Biochemical Systematics and Ecology 106 (2023) 104582

Contents lists available at ScienceDirect

Biochemical Systematics and Ecology

journal homepage: www.elsevier.com/locate/biochemsyseco

Banana peel as bioremediation agent in textile dyes decolorization for wastewater management

Nisaporn Muhamad [a,*], Piyasiri Soontornnon Sinchai [b], Ubol Tansom [c]

[a] *Cosmetic Science and Beauty Program, Faculty of Science Technology and Agriculture, Yala Rajabhat University, Thailand*
[b] *General Science Program, Faculty of Science Technology and Agriculture, Yala Rajabhat University, Thailand*
[c] *Chemistry Technology and Innovation Program, Faculty of Science Technology and Agriculture, Yala Rajabhat University, Thailand*

ARTICLE INFO

Keywords:
Banana peels
Bioremediation
Textile dyes
Wastewater management

ABSTRACT

The aim of this study is to investigate the possibility of utilizing enzymatic and adsorbent banana peel extract as a bioremediation agent by evaluating its adsorption capacity on selected reactive dyes commonly used in the textile industry. The effects of polyphenol oxidase and peroxidase enzyme, pH, temperature, dye concentration on adsorption capacity were examined. The polyphenol oxidase enzyme isolated from banana peel extracted with buffer pH 6.5 showed highest decolorization of Methylene blue and Basic fuchsin while the polyphenol oxidase enzyme isolated from banana peel extracted with buffer pH 7.5 had the greatest decolorization. Complete adsorption was observed after 24 h of incubation for all banana peel extract concentrations. At pH 6–11, the adsorption capacity of banana peel was 60%, 70%, and 85%, respectively, and peaked after 24 h (96%). When the temperature was greater than 50 °C, the adsorption capacity increased overtime and reached 98% after 24 h. It can be concluded that banana peel can be utilized as an effective bioremediation agent due to its high adsorption capacity on selected textile dyes.

1. Introduction

Textile industrial wastewater issues are regarded as serious matter that requires immediate attention. Methylene blue, Acid fuchsin and Basic fuchsin are selected for this study because they are the most commonly used cationic dye for various material in textile industry. Although Methylene blue itself may not be considered highly toxic, however, it can cause respiratory problems, vomiting, irritation, diarrhoea, and nausea in humans and animals when consumed at high dose. While Basic fuchsin and Acid fuchsin are generally reported to be toxic and carcinogenic. The extensive use of these dyes has resulted in highly colored effluents that may have adverse impact on receiving water bodies (Zoolinger, 1987 and Umbuzeiro et al., 2005). The removal of these dyes from wastewater systems is of great concern and should be addressed and implemented urgently. The use of chemicals to treat wastewater is not cost-effective approach (Sarasa et al., 1998). Thus, various conventional methods are applied and dye adsorption is a novelty method. As a result, various conventional methods are used, with dye adsorption being a novel method.

Banana is widely consumed in the three southern border provinces of Thailand, resulting in a substantial amount of waste banana peels. Banana peels are reported to contain high amounts of polyphenol oxidase and peroxidase (Wuyts et al., 2006; Muhamad et al., 2012). Previous studies highlighted potential of various bioremediation agent for dye removal such as peroxidase enzyme extracted from rubber and its capacity to remove Azo dye (Chanwun et al., 2013), Bamboo shoot extract to remove Methylene blue (Ozer et al., 2007), Banana peel to remove Malachite green and Methylene blue (Muntaka et al., 2018) and Congo red (Mondal and Kar, 2018) and Banana peel biochar to remove Black 5 dye (Kapoor et al., 2022). The adsorption method has captivated the interest of many researchers because it is both environmentally friendly and cost-effective (Ruan et al., 2019). Various adsorbents can be chosen based on their adsorption capacity and potential for reuse. This study is aimed at determining the possibility of utilizing banana peel as bioremediation agent for dye removal due to its physiological characteristic and chemical compositions. The potential of enzymatic and absorbent banana peel was examined for variable extract pH, adsorbent concentration, temperature and contact time, followed by morphological characteristic observation of the banana peel.

* Corresponding author.
E-mail address: nisaporn.m@yru.ac.th (N. Muhamad).

https://doi.org/10.1016/j.bse.2022.104582
Received 28 September 2022; Received in revised form 10 December 2022; Accepted 29 December 2022
Available online 2 January 2023

2. Materials and methods

2.1. Preparation of banana peel extract

Bananas (*Mussa* ssp.) purchased from a local stand in Yala Province was extracted with 0.2 M Phosphate buffer solution containing 3% PVP and 0.25% Triton X-100. After that, all BP samples were centrifuged at 4 °C for 20 min at 10,000 rpm.

2.2. Polyphenol oxidase activity determination

Polyphenol oxidase (PPO) activity was determined by measuring the initial rate of quinone formation, as indicated by an increase in the absorbance units (AUs) at 420 nm. An increase in absorbance of 0.001 min^{-1} was taken as one unit of enzyme activity. The increase in absorbance was linear with time for the first 120 s. The sample contained 1 mL of a 0.1 M catechol substrate solution prepared in Phosphate buffer (0.1 M, pH 6.5) and 0.04 mL of the BP extract.

2.3. Peroxidase activity determination

Peroxidase activity was determined spectrophotometrically as described by Perez et al. (2002). Guaiacol was used as a substrate. The reaction mixture contained 0.25% guaiacol in 0.01 M potassium phosphate, pH 7.0, the 0.1 M H_2O_2 and the 100 µl of the BP extract. The enzymatic activity was estimated by measuring the absorbance of colored product at 470 nm using a UV–vis spectrophotometer. One unit of peroxidase activity represents the amount of enzyme catalyzing the oxidation of 1 µmol of substrate within 1 min.

2.4. Adsorption capacity determination

Banana peel were washed at least five times with distilled water, then dried at 60 °C for 48 h to remove dirt and moisture. The dried BP was crushed and sieved to a size of 0.5–1 mm before being cured with each dye at a concentration of 13 mg/L. Different amounts of dried BP (0.1, 0.2, 0.4, 0.8, and 1.6 g) were added to 100 mL of dyes, then incubated for 1, 2, 3, and 24 h for Methylene blue and 20, 40, 60, 80, 100, 120 min for Acid Fuchsin and Basic fuchsin. The percentage of adsorption was calculated using the formula below:

$$\% \ Adsorption = \frac{ODi - ODe}{ODi} x\ 100 \tag{1}$$

where ODi is the absorbance before adding the BP and ODe is the absorbance after adding the BP.

2.5. Effect of pH on adsorption capacity

The optimum acid-base conditions were examined with different pH values (pH 3–11), using a set of 250 mL Erlenmeyer flask containing 13 mg/L of each dye. Then the 0.1 g of BP was added to each flask. The incubation was conducted at 1, 2, 3, and 24 h for Methylene blue and 20, 40, 60, 80, 100 and 120 min for Acid fuchsin and Basic fuchsin. The adsorption capacity was determined using a UV-spectrophotometer at a wavelength of 667 nm (Methylene blue), 546 nm (Acid fuchsin) and 545 nm (Basic fuchsin) before and after the adsorption.

2.6. Effect of temperature on adsorption capacity

The effect of temperature on adsorption capacity was determined using a set of 250 mL Erlenmeyer flasks containing 13 mg/L of each dye. Each flask was added 0.1 g of BP and incubated for 1, 2, 3, and 24 h for Methylene blue and 20, 40, 60, 80, 100, and 120 min for Acid fuchsin and Basic fuchsin. A UV spectrophotometer was used to evaluate the percentage of dye absorption at wavelengths of 667 nm (Methylene blue), 546 nm (Acid fuchsin), and 545 nm (Basic fuchsin) before and after the adsorption.

Table 1
Enzymatic effects on adsorption capacity at various pH of extraction buffer.

Enzyme	pH	% Adsorption		
		Methylene blue	Acid fuchsin	Basic fuchsin
Polyphenol oxidase	6.0	95.23 ± 0.31	98.33 ± 1.67	96.75 ± 0.88
	6.5	97.69 ± 0.16	100	96.72 ± 1.16
	7.5	96.51 ± 0.16	100	99.01 ± 0.14
Peroxidase	6.0	95.23 ± 0.31	98.33 ± 1.67	96.75 ± 0.88
	6.5	97.69 ± 0.16	100	96.72 ± 1.16
	7.5	96.51 ± 0.16	100	99.01 ± 0.14

Table 2
The percentage of adsorption of Methylene blue on 0.1 g Banana peel (BP) extract for various values of dye concentration.

Dye concentration (mg/L)	% Adsorption			
	1 h	2 h	3 h	24 h
6.5	92.28 ± 3.41	93.05 ± 2.59	100	100
13	81.30 ± 7.83	85.97 ± 4.13	94.25 ± 5.63	100
26	72.81 ± 6.82	80.77 ± 5.42	93.41 ± 3.15	99.22 ± 1.15
39	70.09 ± 1.45	77.67 ± 2.51	89.63 ± 2.64	97.84 ± 1.62
52	66.39 ± 4.07	73.44 ± 1.82	86.23 ± 4.97	95.17 ± 2.46
65	47.49 ± 2.68	66.76 ± 4.37	78.98 ± 6.28	94.18 ± 3.41

3. Results and discussion

3.1. Enzymatic effects on dye removal

The polyphenol oxidase (PPO) enzyme isolated from banana peel extract with an extraction buffer pH of 6.5 had the highest ability to remove methylene blue. The polyphenol oxidase enzymes extracted with buffer pH 7.5 removed the most Acid fuchsin and Basic fuchsin. Peroxidase enzyme had a similar effect, with extraction buffer pH 6.5 yielding the greatest decolorization of Methylene blue and buffer pH 7.5 yielding greater removal of Acid fuchsin and Basic fuchsin (Table 1).

3.2. Effect of dye concentrations on adsorption capacity

The results showed that the Methylene blue adsorption capacity of BP at 0.1 g concentration varies with increasing time. Complete dye adsorption was achieved with BP samples at all concentrations after 24 h of incubation (Table 2). Similar trend was observed for Acid fuchsin and Basic fuchsin (Table 3). The findings revealed that after 1 h of incubation with BP extract, the dye at a concentration of 6.5 mg/L was absorbed up to 92.28%, and the dye was completely absorbed after 3 h. It implies that increasing the dye concentration and the amount of time spent incubating with BP extract improves dye adsorption. The adsorption ability of Acid fuchsin and Basic fuchsin was enhanced by increasing the dye concentration and the amount of time spent incubating with BP extract. Our findings are consistent with previous study on the Methylene Blue adsorption capacity of bamboo shoots. Because surface area is proportional to adsorbent amount, increasing adsorbent amount leads to a higher percentage of Methylene Blue adsorption (Ozer et al., 2007).

3.3. Effects of pH on adsorption capacity

When 0.1 g of BP was incubated with Methylene blue for 1, 2, and 3 h

Table 3
The percentage of adsorption of Acid fuchsin and Basic fuchsin on 0.1 g Banana peel (BP) extract for various values of dye concentration.

	Concentration (mg/L)	% Adsorption					
		20 min	40 min	60 min	80 min	100 min	120 min
Acid Fuchsin	6.5	11.04 ± 1.31	12.64 ± 0.22	13.14 ± 0.13	15.18 ± 0.45	6.76 ± 1.74	8.31 ± 1.30
	13	7.03 ± 0.57	5.91 ± 0.31	5.93 ± 0.85	7.17 ± 0.32	4.21 ± 0.84	4.08 ± 0.40
	26	2.77 ± 0.36	3.31 ± 0.26	3.59 ± 0.26	4.06 ± 0.19	1.70 ± 0.14	1.37 ± 0.14
	39	3.94 ± 0.15	4.41 ± 0.17	4.81 ± 0.16	5.10 ± 0.10	1.49 ± 0.07	1.54 ± 0.10
	52	2.20 ± 0.11	2.49 ± 0.14	2.76 ± 0.10	2.96 ± 0.08	1.01 ± 0.21	1.07 ± 0.19
	65	3.25 ± 0.12	3.72 ± 0.27	3.87 ± 0.28	4.09 ± 0.17	1.06 ± 0.09	0.87 ± 0.15
Basic Fuchsin	6.5	87.52 ± 0.24	89.99 ± 0.97	91.44 ± 0.39	96.78 ± 1.75	85.07 ± 3.80	93.91 ± 5.7
	13	61.58 ± 21.42	76.13 ± 18.09	86.02 ± 6.42	92.35 ± 2.82	81.16 ± 3.48	80.63 ± 12.09
	26	44.93 ± 28.33	68.04 ± 28.15	87.17 ± 6.41	88.6 ± 5.4	81.2 ± 2.91	62.45 ± 21.45
	39	25.89 ± 8.89	39.18 ± 9.22	63.34 ± 5.2	78.58 ± 4.02	74.99 ± 3.02	76.91 ± 2.17
	52	4.15 ± 3.61	28.79 ± 4.66	57.23 ± 2.79	67.53 ± 2.53	69.12 ± 3.01	65.42 ± 1.84
	65	3.94 ± 0.96	15.07 ± 0.96	17.94 ± 2.43	23.36 ± 0.17	36.76 ± 10.31	43.17 ± 2.16

Table 4
The percentage of adsorption of Methylene blue on 0.1 g Banana peel (BP) extract at various pH.

pH	%Adsorption			
	1 h	2 h	3 h	24 h
3	39.25 ± 0.64	48.11 ± 2.06	58.53 ± 2.24	81.58 ± 1.63
4	41.77 ± 0.69	49.53 ± 2.16	63.41 ± 1.59	90.76 ± 2.96
5	47.33 ± 1.56	59.48 ± 0.92	72.89 ± 2.69	95.19 ± 1.13
6	64.93 ± 1.68	78.99 ± 1.94	86.89 ± 1.57	97.11 ± 0.24
7	58.51 ± 0.61	82.66 ± 1.02	88.49 ± 1.12	97.54 ± 4.46
8	61.45 ± 3.39	84.57 ± 4.27	89.94 ± 4.59	98.02 ± 0.32
9	65.02 ± 2.76	72.96 ± 3.44	90.34 ± 2.62	97.27 ± 0.68
10	62.31 ± 4.18	69.79 ± 3.54	86.89 ± 1.33	96.67 ± 2.26
11	73.4 ± 3.53	82.74 ± 2.36	92.44 ± 3.46	96.59 ± 0.24

at pH 6–11, the adsorption capacity of BP was 60%, 70%, and 85%, respectively, and when the contact time reached 24 h, the greatest adsorption capacity was observed (96%) (Table 4). A similar trend was observed for Acid fuchsin that the adsorption capacity of the banana peel was found to be greater than 60% after 80 min at pH 9–11. The adsorption capacity of banana peel (BP) extract also increased at higher pH levels for Basic fuchsin (pH 9–11) as shown in Table 5.

This is due to the fact that BP has a greater adsorption capacity for reactive dyes in neutral and basic than in acidic solutions. Because the adsorbent is affected by the pH of the solvent. This may have an impact on the solute's ionic dissociation because of the hydrogen ions in acidic conditions, it clings effectively to the adsorbent surface, making the adsorbent less porous. As a result, the ability to absorb dye is reduced.

3.4. Effects of temperature on adsorption capacity

Our findings indicate that the adsorption capacity of banana peel (BP) extract increased with time and temperature. It increased to more than 90% at temperatures above 50 °C, and 95% when contact time was extended by 2–3 h, before peaking after 24 h (Table 6). The adsorption capacity of banana peel (BP) extract increased over time and peaked at 80 min for Basic fuchsin, but it was unaffected by Acid fuchsin as shown in Table 7. This is explained by the fact that increasing temperature accelerates the diffusion of the adsorbed substance into the adsorbent porosity, so the adsorption capacity of BP increases with increasing temperature.

3.5. Morphological structure of banana peels (BP)

Before and after the absorption of various dyes from the BP. The morphological structure of BP was examined using a scanning electron microscope (SEM) type JSM-5800LV from JEOL, Japan. The porosity of BP was observed to be relatively high prior to adsorption. However, once the dye has been absorbed, the dye molecules may have entered the BP porosity, causing the pore size to change, resulting in a reduction in pore size (Fig. 1).

Table 5
The percentage of adsorption of Acid fuchsin and Basic fuchsin on 0.1 g Banana peel (BP) extract at various pH.

	pH	% Adsorption					
		20 min	40 min	60 min	80 min	100 min	120 min
Acid fuchsin	3	6.56 ± 0.22	12.24 ± 0.28	13.36 ± 0.27	15.12 ± 0.27	11.71 ± 0.11	6.84 ± 0.38
	4	3.67 ± 0.34	5.26 ± 0.43	6.58 ± 0.09	7.71 ± 0.00	4.88 ± 0.38	4.23 ± 0.38
	5	1.60 ± 0.30	3.69 ± 0.20	4.47 ± 0.15	6.43 ± 0.37	5.60 ± 0.11	3.96 ± 0.50
	6	3.25 ± 0.62	4.45 ± 0.34	5.94 ± 0.52	6.96 ± 0.43	5.31 ± 0.43	4.90 ± 0.36
	7	6.25 ± 0.97	10.54 ± 0.85	13.60 ± 0.37	16.05 ± 0.93	13.19 ± 1.45	11.37 ± 0.54
	8	6.84 ± 2.56	13.60 ± 0.85	18.52 ± 2.61	27.64 ± 1.78	30.22 ± 2.84	32.98 ± 4.84
	9	13.76 ± 15.9	33.03 ± 2.43	40.67 ± 2.80	64.83 ± 5.05	73.36 ± 4.21	84.07 ± 2.30
	10	34.98 ± 2.06	49.17 ± 1.51	63.70 ± 2.06	85.48 ± 4.12	90.85 ± 1.65	92.86 ± 1.12
	11	51.11 ± 2.78	56.89 ± 2.04	68.89 ± 4.07	82.22 ± 2.04	81.06 ± 4.42	89.70 ± 4.76
Basic fuchsin	3	12.20 ± 1.97	31.28 ± 2.03	46.57 ± 1.20	51.26 ± 0.70	57.26 ± 084	48.00 ± 0.63
	4	32.81 ± 1.01	41.39 ± 0.94	45.86 ± 2.25	52.32 ± 2.16	40.49 ± 3.02	38.80 ± 7.04
	5	43.70 ± 5.09	55.24 ± 9.12	59.88 ± 6.40	64.06 ± 6.27	45.01 ± 2.60	42.43 ± 6.48
	6	65.29 ± 5.32	77.11 ± 2.64	79.87 ± 1.40	81.62 ± 1.15	50.15 ± 9.20	31.50 ± 8.79
	7	50.55 ± 5.46	83.19 ± 0.97	84.60 ± 0.53	86.25 ± 1.08	73.60 ± 3.78	25.33 ± 1.84
	8	51.69 ± 4.84	56.47 ± 1.69	67.15 ± 3.86	70.00 ± 1.63	40.50 ± 2.98	38.61 ± 3.76
	9	51.73 ± 2.41	53.58 ± 1.77	55.44 ± 0.72	59.11 ± 0.61	16.37 ± 2.77	15.29 ± 2.27
	10	84.75 ± 0.44	88.71 ± 1.34	93.17 ± 1.03	94.61 ± 1.32	78.47 ± 1.78	86.13 ± 164
	11	81.21 ± 0.32	83.56 ± 0.81	86.07 ± 0.39	94.21 ± 0.23	87.45 ± 1.83	91.60 ± 0.56

Table 6
The percentage of adsorption of Methylene blue on 0.1 g Banana peel (BP) extract at various temperature.

Temperature (°C)	% Adsorption			
	1 h	2 h	3 h	24 h
25	71.08 ± 4.06	79.47 ± 2.76	88.95 ± 3.01	97.75 ± 1.29
30	68.82 ± 10.73	80.57 ± 9.17	83.26 ± 9.09	98.43 ± 0.61
40	79.95 ± 3.88	84.16 ± 3.63	89.83 ± 2.28	98.53 ± 0.19
50	85.28 ± 3.78	92.40 ± 1.82	95.08 ± 0.60	98.83 ± 0.17
60	88.87 ± 3.13	93.32 ± 0.94	95.29 ± 1.06	98.41 ± 0.44
70	90.35 ± 0.41	92.70 ± 1.65	94.22 ± 2.67	99.12 ± 0.18
80	90.99 ± 4.37	94.65 ± 1.02	96.17 ± 0.54	97.59 ± 1.63
90	93.11 ± 0.65	95.20 ± 2.37	95.49 ± 2.61	97.54 ± 0.73
95	93.42 ± 0.90	96.05 ± 0.56	96.53 ± 0.3	99.37 ± 0.19

4. Conclusions

This study focuses on the adsorption capacity of textile dyes by means of bioremediation. Methylene blue, Acid fuchsin, and Basic fuchsin are widely used in the textile industry. Our results show that the adsorption capacity of banana peel extract increased with contact time. Complete dye adsorption was achieved after 24 h. Results obtained from the effect of pH on adsorption capacity imply that banana peel extract becomes more efficient in neutral and basic solutions rather than in acidic solutions that may result from hydrogen ions in acidic conditions that cling more to the adsorbent surface, making the adsorbent less porous and thus reducing adsorption capacity. The effect of temperature on adsorption capacity was also observed in Methylene Blue and Basic Fuchsin, where the adsorption was higher than 90% at temperatures above 50 °C before peaking after 24 h. This can be explained by the fact that increasing temperature accelerates the diffusion of the adsorbed substance into the adsorbent porosity, resulting in increased adsorption capacity. It can be concluded that banana peel can be utilized as an effective bioremediation agent due to its high adsorption capacity of selected textile dyes; however, further studies are required to effectively evaluate the efficacy of banana peel in different environmental conditions.

Table 7
The percentage of adsorption of Acid fuchsin and Basic fuchsin on 0.1 g Banana peel (BP) extract at various temperature.

	Temperature (°C)	%Adsorption					
		20 min	40 min	60 min	80 min	100 min	120 min
Acid fuchsin	25	6.01 ± 0.48	7.49 ± 0.48	8.44 ± 0.18	9.14 ± 0.16	4.30 ± 0.77	3.99 ± 0.48
	30	11.04 ± 0.42	11.77 ± 0.26	12.46 ± 0.31	12.88 ± 0.27	3.23 ± 0.36	3.96 ± 0.44
	40	12.50 ± 0.10	13.25 ± 0.26	14.24 ± 0.27	15.13 ± 0.33	4.25 ± 0.53	4.68 ± 0.82
	50	15.22 ± 0.37	17.02 ± 0.48	18.52 ± 0.16	19.61 ± 0.10	5.82 ± 0.43	4.26 ± 0.78
	60	15.53 ± 0.16	17.15 ± 0.27	19.01 ± 0.21	19.90 ± 0.39	5.83 ± 0.18	4.65 ± 0.50
	70	16.35 ± 0.21	17.81 ± 0.28	19.06 ± 0.38	20.10 ± 0.28	6.06 ± 0.62	5.58 ± 0.37
	80	18.46 ± 0.48	19.43 ± 0.63	21.33 ± 0.42	22.75 ± 0.49	6.62 ± 0.44	7.77 ± 0.29
	90	18.65 ± 0.41	19.41 ± 0.26	20.76 ± 0.59	22.00 ± 0.22	5.39 ± 0.46	5.53 ± 0.24
	95	20.81 ± 0.41	21.84 ± 0.47	22.74 ± 0.33	24.19 ± 0.26	4.84 ± 0.33	4.28 ± 1.08
Basic fuchsin	25	66.78 ± 2.87	68.41 ± 5.05	69.78 ± 5.43	71.42 ± 4.31	28.83 ± 11.76	41.69 ± 2.07
	30	86.18 ± 1.85	88.27 ± 0.11	92.12 ± 0.28	92.70 ± 0.14	48.50 ± 6.38	57.82 ± 1.82
	40	93.85 ± 1.61	96.59 ± 0.72	97.784 ± 0.26	98.22 ± 0.26	76.58 ± 8.17	68.13 ± 11.62
	50	93.54 ± 1.50	98.04 ± 0.73	98.51 ± 0.09	99.40 ± 0.09	94.48 ± 1.74	96.18 ± 0.52
	60	91.85 ± 0.36	97.91 ± 0.62	98.71 ± 0.36	99.41 ± 0.41	96.46 ± 2.49	94.19 ± 4.21
	70	95.41 ± 0.61	95.99 ± 0.61	97.03 ± 0.90	97.78 ± 0.59	61.91 ± 9.93	79.48 ± 5.12
	80	92.13 ± 2.61	94.44 ± 0.39	95.74 ± 0.79	97.62 ± 0.19	77.64 ± 4.29	44.06 ± 4.14
	90	94.49 ± 0.11	95.17 ± 0.11	96.58 ± 0.05	96.85 ± 0.05	58.68 ± 1.13	66.66 ± 1.00
	95	93.06 ± 0.46	94.45 ± 0.19	94.97 ± 0.14	95.3 ± 0.08	44.68 ± 2.52	40.69 ± 1.14

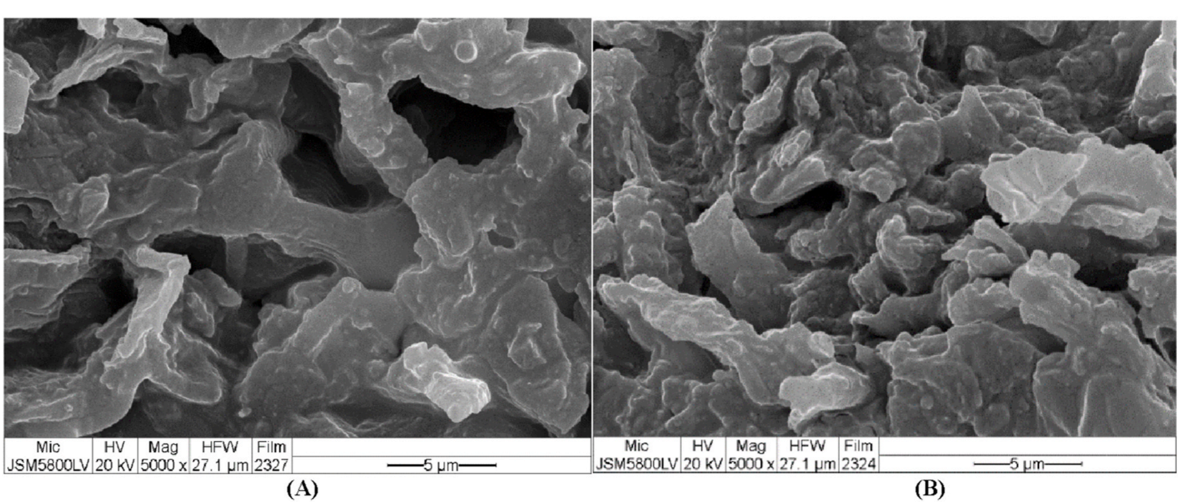

Fig. 1. The morphological structure of BP was examined using a scanning electron microscope (SEM) before (A) and after (B) dye adsorption.

Funding

This research was financially supported by the 2017 Government fund, Yala Rajabhat University.

Ethical approval

This research does not involve any animal or human subjects.

Authors' contributions

Conceptualization & Methodology; Nisaporn Muhamad, Formal analysis, Investigation & Data curation; Nisaporn Muhamad, Piyasiri Soontornnon Sinchai & Ubol Tansom, Writing – original draft; Nisaporn Muhamad, Piyasiri Soontornnon Sinchai & Ubol Tansom, Writing – review & editing; Nisaporn Muhamad, Project administration; Nisaporn Muhamad, Funding acquisition; Nisaporn Muhamad.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank the Yala Rajabhat University for providing a research fund and facilities.

References

Chanwun, T., Muhamad, N., Chirapongsatonkul, N., Churngchow, N., 2013. *Hevea brasiliensis* cell suspension peroxidase: purification, characterization and application for dye decolorization. Amb. Express 3, 14.

Kapoor, R.T., Rafatullah, M., Siddiqui, M.R., Khan, M.A., Sillanpaa, M., 2022. Removal of reactive Black 5 dye by banana peel biochar and evaluation of its phytotoxicity on tomato. Sustainability 14, 4176.

Mondal, N.K., Kar, S., 2018. Potentiality of banana peel for removal of Congo red dye from aqueous solution: isotherm, kinetics and thermodynamics studies. Appl. Water Sci. 8, 157.

Muntaka, D., Zakariyya, U.Z., Maje, A.H., 2018. Cationic dyes removal using low-cost banana peel biosorbent. Am. J. Mater. Sci. 8 (2), 32–38.

Muhamad, N., Chirapongsatonkul, N., Churngchow, N., 2012. Defense-related polyphenol oxidase from *Hevea brasiliensis* cell suspension: purification and characterization. Appl. Biochem. Biotechnol. 167 (1), 177–189.

Ozer, D., Dursum, G., Ozer, A., 2007. Methylene blue adsorption from aqueous solution by dehydrated peanut hull. J. Hazard Mater. 144, 171–179.

Perez, F.J., Villegas, D., Mejia, N., 2002. Ascorbic acid and flavonoid-peroxidase reaction as a detoxifying system of H_2O_2 in grapevine leaves. Phytochemistry 60, 573–580.

Ruan, W., Hu, J., Qi, J., Hou, Y., Zhou, C., Wei, X., 2019. Removal of dyes from wastewater by nanomaterials: a review. Adv. Mater. Lett. 10 (1), 9–20.

M. P Sarasa, J.R., Ormad, M.P., Gimeno, E., Puig, A., Ovelleiro, J.L., 1998. Treatment of a wastewater resulting from dyes manufacturing with ozone and chemical coagulation. Water Res. 32 (9), 2721–2727.

Umbuzeiro, G.A., Freeman, H.S., Warren, S.H., Oliveira, D.P., Terao, Y., Watanabe, T., Claxton, L.D., 2005. The contribution of azo dyes to the mutagenic activity of the Cristais River. Chemosphere 60, 55–64.

Wuyts, N., Waele, D.D., Swennen, R., 2006. Extraction and partial characterization of polyphenol oxidase from banana (*Musa acuminata 'Grande naine'*) roots. Plant Physiol. Biochem. 44, 308–314.

Zoolinger, H., 1987. Color Chemistry-Syntheses, Properties and Applications of Organic Dyes and Pigments. VCH, New York.