 30 minutes, the adsorbent weighs 15 grams, and the lead (Pb) concentration is 1.692 ppm with an adsorption efficiency of 83.08%.	(Almuchty et al., 2020)
		Copper and Lead ions	Cu and Pb ions reached their adsorption equilibrium in under 10 minutes, with respective adsorption capacities of 0.90 and 9.64 $mg.g^{-1}$. Cu(II) and Pb(II) had pseudo-2nd order kinetic mechanisms, with k values of $9.50x10^{-2}$ and 3.28 $g.mg^{-1}.min^{-1}$, respectively, that were consistent with the Ho kinetic model.	(Winata et al., 2020)
		Copper ions	For a solution concentration of 50 mg/L and a solution concentration of 100 mg/L, respectively, the optimal adsorbent mass for removing Cu(II) is 0.2 g/L and 0.4 g/L. The Langmuir model is the most suitable adsorption isotherm.	(Selvanathan et al., 2017)

		Malachite Green, Procion Red, and Congo Red Dyes	Red procion had the maximum adsorption capacity of 182.40 mg/g.	(Hasanah et al., 2022)
		Dyes (basic Fuhchin)	The optimum period for absorption was 30 minutes, while the optimum pH was just over 7. The Langmuir isotherm model's maximal absorption capacity was 108.70 mg/g.	(Lee & Ong, 2017)
		Malachite green	It was discovered that the contact time, starting dye concentration, and solution temperature increased MG dyes' adsorption. The MG adsorption on rambutan peel-based activated carbon was more favorable in pH >8 solutions.	(Ahmad & Alrozi, 2011)
		Methylene Blue	The optimum pH is greater than 4, and the Langmuir adsorption isotherm model has an adsorption capacity of 231.34 mg/g.	(Alrozi et al., 2012)
		Methylene Blue	The pH and temperature parameters of the solution were investigated for this investigation. As temperature and concentration increased, so did absorption. The most appropriate isotherm model, with an R^2 value of 0.90, is Freundlich based on the equilibrium data.	(Krishnaiah et al., 2014)
2	**Rambutan Seeds**	Cd^{2+} ions	The optimal adsorption condition is 14.25 mg/g at pH 5, 14 mg/g at a concentration of 250 ppm, 13.48 mg/g at 90 minutes, and 14.96 at contact time for 60 minutes with a speed of 150 rpm.	(Dewi & Dewata, 2019)
		Malachite green	The ideal adsorbent absorption conditions, measured in terms of contact time, pH, and temperature, are consecutively 1 hour, pH 8, and temperature 802°C, with an absorption percentage of 91.45%.	(Ahmad et al., 2016)
		Methyl red	The optimum condition is at pH 3, a starting concentration of 690 mg/L, an ideal mass of 0.1 g, an agitation speed of 50 rpm, and a contact period of 20 minutes. The Freundllich model is the comparable isotherm model.	(Zein et al., 2015)
3	**Rambutan Leaves**	Pb ions	Pb ions had a 98.83% adsorption efficiency at a concentration of 25 mg/L, a contact time of 45 minutes, and an ideal stirring speed of 80 rpm. According to observational data, the adsorption of lead metal (Pb) fits the Langmuir isotherm model, with a r value of 0.99.	(Mapiliandari & Herawati, 2020)
4	**Rambutan Stems**	Copper ions	At 120 minutes, the rise in adsorbed copper concentration peaked at a metal removal rate of 43.8%.	(Haryanto et al., 2021)

Results and Discussions

Characterization of Adsorbent

Several researchers have characterized adsorbents from rambutan peels, seeds, and leaves. Characterization helps to show how characteristics and adsorption affinity are related. FTIR (*Fourier Transform Infrared*) is a regularly used technique for characterization. FTIR reveals the surface functional groups of the biosorbent. Based on the FTIR analysis of rambutan peels performed by (Rinaldi et al., 2018) and (Hasanah et al., 2022), which revealed the presence of non-ionic carbonyl groups in the range of 1705.07 cm^{-1} to 1716.81 cm^{-1}, it was determined that rambutan peels contained lignin-cellulose, which vanishes during activation. These results indicated that the cellulose-lignin link is disrupted due to a result of a hydrolysis reaction to the methyl ester. There was also an O-H group with a peak at 3419.33cm^{-1} to 3425.58cm^{-1}; this hydroxide group (O-H) was created using a delignification method to give the adsorbent an extra active surface. At the peak of 1434.67cm^{-1} to 1442.75cm^{-1}, symmetrical carboxylate (-COO) groups were also found. In addition, the aromatic C-H group was found at the vibration of 756.1cm^{-1}, and the aliphatic C-H group was found at the peak of 1620.21 cm^{-1}.

The rambutan seed spectra revealed several peaks, including O-H bonds in alcohol at a peak range of 3330.61 cm^{-1} to 3865 cm^{-1} and C=O bonds in carboxylic acids at a peak of 1709,58 cm^{-1} to 1735 cm^{-1}. The peak shift happened after adsorption was completed, indicating interaction between the adsorbent and the adsorbate. Another peak found in the spectra results is the peak of 2850.01 cm^{-1}, which represents C=H stretching, the peak of 1463.39 cm^{-1} to 2525 cm^{-1}, which indicates a C=C bond, the peak of 787 cm^{-1} to 1115.5 cm^{-1}, which indicates the presence of C-O bonds in alcohol, and the peak of 719.30 cm^{-1} to 766.31, which indicates C-H bonds in metabenzene (Ahmad et al., 2016), (Ahmad et al., 2016). The spectrum of the rambutan leaf biosorbent reveals the presence of several groups, including the O-H group at peak 3316.51 cm^{-1}, the C=O group at peak 1720.00 cm^{-1}, the C=C group at peak 1613.27 cm^{-1}, the C-N group at area 1313.8 cm^{-1}, and the presence of the C-O group at area 1037.41 cm^{-1} (Ningsih et al., 2017). According to FTIR spectra, hydroxyl and carbonyl are the primary functional groups on the surface of the biosorbents used in the biosorption process.

The hydroxyl and carbonyl functional groups are essential in the adsorption process due to the strong chemical interactions they can form with the target compounds. These functional groups enable biosorbents to interact with the target compounds, facilitating adsorption. Carbonyl groups contain oxygen that can act as a hydrogen bond donor. This allows carbonyl groups to form hydrogen bonds with compounds that have available hydrogen to bond. This interaction is crucial in adsorbing compounds with hydroxyl or amide groups. Hydroxyl groups are strong hydrogen bond acceptors. They can form bonds with compounds that have acidic hydrogens. Hydroxyl groups in biosorbents can interact with compounds containing carboxyclic acid or phenolate groups, facilitating the adsorption of these compounds. (Rinaldi et al., 2018), (Ningsih et al., 2017).

Effect of Concentration

Concentration has an impact on adsorption as well. The variation in concentration impacts the number of particles in the solution. Since a solution contains more particles at greater concentrations, more solutes can be absorbed until it reaches equilibrium (Dewi & Dewata (2019). Because there are more adsorbate molecules when the starting concentration is high, it will take longer for the contact time to reach equilibrium (Ahmad & Alrozi, 2011). According to (Setiawan, 2018), Zn and Cu ion adsorption increased up to a specific concentration limit the more significant the solution concentration was In terms of dyes. Study by Ahmad et al., (2016) found the percentage of color loss reduced as the original dye's concentration was increased, and the percentage of color loss reduced. Table 3 show the effect of concentration.

Effect of Contact Time

Variating the contact time is one approach to assess an adsorbent's efficiency in adsorbing adsorbate; the optimum time will be observed with the optimum adsorption capacity. Researchers have tested rambutan peels, seeds, leaves, and stems as potential adsorbents. According to the findings of these investigations, the adsorption capacity will eventually start to decline after reaching the optimum point. These results from an increase in the adsorbate's adsorption by the adsorbent over time, followed by a gradual decrease in adsorption until saturation is reached. The saturation point is the point at where the adsorbent absorbs the most adsorbate.

Table 3. Effect of Concentration

Adsorbent	Adsorbate	Initial concentration	Optimum concentration	Reference
Rambutan Peels	Zn^{2+}, Cu^{2+}	20;40;60;80;100 ppm	Zn^{2+}: 40 ppm Cu^{2+}: 60 ppm	(Setiawan, 2018)
	Basic fuchsin	100;150;200 ppm	100 ppm	(Lee & Ong, 2017)
	Malachite Green	25;50;75;100 ppm	25 ppm	(Ahmad & Alrozi, 2011)
	Methylene Blue	25;50;100;200; 400;500 ppm	500 ppm	(Alrozi et al., 2012)
	Methylene Blue	3;6;9;12;15 ppm	15 ppm	(Krishnaiah et al., 2014)
Rambutan Leaves	Pb^{2+}	25;50;75;100;125 ppm	25 ppm	(Mapiliandari & Herawati, 2020)
Rambutan Seeds	Cd^{2+}	100; 150; 200;250; 300 ppm	250 ppm	(Dewi & Dewata (2019)
	Malachite Green	25;50;100;200; 300;400;500 ppm	25 ppm	(Ahmad et al., 2016)
	Methyl Red	25;50;75;100;125;150;175;200 ppm	25 ppm	(Zein et al., 2015)

Table 4 demonstrates the impact of contact time on optimum adsorption. The optimum contact time for the adsorbent to absorb the adsorbate is less than an hour, precisely 5, 20, 30, 45, and 60 minutes for each adsorption. This has an impact on both the adsorbate and the type of adsorbent.

Table 4. Effect of Contact Time

Adsorbent	Adsorbate	Contact time	Optimum time	Reference
Rambutan Peels	Ni^{2+}, Cu^{2+}	10 – 240 minutes (10 minutes interval)	60 minutes	(Rinaldi et al., 2018)
	Pb^{2+}	5;10;20;30 minutes	5 minutes	(Purwiandono & Haidar, 2022)
	Pb^{2+}	10;20;30 minutes	30 minutes	(Almuchty et al., 2020)
Rambutan Seeds	Cd^{2+}	30;45;60;75;90 minutes	60 minutes	(Dewi & Dewata,2019)
	Methyl Red	5;10;15;20;25 minutes	20 minutes	(Santhi et al., 2010)
Rambutan Leaves	Pb^{2+}	10; 20; 45; 60;90 minutes	45 minutes	(Mapiliandari & Herawati, 2020

One of the study results provided in Table 4 showed that the adsorption of Pb^{2+} utilizing the same adsorbate had different optimum times. Based on the results of Purwiandono et.al., activation was carried out using acid (HNO_3) and base (NaOH). Where HNO_3 served to dissolve biosorbent impurities, activating materials commonly used were HNO_3 and H_2SO_4; this was because both materials possessed H^+ ions that dissolved metal impurities, mainly increasing the number of active sides. It then continued activation with NaOH (Purwiandono & Haidar, 2022). In the results of Almuchty et.al, it was explained that the activation process only used 0.1 M NaOH and soaking was carried out for approximately 24 hours. Theoretically, soaking with NaOH aims to remove lignin compounds in biosorbents (Almuchty et al., 2020) . Therefore, the different optimum time in the adsorption utilizing the same adsorbate (Pb^{2+}) is influenced by difference in treatment of adsorbent preparation, which is called as activation stage.

Effect of pH

Potential Hydrogen (pH) is one variable that determines adsorption capacity by influencing the adsorption process. Table 5 shows that the pH at which metal ion solutions absorb most efficiently is pH 5. Because there is a repulsive force at low pH, H^+ ions will stop metal ions from approaching the surface of the adsorbent. Contrarily, as the pH increases, the amount of H^+ ions present decreases, making the surface of the adsorbent negative and making metal ions more amenable to adsorption (Pavasant et al., 2006). Table 5 show the effect of PH.

Table 5. Effect of pH

Adsorbent	Adsorbate	pH range	Optimum pH	Reference
Rambutan Peels	Ni^{2+}, Cu^{2+}	2-7	5	(Rinaldi et al., 2018)
	Malachite green	2-8	>8	(Ahmad & Alrozi, 2011)
	Methylene blue	2-12	>6	(Alrozi et al., 2012)
	Methylene blue	2-12	12	(Krishnaiah et al., 2014)
Rambutan Seeds	Cd^{2+}	1-6	5	(Dewi & Dewata (2019)
	Malachite green	2-12	8	(Ahmad et al., 2016)
	Methyl red	2-9	3	(Santhi et al., 2010)

On the other hand, dye contaminants are best absorbed in alkaline pH solutions. Due to the increased number of positive sites at low pH and the reversal of negative sites, adsorption does not take place optimally, which does not facilitate the adsorption of dye cations. Another idea states that an acidic environment will cause an abundance of H^+ ions in the solution to compete with dye cations for adsorption sites, potentially reducing methylene blue adsorption. However, the adsorption of methylene blue appears to increase when the pH is greater than pH > 6 (Baek et al., 2010) (Alrozi et al., 2012). The adsorption of the dye pollutant, which is determined by the cation or anion categorization of the related pollution, determines the pH of the solution (Afroze & Sen, 2018). However, not all dyes will reach optimum conditions at high pH, i.e methyl red. The optimal absorption of methyl red happens at an acidic pH because the H^+ ion will be negatively charged, hindering the adsorption process of methyl red (Santhi et al., 2010) (Mas Haris & Sathasivam, 2009).

Table 6. Effect of Amount of Adsorbent

Adsorbent	Adsorbate	Adsorbent dossage	Optimum dossage	Reference
Rambutan peels	$Zn^{2+,}$ Cu^{2+}	20, 40,60,80,100 mg	40 mg	(Setiawan, 2018)
	Cu^{2+}	0.2;0.4;0.8;1;2;4 g	0.2 g	(Selvanathan et al., 2017)
	Methylene Blue	0.2;0.4;0.5;0.8;1g	0.5 g	(Alrozi et al., 2012)
	Methyl Red	0.1;0.2;0.2;0.3;0.4;05g	0.1 g	(Zein et al., 2015)
Rambutan seeds	Methylene Red	0.1;0.2;0.3;0.4;0.5;0.6 g	0.1 g	(Santhi et al., 2010)

Effect of Amount of Adsorbent

The amount of the utilized adsorbent also influences the adsorption capacity in the adsorption process. The quantity of pollutant-binding sites on an adsorbent is correlated with mass. Therefore, the greater the interaction with pollutants and the better the adsorption, the more active the sites, but this will eventually end. The aggression of adsorption sites, which causes the overall surface area of the adsorbent to shrink, influences this trend, which means that the adsorption capacity will also decrease the more mass there is (Santhi et al., 2010).

According to Table 6, the optimal dose for the adsorption is less than 0.5 grams for dyes and heavy metals.

Adsorption Isotherm

The adsorption isotherm helps to assess the adsorption process between the adsorbent and adsorbate. The Langmuir and Freundlich adsorption isotherm model is the method that is frequently employed. The adsorbent and adsorbate are chemically linked, forming a monolayer layer, and the surface is homogeneous in the Langmuir isotherm equation model. On the other hand, physisorption interactions produce a multilayer in the Freundlich isotherm model. Adsorption interaction is effective and efficient when the R^2 value is between 0 and 1 (Eze et al., 2019). Table 7 shows that the R^2 value is quite close to one. The Freundllich isotherm model is appropriate for the adsorption of heavy metal ions, whereas the Langmuir isotherm model is appropriate for the adsorption of dyes.

Table 7. Adsorption Isotherm

Adsorbent	Adsorbate	Isotherm model used	Isotherm Model	Coefficient	Reference
Rambutan peels	Pb^{2+}	LM, FM	FM	$R^2 = 0.999$	(Purwiandono & Haidar, 2022)
	M^{2+}	LM, FM	FM	$R^2 = 0.999$	(Mohadi et al., 2022)
	Ni^{2+}, Cu^{2+}	LM, FM	FM	$R^2 = 0.948$ Ni^{2+}, $R^2 = 0.990$ Cu^{2+},	(Rinaldi et al., 2018)
	Methylene Blue	LM, FM, TM	LM	$R^2 = 0.98$	(Alrozi et al., 2012)
	Methylene Blue	LM, FM, TM	FM	$R^2 = 0.898$	(Krishnaiah et al., 2014)
Rambutan leaves	Pb^{2+}	LM, FM	LM	$R^2 = 0.999$	(Mapiliandari & Herawati, 2020
Rambutan seeds	Cd^{2+}	LM	LM	$R^2 = 0.991$	(Dewi, & Dewata, 2019)
	Malachite green	LM, FM, TM, SIPS RP, VS, BS, DR	FM	$R^2 = 0.985$	(Ahmad et al., 2016)
	Methyl Red	LM, FM, TM	LM	$R^2 = 0.914$	(Santhi et al., 2010)

*Note: LM= Langmuir, FM= Freundlich, TM= Temkin

Challenges for Industrial Application

Using the peels, seeds, leaves, and stems of rambutan as biosorbent on an industrial scale poses several challenges. Ensuring a consistent supply of rambutan biomass with varying qualities due to seasonal changes and environmental conditions can be problematic. Preparing and pre-treating the biomass for optimal biosorption demands labor-intensive and time-consuming processes. At an industrial scale, achieving and controlling the ideal biosorption conditions, including pH, contact time, and concentration, can be complex. Moreover, competing with conventional adsorbents, such as activated carbon or synthetic resins, in terms of efficiency is a requirement. Regenerating and reusing the biosorbent while preserving its adsorption capacity is vital for economic viability. Scaling up laboratory processes, waste management, quality control, cost-effectiveness and compliance with regulatory and environmental standards must be addressed for the booming industrial use of rambutan-based biosorbents. A multidisciplinary approach encompassing chemistry, engineering, and environmental science is crucial in overcoming these challenges and creating sustainable industrial processes with rambutan biomass as a biosorbent.

Conclusion

The rapid development of the times is directly proportionate to the expansion of the industry. Not only heavy metals but also textile industry dyes are another issue that needs to be taken into account. These issues will worsen, putting the health of anyone who come into contact with polluted waters in danger if not taken seriously. Adsorption is one of the methods to get rid of pollutants due to its effectiveness in terms of cost and adsorption. The peels, seeds, leaves, and stems of rambutan, which are frequently not processed, are targeted for reprocessing into adsorbents. As determined by FTIR characterization, the adsorbent's active surface is provided by carboxylic and hydroxyl groups.

Rambutan demonstrated that cationic pollutants could be removed in a pH range of 6.0 to 12.0 while anionic pollutants could be removed at pH 5.0 or lower. The optimal pH of the solution during this adsorbent's adsorption will reach a certain point before adsorption starts to decline. Similar to the amount of the adsorbent utilized, the aggressiveness of the adsorption sites related to surface area will result in a decline in adsorption after reaching the optimum point. The adsorbent dose with a combination of less than 0.5 g in this review exhibits the best adsorption. Similar to the contact time, the adsorption will decrease as it approaches saturation. Rambutan seeds and peels demonstrated optimal adsorption contact times of less than an hour. The best adsorption isotherm model also depends on the kind of adsorbent being utilized; the Freundlich isotherm model is appropriate for the adsorption of heavy metal ions, whereas the Langmuir isotherm model is appropriate for the adsorption of dyes.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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