Short Communication

Experimental optimization of *Moringa oleifera* seed powder as bio-coagulants in water treatment process

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Abstract
The *Moringa oleifera* is an important commodity plant which has been traditionally used for the treatment of water in tropical area of the world. This study therefore investigated the use of *M. oleifera* seeds powder as bio-coagulant for water treatment. The effects of parameters such as dosage, high speed time, high speed, low speed and low speed time on the residual turbidity were evaluated using the response surface methodology. The results obtained from the preliminary studies conducted, provided three independent factors, viz low speed (40–80 rpm), low speed time (20–60 min) and dosage (0.25–1.25 mg/L) which were optimized using the optimal water turbidity. However, the high speed and the high speed time were fixed at 100 rpm and 6 min, respectively. The results obtained from experimental design placed the optimum condition at low speed, low speed time and dosage as 40 rpm, 60 min and 0.75 mg/L, respectively. Under this condition, the predicted (theoretical) residual turbidity was 4.73 NTU. The result of the ANOVA for the optimization of the residual turbidity showed that the quadratic model was significant at 95% confidence level ($p < 0.05$). Moreover, the low speed time (B) and dosage (C) were both significant, whereas the low speeds (A) were not significant factors in the optimization of residual turbidity. Finally, the result obtained therefore showed the potential of *M. oleifera* residue as natural coagulants in the effective treatment of water for drinking purpose. The lower turbidity (< 5 NTU) achieved from this study confirmed the potential of this important eco-friendly natural product for the treatment of water.

Keywords Bio-coagulant · Turbidity · *Moringa oleifera* residue · Water treatment

1 Introduction

In recent times, the worldwide consumption of useable water had increased due to the surge in human population [1]. As a result of this, developing and third world countries who have inadequate financial resources have their special attention on the pollution of water as an environmental issue which causes shortage of water supply [2]. Meanwhile, large volume of wastewater contains contaminant comprising of pathogens, heavy metals, nutrients and suspended solids which are harmful and dangerous for human and the environment. [3, 4]. If they are kept untreated, safely disposed back to the sea or reused of the wastewater will be prevented [5]. Drinking water supplies have been identified to have thousands of chemicals which are potentially hazardous to human health at relatively high concentrations as maintained by World Health Organization 2004 [6].

Safe and pure water is extremely important for human health and welfare, and water must undergo for purification and treatment to reach the world standard of drinking water before consumption. Different water purification and treatment methods are used to make water safe and healthy to the consumer. The treatment method used depends on the character of the raw water. A major problem with treatment of surface water is due to large seasonal variation in turbidity [7]. Water treatment method in many developed countries is based on arbitrary guidelines,

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they particularly relate to the dosage of chemicals which is not a good approach. In the treatment of these large volumes of water for drinking purposes, the following processes are always employed in sequential order and these include flocculation, sedimentation, filtration and disinfection [1]. Moreover, previous study proposed different natural coagulants for the treatment of water for safe drinking viz ferric sulphate, aluminium sulphate and ferric chloride which called synthetic coagulant [8]. On the other hand, there is a natural coagulant which is usually recommended in place of synthetic coagulants, because the synthetic coagulant have side effect to environment due to chemical involved in this coagulant. Recently, there is an increase in the research of plant to be used as natural coagulant for various traditional water purification systems. However, there are also several other plants which can act as natural coagulant in water treatment such as peanut seeds, watermelon seeds, *Vigna unguiculata*, *Parkinsonia aculeata*, *Cicer arietinum* and *Dolichos lablab*, *Cassia alata* and *Opuntia ficus-indica*. [9].

The *M. oleifera* is an important commodity plant which has been traditionally used for the treatment of water in tropical area of the world [10]. Therefore, *M. oleifera* seeds provide a lot of advantages compared to conventional coagulants towards the water treatment. The advantages of *M. oleifera* are cost-effective, eco-friendly, no pH alteration required, no necessity for alkalinity addition and reduction in sludge volumes [11]. Although many researchers studied the use of *M. oleifera* as bio-coagulants, none had employed the use of its residue for the treatment of water [12–14]. This study therefore investigated the use of *M. oleifera* seed residue as bio-coagulant for water treatment. The effects of treatment factors such as dosage, high speed time, high speed, low speed and low speed time on the residual turbidity were carefully examined.

2 Material and method

2.1 Sample collection and preparation of Moringa seed power

The *M. oleifera* seed was purchased from Mitomasa Sdn. Bhd., Kuala Lumpur. The seeds were de-husked and the kernel was then dried at room temperature for 1 day and pulverized to a fine powder using a GrindoMix domestic grinder. The fine powder was then sieved through a 2 mm-mesh. It is important to note that the seed powder has a strong affinity to attract moisture during or after grinding; this makes it a necessity to dry the power at 40 °C for 10 min to reduce moisture content. The seeds powder was thereafter left to cool and packed into clean sealed polythene bags after drying. The bag was kept in a chiller at 4 °C to maintain freshness and dryness for further use. Moreover, the water sample was collected from Belat River, Kuantan, Malaysia, and different dosage of *M. oleifera seeds powder* was used to test the water quality status.

2.2 Design of experiment

In this study, the effect of variables such as dosage, high speed time, high speed, low speed and low speed time on the residual turbidity were evaluated using the response surface methodology (RSM). Design–Expert 7.0 software® (Version 7.1.6, Stat-Ease Inc., Minneapolis, USA) was used for the experimental design and analysis of the results. The high speed and the high speed time were fixed at 100 rpm and 6 min, respectively [2]. However, according to the results obtained from the preliminary studies conducted, three independent factors, viz low speed (40–80 rmp), low speed time (20– 60 min) and dosage (0.25–1.25 mg/L), were optimized using the response surface methodology (RSM) for optimal water turbidity (Table 1).

2.3 Jar test procedure

The clear water sample (500 mL) was divided into six different beakers and then placed into the Jar Test apparatus. A known quantity of the seed powder was mixed with each water sample in the Jar Test apparatus and operated at a constant high speed time of 100 rpm and 6 min. Other parameters such as the low speed, dosage and low speed time were applied in accordance with the experimental design matrix. The paddles and the water was left to settle down for 1 h and the clear water was collected into conical flask and stored at 4 °C for further analysis [15].

3 Results and discussion

3.1 Preliminary investigation of best particle sizes and coagulant quantity (turbidity test)

This research was conducted to determine the best particle sizes and *M. oleifera* seeds powder (MOSP) dosage for the water treatment. This was achieved by varying the

Table 1 Coded and actual design range

Independent factor	Designation	Units	Coded level	
			−1	+1
Low speed	A	Rpm	40	80
Low speed time	B	Min	20	60
Dosage	C	mg/L	0.25	1.25

amount of MOSP (0.00–10.0 g) at different particle sizes (2 mm, 1 mm, 500 µm and 250 µm). The highest turbidity removal was obtained at an average particle size of 2 mm. However, at particle sizes below 2 mm, agglomeration tends to occur due to the sticking together of the particles. This explains why at particle sizes 1 mm, 500 µm and 250 µm, the turbidity removal was lower when compared with 2 mm as presented in Fig. 1.

Singh [16] corroborated the occurrence of agglomeration where sintering or coalescence takes place instead of settling as in the case of coagulation. However, finely divided *M. oleifera* powder presented a larger surface area for coagulation site but care must be taken to select the best particle size without resulting to agglomeration of the particles [17]. The result obtained therefore indicated that the coagulant concentration exceeded the optimum dosage with an increased turbidity due to the neutralization and precipitation of all the colloidal suspension at optimum dosage [18]. On the other hand, using an excess mass of MOSP coagulant beyond 0.05 g reduces the interaction between the treated water and the oppositely charged colloidal particles.

3.2 Optimization study of operating parameters in water treatment

Table 2 presents the experimental design and results for the optimization of water turbidity under the effects of three parameters, namely, low speed (A), low speed time (B) and dosage (C). The results obtained from experimental design placed the optimum condition at low speed, low speed time and dosage as 40 rpm, 60 min and 0.75 mg/L, respectively. Under this condition, the predicted (theoretical) residual turbidity was 4.73 NTU.

Furthermore, the quadratic and interaction regression coefficients of the models were evaluated using Design–Expert software®. The result of the ANOVA for the optimization of the residual turbidity shows that the quadratic model is significant at 95% confidence level ($p < 0.05$). Moreover, the low speed time (B) and dosage (C) were both significant, whereas the low speeds (A) were not significant factors in the optimization of residual turbidity. Additionally, AB, AC, BC, A^2 and B^2 were insignificant interactions, while only C^2 has a significant contribution to the response setting. The statistical analysis gives many

Table 2 Experimental design and results obtained from optimization

Test	Low speed (rpm)	Low speed time (min)	Dosage (mg/L)	Residual turbidity (NTU)
1	60.00	40.00	0.75	4.00 ± 0.12
2	80.00	20.00	0.25	13.00 ± 0.14
3	40.00	60.00	1.25	14.00 ± 0.06
4	60.00	20.00	0.75	7.10 ± 0.03
5	80.00	60.00	1.25	11.62 ± 0.07
6	80.00	40.00	0.75	4.40 ± 0.11
7	80.00	20.00	1.25	7.64 ± 0.19
8	40.00	20.00	0.25	9.00 ± 0.01
9	40.00	20.00	1.25	10.21 ± 0.04
10	60.00	40.00	0.75	7.44 ± 0.02
11	40.00	60.00	0.25	13.55 ± 0.01
12	60.00	40.00	0.25	14.43 ± 0.21
13	60.00	40.00	0.75	4.20 ± 0.18
14	60.00	40.00	0.75	5.10 ± 0.22
15	60.00	40.00	0.75	5.77 ± 0.05
16	60.00	40.00	1.25	8.46 ± 0.34
17	80.00	60.00	0.25	13.92 ± 0.01
18	40.00	40.00	0.75	5.00 ± 0.02
19	60.00	40.00	0.75	10.00 ± 0.01
20	60.00	60.00	0.75	8.80 ± 0.21

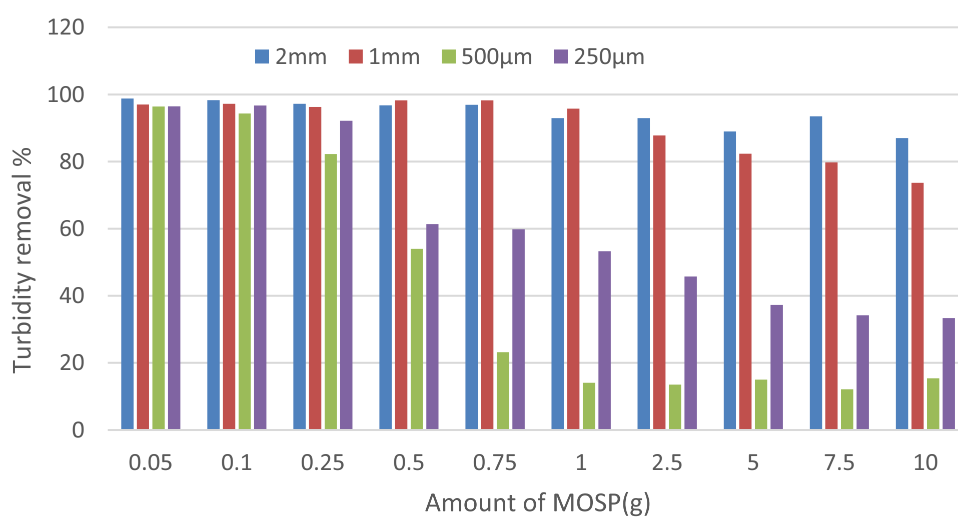

Fig. 1 Turbidity removal of water treated with MOSP

comparative measures for the model selection and this indicated that the quadratic model has a significant contribution with lower standard deviation (1.93) and higher coefficient of regression ($R^2 = 0.9847$). The lack of fit is not significant in relation to the pure error. It is pertinent to note that an insignificant lack of fit is desirable for the adequacy of all the model terms. It indicated that the model is adequate to describe the observed data (Table 3).

Figure 2a shows the result of interaction effects between the low speed and low speed time. The result obtained revealed that the residual turbidity decreased with a low speed time between 50 and 70 min when a low speed varied between 30 and 50 rpm. However, Fig. 1b indicated that the *M. oleifera* residual dosage was used between 0.5–1.00 mg/L against the low speed of 50–70 rpm. The low speed mixing time decreased between 30 and 50 min when the dosage was between 0.5 and 1.00 mg/L as presented in Fig. 1c.

Table 3 Analysis of variance for response surface quadratic model

	Sum of squares	*df*	Mean square	*F* value	*p* value
Model	206.40	9	22.93	26.18	0.0044[a]
A	0.14	1	0.14	0.038	0.8503[b]
B	22.32	1	22.32	16.01	0.0341[a]
C	14.33	1	14.33	33.86	0.0078[a]
AB	1.48	1	1.48	0.40	0.5420[b]
AC	10.86	1	10.86	2.93	0.1180[b]
BC	0.66	1	0.66	0.18	0.6819[b]
A^2	6.16	1	6.16	1.66	0.2266[b]
B^2	8.45	1	8.45	2.28	0.1622[b]
C^2	75.74	1	75.74	20.41	0.0011[a]
Residual	37.11	10	3.71		
Lack of fit	10.98	5	2.20	0.42	0.8185[b]
Pure error	26.13	5	5.23		
Cor total	243.51	19	–	–	–
SD	1.93		*R*-squared	0.9847	
Mean	8.88		Adj *R*-squared	0.9810	
C.V.%	21.69		Pred *R*-squared	0.9795	
PRESS	4.16		Adeq precision	47.444	

A low speed, *B* low speed time, *C* dosage

[a]Significant; [b]insignificant

3.3 Validation of predictive model

In this study, the response was correlated using three parameter settings with quadratic model and the coefficient of regression. The significance of the three variables (i.e. low speed, low speed time and dosage) on the residual turbidity was evaluated using the Design–Expert® software. It should be noted that the single parameters indicated the effect of that particular factor, whereas with two variables represent the interaction between those two factors, while the second-order terms indicated their quadratic effects. The positive and negative sign is an indication of synergistic and antagonistic effects of the terms, respectively [4]. From the result generated, the regression model for the residual turbidity is presented in Eq. (1) below.

$$\begin{aligned}\text{Turbidity} = {} & 30.342 + 0.0673A - 0.954B - 23.654C + 0.0132B^2 \\ & + 18.765C^2 - 0.0002AB - 0.0787AC - 0.0463BC\end{aligned} \quad (1)$$

The above model was validated by conducting a replicate experiment for the residual turbidity. The optimal condition was generated from the Design–Expert software with a single solution. Under this condition a number of replicate experiments were performed and a comparison between the observed and predicted results from the model equation was made, with the minimum residual turbidity selected as the optimum condition. The results obtained

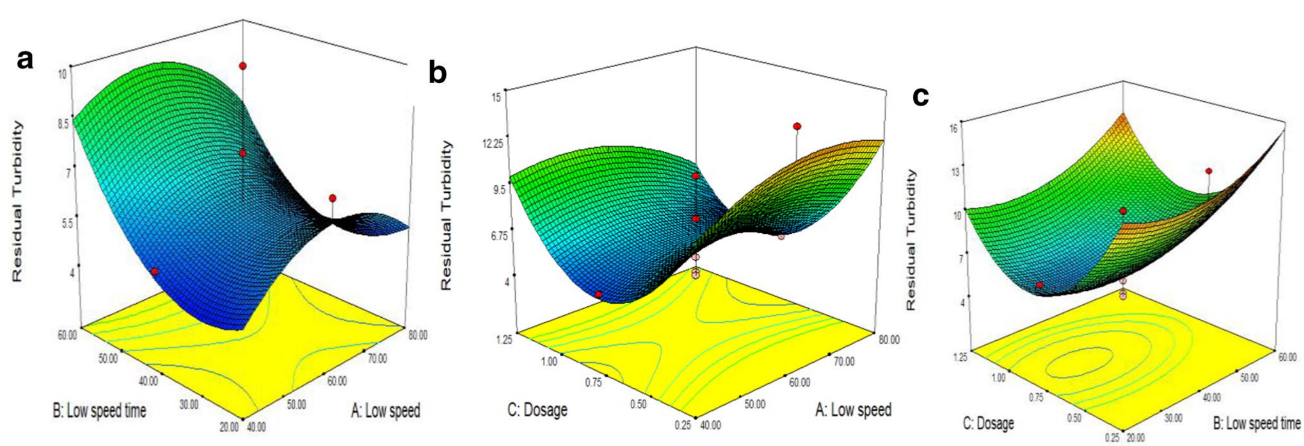

Fig. 2 Interaction plot **a** low speed and low speed mixing time, **b** dosage and low speed and **c** dosage and low speed time

from experimental design placed the optimum condition at low speed, low speed time and dosage as 40 rpm, 60 min and 0.75 mg/L, respectively. Under this condition, the predicted (theoretical) residual turbidity was 4.73 NTU. A close agreement between the theoretical and experimental best residual turbidity was estimated using Equ. [2].

$$\text{Percentage Error} = \sum_{n=1}^{3} \left| \frac{\text{Theoretical}_{\text{Turbidity}} - \text{Experimental}_{\text{Turbidity}}}{\text{Theoretical}_{\text{Turbidity}}} \right| \times 100 \quad (2)$$

The percentage error was used to examine the validity of the best response setting in the wastewater treatment using a residual *M. oleifera*. Shan et al. [15] reported that for the best condition to be valid, the percentage error must not exceed 10% at 95% confidence level. The test shows that there is no significant difference between the theoretical and experimental turbidity settings with a percentage error value of 1.6913. The percentage error obtained is therefore negligible when compared with the 10% cut-off value at 95% confidence. The lower turbidity (< 5 NTU) achieved from this study confirmed the potential of this important eco-friendly natural product for the treatment of water.

4 Conclusion

The significance of parameters such as dosage, high speed time, high speed, low speed and low speed time on the residual turbidity was succinctly investigated. The ANOVA result generated shows a significant quadratic model with a 95 % confidence level ($p < 0.05$) in the optimization of the residual turbidity. The low speed time (B) and dosage (C) were both obtained as significant factors, while the low speeds (A) were not significant factors in the optimization of residual turbidity for water treatment using *M. oleifera* seed powder. Under the optimal condition, the water turbidity was less than the recommended value (< 5.0 NTU) which invariably validated the efficacy of *M. oleifera* powder in the treatment of river water for both domestic and industrial use.

Compliance with ethical standards

Conflict of interest The authors declare that there is no competing interest whatsoever.

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