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Development of Fruit-Based Waste Material as Bioflocculant for Water Clarification

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ABSTRACT

Access to clean water is the major priority in all countries in the world in which millions of humans and living organisms die due to contaminated water-related diseases every year. Flora and fauna particularly urban rivers are losing attraction due to the problem of high turbidity in the water resources. Sedimentation and filtration had been regarded as efficient approaches in tackling turbidity of wastewater. The primary objective of this research is to investigate the possibility of converting Malaysian natural resource wastes (fruit-based) into bioflocculants for the potential application in turbidity removal in wastewater treatment process. The coagulation-flocculation potential in treating turbid water of four different fruit wastes which were inclusive of banana peels, jackfruit peels, pomelo peels and papaya seeds were investigated. The results revealed that banana peels demonstrated the most effective turbidity removal at 70.78 % in relative to other fruit wastes, without optimization processes. Interestingly, after the bioflocculation treatment using banana peels, residual pH of the treated water was 6.73, which was very close to neutral pH at 7.0 and fall within the WHO recommended pH value for drinking water quality (6.5 – 8.5). This implies that with further optimization study to enhance the turbidity removal and appropriate disinfection, if need be, the treated water using banana peel is suitable for human consumption. The exploitation of naturally available resources or waste materials into bioflocculants in this research had shed some lights in the discovery of efficient, biodegradable and green flocculants

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as potential replacement to conventional synthetic chemical coagulants in reducing water turbidity.

Keywords: *Water; Turbidity; Bioflocculation; Fruit Waste.*

Introduction

Industrial effluents are one of the major contributes to water pollution. The industrial effluents are harmful with the presence of high chemical oxygen demand (COD), biological oxygen demand (BOD), suspended and colloidal particles and dyes [1]. The dye molecules contained in the water discharge from industrial effluents are highly conjugated and extremely detrimental to human and aquatic life because dyes in the water can inhibit sunlight penetration into the water and subsequently reduce photosynthetic reaction of the plant in the water [2]. In order to remove contaminants and suspended solids from wastewater, there are some conventional methods that had been extensively applied such as coagulation, flocculation, reverse osmosis and activated carbon adsorption [3, 4]. Yet, reverse osmosis and activated carbon adsorption are not efficient and economically feasible for a large scale wastewater treatment. Therefore, in industrial point of view, coagulation-flocculation remains as the preferable wastewater treatment technology or approach, owing to its advantages such as ease of operation and low operating cost [5].

In the work of Al-Mamun and Ahmad Tsaqif [6] who reported white popinoc as a potential phyto-coagulant to reduce turbidity of river water, they found that rate determining step of the wastewater treatment process was highly dependant on the efficacy of coagulation process in the primary and secondary treatment. Various types of coagulants and flocculants are widely employed in the conventional water treatment processes for this purpose. Among all, chemical coagulants such as aluminium sulphate, polyacrylamide and aluminium chlorohydrate had been widely utilized in regards to their excellent flocculating activity and low processing cost [7]. However, utilization of such chemical coagulants particularly alum as in the process is not a good solution in the long run. Potential problems that are associated with them are inclusive of lacking in biodegradability that can lead to environmental hazards and results in the increase of metal concentration or residual of aluminium in the treated water. Pertaining to this problem, it poses a threat and danger to human health that is related to carcinogenic and several neuropathological diseases including percentile dementia and Alzheimer's disease [8, 9].

In recent years, a growing research interest had been prompted to study on plant based bioflocculants and aluminium sulphate (alum) in the respective coagulation-flocculation behavior in the wastewater treatment process. Alum is a chemical coagulant that is being commonly used to remove the contaminants in the water such as suspended solid, colloidal particles, COD and BOD. Following that, the turbidity of water will be reduced through coagulation/flocculation process in the wastewater treatment process [9]. Plant based bioflocculants on the other hand, are natural organic flocculants that consisted of natural polymers or polysaccharide complexes formed from the sugars of different monosaccharides such as starch, cellulose, chitosan, natural gums and mucilage [8]. The compounds had been widely recognized for their excellent flocculating properties in the wastewater treatment. Polysaccharides are naturally occurring carbohydrate polymers in which monosaccharride residues are linked directly through glycosidic linkage [10].

These polysaccharides exhibit high potential to be further explained as flocculants due to the availability of reactive functional group inclusive of hydroxyl, acetamido or amino functions in the polymer chains [11]. Consequently, excellent physico-chemical characteristics namely high chemical stability selectivity and reactivity on aromatic compounds and metals are associated with this natural polymer [5]. Due to the constraints posed by chemical coagulant, focuses had been directed to biodegradable flocculants to replace conventional alum because they are eco-friendly, non-toxic and easily extracted from reproducible agricultural resources [12, 13]. As recently described by Lee et al. [8], bioflocculants are renewable sources that incur lower cost, demonstrate high removal capability in terms of suspended solids, turbidity and dyes as well as addressing the concerns on public health issues and environmental pollution problems. In regards to the performances of wastewater treatment process by using plant based bioflocculants, Renault et al. [13] stated that they were not sensitive to pH which indicated that no adjustment of pH was required prior to the wastewater treatment and relatively lower sludge volume was produced as compared to chemical coagulants.

In addition to that, residual aluminium in alum treated water also causes the phosphorus uptake by the plants from inorganic phosphorus absorption and subsequently lead to aluminium phytotoxicity [8]. Also, on the contrary of the exceptional performance of alum in water treatment, the major drawback associated with chemical coagulant is generation of large volumes of sludge. The treatment process involving alum is also highly sensitive to pH in which according to Sun et al. [4], adjustment of pH in the wastewater is required prior to the wastewater treatment.

Various successful reports concerning the use of natural coagulants of vegetables or plant origin in treating water with high turbidity has gradually gaining attention in the field of bioflocculation. For instance, the seed of coccinia, the pod of drumstick tree, the mucilage of okra gum had been identified as a potential bioflocculation that exhibited comparable results to the efficacy of alum in reducing turbidity level in wastewater. The sources of these natural coagulant/flocculant ranged from the seed of various plants to exoskeleton of shellfish have been reported to be effective in water clarification without the generation of excessive sludge volume. Nevertheless, the exploitation of naturally available resources or waste materials into bioflocculants remained at its infancy with little knowledge on their respective potential in Malaysia. Not much had been done to explore the possibility of converting plant/fruit based waste materials into bioflocculant, in the effort to discover efficient, biodegradable and green flocculants to reduce the turbidity of water.

Materials and Methods

Materials

Four different fruit wastes namely banana peels, jackfruit peels, pomelo peels and papaya seeds were screened for the potential to be utilized as bioflocculant. The fruit wastes were collected from the local night market in Taman Connaught, Cheras, Malaysia.

Preparation of Bioflocculants

The preparation of bioflocculants was conducted based on the methods described by Zurina et al. [7] with slight modifications. The samples were washed with distilled water several times to remove dirt and contaminants, followed by drying in a hot air oven at 80 °C for at least 24 hours. The dried samples were then grinded or crushed using pestle and mortar, sieved well in fraction of 150 µm. The powdered sample then was stored in an airtight container prior to bioflocculant extraction processes. In the preparation of bioflocculants, dried raw materials were soaked in distilled water at room temperature and stirred for 1 hour. The suspension was filtered through muslin cloth and the filtered extract was then used in the experiments.

Preparation of Synthetic Turbid Water

Kaolin was used as the model wastewater. Stock kaolin suspension was prepared by dissolving kaolin in distilled water at room temperature. The suspension was stirred under moderate speed for at least 10 minutes in a jar apparatus to obtain uniform dispersion of kaolin particles. The initial turbidity prior to bioflocculation was maintained approximately at 220 NTU.

Coagulation/Flocculation Properties of Bioflocculants

The flocculation testing was performed using JAR floc test. The study involved stages such rapid mixing, slow mixing and sedimentation in a batch process. For rapid mixing, agitator was turned on at the speed of 200 rpm for 10 minutes once the bioflocculant from all fruit wastes was added into beakers containing 400 ml of synthetic turbid water each [6]. Following that, slow mixing was conducted at 40 rpm for approximately 20 minutes before the samples were left to sediment for 30 minutes. After sedimentation, a few ml of sample was collected without agitating the sediments at bottom to measure the turbidity using a turbid meter. In all coagulation/flocculation studies, 100 ml of the filtered extract from all fruit wastes was added into the synthetic turbid water. The coagulation/flocculation properties were evaluated by measuring the treated water pH and turbidity. The percentage of turbidity removal was determined by using Equation (1):

$$\text{Turbidity removal percentage} = \frac{\text{final turbidity} - \text{initial turbidity}}{\text{initial turbidity}} \times 100 \qquad (1)$$

Results and Discussions

Different types of solvent such as water, organic solvents and salt solutions had been used to extract bioflocculants conventionally. Success in extracting seed-based flocculants using salt solution had been reported in the literature by numerous researchers [14, 15]. In fact, Zurina et al. [16] reported that better turbidity removal could be achieved by using salt solution as the extraction solvent for Jatropha seed flocculant. According to Zurina et al. [7] and Lee et al. [8], water is by far the most popular choice due to its good polarity, abundancy and is available at no cost. In this preliminary study, distilled water was selected as the solvent in the preparation of bioflocculant extract from different fruit wastes. Figure 1 shows the extracts from banana peels, jackfruit peels, pomelo peels and papaya seeds, respectively. Bioflocculant extracts with different colour were obtained, probably due to the presence of different colour pigments in different fruit wastes used. Among all, banana peel and papaya seed extracts appeared in darker colour intensity in contrast to jackfruit peels and pomelo peels. In addition, pH of the extracts was also differed in the range of 4.98 – 6.25. This could be contributed by different amount of anthocyanins (a group of naturally occurring phenolic compounds) present in the fruit wastes, which played important role in colour quality and pH of the fruits [17].

Figure 1: Bioflocculant extracts from pomelo peels, banana peels, jackfruit peels and papaya seeds (left to right)

Table 1: pH value of bioflocculant extracts

Fruit Waste	Banana Peel	Jackfruit Peel	Pomelo Peel	Papaya Seed
pH	6.25	6.01	4.98	5.27

Coagulation/flocculation activities of all prepared extracts were evaluated using synthetic turbid water having similar initial turbidities (in the range of 200 – 220 NTU), with initial pH 6.85 and coagulant dosage of 100 ml per 400 ml turbid water. The results of these experiments are presented in Figure 2. The investigated fruit waste extracts showed different coagulation/flocculation activities in turbid water. The turbidity removal percentage varied in the range of 30 – 70 %, with the contradicting result obtained using papaya seed extract that the turbidity of treated water was higher than the initial synthetic turbid water. The extract of banana peels expressed the highest turbidy removal at 70.78 % in comparison with other extracts. On the other hand, an increase in the water turbidity of approximately 20 NTU was recorded in the occasion of using papaya seed extract as the bioflocculant. Even though most of the studies have proven that bioflocculants were workable and effective for treatment of various types of wastewaters, Diaz et al. [18] highlighted that final water turbidity did increase slightly as the alkalinity of the water increased. In their research of utilizing *Prosopis juliflora* coagulant, less efficient removal of turbidity was recorded as the alkalinity of turbid water was increased. In fact, increase in the final turbidity which was similar to the result of papaya seed flocculant was oberved as well. In this study, however, the flocculant dosage was fixed and there was no information about how variations in different types of flocculant to their respective ionic concentration or strength might affect the final turbidity. Therefore, the role of ionic concentration in bioflocculants on the flocculation efficiency will require further investigation.

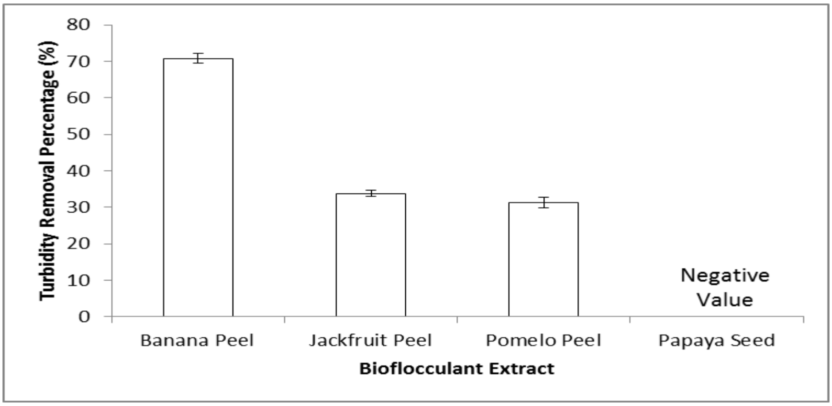

Figure 2: Comparison of coagulation/flocculation properties of different bioflocculant extracts

In regards to the turbidity removal, several possible mechanisms such as charge neutralization, electrostatic patch and polymer bridging had been suggested [8, 19]. For instance, Zurina et al. [16] proposed charge neutralization and adsorption for the coagulation/flocculation mechanisms for Jatropha seed bioflocculant due to its resemblance to the cationic coagulation agent that was reported in *Moringa oleifera*. Apart from that, agricultural-derived bioflocculants were also rich in carbohydrates, ploysaccharides and phytochemicals which had been identified as possible agent promoting coagulation and flocculation process [19]. The role of polysaccharide as an excellent coagulation agent was evidenced with the discovery of significant amount of polysaccharides, particularly amylopectin, in the resulting flocs of *Maerua subcordata* in removing turbidity [20]. This could be correlated to the bridging mechanism in which the biopolymers serve as a bridge, linking all the suspended or colloidal particles together, forming particle-polymer complex as illustrated in Figure 3. Subsequently, increment in the floc size would enhance the overall sedimentation process, thus improve turbidity removal efficiency.

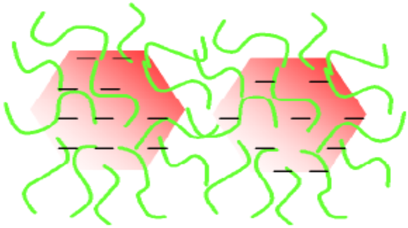

Figure 3: Model of biopolymer bridging flocculation of bioflocculants [21]

In many cases, impurity or suspended particles in water were found to be negatively charged [8]. While most of the reported bioflocculants were verified to be either anionic or neutral, it is presumed that charge neutralization is not the possible mechanism in this study. The most probable unlying mechanism for turbidity removal by bioflocculants from banana peel, jackfruit peel and pomelo peel could be due to polymer bridging.

Noteworthy, bioflocculant from banana peel, as a locally available natural resource, could achieve the recommended pH value for treated water. With the initial turbid water at pH of 6.85, the residual pH of the treated water by using all the extracted bioflocculant is tabulated in Table 2.

Table 2: pH value of treated water using bioflocculant extracts

Fruit Waste	Banana Peel	Jackfruit Peel	Pomelo Peel	Papaya Seed
pH	6.73	5.56	5.64	6.30

WHO [22] reported a pH range of 6.5 – 8.5 as the optimum pH for water that is suitable for human consumption or found in drinking water. pH results in Table 2 revealed that pH adjustment of the treated water is not required using bioflocculant from banana peel as it is already near to neutral and falls within the recommended pH range. This implies that with further optimization study to enhance the turbidity removal and appropriate disinfection, if need be, the treated water using banana peel is suitable for human consumption.

Conclusion

The diverse types of fruit waste-based bioflocculants as discussed in this study have demonstrated promising coagulation/flocculation activities in treating turbid water. Banana peel, jackfruit peel and pomelo peel were proven to be able to reduce the turbidity of water with varying efficiencies. With the preliminary findings, in-depth investigation concerning the processing methods and conditions (preparation, extraction, purification, drying, and storage) of bioflocculants is required to improve the quality and stability of bioflocculants, which is directly influencing the turbidity efficacy. There is also an ample room for further research on comparing the turbidity removal efficiency between the conventional chemical coagulants with bioflocculants, in-light with the health and environmental concerns on chemical coagulants. The use of renewable sources of low cost agricultural or household waste biomass which might requires little processing to produce bioflocculant is considered as a better choice.

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