Analysis of the potential and characteristics of Nipa *(Nypa fruticans)* as a sustainable biofuel alternative source in Indonesia

Cahyo Purnomo Prasetyo[1*], *Agus Jatnika* Effendi[1], and *Mochammad* Chaerul[1]

[1]Department of Environmental Engineering ITB, Bandung, West Java, Indonesia

Abstract. A sustainable energy source, one that doesn't compete with food production, is crucial for enhancing national energy independence. This study assesses the feasibility of Nipa palm (*Nypa fruticans*) as a biofuel source in Indonesia. The research involved vegetation and laboratory analyses to determine Nipa palm's potential for biofuel production. The results revealed a Nipa density of 3,167 trees ha^{-1} with a mesocarp yield of 3.99 tons ha^{-1} and sap yield of 177.35 kL ha^{-1}. The mesocarp contains 39.37% carbohydrates, and the sap has a total sugar content of 13.13%. National estimates for mesocarp and sap production were 3,339,630 tons $year^{-1}$ and 148,443 thousand kL $year^{-1}$, respectively. Estimated bioethanol production from Nipa sap was 13,330 thousand kL $year^{-1}$. Incorporating Nipa bioethanol into the national fuel supply would increase it to 66,766 thousand kL $year^{-1}$ (24.95%), while reducing imports to 14,531 thousand kL $year^{-1}$ (47.86%). In conclusion, Nipa palm offers significant advantages as a potential biofuel feedstock, particularly for bioethanol production, without compromising food supplies.

1 Introduction

The utilization of fossil fuels has exhibited a continuous upward trend since the inception of the Industrial Revolution in the 18th century, dominating the global energy composition for extended periods. This dominance has resulted in heightened emissions of Greenhouse Gas (GHG) and consequential alterations in atmospheric composition. Recent reports underscore that fossil fuels account for more than half of the world's carbon dioxide emissions [1]. Over the past 800,000 years, the concentration of carbon dioxide has escalated by 47.3 percent in comparison to glacial and interglacial epochs. This phenomenon has significantly contributed to global climate transformations, evident in the escalating surface temperatures over the last four decades and the accelerated surge in sea levels at a pace surpassing the rates witnessed in the past two millennia [2]. Consequently, a shift towards renewable energy sources becomes an imperative [3].

Among the myriad of renewable energy alternatives, biofuels emerge as the most auspicious substitute. Nevertheless, prevalent biofuel production relies heavily on

* Corresponding author : kangcahyo08@gmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

agricultural commodities, often derived from staple food crops. Their diversion for energy applications has triggered price hikes in the commodity market [4]. Research signifies that the conversion of sugarcane into bioethanol in Brazil and soybean into biodiesel in the United States has led to price fluctuations in tandem with global crude oil trends [5, 6]. These fluctuations have in turn affected economies and exacerbated the vulnerability of marginalized communities to food scarcity [7, 8]. In light of this, the development of advanced biofuels from non-food plant sources that mitigate GHG emissions without compromising sustainability has become paramount [9], ensuring energy resilience without compromising access, stability, and food security [10].

Indonesia's governmental policies, articulated in the National Energy Policy (NEP), have prescribed a target of at least 23 percent primary renewable energy integration and a reduction in oil consumption to less than 25 percent by 2025. This target encompasses the harnessing of biofuels [11]. To achieve this aim, Indonesia harbors abundant biogenic potential, including the Nipa palm *(Nypa fruticans)*. As the sole species within the *Nypa* genus and *Nypoideae* subfamily, this plant flourishes in tropical regions characterized by warm, humid climates and consistent annual rainfall [12, 13]. Its habitat spans brackish water environments such as estuaries, tidal riverbanks, and coastal zones [14], extending from the Southeast Indian coast through Southeast Asia to northern Australia and the western Pacific islands [15].

Presently, the Nipa palm stands as a provider of ecological advantages by upholding soil stability, guarding against erosion, and mitigating the impact of storms and high sea waves in coastal regions as an integral component of the mangrove ecosystem. However, its economic potential remains underexplored [16]. Multiple studies indicate that Nipa yields products boasting chemical properties akin to renowned biofuel sources. For instance, the mesocarp is rich in carbohydrates [17], surpassing cassava contents [18], and the sap bears sugar levels equivalent to those in sugarcane [19]. Moreover, Nipa does not fuel controversies concerning the trade-off between food and energy, aligning favorably with the criteria for ecofuel feedstocks [20]. Despite these inherent advantages, efforts to harness its biofuel potential have been limited [21]. To date, research on Nipa in Indonesia has predominantly focused on its potential as functional food [22, 23, 24] and pharmaceutical applications [25]. Meanwhile, investigations into its application as a biofuel source remain scarce. Hence, this study strives to evaluate the feasibility of Nipa as a biofuel resource, encompassing an analysis of the characteristics of its sap and mesocarp as feedstocks, along with an exploration of its production potential in fulfilling national biofuel demands.

2 Methods

The primary dataset was acquired from the study site through vegetation analysis and the analysis of characteristics within the mesocarp and sap. Meanwhile, supplementary data for the assessment of Nipa's potential were acquired through a review of various literature sources, including mangrove forest land cover, biofuel feedstock production from other sources, biofuel conversion values from Nipa, national fuel demand, and more.

Field data collection spanned from December 2022 to January 2023. The study site selection, informed by prior studies [26], was situated in the mangrove forest of Wonorejo Village, Surabaya City, East Java, Indonesia. This protected mangrove forest area encompasses 73.28 hectares, inclusive of coastal areas (21.68 hectares), ponds (16.64 hectares), and riverbanks on both the left and right (34.97 hectares).

2.1 Vegetation analysis

The Nipa palm vegetation analysis utilized the Quadrat method, involving the establishment of research plots tailored to vegetation size [27]. Plot selection considered the habitat diversity of the plants at the location [28]. Specifically, 10 m x 10 m square plots were created at three distinct locations with varying environmental conditions (Figure 1).

Fig. 1. Research plot location.

Plot 1 (7°18'23.4"S 112°49'15.2"E) was positioned directly along the slope of the Londo River, experiencing frequent inundation. Plot 2 (7°18'47.8"S 112°49'32.6"E) was situated approximately 10 m away from the Wonorejo River and experienced occasional inundation. Meanwhile, plot 3 (7°18'48.5"S 112°48'53.8"E) had the lowest frequency of inundation, as it lacked bodies of water (Figure 2).

Fig. 2. Nipa palms at the research locations.

On-site Nipa vegetation analysis within the research plots was conducted to obtain data on the number of fruit-bearing trees and bunches per tree. Nipa palm density per hectare was determined in accordance with SNI 7717:2011 on Mangrove Survey and Mapping [29]:

$$\textit{Nipa palm density} = (\textit{number of individuals}) / (\textit{observation plot area}) \qquad (1)$$

Off-site data encompassed the number of fruits per bunch and mesocarp weight. For this purpose, purposive sampling was employed on three mature fruit bunches from each plot. Selection criteria included hard-textured mesocarp, non-transparent white color, and liquid impermeability [23].

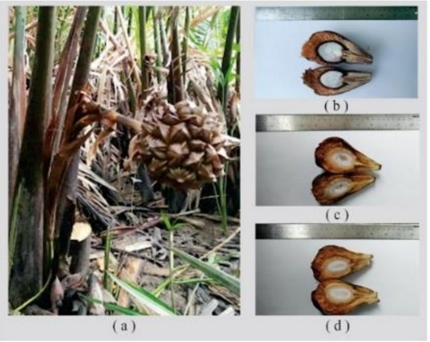

Fig. 3. (a) nipa fruit bunch, nipa mesocarp from: (b) plot 1, (c) plot 2, (d) plot 3.

Subsequently, the number of fruits and mesocarp weight from the obtained bunches were recorded (Figure 3).

2.2 Mesocarp characteristic analysis

Continuing from the vegetation analysis, the characteristics of the mesocarp were examined. One fruit bunch sample was chosen from the ripest within each plot. Thus, three mesocarp samples, each weighing 200 grams, were obtained for laboratory analysis. To ensure sample integrity during transportation, the samples were double-bagged and stored in a cooling box with ice packs [30]. Chemical characterization of Nipa mesocarp was performed at the Saraswanti Indo Genetech (SIG) Laboratory in Surabaya. Proximate analysis, including moisture content, ash content, total fat, protein, carbohydrates, and crude fiber, was conducted using the SNI 01-2891-1992 method on Food and Beverage Testing [31].

The determination of moisture content was carried out using the direct drying method. Mesocarp samples (1-2g) were weighed in a covered weighing bottle and dried in an oven at 150°C for 3 hours. The samples were then cooled in a desiccator and reweighed. This process was repeated until a constant weight was achieved.

Ash content was determined through the direct ashing method. Mesocarp samples (2-3g) were weighed in a porcelain crucible and ashed in a furnace at 550°C until complete ashing occurred. The ash was cooled in a desiccator and then weighed until a constant weight was obtained.

The Weibull hydrolysis method was employed for fat content determination. Mesocarp samples (1-2g) were weighed in a glass beaker, and then 30ml of 25% HCl and 20ml of water were added. The mixture was boiled for 15 minutes. The hot solution was filtered and washed, and the filter paper was dried at 100-105°C. It was then placed in a paper thimble for extraction with hexane for 2-3 hours at 80°C. The hexane solution was distilled, and the fat extract was dried at 100-105°C, cooled, and weighed.

For protein determination, the Kjeldahl method was applied. Mesocarp samples weighing 0.51g were weighed into a 100ml Kjeldahl flask. Then, 2g of selenium mixture and 25ml of concentrated H_2SO_4 were added, and the mixture was heated to boiling for 2 hours. The solution was cooled, diluted, and transferred to a 100ml measuring flask. A 5ml aliquot was taken and placed in a distillation apparatus, followed by the addition of 5ml of 30% NaOH and PP indicator. Distillation was carried out for 10 minutes, and the distillate was collected in an Erlenmeyer flask with 10ml of 2% boric acid, followed by titration with 0.01N HCl. The drying process was repeated until a constant weight was reached.

Carbohydrate content was determined using the Luff Schoorl method. Mesocarp samples weighing 5g were weighed into a 500ml Erlenmeyer flask. Then, 200ml of 3% HCl solution was added, and the mixture was boiled for 3 hours. The solution was cooled and neutralized with 30% NaOH, and 3% CH_3COOH was added. The solution was transferred to a 500ml volumetric flask, and a 10ml aliquot was taken. It was placed in a 500ml Erlenmeyer flask, and then 25ml of Luff and 15ml of distilled water were added. The mixture was boiled for 10 minutes, rapidly cooled, and after cooling, 15ml of 20% KI and 25ml of 25% H_2SO_4 were added. The titration was performed with 0.1N thiosulfate.

The determination of crude fiber was performed using the gravimetric method. Mesocarp samples (2-4g) were carefully weighed, and fat was separated by extraction. The extracted fat was dried, placed in a 500ml Erlenmeyer flask, and 50ml of 1.25% H_2SO_4 solution was added. The mixture was boiled for 30 minutes. Then, 50ml of 3.25% NaOH solution was added, and the mixture was boiled again for 30 minutes. The hot solution was filtered, the precipitate was washed with hot 1.25% H_2SO_4, hot water, and 96% ethanol. The filter paper with its contents was dried at 105°C, cooled, and then weighed.

2.3 Sap characteristic analysis

This analysis involved Nipa sap samples obtained through the tapping process of fruit stalks. Purposive sampling was used to select stalks with high sap potential, characterized by their large size and length [32]. Additionally, pre-treatment of the stalks before tapping was performed [33]. In this study, pre-treatment involved swinging and striking the fruit stalks for seven days. The tapping process began with cutting the fruit stalk and making surface incisions about 1-2 mm thick [33] (Figure 4).

Fig. 4. Tapping process on: (a) nipa palm 1, (b) nipa palm 2, (c) nipa palm 3.

To maintain the chemical composition integrity, the sap collection container was rinsed with distilled water before tapping, and the container was covered to prevent accelerated fermentation due to sunlight exposure during tapping [34]. Nipa sap obtained after 24 hours of collection was stored in 100 ml HDPE plastic bottles in a cooling box with ice packs and promptly sent to the laboratory to avoid hydrolysis. The chemical characteristics of Nipa sap were measured in the SIG Surabaya laboratory using parameters such as total sugar, sucrose, reducing sugars (glucose), and reducing sugars (fructose). The samples were analyzed using high-performance liquid chromatography (HPLC) with a Metacarb 87C column, deionized water as the eluent, a flow rate of 1 mL min-1, and a temperature of 80°C.

2.4 Potential analysis

The potential analysis of Nipa palm is derived from comprehensive field data processing. To begin, the following steps were undertaken: First, the determination of bunches per hectare, the number of fruits per hectare, and mesocarp yield per hectare was carried out, as previously documented [35]. Additionally, the estimation of national mesocarp production was conducted, assuming that the Nipa palm area constitutes 30 percent of the total mangrove forest area in Indonesia, as indicated in previous studies [36]. The calculations involved are as follows:

Bunches per ha = (nipa palm density) x (bunches per tree) (2)
Fruits per ha = (bunches per ha) x (fruits per bunch) (3)
Mesocarp yield per ha = (fruit per ha) x (mesocarp weight) (4)
National mesocarp production = (mesocarp yield per ha) x (area of Nipa palm) (5)

Next, sap yield per hectare and national sap production were determined, referencing previous research [32]:

Sap yield per ha = (sap yield per tree) x (tapping duration) x (Nipa palm density) (6)
National sap production = (sap yield per ha) x (area of Nipa palm) (7)

Subsequently, the analysis extended to national biofuel production, drawing insights from prior studies [21]:

National biofuel production = (sap production) x (conversion factor) (8)

The estimation of mesocarp and sap production of Nipa palm as biofuel feedstock will be compared with other plants in Indonesia, as reported by the Ministry of Agriculture and the Central Bureau of Statistics [37; 38]. Furthermore, the capacity of potential biofuel production from Nipa palm to meet national fuel demands was determined based on the fuel requirements in Indonesia, as outlined by the Ministry of Energy and Mineral Resources [39].

3 Results and discussion

3.1 Nipa mesocarp

3.1.1 Chemical characteristics

The utilization of Nipa fruit as feedstock for biofuel, specifically bioethanol, relies on the presence of carbohydrates in its mesocarp. Proximate analysis results indicate that the primary components in Nipa mesocarp are carbohydrates (39.37±9.26) percent and moisture (55.89±9.75) percent (Table 1). The carbohydrate content in the mesocarp is lower compared to what was reported by Osabor et al. (51.08±1.71) percent [17] and Subiandono et al. (56.41) percent [40] but higher than that found by Chau sum et al. (21.40±0.46) percent [41]. On the other hand, the moisture content in the mesocarp is higher compared to Osabor et al. (41.96±0.28) percent [17], Subiandono et al. (38.96) percent [40], and Chau sum et al. (35.71±1.19) percent [41].

Table 1. Chemical composition of nipa mesocarp.

Composition	East Java, Indonesia (current study)	Nigeria [a]	East Borneo, Indonesia [b]	Malaysia [c]
Ash (%)	0.88±0.02	2.70±0.11	0.98	1.11±0.08
Fat (%)	0.80±0.01	0.94±0.01	0.70	4.33±0.39
Moisture (%)	55.89±9.75	41.96±0.28	38.96	35.71±1.19
Carbohydrate (%)	39.37±9.26	51.08±1.71	56.41	21.40±0.46
Protein (%)	3.06±0.51	2.27±0.010	2.95	4.02±0.17

Crude fiber (%)	5.53±0.45	2.50±0.19	-	15.11±0.67

[a] Osabor et al. [17]; [b] Subiandono et al. [40]; [c] Chau Sum et al. [41]

The data show that high carbohydrate content is found in mesocarp with low moisture, and vice versa. This relationship is attributed to the fruit's ripeness, which affects the carbohydrate and moisture content in the mesocarp [41]. Therefore, the low carbohydrate content in this study, compared to Osabor et al. [17] and Subiandono et al. [40], is likely due to the Nipa mesocarp not being fully ripe. Furthermore, Chau sum et al. added that factors such as climate, soil, and plant nutrition in the geographical location also have an influence [41]. Previous studies found that the Nipa plant habitat at the study site has characteristics of dusty clay loam sediment and low nitrogen content [42]. It is highly likely that these factors inhibit Nipa growth and contribute to the low carbohydrate content in the mesocarp.

3.1.2 Production potential

Field observations found that Nipa trees at the study site had varying quantities (Table 2). The fewest Nipa trees were found in plot 2, which is located along the Wonorejo River. Previous studies indicated that the water quality in this area did not meet the seawater quality standards for mangroves according to Minister of Environment Decree Number 51 of 2004, with average turbidity ranging from 351.5 to 613 NTU and total suspended solids (TSS) ranging from 363-1,286 mg/L [42]. Since mangrove plants are highly susceptible to changes in water quality, despite their high adaptability to salinity changes [43], it is very likely that the hindered growth of Nipa trees, especially in plot 2, is due to the poor water quality.

Table 2. Yield of nipa mesocarp.

Plot	Nipa palm		Nipa bunch		Nipa fruit		Nipa mesocarp	
	Fruit-bearing trees	Nipa density (trees ha^{-1})	Bunches tree^{-1}	Bunches ha^{-1}	Fruits bunch^{-1}	Fruits ha^{-1}	Weight (g)	Yield (tons ha^{-1} year^{-1})
1	36	3,600	1.08	3,899	31.67	123,475	45.90	5.67
2	22	2,200	1.14	2,499	39.33	98,294	20.57	2.02
3	37	3,700	1.08	4,000	37.67	150,669	28.50	4.29
Average	**32**	**3,167**	**1.10**	**3,466**	**36.22**	**124,146**	**31.66**	**3.99**

Nipa palm density calculation using equation (1); Nipa bunches per ha using equation (2); Nipa fruits per ha using equation (3); Nipa yield using equation (4)

Further, vegetation analysis results at the study site showed that there were 32 Nipa trees bearing fruit, with an average of 1.10 bunches tree^{-1}, 36.22 fruits bunch^{-1}, and mesocarp weight of 31.66 grams. Based on the calculations, the number of Nipa trees bearing fruit was 3,167 per hectare (trees ha^{-1}), the number of bunches was 3,466 per hectare (bunches ha^{-1}), and the number of fruits was 124,146 per hectare (fruits ha^{-1}). Assuming Nipa fruit is harvested once a year, the estimated Nipa mesocarp yield at the study site is 3.99 tons ha^{-1} year^{-1}.

To estimate the national production of Nipa mesocarp, it is assumed that the Nipa plant area is 30 percent of the mangrove forest area [36]. According to data from the Ministry of Environment and Forestry, the mangrove forest area in 2018 was 2,788,600 hectares [44].

Based on this data, it can be estimated that the total Nipa planting area in Indonesia is 837,000 hectares.

Table 3. Production of nipa mesocarp in Indonesia.

Nipa mesocarp yield (tons ha^{-1} $year^{-1}$)	Area of nipa palm (ha)	National mesocarp production (tons $year^{-1}$)
3.99	837,000	3,339,630

National mesocarp production calculation using equation (5)

With a mesocarp yield of 3.99 tons ha^{-1} $year^{-1}$ and a Nipa planting area of 837,000 hectares, the estimated mesocarp production of Nipa in Indonesia is 3,339,630 tons $year^{-1}$ (Table 3).

3.2 Nipa sap

3.2.1 Chemical characteristics

The characteristics of Nipa sap were measured on a composite sample from plot 3, which resulted from tapping fruit stalks on three trees. This was due to insufficient sap volume obtained from plots 1 and 2 for laboratory analysis. The low sap yield was likely because of the short pre-tapping time in this study (7 days). It is recommended to conduct pre-treatment on fruit stalks for at least 25 days to achieve a high sap yield [33]. Additionally, Nipa trees in both plots were often submerged because they were located near bodies of water, with plot 1 by the Londo River and plot 2 by the Wonorejo River. This could have hindered the development of fruit stalks, resulting in a low sap yield [32].

The total sugar content in palm sap is the basis for its utilization as a bioethanol feedstock. The analysis results show that Nipa sap contains a total sugar content of 13.13 percent, sucrose 12.74 percent, and fructose 0.21 percent (Table 4). The total sugar content is lower than that found by Tamunaidu et al. at 16.98 percent [19]. The low total sugar content in the sap is attributed to the sampling being carried out in December. During this period, high rainfall and extensive waterlogging occur, leading to reduced sugar production [32].

Table 4. Chemical composition of nipa sap.

Composition	East Java, Indonesia (current study)	Thailand [a]	Malaysia [b]
Total sugar (%)	13.13	16.98	-
Sucrose (%)	12.74	9.78	7.31
Glucose (%)	nd [c]	5.68	3.01
Fructose (%)	0.21	1.53	2.93

[a] Tamunaidu et al. [19]; [b] Van Nguyen et al. [45]; [c] nd = not detected

The sucrose content in Nipa sap is higher than that found by Tamunaidu et al. at 9.78 percent [19] and Van Nguyen et al. at 7.31 percent [45]. However, the analysis of Nipa sap did not find monosaccharide glucose, only fructose at 0.21 percent. In contrast, a high content of reducing sugar was found by Tamunaidu et al. with glucose (5.68%) and fructose (1.53%) [19], as well as by Van Nguyen et al. with glucose (3.01%) and fructose (2.93%) [45]. In theory, within 24 hours, sucrose levels in sap will decrease with an increase in reducing sugar

[46]. Thus, the low content of reducing sugar in this study indicates that Nipa sap is fresh and has not undergone hydrolysis due to correct tapping, storage, and sap preservation processes.

3.2.2 Production potential

The estimated production of Nipa sap in Indonesia is shown in Table 5. Based on previous calculations, the Nipa tree density is 3,167 trees ha^{-1}. It is further assumed that sap production is 1 L $tree^{-1}$ day^{-1}, with a tapping duration of 56 days $year^{-1}$ [32]. Therefore, the estimated Nipa sap yield at the study site is 177,352 L ha^{-1} $year^{-1}$.

Table 5. Production of nipa sap in Indonesia.

Nipa density (trees ha^{-1}) [a]	Nipa sap yield (L $tree^{-1}$ day^{-1}) [b]	Tapping duration (day $year^{-1}$) [b]	Nipa sap yield (L ha^{-1} $year^{-1}$)	Area of nipa palm (ha)	Nipa sap national production (L $year^{-1}$)
3,167	1	56	177,352	837,000	148,443,624,000

[a] Current study; [b] Matsui et al. [32]
Nipa sap yield calculation using equation (6); nipa sap national production using equation (7)

By multiplying the Nipa sap yield of 177,352 L ha^{-1} $year^{-1}$ by the Nipa planting area of 837,000 hectares in Indonesia, the estimated national sap production is 148,443,624,000 L $year^{-1}$.

3.3 Nipa as biofuel

The potential of Nipa as a biofuel feedstock will be examined by comparing it with several other food-source plants: sugarcane, corn, cassava, and sweet potatoes. Based on chemical characteristics, the carbohydrate content in Nipa mesocarp is 39.37 percent, which is higher than sweet potatoes at 12.70 percent and cassava at 38.06 percent but lower than corn at 74.26 percent. However, the total sugar content in nipa sap at 13.13%, while slightly lower, is comparable to sugarcane at 17.00 percent (Table 6).

Table 6. Chemical composition of nipa and other food crops.

Crop	Composition	
	Carbohydrate (%)	Total sugar (%)
Nipa mesocarp	39.37 [a]	-
Nipa sap	-	13.13 [a]
Sugarcane	-	17.00 [b]
Corn	74.26 [c]	-
Cassava	38.06 [c]	-
Sweet potato	12.70 [d]	-

[a] Current study; [b] Tamunaidu & Saka [19]; [c] Bayata [18]; [d] El Bassam [47]

The relatively high carbohydrate content in Nipa mesocarp classifies it as a starch-based bioethanol feedstock. To produce ethanol, a series of processes, including milling, liquefaction, saccharification, fermentation, distillation, and dehydration, are required [48]. On the other hand, Nipa sap, with its comparable total sugar content to sugarcane, is classified as a sugar-based feedstock. Ethanol production from sap involves clarification, filtration, concentration, fermentation, distillation, and dehydration processes [49].

Furthermore, production quantities of Nipa (mesocarp and sap) as a feedstock, as well as national biofuel production estimates, are compared with other food crops (Table 7). Based on the quantity as a feedstock, Nipa mesocarp production of 3,339,630 tons year-1 is higher than sweet potatoes at 1,424,147 tons year^{-1} but lower than corn at 23,042,765 tons year^{-1} and cassava at 15,730,971 tons year^{-1}. Meanwhile, Nipa sap production is 148,443,624,000 L year^{-1}.

Table 7. Production of feedstock and Biofuel from nipa and other food crops.

Crop	Feedstock production		Ethanol conversions		Biothanol production (L year^{-1})
	tons year^{-1}	L year^{-1}	L ton^{-1}	%	
Nipa mesocarp	3,339,630 [a]	-	-	-	-
Nipa sap	-	148,443,624,000 [a]	-	8.98 [e]	13,330,237,435
Sugarcane	31,734,203 [b]	-	81 [d]	-	2,570,470,419
Corn	23,042,765 [c]	-	410 [d]	-	9,447,533,650
Cassava	15,730,971 [c]	-	180 [d]	-	2,831,574,780
Sweet potato	1,424,147 [c]	-	125 [d]	-	178,018,375

[a] Current study; [b] BPS-Statistics Indonesia [38]; [c] Ministry of Agriculture [37]; [d] Johnston et al [50]; [e] Hidayat [21]
The sugarcane production was obtained by dividing the total sugar production from BPS-Statistics Indonesia (2,348,331 tons) by the sugar crystals conversion factor (7.4%) [51].
Bioethanol production calculation using equation (8).

Due to the lack of conversion data from mesocarp, the focus for ethanol production is solely on utilizing Nipa sap as a feedstock. Based on the estimation results, the bioethanol production from Nipa sap is 13,330,237,435 L year^{-1}, surpassing corn at 9,447,533,650 L year^{-1}, cassava at 2,831,574,780 L year^{-1}, sugarcane at 2,570,470,419 L year^{-1}, and sweet potatoes at 178,018,375 L year^{-1}. Even though this estimation allocates the entire production of food crops as bioethanol feedstock.

The low national bioethanol production estimate from food crops is attributed to insufficient crop production quantities. In fact, to meet domestic consumption needs, imports are still required [37; 38]. As a result, these food crops do not meet the primary criteria as potential biofuel feedstocks as outlined by the Ministry of National Development Planning [52]. Since the choice of feedstock significantly impacts biofuel production costs, with feedstock representing over 75 percent of total costs, it is essential to select feedstocks that ensure low production costs and provide a competitive advantage over fossil fuels [53]. For reference, the three largest bioethanol producers globally, the United States, Brazil, and India, are also major producers of food crops [54]. Specifically, the United States is a corn producer, while Brazil and India are the world's largest sugarcane producers [55]. In the Indonesian context, it is challenging to follow in the footsteps of these countries solely relying on domestic food crop feedstocks. Therefore, Nipa, as a non-food crop with abundant production, has significant potential to be used as a bioethanol feedstock without concerns about scarcity or commodity price increases in the market. Moreover, the national bioethanol production estimate from Nipa sap far surpasses well-known food crop feedstocks, opening up the opportunity for Nipa to serve as a substitute for fossil fuels to meet domestic fuel demands.

3.4 Nipa as a national biofuel

The Ministry of Energy and Mineral Resources, in the Handbook of Energy & Economic Statistics of Indonesia, reported that fuel production in 2022 was 53,436 thousand kL, consumption was 75,967 thousand kL, and imports were 27,861 thousand kL [39] (Table 8). National fuel supply from refinery production has shown a rising trend in the last ten years, but it still cannot meet the very high demand. Consequently, there is always a gap that needs to be filled by imports.

Table 8. Production, consumption, and import of fuels in Indonesia (2013 - 2022).

Year	Fuel Production (1000 kL) [a]	Fuel Consumption (1000 kL) [b]	Fuel Imports (1000 kL) [c]
2013	40,565	70,761	32,693
2014	42,993	69,411	33,242
2015	41,183	66,006	28,293
2016	46,066	64,844	23,500
2017	45,954	67,623	27,496
2018	50,777	71,704	28,225
2019	52,948	72,158	24,729
2020	48,575	63,855	19,929
2021	50,947	68,365	22,087
2022	53,436	75,967	27,861

[a] Fuel productions represent the cumulative production of oil-based fuels, including Gasoline, Gasoil, MDF (Marine Diesel Fuel), Kerosene, Fuel Oil, Avtur (Aviation Turbine Fuel), and AvGas (Aviation Gasoline), as well as biodiesel.
[b] Fuel Consumptions represent the consumption of fuels and blending products, such as gasoil and biodiesel.
[c] Fuel Imports represent the total importation of oil-based fuels, including Gasoline, Gasoil, MDF, Fuel Oil, Avtur, Avgas, and Naphta.

Simulations based on the data in Table 8 will now be conducted to assess the potential of Nipa bioethanol to increase supply and meet fuel demand in Indonesia. In the first scenario, national fuel supply will only include oil fuel and biodiesel. In the second scenario, Nipa bioethanol will be added to the supply, alongside oil fuel and biodiesel (Figure 5).

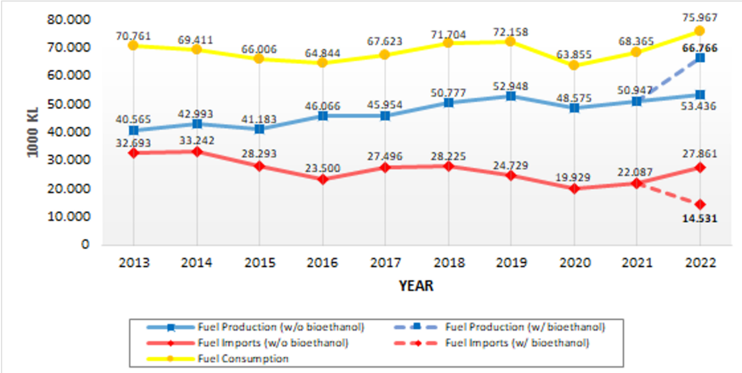

Fig. 5. Fuel Production and Import Scenarios in Indonesia (with & without Bioethanol). The value of fuel production (w/ bioethanol) in 2022 is derived from fuel production w/o bioethanol (53,436 thousand kL) + estimated Nipa bioethanol production (13,330 thousand kL).
The value of fuel imports (w/ bioethanol) in 2022 is obtained from fuel imports w/o bioethanol (27,861 thousand kL) - estimated Nipa bioethanol production (13,330 thousand kL).

The simulation results indicate that if Nipa bioethanol were included in Indonesia's fuel production in 2022, the supply would increase to 66,766 thousand kL (a 24.95% increase). Assuming no changes in demand, the import volume would decrease to 14,531 thousand kL (a 47.86% reduction). This demonstrates that Nipa bioethanol has the potential to increase domestic fuel supply and reduce imports.

In its report, the Ministry of Energy and Mineral Resources also stated that the increase in fuel production in Indonesia over the last ten years is primarily due to the contribution of palm oil-based biodiesel [39]. However, without bioethanol production, the increase in supply alone will not be able to meet the ever-increasing annual demand. Gasoline is the most widely consumed fuel by the public, representing 79 percent of the import share in 2022 [39]. Only with bioethanol production as a substitute can the national fuel deficit resulting from increased gasoline consumption be alleviated. A study by Widodo et al. stated that the most significant challenge to bioethanol production in Indonesia and several other countries is the supply of feedstock [56]. Therefore, Nipa, as a non-food crop with abundant production, has great promise as a bioethanol feedstock and as a substitute for gasoline to meet domestic fuel needs.

4 Conclusion

This study reveals that Nipa is a feasible feedstock for bioethanol production. This is evidenced by its chemical characteristics that are conducive to bioethanol production, with carbohydrate content in the mesocarp and total sugar content in the sap comparable to those of food-source feedstocks. Furthermore, as it is not a food crop, its utilization as a bioethanol feedstock is more sustainable without triggering food versus energy controversies. The estimated production results for bioethanol nationally also surpass those of Sugarcane, Corn, Cassava, and Sweet Potato. With such quantities, Nipa bioethanol can increase domestic fuel supply, reduce imports, and support the government's goal of achieving a 23 percent primary energy mix by 2025.

References

1. United Nations Environment Programme (UNEP), *The Closing Window.* United

Nations Environment Programme (UNEP), (2022).
2. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2021 – The Physical Science Basis*, Intergovernmental Panel on Climate Change (IPCC), (2021).
3. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022 – Impacts, Adaptation and Vulnerability*, Intergovernmental Panel on Climate Change (IPCC), (2022).
4. M. A. H. Khan *et al.*, *Investigation of Biofuel as a Potential Renewable Energy Source*, *Atmosphere (Basel).*, vol. 12, no. 10, (2021).
5. C. R. A. Lima, G. R. de Melo, B. Stosic, and T. Stosic, *Cross-Correlations between Brazilian Biofuel and Food Market: Ethanol versus Sugar*, Phys. A Stat. Mech. its Appl., vol. 513, pp. 687–693, (2019).
6. T. Tanaka, J. Guo, and X. Wang, *Price Interconnection of Fuel and Food Markets: Evidence from Biodiesel in the United States*, GCB Bioenergy, vol. 15, no. 7, pp. 886–899, (2023).
7. Y. Subramaniam, T. A. Masron, and N. H. N. Azman, *The Impact of Biofuels on Food Security*, International Economics, vol. 160. pp. 72–83, (2019).
8. M. Boly and A. Sanou, *Biofuels and Food Security: Evidence from Indonesia and Mexico*, Energy Policy, vol. 163, no. March, p. 112834, (2022).
9. International Energy Agency (IEA), *World Energy Outlook 2022*, International Energy Agency (IEA), (2022).
10. J. Guo and T. Tanaka, *Energy Security versus Food Security: An Analysis of Fuel Ethanol-Related Markets Using the Spillover Index and Partial Wavelet Coherence Approaches*, Energy Econ., vol. 112, no. September 2021, p. 106142, (2022).
11. National Energy Council (NEC), *Indonesia Energy Outlook 2022*, Secretary General of the National Energy Council, Jakarta, (2022).
12. A. V. F. C. Bobrov, D. H. Lorence, M. S. Romanov, and E. S. Romanov, *Fruit Development and Pericarp Structure in Nypa fruticans Wurmb (Arecaceae): A Comparison with Other Palms*, Int. J. Plant Sci., vol. 173, no. 7, pp. 751–766, (2012).
13. T. K. Lim, *Edible Medicinal and non-Medicinal Plants*, Edible Med. Non-Medicinal Plants, vol. 1, pp. 1–738, (2012).
14. K. Tsuji *et al.*, *Genetic Diversity and Geographical Differentiation of Nipa (Nypa fruticans Wurmb.) Populations in Peninsular Malaysia Based on AFLP*, Japan Agric. Res. Q., vol. 50, no. 1, pp. 49–56, (2016).
15. J. A. Mantiquilla *et al.*, *Deep Structured Populations of Geographically Isolated Nipa (Nypa fruticans Wurmb.) in the Indo-West Pacific Revealed Using Microsatellite Markers*, Front. Plant Sci., vol. 13, no. October, pp. 1–18, (2022).
16. T. M. Ibrahim, E. Julianti, T. Supriana, and Delvian, *Potential Analysis of Nipa Palm (Nypa Fruticans) in Singkil*, IOP Conf. Ser. Earth Environ. Sci., vol. 1115, no. 1, (2022).
17. V. N. Osabor, G. E. Egbung, and P. C. Okafor, *Chemical Profile of Nypa Fruiticans from Cross River*, Pakistan J. Nutr., vol. 7, no. 1, pp. 146–150, (2008).
18. A. Bayata, *Review on Nutritional Value of Cassava for Use as a Staple Food*, Sci. J. Anal. Chem., vol. 7, no. 4, pp. 83–91, (2019).
19. P. Tamunaidu and S. Saka, *Comparative Study of Nutrient Supplements and Natural Inorganic Components in Ethanolic Fermentation of Nipa Sap Pramila*, J. Japan Inst. Energy, vol. 65, no. 2, pp. 122–125, (2013).
20. A. G. Capodaglio and S. Bolognesi, *Ecofuel Feedstocks and Their Prospects*, in Advances in Eco-Fuels for a Sustainable Environment, Elsevier Ltd., 2019, pp. 15–51.
21. I. W. Hidayat, *Economic Valuation of Nipa Palm (Nypa fruticans Wurmb.) Sap as Bioethanol Material*, IOP Conf. Ser. Earth Environ. Sci., vol. 166, no. 1, (2018).
22. Ulyarti, Nazarudin, and D. W. Sari, *The Study of Functional Properties of Nypa Fruticans Flour*, AIP Conf. Proc., vol. 1823, no. March, (2017).
23. H. Hermanto, R. C. Mukti, and A. D. Pangawikan, *Nipah (Nypa fruticans Wurmb.) Fruit as*

a Potential Natural Antioxidant Source, IOP Conf. Ser. Earth Environ. Sci., vol. 443, no. 1, (2020).
24. R. Nofiani, J. Romengga, and T. A. Zaharah, *Characterization of Old Nipah (Nypa fruticans Wurmb) Fruit Endosperm Flour and Its Application for Gluten-Free Cookies*, agriTECH, vol. 41, no. 4, p. 354, (2021).
25. Sulfahri, R. Wardhani, F. A. Makatita, and I. W. Iskandar, *Utilization of Nypa fruit in Alzheimer's Disease: An in Silico Approach*, J. Phys. Conf. Ser., vol. 1341, no. 2, (2019).
26. F. K. Muzaki, D. Saptarini, N. D. Kuswytasari, and A. Suliestyono, *Menjelajah Mangrove Surabaya*. Surabaya: Pusat Studi Kelautan LPPM ITS, (2012).
27. D. Mueller-Dombois and E. Heinz, *Ekologi Vegetasi: Tujuan dan Metode*, 1st ed. Jakarta: LIPI Press, (2016).
28. I. W. Hidayat, *Natural Production Potency of Nipa (Nypa fruticans) sap as Production Commodity for Bioethanol*, Pros. Semin. Nas. Masy. Biodiversitas Indones., no. January, (2015).
29. Badan Standarisasi Nasional (BSN), *SNI 7717 :2011 Survei dan Pemetaan Mangrove*. Jakarta: Badan Standarisasi Nasional, (2011).
30. International Standard Organization (ISO), *ISO 7218:2007 Microbiology of Food and Animal Feeding Stuffs — General Requirements and Guidance for Microbiological Examinations*. Geneva: International Standard Organization (ISO), (2007).
31. Badan Standarisasi Nasional (BSN), *SNI 01-2891-1992 Cara Uji Makanan dan Minuman*. Jakarta: Badan Standarisasi Nasional, (1992).
32. N. Matsui, Y. Okimori, F. Takahashi, K. Matsumura, and N. Bamroongrugsa, *Nipa (Nypa fruticans Wurmb) Sap Collection in Southern Thailand I. Sap Production and Farm Management*, Environ. Nat. Resour. Res., vol. 4, no. 4, pp. 75–88, (2014).
33. A. E. A. Päivöke, *Tapping Practices and SAP Yields of the Nipa Palm (Nypa Fruticans) in Papua New Guinea*, Agric. Ecosyst. Environ., vol. 13, no. 1, pp. 59–72, (1985).
34. D. Van Nguyen, Harifara, Rabemanolontsoa, and S. Saka, *Sap from Various Palms as a Renewable Energy Source for Bioethanol Production*, Chem. Ind. Chem. Eng. Q., vol. 22, no. 4, pp. 355–373, (2016).
35. N. M. Heriyanto, E. Subiandono, and E. Karlina, *Potensi dan Sebaran Nipah (Nypa fruticans (Thunb.) Wurmb) sebagai Sumberdaya Pangan*, J. Penelit. Hutan dan Konserv. Alam, vol. 8, no. 4, pp. 327–335, (2011).
36. B. Irawan, J. Khabibi, and A. Agustina, *The Potential of Nipah (Nypa Fruticans Wurmb) as Bioenergy Resources*, 1st Int. Conf. Green Dev. – Univ. Jambi - 2016, pp. 83–86, (2016).
37. Kementerian Pertanian, *Laporan Tahunan 2021*. Jakarta: Kementerian Pertanian, (2022).
38. Badan Pusat Statistik (BPS), *Statistik Tebu Indonesia 2021*. Jakarta: Badan Pusat Statistik Indonesia, (2022).
39. Ministry of Energy and Mineral Resources, *Handbook of Energy and Economic Statistics of Indonesia (HEESI) 2022*. Jakarta: Ministry of Energy and Mineral Resources, 2023.
40. E. Subiandono, N. M. Heriyanto, and E. Karlina, *Potensi Nipah (Nypa fruticans (Thunb.) Wurmb.) sebagai Sumber Pangan dari Hutan Mangrove*, Bul. Plasma Nutfah, no. 5, pp. 54–60, (2011).
41. P. Chau Sum, H. Eng Khoo, and A. Azlan, *Comparison of Nutrient Composition of Ripe and Unripe Fruits of Nypa fruticans*, Fruits, vol. 68, no. 6, pp. 491–498, (2013).
42. R. T. Setiawati and H. S. Titah, *Strategi Pengelolaan Mangrove di Ekowisata Mangrove Wonorejo Surabaya*. Surabaya: Program Magister Bidang Keahlian Teknik Lingkungan, Institut Teknologi Sepuluh Nopember (ITS), (2019).
43. J. N. Schaduw, *Distribusi dan Karakteristik Kualitas Perairan Ekosistem Mangrove Pulau Kecil Taman Nasional Bunaken*, Maj. Geogr. Indones., vol. 32, no. 1, p. 40, (2018).
44. Kementerian LHK (KLHK), *Rekalkulasi Penutupan Lahan Indonesia Tahun 2018*. Jakarta: Direktorat Inventarisasi dan Pemantauan Sumber Daya Hutan. Jakarta., (2019).

45. D. Van Nguyen, P. Sethapokin, H. Rabemanolontsoa, E. Minami, H. Kawamoto, and S. Saka, *Efficient Production of Acetic Acid from Nipa (Nypa fruticans) Sap by Moorella thermoacetica (f. Clostridium thermoaceticum)*, Int. J. Green Technol., no. February 2017, (2016).
46. P. Tamunaidu and S. Saka, *On-Site Sugar Analysis and Pre-treatment of Nipa Saps*, Green Energy Technol., vol. 108, (2011).
47. N. El Bassam, *Handbook of Bioenergy Crops - A Complete Reference to Species, Development and Applications*, 1st ed. London: Earthscan, (2010).
48. B. A. Saville, W. M. Griffin, and H. L. MacLean, *Ethanol Production Technologies in the US : Status and Future Developments*. Elsevier Inc., (2016).
49. R. C. Ray, K. B. Uppuluri, C. Trilokesh, and C. Lareo, *Sweet Sorghum for Bioethanol Production : Scope, Technology, and Economics*. Elsevier Inc., (2019).
50. M. Johnston, J. A. Foley, T. Holloway, C. Kucharik, and C. Monfreda, *Resetting Global Expectations from Agricultural Biofuels*, Environ. Res. Lett., vol. 4, no. 1, (2009).
51. D. Khatiwada, B. K. Venkata, S. Silveira, and F. X. Johnson, *Energy and GHG balances of Ethanol Production from Cane Molasses in Indonesia*, Appl. Energy, vol. 164, pp. 756–768, (2016).
52. Kementerian PPN/Bapenas, *Kajian Pengembangan Bahan Bakar Nabati (BBN)*, Jakarta, (2015).
53. A. H. Hirani, N. Javed, M. Asif, S. K. Basu, and A. Kumar, *A Review on First- and Second-Generation Biofuel Productions*, Biofuels Greenh. Gas Mitig. Glob. Warm. Next Gener. Biofuels Role Biotechnol., pp. 141–154, (2018).
54. International Energy Agency (IEA), *Renewable Energy Market Update Outlook for 2021 and 2022*, International Energy Agency (IEA), (2022).
55. FAOSTAT, *Crops and Livestock Products*, Food and Agriculture Organization of The United Nations, (2023).
56. Y. Widodo, S. Wahyuningsih, and J. Newby, *Fuelling Cassava Development to Meet the Greater Demand for Food and Bio-fuel in Indonesia*, Energy Procedia, vol. 65, pp. 386–394, (2015).