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REVIEW PAPER

The Potency of Indonesia Native Plants as Natural Coagulant: a Mini Review

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Abstract Indonesia is a tropical country which is known for its high variety of natural resources. However, there is limited access to clean water, thus forcing people in rural areas to use turbid water. Furthermore, some of water sources in Indonesia are already polluted by heavy metals with high biological oxygen demand (BOD) and chemical oxygen demand (COD) value. Simple and easy water purification methods are needed to overcome this situation. Coagulation and flocculation are widely used method to treat water. However, chemical coagulants (alum, ferrum, PAC, etc.) are not easily obtained and could cause some health problems if treated water is consumed. Natural coagulants have a good potential to solve these problems. Various possible plant-based natural coagulants which are abundant in Indonesia are highlighted in this paper. Fruit wastes and inedible legumes are suggested to be used as natural coagulant as there are no food competition presents. Further research is needed especially to scale up laboratory scale research that has been done in these years; thus, it can be applied to solve clean water scarcity problem.

Keywords Coagulation · Plant-based natural coagulant · Turbidity removal · Water treatment · Indonesia

Introduction

Water is essential to support human life. Although 75% of the earth is covered with water, limited water access still exists especially in third world countries, including Indonesia. Indonesia consists of about 18,000 islands with almost 260 million populations [110]. Recently, Indonesia has shown great development on economic growth with annual growth rates of 6%, gross domestic product about $3000, and poverty of 7% [74]. Although there are some great achievements in economic growth, there are some aspects, such as sanitation and access to clean water, that need more attention [74]. Based on data presented in Fig. 1, households in Indonesia are still lacking access to clean and drinking water. The Java-Bali region has the best access than other regions due to focus of growth only in this region. This inequality of growth has caused other regions to have clean water access below 70% with average access of 67.44% in 2015 [29]. This number is lower compared with Indonesia neighbouring countries, such as Malaysia and Singapore, which have achieved 100% access to clean and drinking water [106]. Limited access to clean water resulted in utilization of turbid water to fulfil daily needs, such as river water. This practice is highly discouraged as some waterborne diseases are associated with utilization and consumption of turbid water. Consumption of turbid water could cause gastrointestinal diseases [61, 66, 88] that lead to morbidity. Furthermore, some Indonesia rivers are polluted with heavy metals and faecal bacteria. River water in Jakarta (Java) was found to have poor and very poor quality and also polluted by heavy metals such as Cu, Pb, Cd, Zn, and Hg [72]. Recent study by [56] in West Java and Kalimantan showed that river water in those regions has high chemical oxygen demand (COD) level, with contamination of *Escherichia coli* and Hg [56].

Coagulation and flocculation have been used as primary treatment of water. Metal salts such as aluminium sulphate and ferric chloride [101], and prehydrolized coagulant such as polyaluminium chloride (PAC), polyferrous sulphate (PFS), and polyferric chloride (PFC) [108] have been widely

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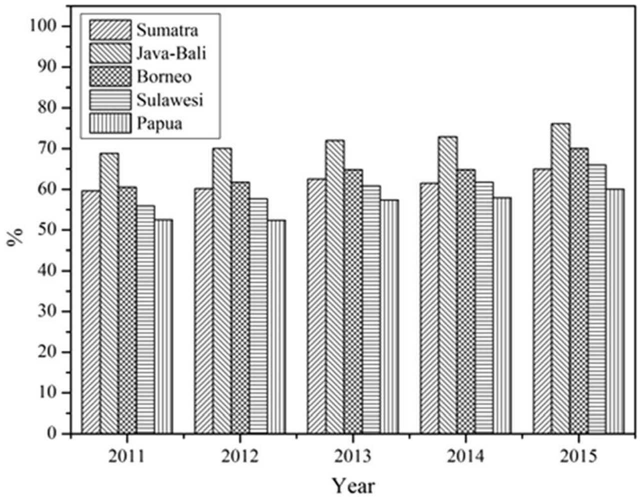

Fig. 1 Percentage of average household access to clean and drinking water in various regions (reproduced from [29])

used to treat water and various wastewater. Although these coagulants give great performance in water treatment, there are some disadvantages such as reduction in pH to acidic, inefficiency in low temperatures, potential cause of health problem (such as Alzheimer's disease and presenile dementia [96]) when the water is consumed, relative high coagulant cost, and large sludge volume [101, 111]. There is also some evidence that ferric salt and PFS could accelerate pipe corrosion when used in water treatment [92]. Alternative coagulants are needed to overcome these disadvantages. Plant-based coagulant has been used for 2000 years in India, Africa, and China [10], even its utilization can be tracked back for 4000 years [99].

Agriculture is one of the major sectors in Indonesia. About 29% from 190 million hectares of its land area is agricultural [79]. Indonesia is also known as one of the major tropical fruit producer in the ASEAN [5]. Each species of these crops could consist of tens and hundreds of subspecies and variety [103]. The focus in this paper is to present some potential plant-based natural coagulant in Indonesia, based on the production capacity and availability of crops species. Some of these plants have been utilized as natural coagulant or coagulant aid, but some plants could be explored for this application.

Mechanism of Coagulation

It is known that there are four coagulation mechanisms, namely double layer compression, polymer bridging, charge neutralization, and sweep coagulation [26, 27]. Double layer compression is caused by high electrolytes concentration in the solution. The high ionic concentration causes compression in the volume of double layer surrounding colloid particles, thus lowering the repulsive force of colloid particles. This phenomenon makes colloids unstable and increasing possibilities of coagulation, followed by flocculation. Polymer bridging usually happens when long-chain polymer adsorbed on the particles and leaving dangling coagulant polymer segments to bridge particles together. High molecular weight and linear polymers are favourable for bridging mechanism [27]. It is known that bridging mechanism form strong flocs, even at elevated stirring. However, at turbulent condition, the irreversible floc breakage could happen due to polymer scission. The dosage of polymer plays important role in bridging mechanism. Sufficient unoccupied colloid particle surface is needed for attachment of the dangling polymer segments [105]. However, at higher dosage, the colloid particles were restabilized due to steric repulsion of polymers covering the particles, while at low dosage, there is not enough polymer chain to form the bridges.

Charge neutralization happens when opposite charged coagulant polymer is adsorbed on particle surfaces, thus neutralizing the colloid particle charges. High charge density coagulant with low molecular weight is known to give effective coagulation performance [27, 105]. At optimum coagulant dosage, zero zeta potential is expected; however, in practice, slightly positive [68] or negative [47] zeta potential is achieved. The reduction of particles surface charges results on the decrease of electrostatic repulsion between colloid particles, thus making coagulation possible. Sweep coagulation occurs when metal coagulants are added in dosages much higher than the solubility of the amorphous hydroxides, thus precipitation occurs [37]. The colloid particles are entrapped within the precipitate, and then removed from the suspension. However, the drawbacks of this mechanism are more metal coagulants used and also larger amount of sludge is produced, and both could lead to higher cost for water treatment.

Among four coagulation mechanism, both polymer bridging and charge neutralization are considered to be the most possible coagulation mechanism of plant-based coagulant [27, 111]. These mechanisms are preceded by adsorption forming polymer coagulant-particle complex. Utilization of isotherm adsorptions such as Langmuir and Freundlich have been used to proof that adsorption is the controlling stage of coagulation process, for dyes coagulation [18, 20, 31], turbidity [50], and hardness removal [41]. Linear form of Langmuir and Freundlich isotherm adsorptions are presented in Eqs. 1 and 2, respectively [31], where Ce ([mg] $[L]^{-1}$) is equilibrium concentration in solution, q_e ([mg]. [mg of coagulant]$^{-1}$) equilibrium concentration in solution, q_{max} Langmuir maximum adsorption capacity, K_L ([L] $[mg]^{-1}$) and K_f ([L^n].[mg of coagulant]$^{-1}$) are constants for Langmuir and Freundlich isotherm, and n is Freundlich adsorption order.

$$\frac{C_e}{q_e} = \frac{1}{q_{max} K_L} + \frac{C_e}{q_{max}} \quad (1)$$

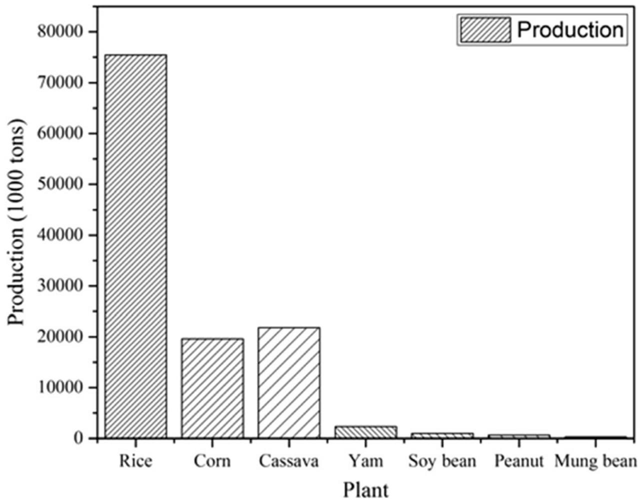

Fig. 2 Indonesia production capacity of main starch-containing plants and nuts-legumes in 2015 (reproduced from [30])

$$\log q_e = \frac{1}{n}\log C_e + \log K_f \quad (2)$$

Classification of Plant-Based Coagulant

The classification in this paper is made based on the source of active coagulant agents which are starch, proteins, and others. The presented plants have a great potential to be used as natural coagulant due to its availability, represented by the number of their production (Fig. 2). Some of these plants have been studied as natural coagulants, presented in Table 1.

Starch Containing Plants

Rice along with corn, cassava, sago, and yams are known as staple food in Indonesia [36, 94]. All those mentioned plants have high starch content, thus providing macronutrients when consumed. Starch is a natural polysaccharide composed of amylose and amylopectin. Amylose has linear structure of glucose polymer bonded by α (1 → 4) glycosidic bond, and amylopectin, the branched structure of glucose polymer with α (1 → 4) backbone and α (1 → 6) branches [114]. Starch can be used as natural coagulant due to its low cationic polyelectrolyte properties [70].

Rice (*Oryza sativa*) has been utilized as natural coagulant to treat palm oil mill effluent (POME) with total suspended solid (TSS) and COD removal of 92.5 and 30.91%, respectively, at its optimum condition [100]. There are also some findings that rice hull ash (RHA) has potential to be utilized as coagulant aid [3, 4]. This is possible due to high silica content in rice hull. When carbonized, its ash contains active silica that could give a stable solution with negative surface charge which aids Al or Fe coagulant by forming bigger and denser floc [3].

There are also some studies in utilization of sago starch as natural coagulant. Sago is a byproduct obtained from the processing of cassava (*Manihot utilissima*) into tapioca. An 82% of turbidity removal has been achieved by utilization of unmodified sago starch [107]. Other study has obtained 100% of turbidity removal when sago starch was used to treat turbid water [85]. Utilization of corn (*Zea mays*) also has successfully done to remove turbidity with 90% removal, with significant bacterial removal is also obtained [60]. Corn seed powder also can be used to remove COD, biological oxygen demand (BOD), colour, and turbidity in textile wastewater [73]. Starch from sago trunk has also been utilized to treat semi aerobic landfill leachate as coagulant aid. Combination of sago trunk starch and poly aluminium chloride (PAC) gave 98.9, 94.7, and 99.2% removal in turbidity, colour, and SS, respectively [11]. Potato (*Solanum tuberosum)* also showed great performance as natural coagulant to remove azo dyes in textile waste water [113].

In recent study done by [33], it was observed that the size starch granule plays important role in coagulation process. There was higher turbidity removal efficiency with increase of the size of starch granule [33]. Furthermore, autoclaved starch gave better performance than non-autoclaved one, due to the rupture of individual starch granule, thus releasing enclosed starch content which facilitates bridging coagulation mechanism [33]. Compared with other starch (corn, potato, and wheat), rice gave the best performance of turbidity removal due to its bigger polymer chain compared with other starch.

Legumes

Legumes are mainly composed of proteins, which are stored in seed organelles to provide nutrition for seeds growth and development [38]. These proteins are known as storage proteins, which can be classified by its solubility properties. There are albumins, water soluble proteins, globulins, which are soluble in dilute salt solutions, prolamins, in alcohol/water mixtures, and gluteins, which are soluble in dilute acid or alkali [91]. Globulins are also known as the major constituent of proteins in legumes [23]. These proteins content in legumes play important role when it is used as natural coagulant.

Direct utilization of some legumes such as soybean (*Glycine max*), peanut (*Arachis hypogea*), and pea (*Pisum sativum*) have been done by Mbogo [64] with turbidity removal around 97 to 100%. Combination of these legumes as coagulant aid with alum (80% legumes, 20% alum) could give 100% turbidity removal [64]. Mung bean powder (*Vigna radiata* (*L.*) *Wizek*) also has been tested as natural coagulant. For direct use of mung bean powder, it gave lower turbidity removal, compared with *Moringa oleifera* and *Tamarindus indica* [75]. As coagulant aid, 1 mg/L mung bean powder combined with 70 mg/L alum could give 77% of turbidity removal.

Table 1 Recent studies on natural coagulant for various wastewater

Coagulant	Treated water	Optimum condition		Result at optimum condition	References
		pH	dosage		
Parboiled rice husk ash	Turbid water	7.55	12 g	Turbidity removal: 95%	[4]
Unparboiled rice husk ash	Turbid water	8.15	8 g	Turbidity removal: 94.99%	
Rice starch (unmodified)	Palm oil mill effluent	2.28	0.74 g/L	TSS removal: 92.50% COD removal: 30.91%	[100]
Rice starch	Synthetic turbid water	4	120 mg/L	Turbidity removal: 50%	[33]
Potato starch	Wastewater from textile dye house	3.0	2% (*w*/*v*)	TDS removal: 90.0% Turbidity removal: 87.0%	[113]
Sago (dry tapioca root)	Water from Mudasarlova, India	6–8	0.1–0.2 g/L	Colour reduction: 99.93% Chloride removal: 78.57% Hardness removal: 87.50% Turbidity removal: 70–100%	[85]
Native sago trunk starch (NSTS)	Water from Pulau Burung Landfill Site	4	7000 mg/L	Colour reduction: 13.1% SS reduction: 27.9% NH3-N reduction: 8.2% COD reduction: 1.7% Organic UV254 reduction: 43.8% Cd reduction: 25.5% Ni reduction: 44.1%	[11]
Commercial sago starch (CSS)	Water from Pulau Burung Landfill Site	4	6000 mg/L	Colour reduction: 15.1% SS reduction: 29.5% NH3-N reduction:10.7% COD reduction: 28.0% Organic UV254 reduction: 51.6% Cd reduction: 33.2% Ni reduction: 16.3%	
Zea mays	Wastewater from textile industry	–	30 g/L	COD removal: 68.82% BOD removal: 58.88% Colour removal: 47.0%	[73]
Moringa oleifera	Model turbid water	–	50 mg/L	Turbidity removal: 83.7% *E. coli* reduction: 88.0%	[77]
	Reservoir water	–	750 mg/L	Reduction in colour: 52.4% TC reduction: 73.6%	
	Low turbidity river water	–	500 mg/L	Colour reduction: 41.4% TC reduction: 76.8% *E. coli* reduction: 81.8%	
	Turbid water	–	250 mg/L	Colour reduction: 75.8% Turbidity removal: 74.0% TC reduction: 93.9% *E. coli* reduction: 92.6%	
	Hybrid water	–	1000 mg/L	Colour reduction: 82.5% Turbidity removal: 97.2% (*E. coli* reduction: 65.8%	
Moringa oleifera	Turbid water	–	50 mg/L	*E. coli* reduction: 88.0% Turbidity removal: 83.7%	[78]
	Reservoir water	–	750 mg/L	Colour reduction: 52.4% Total count reduction: 73.6%	
	Turbid river water	–	250 mg/L	Colour reduction: 75.8% Turbidity removal: 74.0% Total count reduction 93.9% *E. coli* reduction 92.6%	
Moringa oleifera	Lake water	–	–	Reduced growth of *Staphylococcus aureus* and *Escherichia coli*	[42]
Moringa oleifera	Chicago Sky Blue 6B synthetic wastewater	8	250 mg/L	Chicago sky blue removal: 99%	[16]
Moringa oleifera	Water containing heavy metal	7	200 mg/L	Pb removal: 81%	[12]
	Water containing heavy metal	7	400 mg/L (ratio 1:1)	Ni removal: 74%	[12]

Table 1 (continued)

Coagulant	Treated water	Optimum condition		Result at optimum condition	References
		pH	dosage		
Moringa oleifera with *Musa cavendish* (banana peel)				Cd removal: 97%	
Moringa oleifera	Tapioca starch waste water	–	150 mg/L	BOD removal: 99.6% COD removal: 99.7% TSS removal: 91.5%	[98]
Glycine max	Turbid water	–	1000 mg/L	Turbidity removal: 98.9%	[64]
Arachis hypogea	Turbid water	–	1000 mg/L	Turbidity removal: 96.7%	
Pisum sativam	Turbid water	–	1000 mg/L	Turbidity removal: 99%	
Tamarindus indica	River water	–	2 mg/L	Turbidity removal: 76%	[75]
Salt extracted peanut seeds	Palm oil mill effluent (POME)	–	5000 mg/L	Turbidity removal: 94.6% TSS removal: 94.6% COD removal: 77%	[25]
Peanut seeds	Synthetic water	–	20 mg/L	Turbidity removal: 92%	[24]
Grape seed extract	Water containing malachite green and crystal violet	–	5% *v*/*v* in ethanol mixtures	Fast decolourization followed by gradual floc formation	[51]
Orange peel	Synthetic turbid waste water	4	1 mg/L	Turbidity removal: 99.01%	[48]
Orange peel	Laundry wastewater	–	6 mL/L	Turbidity removal: 89.5% TSS removal: 81.5% COD removal: 56.4% Anionic surfactant removal: 77.4%	[65]
Banana peel	Grey water	–	30 g/L	pH increased for 14% Turbidity removal: 66% Hardness: 135 mg/L DO: 5.123 mg/L BOD: 520 mg/L COD: 250 mg/L TDS: 1720 mg/L TSS: 100 mg/L	[63]
Banana pith	River water	4	0.1 kg/m^3	Turbidity removal: 98.5% COD removal: 54.3% SS removal: 96.03% Sulphates removal: 98.9% Nitrates removal: 88.7% Copper removal: 100% Chromium removal: 100% Iron removal: 92% Zinc removal: 81% Lead removal: 100% Manganese removal: 60%	[55]
Banana stem juice	Spent coolant waste water (oil filtered)	7	90 mL juice/300 mL sample water	COD removal: 80.1% SS removal: 88.6% Turbidity removal: 98.5%	[6]
Carica papaya seed	River water	–	100 seeds/100 L	Turbidity removal: 90%	[112]

Various salt extracts of peanut (*Arachis hypogaea*) seeds have been utilized as natural coagulant with 93.2% removal of kaolin suspension by NaCl extraction [24]. It is known that peanut seeds contain arachin and coarachin, which are globulin proteins [52]. De-oiled peanut seed extract was also utilized for POME treatment. The biggest TSS and COD removal was obtained at 2 mol/L NaCl extract with 94.7 and 73.5% removal, respectively [25]. However, distilled water extract of peanut cake also gave good result of 90 and 66% removal of TSS and COD, respectively. This was possible due to albumin content of peanut seed, which is soluble in water [89].

M. oleifera has been known for its performance as natural coagulant, its activity due to its water soluble protein lectin [42]. *M. oleifera* seeds has been widely known for its application as natural coagulant. [99] noted its application in various countries such as Sudan, Indonesia, South America, and North East Africa [99]. *M. oleifera* seed extract has antibacterial properties against *Staphylococcus aureus* and *E. coli* [7, 42]. Various wastewaters have been treated using *M. oleifera*, including azo dye [16], turbidity [7, 68], heavy metals [12], tapioca starch industry [98], dairy industry [43], surfactant [21], batik effluent [39], and so on. There are also some efforts

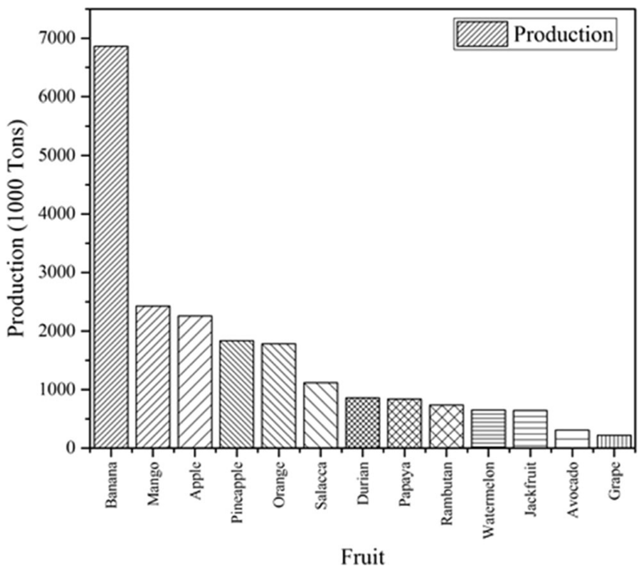

Fig. 3 Indonesia production capacity of major fruits in 2014 (reproduced from [28])

to isolate lectin from *M. oleifera* using saline extraction [59, 69] followed by single-step [44] or two-step [82] ion exchange, and affinity chromatography [84]. Protein extract and isolate of *M. oleifera* showed better performance than direct usage of *M. oleifera* seed.

There are also some indigenous legumes that have potential to be used as natural coagulants. Some legumes such as Calopo (*Calopogonium mucunoides*), Centro (*Centrosema pubescens*), Puero (*Pueraria phaseoloides*), Leucaena (*Leucaena leucocephala*), and Gliricideae (*Gliricideae maculate*) are known for its high content of protein and usually used as forage [40]. However, some of these legumes contain toxic substances, such as phytohemagglutinin, cyanogenetic compounds, and so on [45]. Some of these toxic substances, such as cyanogenic glycosides, are water soluble [109]; thus, direct utilization of these legumes to treat water raised some concern that the toxic substances could leach to water. There are some pretreatments that can be used to lower or destroy toxic substances, such as heating, autoclaving, etc. [45]. The effect of these pretreatments to coagulant activities of the legumes should be further studied.

Fruit Wastes and Others

Food and agricultural wastes, especially fruit wastes, contain polyphenols even higher than the edible part of the fruit [57]. There are some studies suggesting potential benefits of utilizing polyphenols from these wastes for bioremediation, including coagulation. Successful removal of various cationic dyes has been done using polyphenol extract, namely catechin and tannic acid, from grape (*Vitis vinifera*) seed [51]. Tannic acid, or tannin, is water-soluble polyphenols with molecular weight between 500 and 3000 D and contains a large number of hydroxyl or other functional groups (such as carboxyls) [15, 34]. There are some evidence that tannin has good performance as natural coagulant [19, 21, 22]; furthermore, a commercial coagulant-coagulant aid, Tanfloc, has been derived from *Acacia mearnsii* tree bark [81, 93]. Located in equator line, Indonesia has plenty of tropical fruit production, presented in Fig. 3. Some of these fruit residues have been studied as natural coagulant before, but most of them have not been tested. However, these untested fruit residues have potential to be used as natural coagulant.

Utilization of orange (*Citrus sinensis*) pith (inner white skin) as natural coagulant was done by Mohan [65] to treat laundry waste surfactant. Salt extract of orange pith gave good performance of 89.5, 81.5, and 56.4% removal of turbidity, TSS, and COD, respectively, when combined with sand filtration and activated carbon adsorption [65]. Extract of orange pith also gave better performance of turbidity removal than industrial flocculant [48]. This good performance of orange pith was possible due to high pectin and polyphenols in its pith. Pectin is an anionic polysaccharides [71] with smooth α D $(1 \rightarrow 4)$ galacturonan and rhamnogalacturonan substituted with neutral sugar as side chain [86]. Banana peel is also known for its high content of pectin. Banana peel powder as natural coagulant has been used to remove turbidity of grey water. Sixty-six percent of turbidity removal is obtained; however, no COD/BOD removal is obtained within the coagulation process [63]. Banana pith is also feasible to be used as natural coagulant. Banana pith comes from the inner part of stem, which is sometimes used as food for livestock, and usually considered as waste. Banana pith powder was used as natural coagulant for river water and gave great performance to remove turbidity, suspended solids, and some heavy metals [55]. It was possible due to large number functional groups of banana pith such as hydroxyl, carboxylic, and ether groups of polysaccharides. Banana pith juice was also used to treat spent coolant wastewater with removal of COD, SS, and turbidity of 80.1, 88.6, and 98.5%, respectively, [6]. [6] proposed that inulin content in the juice was the active coagulant agent with high bonding capacity to form bridges of flocs.

Papaya (*Carica papaya*) seeds have been used to treat stream water because of its performance to remove turbidity and microorganism (heterotrophic bacteria, yeast, faecal

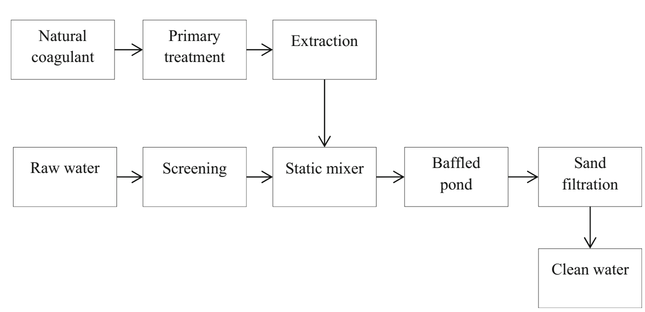

Fig. 4 Water treatment scheme in rural areas

coliform). Sixty-three to seventy-two percent removal of turbidity was obtained at low turbidity (<35NTU), and 90% removal at higher turbidity (120NTU), while 40–98% removal of microorganism was obtained [112]. Papaya seeds are known for its antimicrobial activities due to numerous phytochemical contents [76]. Around 10% of papaya seed protein belongs to albumin type [62], which could also act as coagulant agent.

Jackfruit (*Artocarpus heterophyllus Lam*) seeds extract have been used to treat community drinking water in Uganda. It gave comparable even better result than *M. oleifera* seeds, with highest turbidity removal of 95% for distilled water extract at low turbidity water [67]. It is known that jackfruit seeds have high starch content [104], and also lectins, known as jacalin [53], that could contribute to its performance as natural coagulant. Jackfruit seeds also possess antimicrobial properties due to high antioxidant and polyphenols content [14], with comparable abilities with *M. oleifera* [67].

There are also some indigenous tropical fruit waste that has not been studied as natural coagulant, namely mango, avocado, rambutan, and durian. Mango (*Mangifera indica L.*) seed kernel has a potential to be used as source of fat, while its residue is a promising natural coagulant. Mango seed kernel has high content of polyphenols that give antimicrobial properties [2, 54], and it is also known that mango kernel seed contains condensed tannin [9], which is one of the highest phenolic compounds [1], that could act as natural coagulant. Avocado seed is known for its high phenolic content, even higher than its pulp [95]. Its extract also has antimicrobial properties against yeast, gramme positive and gramme negative bacteria [32]. Rambutan (*Nephelium lappaceum*) is a seasonal tropical fruit which has hairy red peel and tangy pulp that could be consumed fresh or canned [35]. Rambutan peel is known to have higher phenolic compound than its seed [102]. Furthermore, rambutan peel has antimicrobial properties which is not found in its seed [102]. Durian (*Durio zibbethinus*) is a seasonal fruit, which is also known as king of fruits in Southeast Asia countries [35], with distinctive thorn-covered husk. While its fruit pulp is consumed, its husk and seed, which is about two thirds of total fruit weight [8], are rarely utilized. Durian seed is known to have water-soluble gum [8]. Plant-based gum such as guar gum [77], *Cassia obtusifolia* seed gum [90, 97], *Ipomoea dasysperma* seed gum [83], and so on have been utilized as coagulant and coagulant aid in various water treatment.

Potential Application in Indonesia for High Turbid Water

Simple and clear instructions for utilization plants as natural coagulant, such as presented in [58], must be provided so that it can be easily and effectively applied. Simple construction of water purification units could be done to provide clean water in rural areas. Detailed instruction and guidance have been provided by Schulz and Okun [87], emphasizing simple and practical technologies in water supply facilities for rural areas [87]. Furthermore, the technologies used should be as simple as possible, with easily procured equipment, and using indigenous resources to minimize the operation cost. Utilization of sophisticated automated system is discouraged due to some limitations (such as shortage of skilled personnel, capacity to pay for water is low, etc.) that are present in rural areas [87].

Combination of alum and tamarind seed as coagulant for treatment in Thailand rural area has been applied by Pengchai et al. [75]. The pilot scale water treatment unit has been able to provide cleaner water for villagers, with 76% of turbidity removal [75], and the utilization of plant-based coagulant was said to be an alternative to solve high operation cost of the water treatment unit. However, the water result obtained by Pengchai et al. [75] still ranged between 9 and 24 NTU, which still exceeded acceptable value of clean water. Thus, utilization of plant coagulation alone is not enough and could be coupled with sand filtration, as suggested by Schulz and Okun [87]. Pebble matrix filtration could also be used to treat surface water [80]. Lab scale experiment of *M. oleifera* seeds as coagulants coupled with sand filtration have been studied by Yongabi et al. [112], resulting 85–95% of turbidity and bacterial counts [112]. Babu and Chaudhuri studied house scale water treatment unit using *M. oleifera* and followed with sand filter, resulting low turbid water (<5 NTU), with high removal of heterotrophic bacteria and faecal coliforms [13]. A pilot scale plant of water treatment using *M. oleifera* extract as flocculant has been studied by Beltrán-Heredia and Sánchez-Martín [17]. Seventy-eight percent removal of turbidity was observed due to sedimentation process after flocculation, and 100% removal of turbidity and faecal coliforms was obtained when flocculation-sedimentation was combined with slow sand filtration [17].

A simple scheme that can be applied as water supply facilities is presented in Fig. 4. As mentioned by Yin [111], natural coagulant is firstly treated to remove unwanted part of the plants, sliced, dried, and powderized [111]. Oil removal from some natural coagulant, especially legumes such as peanut, *M. oleifera*, etc., could also increase its performance [58]. This powderized natural coagulant then could be extracted using water or saline, to isolate the active coagulating agent, and also to ease the feeding and mixing process with raw water, as has been demonstrated by Pengchai et al. [75]. Furthermore, this extraction step could minimize the increase of organic content from the plant that could increase organic loading in the water [111]. Static mixer could be used for rapid mixing of coagulant and raw water, while baffled pond could be used to induce floc formation and settling. Lastly, filtration of this water could be done using sand filter to ensure complete removal of suspended solids.

Further study of larger scale application is needed, especially to obtain high turbidity removal, as obtained in lab scale experiments. Furthermore, utilization of plant-based coagulant should be considered carefully as some of potential coagulants—coagulant aids—belong to edible part of the plant, while Indonesia, especially in rural areas, is still food deficit [46]. It is also known that 40% of Indonesian population is suffering from micronutrient deficiency [49], thus leaving fruit wastes and inedible legumes as potential plant-based coagulant.

Conclusion

Some plant-based natural coagulants that are abundantly available in Indonesia are presented in this paper. These natural coagulants have been proven to treat various water quality, namely turbid water, heavy metal-containing water, and high BOD/COD water. To solve the problem of clean water scarcity in rural areas, natural coagulant should be considered. Simple construction of water treatment units are possible solution for this problem. Fruit wastes and inedible legumes are potential plant-based natural coagulant, as there is no competition with food. Furthermore, future research about the application of natural coagulant in large scale water treatment plant is needed.

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