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The potential of *Nypa Frutican* as an energy source in Indonesia: A review

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KEYWORDS

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ABSTRACT

Nipa (*Nypa fruticans Wurmb*.) belongs to the Arecaceae family, covering 30% of over 4 million ha of mangrove forest in Indonesia. The most valuable part of nipa is the fruits for food, drink, handicrafts, and medicine, leaving empty fruit bunches as waste. The empty fruit bunch waste reaches 75% of the total weight of nipa fruit, producing approximately 6 Mt/ha or over 6 million Mt in a year. Nipa empty fruit bunches (EFB) are biomass containing 27.3% lignin, 36.1% cellulose, and 21.8% hemicellulose. Due to Indonesia's increasing nipa fruit harvesting, managing and finding a suitable solution to overcome waste issues is essential. In the present review, nipa EFB's physical and chemical properties were found suitable as a biomass energy source. Nipa's EFB energy recovery was potentially generated from direct combustion, pyrolysis, and briquette making. The harvesting challenge and emission from direct combustion or pyrolysis process limit the nipa utilization. Education and technology dissemination is required for the coastal communities to assist in utilizing nipa.

Introduction

Nypa fruticans Wurmb. (Nipa) belongs to the Arecaceae family and is a native inhabitant of mangrove forests. This plant grows along rivers that are affected by tides. In Indonesia, the distribution of nipa covers Kalimantan, Java, Sumatra, Maluku, and Irian Jaya, occupying approximately 30% of the mangrove forests' total area. The nipa spreading area is estimated to reach over 4 million ha in Indonesia (Imra et al., 2016; Irawanto, 2013). All parts of the nipa plant are useful, especially the leaves and fruits. The leaves are used for the traditional roof, and the fruits are for food and drink. The waste of fruit collection is empty fruit bunches (EFB). In large numbers, the nipa empty fruit bunches (shell and husk) can negatively affect the environment. Due to the nipa fruit harvesting in Indonesia, managing and finding a suitable solution to overcome waste issues is essential. Therefore, this paper aims to find the potential of nipa (as an abundant and free biomass) as an energy source to generate heat and power. One of the easiest methods to overcome this is converting nipa's EFB into energy by direct combustion and pyrolysis to produce bio-oil and char.

Direct combustion, the biomass combustion to release the contained chemical energy in the form of heat or combined heat and power in excess oxygen, is one of the oldest energy production methods. The direct combustion of biomass for generating energy faces several problems. Biomass is diverse and generally has an unfavorable combination of low physical and low energy density as a fuel. Poor physical characteristics (such as the high-water content and difficulty in handling) generally mean that collection, transportation, and use are challenging in terms of logistics and processing and questionable in terms of overall environmental benefits, i.e. the combustion of glycerol (Setyawan et al., 2013). Also, the direct

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combustion of biomass may result in a lost opportunity regarding the co-production of chemicals and energy fields (Wan et al., 2018).

The other option that can be used for thermal-based biomass valorization is pyrolysis (Arshadi and Sellstedt, 2015). Pyrolysis is a simple process to decompose biomass by low oxygen combustion/incomplete combustion (Zhang et al., 2017). This process includes reducing organic compounds of biomass to liquid and gas products by releasing bonds of inorganic materials (Zhang et al., 2017). Pyrolysis products generally consist of three types, namely gas (i.e., H_2, CO, CO_2, H_2O, and CH_4), tar (i.e,. pyrolytic oil), and charcoal (Ramadhan and Ali, 2012). These products could increase the value of nipa's EFB.

Discussion

Physical and chemical properties of nipa fruit

Table 1 shows the physical properties of unripe and ripe nipa fruit: whole fruit bunch, individual fruit, and endosperm (Prasad et al., 2013). Figure 1 shows an image of a nipa fruit bunch. Like coconut, the middle part is edible, and the remaining is EFB. A mature nipa fruit contains 13.57% water, 61.53% starch, 0.06% fat, 6.39% protein, 2.22% ash, and 20,19% crude fibre (Heriyanto et al., 2011). Nipa EFB contains 27.3% lignin, 36.1% cellulose, and 21.8% hemicellulose (Tamunaidu and Saka, 2011). Table 2. shows the antioxidant activity of the nipa plant (Aziz and Ribun, 2015). It can be seen that young leaf extracted with ethyl acetate solvent contains the highest antioxidant. Other parts of the nipa plant also contain antioxidants, such as the fruit husk, matured leaf, and young leaf.

Table 1 Physical parameters of nipa fruit (Prasad et al., 2013)

Plant Parts	Unripe	Ripe
Whole fruit bunch		
Weight (kg)	7.2 ± 0.19^b	16.1 ± 0.16^a
Length (cm)	25.5 ± 2.5^b	34.5 ± 2.7^a
Perimeter (cm)	81.2 ± 4.5^b	108.9 ± 6.3^a
Individual fruit		
Weight (kg)	138.1 ± 5^b	159.6 ± 7.7^a
Length (cm)	11.1 ± 0.5^b	12.9 ± 0.7^a
Perimeter (cm)	7.8 ± 0.5	8.1 ± 0.3
Endosperm		
Weight (kg)	3.6 ± 1.5^b	19.6 ± 0.8^a
Length (cm)	3.0 ± 0.2^b	4.5 ± 0.5^a
Perimeter (cm)	5.8 ± 0.7^b	10.1 ± 0.5^a

Table 2 Antioxidant activity in parts of the nipa plant (Aziz and Ribun, 2015)

Plant Parts	Solvent Used	IC_{50}
Fruit Husk	Hexane	3.58 ± 1.43^{ab}
	Ethyl acetate	1.54 ± 0.73^b
	Methanol	2.42 ± 0.27^{ab}
Matured Leaf	Hexane	2.06 ± 0.37^b
	Ethyl acetate	0.42 ± 0.07^c
	Methanol	1.52 ± 0.06^b
Young Leaf	Hexane	3.36 ± 0.03^a
	Ethyl acetate	0.32 ± 0.07^c
	Methanol	1.31 ± 0.20^b

Figure 1 Nipa fruit bunch

Figure 2 Nipa empty fruit bunch (EFB)

Table 3 Chemical composition of various parts of nipa (wt%) (Tamunaidu and Saka, 2011)

Nipa parts	Cellulose	Hemicellulose	Lignin	Starch	Protein	Ash
Frond	35.1	26.4	17.8	0.3	1.9	11.7
Shell	45.6	23.5	17.3	-	0.8	8.2
Husk	36.5	21.8	27.3	0.1	1.9	8.1
Leaf	28.9	23.6	32	2.8	3	5.1

Nipa fruit has the potential to be developed for food and medicine. Nipa fruit contains carbohydrates that can be converted into flour and an alternative food source from mangrove forests (Heriyanto et al., 2011). Nipa fruit can be used as a traditional medicine due to its antioxidant properties that inhibit diseases caused by free radicals (Putri and Elfita, 2013). The maturity level of the fruit affects the proximate characteristics. Young nipa fruit contains vitamin C of 0.60 g/100 g (Heriyanto et al., 2011).

Nipa empty fruit bunches (EFB)

Figure 2 shows the image of Nipa EFB. The empty palm fruit bunches' structure contains hard and soft cells (Radam et al., 2018). Nipa EFB has a blackish-brown color (Heriyanto et al., 2011). The anatomical structure of nipa wood fibres, including the nipa frond's length, is 1826 microns, and the fibre diameter is 558 microns (Fatriani et al., 2016). The water content of nipa EFB is 7.4 - 10.1% (Syabana and Widiastuti, 2018).

Table 3 shows the chemical composition of nipa. Cellulose, lignin, and fibre are basic plant structures and cells (Syabana and Widiastuti, 2018). As such, the nipa EFB contains cellulose, hemicellulose, lignin, and other elemental content. Nipa EFB comprises skin and husks (Tamunaidu and Saka, 2011). Cellulose comprises most of the mass of most wood species. It is a linear polymer glucan composed of 9,000-15,000 glucose units bound by 3-(1,4) linkages. Hemicellulose, a heterogeneous group of polysaccharides containing 15-200 pentose and hexose sugars, is a constituent of wood mass with a proportion of 20-35% (Gupta et al., 2019). Lignin is insoluble in water and is an adhesive connecting cellulose and hemicellulose.

A coastal forest's hectare acre could contain approximately 1,982 nipa trees, producing about 1,061 fruit bunches. Nipa can hold 30-50 fruits in one bunch (Heriyanto et al., 2011). The weight of one fruit bunch of the nipa separated from the fruit by manual cutting is ~5 kg, containing ~2 kg of fruit endocarp and ~3kg EFB (Safariyanti et al., 2018). Therefore, a hectare of nipa can produce ~6 tons of EFB per hectare per harvest season. Considering the large cultivation area of nipa in Indonesia, EFB waste is problematic.

Energy recovery from nipa

Nipa can be converted into energy through its sap and biomass production. A nipa tree's sap production is approximately 20 tons per hectare, which can be used to make 14,300 litres of ethanol (Puangpee and Chongkhong, 2016). Young nipa's carbohydrate, sugar, and protein content are higher than that of sugarcane (Tamunaidu et al., 2013). The total sugar content is 27.2 g/100 g, and the carbohydrate content is 56.4 g/100 g. The sap from nipa has 20-25% sucrose content, which can be processed into bioethanol (Riswanto et al., 2017). Nipa can produce 11,000 l/ha/year of alcohol, greater than that produced by sugarcane (5,500 l) and cassava (1,350 l) (Heriyanto et al., 2011). However, nipa sap production is rare due to the difficulties of the tapping process.

All parts of the nipa plant are potential biomass sources. The potential of nipa biomass is 382.4 tons/hectare (Astuti et al., 2016). The EFB is unused biomass produced in the process of harvesting nipa fruit and is considered a waste that potentially pollutes the environment. However, nipa shells can be converted into energy due to their high cellulose and lignin content, 36.5% and 27.3%, respectively (Tamunaidu and Saka, 2011). The characteristics of the nipa EFB are similar to that of coconut. It contains carbon, organic, and inorganic carbon, which can be used as an energy source (Putri and Elfita, 2013). The EFB has been attempted to be used as alternative energy in the form of bio-briquettes (Mulyadi et al., 2013). Using waste nipa bunches as briquette raw material is considered beneficial to substitute a low-energy process. Briquettes are relatively more environmentally friendly due to their lack of toxic gas emissions (Shuma and Madyira, 2019).

***Technology to obtain energy from nipa* EFB**

As biomass, the nipa EFB can be burned directly, pyrolyzed, or converted into charcoal briquettes.

a. *Direct combustion*

Combustion is the rapid oxidation of fuel accompanied by heat and light. The formation of a flame front characterized the release of heat and light. Combustion occurs when hydrocarbons react with oxygen, producing carbon dioxide and water. Combustion can only happen if there is an adequate supply of oxygen. Combustion is carried out with excess air to ensure the completion of the reactions. The main products of combustion are carbon dioxide (CO_2) and water vapor (H_2O), and heat (Setyawan, 2018).

Biomass is an organic substance obtained from plants, e.g., a coconut shell, with similar characteristics to nipa EFB. During the direct combustion process of coconut shells, the reaction between oxygen (O_2) with elements C, H, and S, Eq. 1, is obtained:

$$C + O_2 \longrightarrow CO_2$$
$$\text{1 Kg C} \quad \text{2.67 Kg } O_2 \quad \text{3.67 Kg } CO_2$$

$$2H_2 + O_2 \longrightarrow 2HO_2$$
$$\text{1 Kg H2} \quad \text{8 Kg } O_2 \quad \text{9 Kg } CO_2$$

$$S + O_2 \longrightarrow SO_2$$
$$\text{1 Kg S} \quad \text{1 Kg } O_2 \quad \text{2 Kg } SO_2 \qquad ..(1)$$

The direct combustion of EFB is common practice for the local community around the mangrove area. However, there is a little-added value from the direct combustion of EFB.

b. *Pyrolysis*

Pyrolysis is the degeneration of biomass by heat with low to no oxygen. The other definition is converting organic matter at high temperatures and breaking it down into smaller molecular bonds, resulting in oil and char production (Kar and Keleş, 2019). The combustion reaction is incomplete if the oxygen used for combustion is lacking (Oluwoye et al., 2020). Incomplete combustion is caused by unburned carbon, indicated by the formation of black smoke and yellow flames. The longer the carbon chain, the incomplete combustion, and vice versa (Atiku et al., 2016). Eq. 2 shows the incomplete combustion reaction.

$$CxHy + O \rightarrow C(s) + CO_2(g) + H_2O(l) + CO(g) \quad ..(2)$$

In pyrolysis, the temperature, time, and type of biomass affect the pyrolysis product. The biomass characteristics that can affect the process and product of pyrolysis are hardness, porosity, grain size, and density (Setyawan et al., 2020). At the beginning of the pyrolysis process, biomass combustion produces smoke and ash. However, the air/oxygen inside the vessel will burn out slowly, and there will be no added oxygen supply outside the combustion vessel. This happens because air is prevented from entering the vessel, so the low-oxygen vessel can burn biomass imperfectly to produce biochar (Kan et al., 2016).

The pyrolysis technique has the advantage of a simpler processing process and does not require high expertise than other biomass conversion technologies. Pyrolysis techniques can eliminate carcinogenic compounds such as PAH (Polycyclic Aromatic Hydrocarbon). It only requires one process with the same tool but can produce three different products, namely bio-char, pyrolysis oil, tar, and dams that are not condensed in the form of CO, CO_2, CH_4, and H_2, all of which are flammable (Alipour Moghadam et al., 2014).

Figure 3 shows the degradation of biomass using the pyrolysis process. The lignocellulose pyrolysis mechanism is divided into four stages: removal of water content, hemicellulose decomposition, cellulose decomposition, and lignin decomposition (Shen et al., 2011). The removal stage of water occurs at temperatures of less than 200ºC. If the water content in the material were too high, it would be at risk of producing large amounts of ash. The hemicellulose decomposition stage occurs at 200-280ºC, producing syngas and pyrolysis oil. The cellulose decomposition stage occurs at temperatures above 240-350ºC, producing syngas, pyrolysis oil, and minor biochar. The final stage is the decomposition of lignin, which occurs at temperatures of 280-500ºC, producing pyrolysis oil and bio-char (Mohamed, 2017).

Figure 4. shows the distribution of the product during the pyrolysis process. The pyrolysis process, called the cracking process, breaks the polymer chains into compounds with lower molecular weight (Singh et al., 2019). The quality and quantity of products produced from pyrolysis depend on the raw material's chemical composition and the temperature used. Based on the temperature, pyrolysis can be divided into three: slow pyrolysis with temperatures around 277-677°C, fast pyrolysis at 577-977 °C, and flash pyrolysis at 777-1027 °C (Basu, 2018). Fast pyrolysis is intended to get the maximum product in liquid form. Flash pyrolysis is intended to get the maximum product. Slow pyrolysis is intended to obtain maximum bio-char, bio-gas, and bio-oil simultaneously.

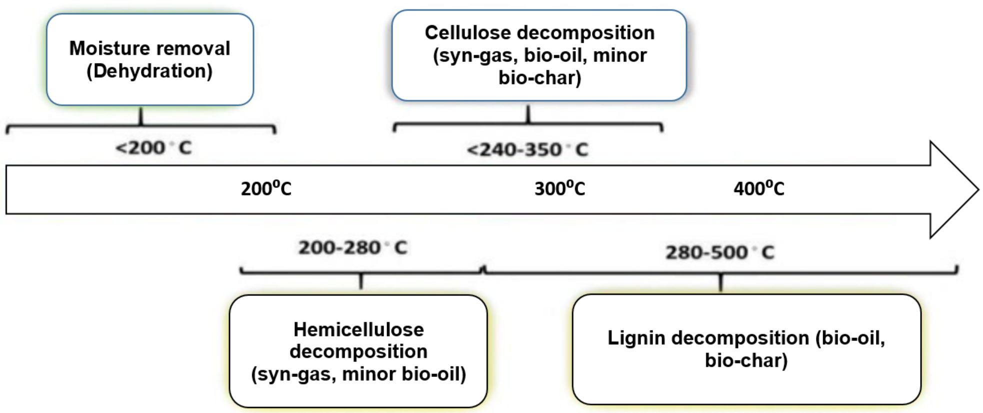

Figure 3 Degradation of biomass (Mohamed, 2017)

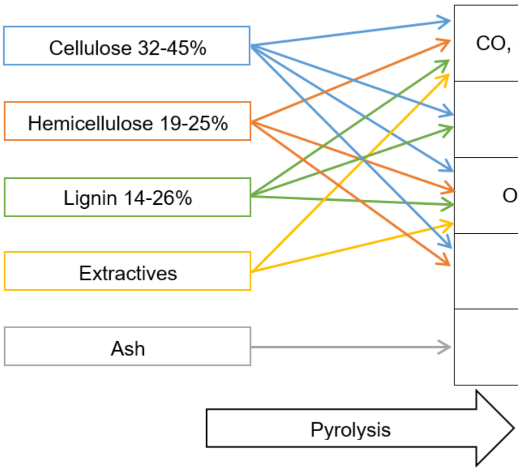

Figure 4 Product distribution in pyrolysis (Mohamed, 2017)

The pyrolysis oil's main components are acidic compounds, phenol derivatives, and carbonyl, which can act as dyes, flavorings, antibacterial, preservatives, and antioxidants (Czernik and Bridgwater, 2004). Pyrolysis oil can be used as an alternative fuel for fossil fuel substitution. To produce fuel, it is necessary to do fractionation to separate liquid smoke from other compounds (Mia et al., 2017). However, there has been no research on making fuel from nipa EFB by pyrolysis. Irawan, Khabibi and Agustina (2016) mentioned the potential conversion of charcoal from nipa EFB, which can later be converted into briquettes.

c. *Briquettes*

Another pyrolysis product is bio-char, an environmentally friendly material that can be used as briquettes for energy and fertilizer for plants (Sunyoto et al., 2016). In the purification industry, biochar is used as a raw material for activated carbon, which can then be used as an adsorbent to absorb heavy metals in food or medicine, liquor, shrimp farming, the sugar industry, gas purification, and fertilizer processing. The activation of biochar from nipa shells has previously been conducted using a chemical activator such as hydrochloric acid (HCl) (Safariyanti et al., 2018). Given HCl's dangerous nature, exploring other activators to manufacture activated EFB biochar is necessary.

The stoichiometric equation in char production (Mohamed, 2017) is as Eq. 3. Processing EFB as charcoal briquettes is more complicated than direct combustion due to its flammability nature (Radam et al., 2018).

$$C_6H_{10}O_5 \rightarrow 3.74\ C + 2.65\ H_2O + 1.17\ CO_2 + 1.08\ CH \quad (3)$$

Nipa's EFB briquette characteristics and the effect of additional material (i.e., tapioca glue and lime) have been studied (Mulyadi et al., 2013). In short, the nipa EFB's briquette can be produced, but the calorific value is lower than that of the Indonesian Briquette Standard. The calorific value of Nipa's EFB briquette is 2000-3000 cal/g, lower than the standard at a minimum of 5000 cal/g. The ash content is 20%, much higher than the maximum of 8% on the standard. Thus, further research on Nipa's EFB briquette is necessary to increase the calorific value and reduce the ash content.

Environmental impact of using nipa or energy

a. Natural availability of nipa's EFB

Nipa is abundant in Indonesia. In East Kalimantan Province, the density of nipa trees is 1,972 in every hectare (Heriyanto et al., 2011), and it is estimated that the EFB of nipa is approximately 7.93 tons per hectare. Indonesia has around 4 million hectares of nipa forests, producing approximately 4,000 tons of EFB annually. However, the issue is the spread of the nipa growing area. Nipa is produced in mangrove forests, which spread in the coastal line, including small islands. Thus, material handling is difficult and can only benefit the local community.

b. Emission from the direct combustion and pyrolysis process

Direct combustion of nipa for heat and power could be an immediate means to recover nipa EFB's energy. However, direct combustion causes pollutants, such as CO, CH_4, and particles like soot and ash. Also, some biomass contains sulphur and nitrogen, causing sulphur oxides and nitric oxide emissions (Silva et al., 2019). Sulphur oxides (SOx) result from sulphur oxidation, which can cause air pollution, harming the respiratory system, such as increased asthma symptoms (Sunyer et al., 2003). Nitric oxides (NOx) emissions are caused by the oxidation of nitrogen oxidation originating from air or fuel. Nitrate can react it causes smog and acid rain (Hong et al., 2017). Therefore, research on the combustion of nipa EFB is required, particularly in EFB pre-treatment and burner design.

Chemicals produced from pyrolysis are CH_4, non-methane, hydrogen gas, and various partially oxidized organic compounds. Methane (CH_4) is an important intermediary chemical in converting hydrogen fuel carbon to H_2O in burning biomass such as nipa. Non-methane emissions / volatile organic compounds (VOC) harm human breathing; these compounds are indirect greenhouse gases because they are the ozone precursor in the atmosphere (Hong et al., 2017). Therefore, proper pyrolysis equipment is required to assist the coastal communities in pyrolyzing nipa EFB.

Prospect and challenges

Conversion of nipa EFB for energy through direct combustion, pyrolysis, and briquette potentially assist the coastal communities in reducing the need to buy energy. Nipa EFB sources are accessible and require low technology to be converted into immediate heat and power. However, the coastal communities' low income and education levels are the general vulnerability factors and internal restrictions in managing sustainable mangrove ecosystems. Therefore, assistance and education are required to disseminate the energy conversion technology based on nipa EFB.

Summary

The harvest of nipa fruit from the mangrove forest in Indonesia produces EFB as waste. Due to the increasing nipa fruit harvesting, managing and finding a suitable solution to overcome the EFB waste issues is essential. A hectare of nipa can produce ~6 Mt of EFB per hectare per harvest season, or roughly over 6 million Mt/year. As biomass, it has the potential to be converted into energy through direct combustion to support the local community. The pyrolysis and briquette conversion of EFB is another combustion means to increase the added value. Nipa EFB's physical and chemical properties were suitable as a biomass energy source. Nipa EFB can be converted into energy due to their high cellulose and lignin content, 36.5% and 27.3%, respectively. Nipas EFB energy recovery was potentially generated from direct combustion. However, there is a little-added value from the direct combustion of EFB. Pyrolysis of nipa EFB is similar to coconut or oil palm EFB, starting with the degradation of biomass and the production of biochar and bio-oil. Nipa EFB briquette calorific value is lower than the Indonesian Standard. The harvesting challenge and emission from direct combustion or pyrolysis process limit the nipa utilization. Education and technology dissemination is required for the coastal communities to assist in utilizing nipa.

References

Alipour Moghadam, R., Yusup, S., Azlina, W., Nehzati, S., and Tavasoli, A. (2014) 'Investigation on syngas production via biomass conversion through the integration of pyrolysis and air–steam gasification processes', *Energy Conversion and Management*, *87*, pp. 670-675

Arshadi, M., and Sellstedt, A. (2015) 'Biomass-based energy production' in Clark, J., and Deswarte, F. (eds.) *Introduction to Chemicals from Biomass*. United States: John Wiley & Sons, Ltd, pp. 249-284.

Astuti, J., Yoza, D., & Sulaeman, R. (2016) 'Potensi biomassa nipah (*Nypa fruticans Wurmb*.) di Desa Lubuk Muda Kecamatan Siak Kecil Kabupaten Bengkalis (The potential of biomass nypa (*Nypa Fruticans Wurmb*.) in The Lubuk Muda Village Siak Kecil District Bengkalis)', *Jurnal Online Mahasiswa Faperta*, *3*(1), pp. 1-10 [In Indonesian]

Atiku, F. A., Mitchell, E. J. S., Lea-Langton, A. R., Jones, J. M., Williams, A., and Bartle, K. D. (2016) 'The impact of fuel properties on the composition of soot produced by the combustion of residential solid fuels in a domestic stove'. *Fuel Processing Technology*, 151, pp. 117-125

Aziz, A., and Ribun, J. (2015) 'Total phenolic content and antioxidant activity in *Nypa Fruticans* extracts', *Journal of Sustainability Science and Management*, 10(1), pp. 87-91

Basu, P. (2018) 'Pyrolysis' in Basu, P. (eds.) *Biomass Gasification, Pyrolysis and Torrefaction (Third Edition)*. United States: Academic Press, pp. 155-187.

Czernik, S., and Bridgwater, A. V. (2004) 'Overview of applications of biomass fast pyrolysis oil', *Energy & Fuels*, 18(2), pp. 590-598

Gupta, P. K., Raghunath, S. R., Prasanna, D. V., Venkat, P., Shree, V., Chithananthan, c., Choudhary, S., Surender, K., and Geetha, K. (2019) 'An update on overview of cellulose, its structure and applications' in Pascual, A. R., and Martín, M. E. E. (eds.), *Cellulose*. London: Intechopen, pp. 1-21

Fatriani, F., Sari, N. M., and Mashudi, M. N. (2016) 'Rendemen tepung buah nipah (*Nyfa Fruticans Wurmb*) berdasarkan jarak tempat tumbuh (Rendement of nipah fruit flour (*Nyfa Fruticans Wurmb*) based on growth distance)', 12(32), pp. 171-174 [In Indonesian]

Heriyanto, N. M., Subiandono, E., and Karlina, E. (2011) 'Potensi dan sebaran nipah (*Nypa fruticans (Thunb.) Wurmb*) sebagai sumberdaya pangan (Potency and distribution of nypa palm (*Nypa fruticans (Thunb.) Wurmb*) as food resource)', *Jurnal Penelitian Hutan dan Konservasi Alam 8*(4), pp. 327-335 [In Indonesian]

Hong, Z., Wang, Z., and Li, X. (2017) 'Catalytic oxidation of nitric oxide (NO) over different catalysts: An overview', *Catalysis Science & Technology*, 7(16), pp. 3440-3452

Imra, Tarman, K., and Desniar. (2016) 'Aktivitas antioksidan dan antibakteri ekstrak nipah (*Nypa fruticans*) terhadap *Vibrio sp.* isolat kepiting bakau (*Scylla sp.*) (Antioxidant and antibacterial activities of nipah (*Nypa fruticans*) against *Vibrio sp.* Isolated From Mud Crab (*Scylla sp.*)', *Jurnal Pengolahan Hasil Perikanan Indonesia*, 19(3), pp. 241-250 [In Indonesian]

Irawan, B., Khabibi, J., and Agustina, A. (2016) 'The potential of nipah (*Nypa Fruticans Wurmb*) as bioenergy resources', *The 1st International Conference on Green Development*, pp. 83-86

Irawanto, R. (2013) 'Peran nipah sebagai vegatasi kunci, habitat burung dan penyebarannya di sungai Ketingan Sidoarjo (Mangrove palm as a key species for bird habitat and thier distribution in Ketingan Sidoarjo)', *Seminar Nasional X Pendidikan Biologi*, pp. 1-6 [In Indonesian]

Kan, T., Strezov, V., and Evans, T. J. (2016) 'Lignocellulosic biomass pyrolysis: A review of product properties and effects of pyrolysis parameters', *Renewable and Sustainable Energy Reviews*, 57, pp. 1126-1140

Kar, T., and Keleş, S. (2019) 'Characterisation of bio-oil and its sub-fractions from catalytic fast pyrolysis of biomass mixture', *Waste Management & Research, 37*(7), pp. 674-685

Mia, M., Islam, A., Rubel, R. I., and Islam, M. (2017) 'Fractional distillation & characterization of tire derived pyrolysis oil', *International Journal of Engineering*, 3, pp. 1-10

Mohamed, S. (2017). *Pyrolysis*. London: InTechOpen.

Mulyadi, A. F., Dewi, I. A., and Deoranto, P. (2013) 'Pemanfaatan kulit buah nipah untuk pembuatan briket bioarang sebagai sumber energi alternatif (Utilization of nipa fruit peels for the manufacture of bioarang briquettes as an alternative energy source) *Jurnal Teknologi Pertanian*, 14(1), pp. 65-72 [In Indonesian]

Oluwoye, I., Altarawneh, M., Gore, J., and Dlugogorski, B. Z. (2020) 'Products of incomplete combustion from biomass reburning', *Fuel*, 274, pp. 1-6

Paivoke, A. E. A. (1985). Tapping practices and sap yields of the nipa palm (*Nypa frauticans*) in Papua New Guinea', *Agriculture, Ecosystems and Environment,*, 13(1), pp. 59-72

Prasad, N., Yang, B., Kong, K. W., Khoo, H. E., Sun, J., Azlan, A., Ismail, A., and Romli, Z. B. (2013) 'Phytochemicals and antioxidant capacity from *Nypa fruticans Wurmb.* Fruit', *Evidence-based Complementary and Alternative Medicine*, 2013, pp. 1-9

Puangpee, S., and Chongkhong, S. (2016) 'Optimization of nipa sap preparation for ethanol production', *Proceedings of the 2016 International Conference on Advanced Materials Science and Environmental Engineering*, pp. 31-33

Putri, I. J., and Elfita, F. (2013) 'Aktivitas antioksidan daun dan biji buah nipah (*Nypa fruticans*) asal pesisir Banyuasin Sumatera Selatan dengan metode DPPH (Antioxidant activity of leaves and seeds of nipah fruit (*Nypa fruticans*) from the coast of Banyuasin, South Sumatra using the DPPH method)', *Maspari Journal*, 5(1), pp. 16-21

Radam, R. M., Lusyiani, Ulfah, D., Sari, N. M., and Violet. (2018) 'Kualitas briket arang yang terbuat dari kulit luar nypah (*Nypa fruticans wurmb*) menjadi energi produk (The qualty of charcoal briquettes that made from nypah (*Nypa fruticans wurmb*) outshel to product energy)', *Jurnal Hutan Tropis, 6*(1), pp. 1-10 [In Indonesian]

Ramadhan, A., and Ali, M (2012) 'Pengolahan sampah plastik menjadi minyak menggunakan proses pirolisis (Processing of plastic waste into oil using a pyrolysis process)', *Envirotek: Jurnal Ilmiah Teknik Lingkungan,* 4(1), pp. 44-53 [In Indonesian]

Riswanto, W. M., Yenti, S. R., and Chairul. (2017) 'Pembuatan bioetanol dari nira nipah menggunakan bakteri *Zymomonas mobilis* dengan variasi pemekatan medium dan waktu fermentasi (Production of bioethanol from nipa nipa using *Zymomonas mobilis* bacteria with variations in medium concentration and fermentation time)', *Jurnal Online Mahasiswa, 4*(2), pp. 1-8 [In Indonesian]

Safariyanti, S. J., Rahmalia, W., and Shofiyani, A. (2018) 'Sintesis dan karakterisasi karbon aktif dari tempurung buah nipah (*Nypa fruticans*) menggunakan aktivator asam klorida (Synthesis and characterization of activated carbon from nipa fruticans (Nypa fruticans) shells using hydrochloric acid activator)', *Jurnal Kimia Khatulistiwa,* 7(2), pp. 1-7 [In Indonesian]

Setyawan, H. Y., Dewi, J. R, Sunyoto, N. M. S., and Wijana, S. (2020) 'Progress on research and development of bio-oil as a fuel in Indonesia', *IOP Conference Series: Earth and Environmental Science*, 475, pp. 1-8

Setyawan, H. Y. (2018) Effect of Impurities on Ignition and Combustion Characteristics of Crude Glycerol as a By-Product of Biodiesel Manufacturing. Thesis. University of Western Australia, Australia.

Setyawan, H. Y., Zhu, M., Zhou, W., and Zhang, D. (2013) 'Effect of methanol addition on combustion characteristics of single droplets of glycerol', *Proceedings of the Australian Combustion Symposium*, 1, pp. 332-335

Shen, D., Xiao, R., Gu, S., and Luo, K. (2011) 'The pyrolytic behavior of cellulose in lignocellulosic biomass: a review', *RSC Advances,* 1(9), pp. 1641-1660

Shuma, R., and Madyira, D. M. (2019) 'Emissions comparison of loose biomass briquettes with cow dung and cactus binders', *Procedia Manufacturing,* 35, pp. 130-136

Silva, D. A., Eloy, E., Caron, B. O., and Trugilho, P. F. (2019) 'Elemental chemical composition of forest biomass at different ages for energy purposes', *Floresta e Ambiente*, 26(4), pp. 1-11

Singh, R. K., Ruj, B., Sadhukhan, A. K., and Gupta, P. (2019) 'Impact of fast and slow pyrolysis on the degradation of mixed plastic waste: Product yield analysis and their characterization', *Journal of the Energy Institute*, 92(6), pp. 1647-1657

Sunyer, J., Atkinson, R., Ballester, F., Le Tertre, A., Ayres, J., Forastiere, F., and Katsouyanni, K. (2003) 'Respiratory effects of sulphur dioxide: A hierarchical multicity analysis in the APHEA 2 study', *Occupational and Environmental Medicine,* 60(8), pp. 1-3

Sunyoto, N. M. S., Zhu, M., Zhang, Z., and Zhang, D. (2016) 'Effect of biochar addition on hydrogen and methane production in two-phase anaerobic digestion of aqueous carbohydrates food waste', *Bioresource Technology,* 219, pp. 29-36

Syabana, D. K., and Widiastuti, R. (2018) 'Karakteristik fisik pada serat pelepah nipah (*Nypa fruticans*) (Physical characteristics of nypa (*Nypa fruticans)* midrib fiber)', *Dinamika Kerajinan dan Batik, 35*(1), 9-14 [In Indonesian]

Tamunaidu, P., Matsui, N., Okimori, Y., and Saka, S. (2013) 'Nipa (*Nypa fruticans*) sap as a potential feedstock for ethanol production', *Biomass and Bioenergy,* 52, pp. 96-102

Tamunaidu, P., and Saka, S. (2011) 'Chemical characterization of various parts of nipa palm (*Nypa fruticans*)', *Industrial Crops and Products,* 34(3), pp. 1423-1428

Wan, Z., Setyawan, H. Y., Zheng, C., Zhang, Q., Zhang, Z., Zhu, M., Huys, B., and Zhang, D. (2018) 'Characterisation of precipitates from spent tyre pyrolysis oil and its distillates after accelerated ageing', *Chemeca*, 163, pp. 1-8

Zhang, Z., Zhu, M., Liu, P., Setyawan, H. Y., and Zhang, D. (2017) 'A kinetic study of pyrolysis of pine wood using a thermogravimetric analyser and a combined model-free and y (α) master plot metho', *11th Asia-Pacific Conference on Combustion 2017*, pp. 234-237