Preliminary analysis of selected tropical fruit seed extracts potential as natural coagulant in water

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Abstract

In this preliminary study, active coagulant extract from tropical fruit (jackfruit, durian, date, Malaysian Longan, tarap) seeds were explored as a potential natural coagulant for turbidity removal in water through multiple parameters (mass, dosage and settling time) by means of response surface methodology and adsorption isotherms. Extraction of active coagulant extracts from these tropical fruit seeds was conducted using sodium chloride solution and characterized using Fourier transform infrared spectrometer (FTIR). FTIR results have indicated the functional groups present in active coagulant extract solution from tropical fruit seeds are mainly proteins. Active coagulant extracts from tropical (jackfruit, durian, date, Malaysian longan, tarap) seeds have displayed total turbidity removal between 31.6 and 72%. Various models of Box-Behnken design for turbidity removal indicated that the linear model was the most suitable model for jackfruit, durian, Malaysian Longan and tarap fruit seeds, while the quadratic model was optimal for date fruit seed. In addition, active coagulant extract from date fruit seed was selected as the best active coagulant extract for turbidity removal in water using the highest R^2 value ($R^2=0.984$). Furthermore, results obtained from regression analysis and three-dimensional surface plots revealed that mass (3 g) and the settling time (90 min) were significant parameters for turbidity removal. Moreover, Langmuir adsorption model was observed to be the most suitable for the adsorption process by coagulant active extract from date fruit seeds with maximum adsorption capacity of 48.08 mg/g. This preliminary study has demonstrated active coagulant extracts from date seed as a promising natural coagulant which can be investigated further.

Keywords Tropical fruit · Seed · Waste · Natural coagulant · Turbidity · Water

1 Introduction

Chemical coagulants such as aluminium chloride, ferric chloride, polyacrylamide derivatives, and polyethylenimine have been employed for the purpose of turbidity removal in drinking water treatment plants [1, 2]. In spite of the effectiveness of turbidity removal in drinking water treatment plants, these chemical coagulants are highly dependent on the pH and alkaline values, generate large

sludge quantities possession selective dispersed medium, and are ineffective towards finer particles [3]. Disposal of large sludge quantities produced by residues of chemical coagulants could lead to various environmental problems. In addition, the presence of chemical coagulants by-products in treated water is known to be closely linked with neurodegenerative disease such as Alzheimer and carcinogenic risk. In order to resolve the problems initiated by these inorganic coagulants and synthetic polymers, a

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search for new coagulants preferably from natural sources is highly favoured [1, 3–6].

In the rise of economy, Malaysia produces a total of 1,767,800 metric tonne tropical fruits annually for local consumption and food industry with export value of USD 269 million/year [7, 8]. Generally, peel and seed are discarded after edible parts of a tropical fruit is consumed, leading to production of massive quantities of waste, which causes disposal problems and greenhouse emission, as well as becoming breeding ground for bacteria and pests [9]. In Malaysia, among majority of the tropical fruit wastes which are generated and discarded in large quantities especially during special seasons are durian, jackfruit, Malaysian Longan and Tarap and date seeds. Studies by Akasha et al. [10], Jaslyn et al. [11], Noor Raihana et al. [12], Fagundes et al. [13] and Kleawkla et al. [14] have demonstrated fruit seeds were found to contain significant amount of protein which can be utilized for various purposes including as natural coagulant in water treatment. According to Ndabigengesere et al. [15], negatively charged particles bind with positively charged proteins via electrostatic interactions to form flocs and settle at the bottom of the water body. However till to date, only study by Zurina et al. [16] have utilized protein extracted from tropical fruit seed (rambutan) as natural coagulant in turbidity removal. Owing to the high efficacy of turbidity removal by rambutan seeds, potential of other discarded tropical fruit seeds as a natural coagulant for turbidity removal in water is still underutilized.

Optimization of multiple operating parameters in coagulation process faces restrictions in terms of the number of experiments, cost, time, physical effort, and chemical availability [2, 17–19]. These restrictions can be eliminated via the Response Surface Methodology (RSM) application. Response Surface Methodology has been verified as an effective statistical tool to establish interactions between multiple parameters and responses [20]. Among RSM methods, Box-Behnken design (BBD) is a robust statistical method with advantages such as ability to minimize the number of experiments, rapidity, combination with mathematical models, ideal for sequential experimental design with significant time and cost effectiveness [21, 22]. In addition to optimized operating multiple parameters, understanding the adsorption isotherms could provide valuable information of suitable isotherms to signify equilibrium state of the adsorption system [6].

The main objective of the present study is to examine the potential of tropical fruit seed extracts as a natural coagulant for turbidity removal in water. The optimal tropical fruit seed waste extract for turbidity removal and its associated optimized parameters (mass, dosage and settling time) was selected by BBD under RSM. Henceforth, adsorption isotherms for prediction of turbidity

removal under given sets of initial conditions were also demonstrated. Lastly, turbidity removal performance of the optimal tropical fruit seed active coagulant extracts and alum in lake water was compared. This study signifies the potential of natural coagulant from tropical fruit seed waste which is an eco-friendly natural coagulant in water treatment. Moreover, it worth mentioning that the utilization of active natural coagulant from tropical fruit seed waste is also a way forward for sustainable waste management which is in respond to 2030 Agenda for Sustainable Development Goal.

2 Method and material

2.1 Extraction of the active component from the tropical fruit seed

Discarded tropical fruit (jackfruit, durian, date, Malaysian Longan, tarap) seeds obtained from the local market of Seri Kembangan city (Selangor, Malaysia) as in Supplementary 1. Tropical fruit seeds were washed using distilled water and dried in drying oven at 105 °C for 48 h until it reached constant weight [23]. Subsequently, external shells were removed from the seeds and grounded to a fine powder using laboratory blender and sieved with 500 µm in order to obtain homogenized powder samples [24]. The homogenized powder samples were added into 400 mL of 70% methanol and was placed for oil extraction for 24 h. Then, the extracted samples were placed in the drying oven for 4 h at 90 °C [25]. Then, the samples were homogenized by using pastel and mortar prior to the process of active coagulant extraction. Different masses (1–3 g) of defatted homogenized tropical fruit seed powder samples were added to 0.5 N of sodium chloride (NaCl) solution. Next, the suspension was vigorously shaken for 1 h using shaker and magnetic stirrer in order to extract active coagulant proteins from the fruit seeds. The active coagulant extract solution was filtered using filter paper (Whatman no. 42) and presence of functional groups in isolated active coagulant extract solution from fruit seed was determined using a Fourier Transform Infrared Spectrometer (FTIR) spectrophotometer (Spectrum 100, PerkinElmer Inc, USA). The filtered active coagulant extract solutions were employed to prepare required dosage concentrations (100, 150, 200 mg/L) by diluting with deionized water.

2.2 Turbidity removal using active coagulant extract from the tropical fruit seed

A conventional jar test was adopted in this study in order to evaluate the turbidity removal performance via active

coagulant extracts from tropical fruit seed and as executed as a batch adsorption test. Synthetic turbid water was prepared by adding 10 g of kaolin in one litre of tap water and used as a stock solution. This synthetic turbid water was stirred for an hour and was allowed to settle for 24 h for the complete dissolution. Lastly, the suspension of synthetic stock turbid solution was diluted to attain desired turbidity (120 NTU). Next 100 mL of synthetic turbid water with 25 mL of required dosage concentrations of active coagulant extract were agitated at rapid mixing (250 rpm) for 1 min and slow mixing (35 rpm) for 90 min. After slow mixing, the samples were allowed to settle for 30, 60, and 90 min. Lastly, a sample was withdrawn using pipette from the middle of the suspension for turbidity measurement using HACH 2100P turbidity meter. The turbidity removal efficiency was calculated using the following Eq. 1.

$$\text{Turbidity removal (\%)} : \frac{\text{Initial turbidity (NTU)} - \text{Final turbidity (NTU)}}{\text{Initial turbidity (NTU)}} \quad (1)$$

2.3 Experimental design

In this study, the experimental design was optimized using RSM via BBD. The BBD was optimized with parameters of different masses (1–3 g), dosage (100–200 mg/L), and settling time (30–90 min) at three levels on turbidity removal from synthetic turbid water (Table 1). Complete experimental design of 17 experiments with five centre points was executed in order to estimate the experimental errors via the Expert 11.0.5 software developed by State-Ease Inc. Additionally, the BBD approach was employed to develop the mathematical empirical models (linear, quadratic, cubic and interactive) in the prediction of turbidity removal within the parameters. Consequently experimental data of turbidity removal was fitted to the second order polynomial equations in order to prevail the regression coefficients. Regression coefficients (R^2) values more than 0.700 with predicted R^2 values in reasonable agreement with adjusted R^2 values were employed to select the optimum fruit seed with active coagulant extract. Through the utilization of the selected fruit seed with active coagulant extract, regression analysis with corresponding F and p values along with three dimensional surface plots were

generated to signify the effects of parameters (mass, dosage and settling time) on turbidity removal.

2.4 Adsorption isotherms to predict turbidity removal

Adsorption isotherm models namely Langmuir and Freundlich were selected to describe the adsorption equilibrium [26]. Adsorption isotherms namely Langmuir adsorption isotherm model (Eq. 2) and Freundlich adsorption isotherm model (Eq. 3) were explored to comprehend the interaction of synthetic turbid water with active coagulant extract from the selected fruit seeds via BBD output under given sets of initial conditions of different masses (1–3 g), dosage (100–200 mg/L) and turbidity measurement after settling time of 90 min. Langmuir constant (slope) and

adsorption capacity (intercept) were obtained from the linear correlation plots between $1/q_e$ and $1/C_e$.

$$1/q_e = 1/Q_0 + 1/Q_0 b C_e \quad (2)$$

where q_e is the ratio of turbidity adsorbed to the dosage of the coagulant (mg/g); Q_0 is the adsorption capacity of coagulant (mg/g); C_e is the equilibrium concentration in solution (mg/L); b is the Langmuir constant (L/g).

Alternatively, Freundlich adsorption isotherm model was selected in order to estimate the adsorption intensity, as provided in Eq. 3. Freundlich constants (slope) and adsorption capacity (intercept) were estimated from linear correlation plots between $\ln q_e$ and $\ln C_e$.

$$\ln q_e = \ln K_f + 1/n \ln C_e \quad (3)$$

where q_e is the ratio of turbidity adsorbed to the dosage of the coagulant (mg/g); C_e is the equilibrium concentration in solution (mg/L); K_f is the adsorption capacity of coagulant (mg/g); n is the a constant related to the intensity of adsorption (L/g).

2.4.1 Comparison of turbidity removal between active coagulant extract from date fruit seeds and alum

Finally, by means of the optimized parameters, the turbidity removal comparisons between active coagulant extract of the selected fruit seed and alum were conducted using lake water. A conventional jar test was adapted with agitation at rapid (250 rpm) for 1 min and slow mixing (35 rpm). Turbidity was measured every 4 h until the value meets the WHO and Malaysian Drinking Water Quality guidelines (< 5 NTU).

Table 1 Parameters with respective levels and values

Variable	Unit	Code	Level		
			–1	0	1
Mass	g	A	1	2	3
Dosage	mg/L	B	100	150	200
Settling time	minute	C	30	60	90

Fig. 1 FTIR absorption spectra of functional groups present in active coagulant extract solution from tropical fruit seeds before and after extraction using NaCl

2.5 Quality assurance and quality control

Various quality assurance and quality control steps were executed in order to ensure the data was reliable and valid. Selected fruit seeds were collected in good condition with no signs of discoloration, softening, or extreme desiccations. In addition, fresh synthetic turbid solutions

were prepared daily and preserved refrigerated in order to prevent any ageing effects (such as change in pH, viscosity, and coagulation activity) and were vigorously shaken before employment. Furthermore, the same shaker and conventional jar test were used throughout the analysis. All the samples were analysed in triplicates in order to increase the accuracy and reduce the bias. Furthermore,

Table 2 Final turbidity value using active coagulant extract from tropical fruit (jackfruit, durian, date, Malaysian Longan, tarap) seed wastes in synthetic water

Mass (g)	Dosage (mg/L)	Time (min)	Initial turbidity (NTU)	Final turbidity (NTU)				
				Jackfruit	Durian	Date	Malaysian longan	Tarap
1	100	30	120	73.6	62.4	68.4	65.6	78
		60	120	70.8	54.1	56	57.1	54.2
		90	120	68	43	34.8	45	34.3
	150	30	120	52.2	50.1	48.7	54.2	38.9
		60	120	44	39.1	38.5	47.1	29.8
		90	120	38.2	38.7	35.2	41.3	30.6
	200	30	120	67.1	61.2	62.4	59.7	35
		60	120	54.4	51.3	50.5	52.3	33.2
		90	120	46.6	36.7	38.5	43.9	33.2
2	100	30	120	72.7	73.5	75.6	72.6	62.1
		60	120	66.9	57.9	59.2	57.7	43.2
		90	120	59.4	46.9	46.7	50.3	34.8
	150	30	120	71.1	70.9	72.1	69.9	61.9
		60	120	65	59.8	59.1	58.2	57.8
		90	120	50.7	43.4	45.1	50.4	33.9
	200	30	120	67.6	66.9	65.9	69.4	61
		60	120	61.2	59	58.8	59.5	53.9
		90	120	47.2	41	43.9	50.1	28.9
3	100	30	120	78.2	71.9	70.8	77.6	67.2
		60	120	71.2	59.5	68.1	67.9	57
		90	120	68.9	46.1	49.5	50.1	57.5
	150	30	120	76.7	73.4	79.8	82.1	79
		60	120	71.4	50.1	55.1	58.1	51.2
		90	120	61.7	37.9	39.1	51.2	58.8
	200	30	120	78.1	71.3	72.9	72.3	71.6
		60	120	66.4	55.9	57	60	58.9
		90	120	51.6	34.4	33.6	50.3	55.2

turbidity meter was calibrated to eliminate any possible error and provide accurate results.

3 Results and discussion

3.1 Functional groups present in active coagulant extract solution from tropical fruit seeds

Figure 1 displays the FTIR absorption spectra of functional groups which were present in active coagulant extract solution from tropical fruit seeds before and after extraction using NaCl. Bands in the region of $1050\text{--}1150\text{ cm}^{-1}$ corresponding to the sugar groups vibrations could be observed in all the FTIR absorption spectra. Moreover, the absorption bands are predominant in the region at $2900\text{--}3300\text{ cm}^{-1}$, attributed to the OH and NH group stretching vibration derived from proteins. According to Christou et al. [27], samples that mainly contain proteins

and polysaccharides have absorption bands in the region at $2500\text{--}4000\text{ cm}^{-1}$.

3.2 Turbidity removal using active coagulant extract solution from tropical fruit (jackfruit, durian, date, Malaysian Longan, Tarap) seeds

Table 2 displays the final turbidity value after treatment with active coagulant extract solution from tropical fruit (jackfruit, durian, date, Malaysian Longan, Tarap) seeds under parameters of mass (1–3 g), dosage concentration (100–200 mg/L) and settling time (30–90 min) with initial turbidity (120 NTU) of synthetic kaolin water. The final turbidity value was between 33.6 and 82.1 NTU. The highest turbidity removal was indicated by active coagulant extract of date fruit seed, while the lowest turbidity removal was Malaysian Longan fruit seed. It was observed that the mass and dosage concentrations of the tropical fruit seed have an influence on the turbidity removal using fruit seeds. According to Cheok et al. [9], tropical

fruit seeds are rich in protein with the capability of assisting in water treatment as natural cationic polyelectrolyte. These proteins involve in charge neutralization and adsorption of a colloidal particle in water. Bodlund [28] has demonstrated that protein content in coagulant active extract influences the coagulation process during turbidity removal. It is known that -active coagulant extract from fruit seed acts as a coagulating agent which is non-ionic and involves in coagulation mechanisms. Through increasing of sedimentation time from 30 to 90 min, the coagulation mechanisms were extended which resulted in higher turbidity removal. However, increasing the concentrations of tropical fruit seed extracts from 150 to 200 mg/L did not enhance the turbidity removal efficiencies. This could be due to the fact that higher concentration resulted in excess of coagulant agent, disturbed the sedimentation process, and re-suspension of the aggregated particles [29]. Although pH values were not obtained in this study, according to Zurina et al. [16], pH value influences the

turbidity removal by fruit seed. In this study, pH values were between 7.6 and 7.9, which were observed to be optimal range for turbidity removal via the protein extract of fruit seed [16]. According to Bazrafshan et al. [29], turbidity removal in alkaline pH range was likely to permit the adsorption and co-precipitation processes onto the hydroxide flocs.

3.3 Selection of the best tropical fruit waste for turbidity removal and associated multiple parameters (mass, dosage and settling time)

Table 3 presents various models generated by BBD for turbidity by means of active coagulant extract from tropical fruit seed (jackfruit, durian, date, Malaysian Longan, tarap) under multiple parameters of mass (1–3 g), dosage concentration (100–200 mg/L), and settling time (30–90 min). It was observed that linear model was the most suitable model for jackfruit, durian, Malaysian Longan and tarap

Table 3 Different models for turbidity removal by tropical fruit seed waste

Source	Sequential <i>p</i> value	F-value	Adjusted R ²	Predicted R ²	Standard deviation	
Jackfruit						
Linear	< 0.0001	10.84	0.678	0.474	5.90	Suggested
2FI	0.7780	0.37	0.611	− 0.119	6.49	
Quadratic	0.2686	1.77	0.699	− 0.722	5.71	Aliased
Cubic	–					
Durian						
Linear	< 0.0001	7.65	0.587	0.359	9.45	Suggested
2FI	0.6191	0.62	0.540	− 0.172	9.97	
Quadratic	0.2520	1.87	0.654	− 0.979	8.66	Aliased
Cubic	–		1		0	
Date						
Linear	0.0002	16.39	0.767	0.619	6.126	Suggested
2FI	0.1226	2.623	0.838	0.554	5.100	
Quadratic	< 0.0001	7.689	0.954	0.837	2.723	Suggested
Cubic	–		1		0	
Malaysian Longan						
Linear	< 0.0001	29.09	0.857	0.761	3.919	Suggested
2FI	0.113	2.74	0.903	0.709	3.226	
Quadratic	0.5780	0.7273	0.892	0.385	3.405	Aliased
Cubic			1		0	
Tara						
Linear	< 0.0001	9.51	0.645	0.492	10.25	Suggested
2FI	0.4640	0.9432	0.640	0.276	10.32	
Quadratic	0.1759	2.48	0.768	− 0.321	8.281	Aliased
Cubic			1		0	

Table 4 Polynomial models with regression coefficients findings for each fruit seed

Equations with significant parameters	R ²	Adjusted R ²	Predicted R ²	Adequate precision	CV (%)	PRESS
Turbidity removal _{Jackfruit} = 62.233 + 7.55A – 4.813B – 7.838C	0.747	0.678	0.474	10.100	9.428	797.368
Turbidity removal _{Durian} = 57.6 + 4.08A – 4.06B – 14.93C	0.676	0.588	0.359	7.794	16.492	1939.943
Turbidity removal _{Date} = 59.1 + 6.7A – 3.64B – 13.14C – 1.4A * B – 6.8A * C + 1.73B * C – 4.26A ² + 3.06B ² – 4.14C ²	0.984	0.954	0.837	17.933	4.834	593.312
Turbidity removal _{Malta Kucing} = 58.87 + 7.0375A – 2.01B – 10.68C	0.888	0.858	0.761	17.512	6.676	360.483
Turbidity removal _{Tarap} = 46.72 + 8.35A – 7.01B – 15.99C	0.722	0.646	0.492	9.197	21.933	2107.451

A, Mass; B, dosage; C, settling time; D, predicted residual error

Table 5 Regression analysis of turbidity removal by date fruit seed

Source	Coefficient estimate	Standard error	F-value	p value (probability > F)
Intercept	59.10	1.57		
A	6.70	0.96	98.422	< 0.0001
B	– 3.64	0.96	14.272	0.01291
C	– 13.14	0.96	186.173	< 0.0001
AB	– 1.40	1.36	1.057	0.351
AC	– 6.80	1.36	94.939	< 0.0001
BC	1.72	1.36	1.605	0.2610
A ²	– 4.26	1.42	9.045	0.0298
B ²	3.06	1.42	4.669	0.0831
C ²	– 4.14	1.42	8.523	0.030

A, Mass; B, dosage; C, settling time

fruit seeds, while the quadratic model was revealed to be the optimum for date fruit seed. A low probability value for sequential with F-values of 10.84, 0.587, 0.9540, 0.8575 and 0.6459 indicated that these models were significant for turbidity removal by jackfruit, durian, date, Malaysian Longan and tarap fruit seeds, respectively. Table 4 presents polynomial models with regression coefficients for each fruit seed extract. It could be observed that R² values higher than 0.700 with the predicted R² values were in reasonable agreement with adjusted R² values. Furthermore, all the adequate precision values for each fruit seed were greater than 4, which signify the adequate signal. The results obtained from regression coefficients revealed that active coagulant extract from date fruit seed possessed the highest R² value close to 1, indicating high correlation between experimental and predicted values, which can be applied to navigate the design space for turbidity removal. Furthermore, the differences between predicted and adjusted R² values were less than 0.2 indicated, which signifies the fewer efficacy of the model.

Through the selection of date fruit seed via regression analysis, the three-dimensional surface plots were established in order to evaluate the interactive effects of associated parameters (mass, dosage and settling time) on predicting the turbidity removal. Table 5 presents the obtained results from regression analysis, indicating that significant parameters namely mass (3 g) and settling time (90 min) were the associated parameters in predicting the turbidity removal. Three-dimensional surface plots could be employed in order to depict the relationships between significant parameters while maintaining the third parameter constant. As can be observed in Fig. 2, three-dimensional surface plots aided in further understanding of the turbidity removal efficiency of significant parameters namely mass (A) and dosage (C) of active coagulant extract

Fig. 2 Three-dimensional surface plots of significant parameters of mass (A) and dosage (C) for active coagulant extract from date fruit seed

Fig. 3 Langmuir adsorption isotherm model with active coagulant extract from date fruit seeds

from date fruit seed. The turbidity removal efficiency was increased with an increase in the amount of fruit mass which was utilized to extract active coagulant from fruit seed (protein extract). Selection of suitable active coagulant extraction from fruit seed is essential in coagulation process and turbidity removal in water. Studies by Hariz Amran et al. [6] and Zurina et al. [16] have indicated that sodium chloride was the most suitable active coagulant extracting solvent from tropical fruit seeds such as rambutan (*Nephelium lappaceum*), *Moringa oleifera* and green bean (*Phaseolus vulgaris*). In addition, it has been reported that increasing the settling time allows adequate duration for the generation of the particles in sedimentation process, which is linked to the turbidity removal performance [30]. Furthermore, current study findings revealed that dosage concentration did not significantly influence the turbidity removal. Similarly, previous studies involving natural

coagulants from fruit seed (*Cicer arietinum*, *Moringa oleifera*, and *Dolichos lablab*) demonstrated that higher dosage did not significantly increase the turbidity removal [25, 30, 31]. Moreover, according to Ramavandi [32], optimization of natural coagulant mass with the optimum required dosage concentration is considered to be appropriate from an economic point of view and large scale utilization.

3.4 Adsorption isotherms for the prediction of turbidity removal

Figure 3 displays the Langmuir adsorption isotherm model where $1/q_e$ changes linearly at a slope of $1/Q_0b$. In addition, Fig. 4 presents the Freundlich adsorption isotherm model with linear correlation between $\ln q_e$ and $\ln C_e$. It can be observed that both Langmuir and Freundlich adsorption isotherm models have exhibited good linearity with

Fig. 4 Freundlich adsorption isotherm model with active coagulant extract from date fruit seeds

Fig. 5 Final turbidity value in lake water after treated with active coagulant extract prepared from date fruit seed

relatively high R^2 values more than 0.83. However, adsorption isotherms of both models were negative due to the negative intercept, indicating that these models did not follow the assumptions. Therefore, these adsorption processes cannot be explained by the model. Considering the R^2 values with positive intercepts, it can be seen that the highest R^2 values obtained by Langmuir and Freundlich adsorption isotherm models were for 2 g with values of 0.9958 and 0.8336, respectively. Langmuir isotherm model was closer to the unity and better fitted than the Freundlich isotherm model with maximum adsorption capacity of 48.08 mg/g. The findings signified that the coagulation mechanism for coagulant active extract from date fruit seeds was through adsorption and bridging. According to Hariz Amran et al. [6], fruit seed based active coagulant contains a coagulating agent which can be utilized for bridging coagulation mechanism in aqueous solution.

3.5 Performance comparison of turbidity removal between active coagulant extract from date fruit seeds and alum in lake water

Figure 5 illustrate the final turbidity value after treatment with active coagulant extracted from date fruit seed using optimized parameters (mass of 2 g and settling time of 90 min) and alum in lake water. It can be observed that alum had a superior turbidity removal performance and obtained the required turbidity value of WHO and Malaysian Drinking Water Quality guidelines (< 5 NTU). However, the pH value of the treated lake water was higher than the treated water with active coagulant extract from date fruit seeds. Furthermore, nearly 2 days were required to complete the process of treatment with alum in order to meet the drinking water guideline for turbidity. However, for lake water treated with active coagulant extract from date fruit seeds, the turbidity value could reach around 30 NTU after 4 days. According to Saritha et al. [17], aluminium salt in water is rapidly hydrolysed to cationic species in order to absorb the negatively charged particles and neutralize

the charges to enable the occurrence of coagulation–flocculation. In addition to the utilization of active coagulant extract from date fruit seeds for turbidity removal in water, incorporation of functionalised nanostructured materials has invoked considerable attention in order to enhance the effectiveness of coagulation–flocculation processes in turbidity removal [33].

4 Conclusion

Active coagulant extracts from tropical fruit seed wastes (jackfruit, durian, date, Malaysian Longan, tarap) demonstrated turbidity removal efficiencies. Box Behnken Design findings revealed that linear model was the most suitable for jackfruit, durian, Malaysian Longan and tarap fruit seeds, while quadratic model was selected for date fruit seed. The most significant parameters for turbidity removal were mass and settling time. Langmuir isotherm model was the most favourable for turbidity removal for active coagulant extract from date fruit seed. Turbidity removal between active coagulant extract from date fruit seed has recommended the need to incorporate functionalised materials to enhance its performance.

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Compliance with ethical statements

Conflict of interest The authors declare that they have no conflict of interest.

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