Utilization of citrus microcarpa peels and papaya seeds as a natural coagulant for turbidity removal

Z Dollah\textsuperscript{1}, N H Masbol\textsuperscript{1}, A A Musir\textsuperscript{1}, N A Karim\textsuperscript{1}, D Hasan\textsuperscript{1} and N J Tammy\textsuperscript{1}

\textsuperscript{1}Faculty of Civil Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Permatang Pauh, Pulau Pinang, Malaysia.

Email: zuraisah@uitm.edu.my

Abstract. Coagulation and flocculation are an essential component of both the treatment of drinking water and the treatment of wastewater. The coagulant is one of the materials or substances that is added to the water to remove, stabilizes and causes colloidal particles to settle. Chemical coagulants such as aluminum sulphate (alum), ferric chloride, and synthetic polymers are the most commonly used coagulants in the industry due to their efficacy in turbidity removal. However, the use of chemical-based coagulants has had some negative impacts on human health and the environment, such as Alzheimer's disease, and has produced a high volume of toxic sludge. In order to reduce negative impacts, this led to the discovery of an alternative to the natural coagulant (plant-based) for drinking water treatment. The coagulant used in this study is a combination of fruit waste containing citrus microcarpa peels and papaya seed with a ratio of 80:20 and 40:60. In addition to determining the potential of the composite natural coagulant, the optimal dosage and the effect of the mixing duration are also studied in order to determine the best mixing duration for each stage of the coagulation-flocculation process. Laboratory-scale studies using jar test experiments were conducted on surface water to determine the percentage of turbidity removal. Fruit waste was collected from the UiTM Pulau Pinang cafeteria, dried in the oven for 24 hours at a temperature of 105°C. The optimum dosage of composite natural coagulant is 90 mg/L using an 80:20 ratio of citrus microcarpa peels and papaya seed with 97% of turbidity removal. The optimum mixing time is determined where the fast mixing time is 180 rpm for 3 minutes, the slow mixing time is 20 minutes with 10 rpm and the settling time is 30 minutes. The study shows that citrus microcarpa peels and papaya seeds have the potential to become effective natural coagulants in the future.

1. Introduction

Water is one of the most important basic needs to human. According to World Health Organization (WHO), half of the world’s population will be living in water-stressed areas in 2025 [1], which mean the lack of access to safe drinking water due to misuse of water coupled with growing population size, industrialization, change in climate and urbanization [2]. Because a lack of access to clean water has resulted in many avoidable deaths, the need for clean water has been one of the goals fought for all over the world. Color, turbidity, pH, nutrients, odour, turbidity, and coliform count all contribute to clean water quality [3]. In several countries, their main resources of drinking water are from surface water and the water is already contaminated by suspended particles causing turbidity due to exposed nature. Therefore, the widely used techniques to remove the suspended particles from water is
coagulation-flocculation due to its simplicity and effectiveness followed by sedimentation, filtration and disinfection [4]. Coagulants used are added to the water to withdraw the forces that stabilizes the colloidal particles and causing the particles to settle in the water [5]. In conventional water treatment, chemical-based coagulants such as aluminum sulphate (alum), ferric chloride and synthetic polymers are the widely used because of their effectiveness on removing turbidity [6]. However, excess intake of aluminium causes excessive toxic sludge which is non-biodegradable [7] due to nature of coagulant and lead to health issues which is related to neurodegenerative illness like Alzheimer’s [8] and senile dementia [9]. Moreover, chemical-based coagulants are high cost due to imported chemicals [10] and ineffective in low-temperature water [11]. Hence, nowadays, natural coagulant has been a great attention in the improvement and potential in water treatment process. These natural coagulants can be classified as plant-based coagulant and non-plant-based coagulant. Plant-based coagulant is from plant material and fruit waste such as moringa oleifera [12], plantago ovata [13], nirmali seeds [8], mangifera indica (duncan mango) seeds, and citrus aurantiifolia (key lime) seeds [6]. Non-plant-based coagulant is usually come from marine’s life such as chitosan and alginates [2]. In contrast to chemical coagulant, natural coagulant are safe to human health, cost effective, biodegradable, toxic free, low production of sludge, non-corrosive [8] and easily obtained [14]. Citrus Microcarpa is one of the members of family Rutaceae that contains active phytochemicals that can protect human’s health. Furthermore, citrus microcarpa is originated from Philippines and known as calamondin or Philippine lime at there. Besides, it also provides an ample supply of vitamin C, folic acid, potassium, minerals, essential oils, dietary fibres and carotenoids which makes citrus a health-benefit fruits [15]. The citrus peels produced a large amount of waste which is 44% higher than the production of juice [8]. So, to counter back the problem arise, peel waste can be used as secondary components that contains antioxidants compare to the other parts of the fruit. Papaya (carica papaya) is from Caricaceae family which is known due to its high nutrition and medicinal-pharmacological properties while its seed are inedible due to presence of some toxicants such as phytates, glucosinolates and tannins which has been used to treat turbid water with fecal bacteria [14]. Its origin is in the tropics of the Americas, perhaps from southern Mexico and neighbouring Central America. According to the Food and Agriculture Organization of the United Nations (FAO), India produces the most papayas - over 5 million tons in 2013. Besides, in several studies from the previous researcher, there is also a combination coagulant used which is combination between chemical-based coagulant and natural-based coagulant for example combination between the moringa oleifera and alum [16]. Therefore, to lessen the use of chemical coagulant, fruit waste also has a potential to remove turbidity in water. These fruit waste can be obtained in almost every household and restaurants. Using the fruit waste, it can reduce the volume of waste and cost of production. Besides, the mishandling of fruit waste could cause a drawback to the environment due to potential leaching into soil and water sources leading to further pollution [8]. Therefore, this study is to determine the optimum dosage of the coagulant used, best mixing duration intensity and percentage of turbidity removal for new composite natural coagulant citrus microcarpa peels and papaya seeds.

2. Procurement selection criteria in the cost control perception

2.1 Sample Collection
Citrus microcarpa peels and papaya seeds were collected from cafeteria around UiTM Pulau Pinang such as food court Nilam, Kristal and Baiduri. The samples were collected from the food court to keep the freshness of the fruit waste. The range of weight of the fruit waste sample collected after sun dried in between 40 g to 55 g every day. Basically, this type of fruits was used in drinks, foods and deserts. For example, citrus microcarpa usually used in preparing drinks and foods while papaya fruit typically ate as desert of fruit juice.

2.2 Surface Water Sample
Surface water sample were collected at Sungai Dua as shown in Figure 1. The in-situ data such as pH, temperature and conductivity were conducted before taking the surface water sample. The sampler should face upstream if there is a current and collect the sample without disturbing the bottom sediment. The water sample was kept in a Coleman cooler box to preserve the characteristic of the water and ice packs were used, which help the contaminants from breaking down while in transit to the laboratory in 30 minutes duration. Then, the surface water sample was kept in the Protech Incubator Model DD-1050 at 6°C.

Figure 1. Particle size distribution of dry quartz sand used in the study.

2.2.1 Preparation of powder natural coagulant
The citrus microcarpa peels and papaya seeds were washed by using tap water and dried for 2-3 days under the bright sun. The peels were dried in oven at temperature of 105°C for 24 hours to get the optimum moisture content 95%. Moisture content is a quantity of water in the material used. It can be determined by using the following equation.

\[
W\% = \frac{(A - B)}{B} \times 100\%
\]  

(1)

Where, W% = Percentage of moisture in the sample  
A = Weight of wet sample (grams), and  
B = Weight of dry sample (grams)

After that, the sample were kept in the air-tight container and placed into the desiccator cabinet to avoid from fungus. Figure 2 shows dried citrus microcarpa peels and papaya seeds from the oven.

Figure 2. Particle size distribution of dry quartz sand used in the study.
2.3 Preparation of stock solution

In general, extraction was the first step of photochemical analysis. This method is to separate the compounds that are being studied mixture of solid or liquids by a suitable solvent. The dry citrus microcarpa peels and papaya seeds were grinded and sieved into a fine powder to obtain the smaller size of solids with diameter less than 1.25 mm. The 8.0 g of fine powder which is from citrus microcarpa peels and 2.0 g of papaya seed for ratio of 80:20, while for ratio 40:60, the 4.0 g of citrus microcarpa peels and 6.0 g of papaya seeds were mixed into 1000 mL of NaCl solution separately. The suitability of NaCl solution, it contains proteinaceous nature of coagulation active compound. Both solutions were stirred continuously using magnetic stirrer for 10-15 minutes to make sure the citrus microcarpa peels and papaya seeds solution mix homogeneously with the sodium chloride solution. Then, insert the solution in the separatory funnel for 24 hours to allow the extraction of the composite material. After 24 hours, the solution was filtered by using vacuum and porcelain funnel with filter paper to get the extraction of the solution. Then, the volume of dosage was measure according to the ratio in this study.

2.4 Jar Test

Jar test is the most proven method that simulates coagulation/flocculation with differing coagulant doses as described in the standard method. Jar test experiment were conducted by using Programmable Lab Stirrer model which is provided at the laboratory as shown in Figure 3. citrus microcarpa peels and papaya seeds coagulant were adjusted by using sodium hydroxide or sulphuric acid to get the constant pH. From the previous researcher the suitable pH for Citrus Microcarpa peels coagulant is pH 4.0-5.0 [17] and pH 6.5 for papaya seeds.

| Mixing duration | Mixing speed (rpm) & mixing duration (min) |
|-----------------|------------------------------------------|
| 1               | 180 rpm - 3 min                          |
|                 | 10 rpm - 20 min                          |
|                 | Settle - 30 min                          |
| 2               | 120 rpm – 3 min                          |
|                 | 50 rpm - 20 min                          |
|                 | Settle - 60 min                          |
| 3               | 200 rpm - 1 min                          |
|                 | 30 rpm - 12 min                          |
|                 | Settle - 60 min                          |

Figure 3. Jar test.
2.5 Laboratory testing (Turbidity Removal)
The laboratory testing was conducted to find the initial turbidity and final turbidity of water tested. Turbidity was measured using turbidity meter (2100Q Portable Turbidimeter) and it was expressed in Nephelometric Turbidity Units (NTU).

\[ \text{Turbidity Removal Efficiency (\%) = } \frac{\text{Ti} - \text{Tf}}{\text{Ti}} \times 100 \]  

Where, \( \text{Ti} = \) initial turbidity 
\( \text{Tf} = \) final turbidity

3. Results and discussion
Table 2 shows a comparative study of turbidity reduction efficiency of coagulants using Citrus microcarpa and Papaya seed extracts corresponding to the different ratio of 80:20 and 40:60.

| Ratio (Citrus microcarpa: Papaya seed) | Mixing Durations (MD) | Dosage used (mg/L) | Initial Turbidity (Low turbid water) (NTU) | Final Turbidity (NTU) | Turbidity removal (%) |
|---------------------------------------|-----------------------|--------------------|------------------------------------------|----------------------|----------------------|
| 80:20                                 | 0                     | 57.53              | 50.80                                    | 11.70                |
|                                       | 1                     | 50                 | 66.67                                    | 7.38                 | 88.53               |
|                                       |                       | 150                | 64.10                                    | 8.47                 | 86.79               |
|                                       |                       | 250                | 61.37                                    | 45.13                | 26.45               |
|                                       |                       | 350                | 61.77                                    | 55.63                | 9.93                |
|                                       |                       | 450                | 55.93                                    | 55.23                | 1.25                |
|                                       | 2                     | 0                  | 53.03                                    | 50.07                | 5.59                |
|                                       |                       | 50                 | 61.23                                    | 9.84                 | 83.94               |
|                                       |                       | 150                | 64.40                                    | 15.75                | 75.54               |
|                                       |                       | 250                | 65.40                                    | 29.53                | 54.84               |
|                                       |                       | 350                | 66.10                                    | 54.03                | 18.26               |
|                                       |                       | 450                | 62.90                                    | 57.33                | 8.85                |
|                                       | 3                     | 0                  | 76.60                                    | 64.27                | 16.10               |
|                                       |                       | 50                 | 86.23                                    | 10.13                | 88.25               |
|                                       |                       | 150                | 91.07                                    | 17.57                | 80.71               |
|                                       |                       | 250                | 83.50                                    | 37.97                | 59.42               |
|                                       |                       | 350                | 93.57                                    | 37.97                | 59.42               |
|                                       |                       | 450                | 91.57                                    | 31.07                | 66.07               |
| 40:60                                 | 1                     | 0                  | 72.93                                    | 58.50                | 19.79               |
|                                       |                       | 50                 | 82.07                                    | 9.74                 | 88.94               |
|                                       |                       | 150                | 83.57                                    | 10.21                | 87.78               |
|                                       |                       | 250                | 85.43                                    | 11.87                | 86.10               |
|                                       |                       | 350                | 84.70                                    | 12.76                | 84.93               |
|                                       |                       | 450                | 89.60                                    | 12.81                | 81.24               |
|                                       | 2                     | 0                  | 64.07                                    | 49.83                | 22.22               |
|                                       |                       | 50                 | 71.87                                    | 9.99                 | 86.10               |
|                                       |                       | 150                | 76.13                                    | 15.51                | 79.63               |
|                                       |                       | 250                | 85.10                                    | 18.10                | 78.73               |
|                                       |                       | 350                | 85.53                                    | 25.67                | 69.99               |
|                                       |                       | 450                | 89.27                                    | 29.40                | 67.06               |
The percentage of turbidity removal in surface water sample was influenced by the amount of dosage of composite natural coagulant used. It is presumption that coagulation activity highly depends on the optimum relationship of coagulant dosage by the increasing of cation inside the water. The effect of citrus microcarpa peels and papaya seeds on the percentage of removal was investigated by the following experiments. The result shown that the increased amount of dosage effects the turbidity removal. From Figure 4, Figure 5 and Figure 6, it shown a line graph from the three different mixing duration with different ratio. For the mixing duration 1, the optimum dosage and turbidity removal for ratio 80:20 were 50 mg/L and 88.93% respectively. While for ratio 40:60 the optimum dosage turbidity removal was 50 mg/L and 88.94% respectively. For mixing duration 2, the optimum dosage and turbidity removal for ratio 80:20 were 50 mg/L and 83.74% respectively. While for ratio 40:60, the optimum dosage turbidity removal was 50 mg/L and 86.1% respectively. Furthermore, from the mixing duration 3, the optimum dosage for ratio 80:20 the optimum dosage and turbidity removal for ratio 80:20 was 50 mg/L and 88.25% respectively. While for ratio 40:60, the optimum dosage turbidity removal was 50 mg/L and 87.62% respectively and 40:60 is 50 mg/L which lead to high percentage of turbidity removal. It shows that, the composite natural coagulant dosage needed to remove turbidity in the surface water sample should be lower. It is because the higher the dosage of natural coagulant used, the lower the turbidity removal which mean the higher dosage does not contributes to the performance of turbidity removal.

Based on the previous study, using papaya seeds as natural coagulant for water purification it shows a potential to remove turbidity of raw water sample with the optimum dosage is 60 mg/L at which 89.14% turbidity was removed from the sample [18]. However, [19] shows the optimum dosage of roselle seed extract in the removal turbidity of 93.11% is 40 mg/L for synthetic wastewater and 60 mg/L for industrial water with the percentage removal 88.83%. Besides, [6] shows a combination of seeds extract and alum by using ratio 60:40 for Duncan mango seed extract and alum and the corresponding turbidity reduction were 95.88% in low turbid water. The highest turbidity removal obtained from the test conducted is 88.94% with optimum dosage 50 mg/L which is from ratio 40:60 of citrus microcarpa peels and papaya seeds using the mixing duration 1. While for 80:20 ratio, the highest turbidity removal is 88.53% with the same optimum dosage. Besides, from the Table 2 shows, the percentage of turbidity removal for the three mixing duration is decreasing rapidly as the dosage of composite natural coagulant increases for ratio 80:20. However, for ratio 40:60 the turbidity removal is decreasing slowly. This is due to the pH of the composite natural coagulant from citrus microcarpa peels and papaya seeds. Coagulant should be within neutral and low alkali. If the coagulant is more to acidic, it will reduce the performance of the coagulant in the surface water sample.

|  | 0  | 67.10 | 53.97 | 19.57 |
|---|---|---|---|---|
| 3 | 50 | 85.47 | 10.58 | 87.62 |
|  | 150 | 76.60 | 12.66 | 83.47 |
|  | 250 | 91.67 | 19.34 | 78.91 |
|  | 350 | 99.53 | 25.20 | 74.68 |
|  | 450 | 101.33 | 27.37 | 72.99 |

The percentage of turbidity removal in surface water sample was influenced by the amount of dosage of composite natural coagulant used. It is presumption that coagulation activity highly depends on the optimum relationship of coagulant dosage by the increasing of cation inside the water. The effect of citrus microcarpa peels and papaya seeds on the percentage of removal was investigated by the following experiments. The result shown that the increased amount of dosage effects the turbidity removal. From Figure 4, Figure 5 and Figure 6, it shown a line graph from the three different mixing duration with different ratio. For the mixing duration 1, the optimum dosage and turbidity removal for ratio 80:20 were 50 mg/L and 88.93% respectively. While for ratio 40:60 the optimum dosage turbidity removal was 50 mg/L and 88.94% respectively. For mixing duration 2, the optimum dosage and turbidity removal for ratio 80:20 were 50 mg/L and 83.74% respectively. While for ratio 40:60, the optimum dosage turbidity removal was 50 mg/L and 86.1% respectively. Furthermore, from the mixing duration 3, the optimum dosage for ratio 80:20 the optimum dosage and turbidity removal for ratio 80:20 was 50 mg/L and 88.25% respectively. While for ratio 40:60, the optimum dosage turbidity removal was 50 mg/L and 87.62% respectively and 40:60 is 50 mg/L which lead to high percentage of turbidity removal. It shows that, the composite natural coagulant dosage needed to remove turbidity in the surface water sample should be lower. It is because the higher the dosage of natural coagulant used, the lower the turbidity removal which mean the higher dosage does not contributes to the performance of turbidity removal.

Based on the previous study, using papaya seeds as natural coagulant for water purification it shows a potential to remove turbidity of raw water sample with the optimum dosage is 60 mg/L at which 89.14% turbidity was removed from the sample [18]. However, [19] shows the optimum dosage of roselle seed extract in the removal turbidity of 93.11% is 40 mg/L for synthetic wastewater and 60 mg/L for industrial water with the percentage removal 88.83%. Besides, [6] shows a combination of seeds extract and alum by using ratio 60:40 for Duncan mango seed extract and alum and the corresponding turbidity reduction were 95.88% in low turbid water. The highest turbidity removal obtained from the test conducted is 88.94% with optimum dosage 50 mg/L which is from ratio 40:60 of citrus microcarpa peels and papaya seeds using the mixing duration 1. While for 80:20 ratio, the highest turbidity removal is 88.53% with the same optimum dosage. Besides, from the Table 2 shows, the percentage of turbidity removal for the three mixing duration is decreasing rapidly as the dosage of composite natural coagulant increases for ratio 80:20. However, for ratio 40:60 the turbidity removal is decreasing slowly. This is due to the pH of the composite natural coagulant from citrus microcarpa peels and papaya seeds. Coagulant should be within neutral and low alkali. If the coagulant is more to acidic, it will reduce the performance of the coagulant in the surface water sample.
3.1 Effect of pH of composite coagulant

From the experiment that have been conducted at the laboratory, the result of the pH test for the composite coagulant as shown in the Table 3 below.

| Natural coagulant          | pH    |
|----------------------------|-------|
| *Citrus Microcarpa* peels | 5.27  |
In the coagulation – flocculation process, pH is very important since the coagulation occurs within a specific pH range for the coagulant. As can be seen in Table 3, pH of the citrus microcarpa peels solution is 5.27 which is acidic, then when it combines with papaya seeds solution, pH of the composite coagulant is 5.38. From the result of pH of the composite coagulant the turbidity removal of ratio 80:20 is less effective than 40:60. The optimal pH range for coagulation is 6 to 7 when using alum and 5.5 to 6.5 when using iron. For high alkalinity water, excessive amounts of coagulant may be needed to lower the pH to the optimal pH range. Based on the previous study, contaminants removal by using banana pith works best under acidic condition pH 4 [20]. Besides, [7] the pH was not significantly changed due to the type of natural coagulant used for example in this research they use banana peel powder, neem leaf powder, papaya seed powder and banana stem juice which the pH is varied between 7.1 and 8.0. This shows that, adjustment of pH would not be required after the coagulation process. Furthermore, pH value between 7–7.5 provides better response in turbidity while using watermelon seeds as a natural coagulant [10]. Thus, coagulant pH is an important factor that affects the enhanced coagulation.

4. Conclusion
The ability of fruit waste from citrus microcarpa peels and papaya seeds as a composite natural coagulant has been experimented and tested to analyse the percentage of turbidity removal instead of using chemical-based coagulant for surface water treatment. The two ratios that have been used which is 80:20 and 40:60 of citrus microcarpa peels and papaya seeds give different percentages of turbidity removal. Besides, the coagulation-flocculation process conducted is also affected by the mixing duration chosen for the test. It is proved that the mixing duration of rapid mixing, slow mixing and settling process affect the turbidity removal. From the results obtained from the jar test experiment, the optimum dosage of composite coagulant is 90 mg/L for ratio 80:20 of citrus microcarpa peels and papaya seeds where the turbidity removal 97.0% respectively. The best mixing duration obtained was MD 1 where the rapid mixing is 180 rpm for 3 minutes, slow mixing within 20 minutes with 10 rpm and 30 minutes for settling time. Hence, it also can be concluded that the longer the time for mixing duration, the effective for low turbid water and the higher turbidity removal can be obtained. As a conclusion, citrus microcarpa peels and papaya seeds has been found to be a new alternative coagulant aid to remove turbidity in water and reduce the amount of chemical-based coagulant used in the conventional water treatment plant. Hence, this could help to reduce the incidence of water borne diseases that is cause by the aluminium and it is eco-friendly method of water treatment.

Acknowledgement
We would like to express our special thanks of gratitude to our laboratory technicians, Mr. Faizal Zakaria for their help in laboratory exercise and the author also would like to acknowledge Universiti Teknologi MARA (UiTM), Cawangan Pulau Pinang for financial support in this research work.

References
[1] Assembly U N G 2018 Drinking-water, pp. 1–4.
[2] Kumar V, Othman N and Asharuddin S 2017 Applications of Natural Coagulants to Treat Wastewater – A Review, vol. 06016, pp. 1-9.
[3] Owodunni A A and Ismail S 2021 Revolutionary technique for sustainable plant-based green coagulants in industrial wastewater treatment - A review, Journal of Water Process Engineering, vol. 42, no. 2, p. 102096, doi: 10.1016/j.jwpe.2021.102096.
[4] Kang J Evaluating Moringa Oleifera 2017 Papaya, and Pumpkin Seed as a Natural Coagulant, vol. 5, no. 2, pp. 126–131.
[5] Binayke M S R A and Jadhav P M V 2013 *Application of Natural Coagulants In Water Purification,*” no. 1, pp. 118–123.

[6] Seghosime S O K A, Awudza J A M, Buamah R and Ebeigbe A. B 2017 *Effect of Locally Available Fruit Waste on Treatment of Water Turbidity,* vol. 9, no. 7, pp. 7–15.

[7] Maurya S and Daverey A 2018 Evaluation of plant - based natural coagulants for municipal wastewater treatment, *3 Biotech,* vol. 8, no. 1, pp. 1–4, doi: 10.1007/s13205-018-1103-8.

[8] Choy S Y, Prasad K M N, Wu T Y, Raghunandan M E and Ramanan R N 2014 Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification,” *J. Environ. Sci. (China),* vol. 26, no. 11, pp. 2178–2189, doi: 10.1016/j.jjes.2014.09.024.

[9] Agri A J 2018 *The used of dragon fruit peels as eco-friendly wastewater coagulants,* no. 66, pp. 66–71.

[10] Muhammad I M, Abdulsalam S, Abdulkarim A and Bello A A 2015 *Water Melon Seed as a Potential Coagulant for Water Treatment,*” vol. 15, no. 1.

[11] Antov M G, Šćiban M B, and Prodanović J M 2012 Evaluation of the efficiency of natural coagulant obtained by ultrafiltration of common bean seed extract in water turbidity removal, *Ecol. Eng.,* vol. 49, pp. 48–52, doi: 10.1016/j.ecoleng.2012.08.015.

[12] Camacho F P, Sousa V S, Bergamasco R and Teixeira M R 2016 The use of Moringa oleifera as a natural coagulant in surface water treatment,*Chem. Eng. J.,* doi: 10.1016/j.cej.2016.12.031.

[13] Ramavandi B 2014 Treatment of water turbidity and bacteria by using a coagulant extracted from Plantago ovata, *Water Resour. Ind.,* vol. 6, pp. 36–50, doi: 10.1016/j.wri.2014.07.001.

[14] Kristianto H, Kurniawan M A, and Soetedjo J N M 2018 *Utilization of Papaya Seeds as Natural Coagulant for Synthetic Textile Coloring Agent Wastewater Treatment,*” vol. 8, no. 5, pp. 2071-2077.

[15] Rafaq S, Kaul R, Sofi S A, Bashir N, Nazir F and Ahmad G 2016 Citrus peel as a source of functional ingredient: A review, *J. Saudi Soc. Agric. Sci.,* vol. 17, no. 4, pp. 351–358, doi: 10.1016/j.jssas.2016.07.006.

[16] Pise C P and Halkude S A 2015 A New Technique for Purification of Water Using Natural Coagulant, *Int. J. Eng. Technol.,* vol. 6, no. 6, pp. 2564–2572.

[17] Jayalakshmi G and Saritha V 2016 Legitimate Use of Plant Waste Products for Drinking Water Treatment, *vol. 11, no. 02.*

[18] George D and Chandran A J 2018 Coagulation Performance Evaluation of Papaya Seed for Purification of River Water, *Int. J. Latest Technol. Eng.,* vol. VII, no. I, pp. 50-66, [Online]. Available: www.ijltemas.in.

[19] Fathinatul N and Nithyanandam R 2014 *Wastewater Treatment by using Natural Coagulant,* pp. 2–3.

[20] Kakoi B, Kaluli J W, Ndiba P and Thion’o G 2016 Banana pith as a natural coagulant for polluted river water, *Ecol. Eng.,* vol. 95, pp. 699-705, doi: 10.1016/j.ecoleng.2016.07.001.