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Future prospective of bioethanol production from sugar palm sap

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Abstract

The availability of fossil fuels is decreasing along with increasing environmental temperatures due to their use. Therefore, there is a need for other alternatives to overcome this problem, such as the use of bioethanol as an environmentally friendly renewable energy. This research was aimed to identify the potency of sugar palm (Arenga pinnata Merr) sap as a feedstock for bioethanol production. Two major aspects of the identification focus were the feedstock availability and the bioethanol production process. The feedstock identification was conducted by surveying the industry of sugar palm and collecting data of the volume of sugar palm sap. Then, the production process of bioethanol as final product was conducted in four stages. They are characterization of samples, pasteurization, fermentation, and distillation. The results show that sap samples collected from the farmers have pH = 3.1-3.2, density 0.96 gr/mL, and carbohydrate content 1.51%, respectively. Sugar palm sap was fermented with 0.03 m/v fermentation agent of yeast within 72 hours. After the fermentation process, the sugar palm sap contains 1.51% carbohydrates, 74% alcohol, and 63.96% ethanol. Furthermore, the distillation temperature of 78-80^{o}C resulted in a 7.44% v/v ratio of extract amount from the total volume of the distillation results. The bioethanol quantity can be increased by considering the process, especially during the fermentation.

Keywords: *Arenga pinnata Merr; bioethanol; distillation; feedstock; fermentation*

1. INTRODUCTION

Sugar palm (*Arenga pinnata Merr*), one of the conserved trees in Indonesia, is a plant that is classified in palm or areca nut palm like coconut and nipa palm (*Nypa fruticans*). It grows naturally like other palm families in tropical regions mainly in hills areas, sloping areas, and riverbanks with high humidity for ideal condition even though it can also adapt to a 1.400 m height above the sea level (1). According to Indonesia Directorate General of Plantations, sugar palm is categorized as plantation crops (2). The trunk can reach 2.500 cm in length and 65 cm in diameter. It also has physical features like thick, black fibers at the top of the trunk. Its stalk leaf or petiole length is up to 500 cm with the leaf is 140 cm long and 7 cm wide (1). Furthermore, palm plants have various height depending on the species such as Genjah palm. Generally, it has the lowest height than the other palm trees and the shortest of flower and leaf stalks (3).

Sugar palm (*Arenga pinnata*) has male and female flowers that male flowers are smaller than female flowers (4). It shows that sugar palm has different morphologies based on the conditions of the area where they grow. In Gorontalo, palm tree is a potential forestry with important consideration from the government. It is considered from several aspects such as less application of palm trees in daily utilization or other products

by society. In certain areas, such as Botumoito Village, only around 3% of palm trees are used. Moreover, in 2022 Bone Bolango Regency planted 5000 sugar palm trees in Bulango Ulu District to celebrate Environment Day (5). In the same year, the estimated area of sugar palm trees in Gorontalo will be around 859 hectares, consisting of the area of mature plantations and the area of smallholder plantations of 535 ha and 184 ha, respectively (2). Second, sap from one sugar palm tree can be taken for 2-3 months with daily production reaching 15-25 liters per day (1), (6), (7), (8), (9), including early Genjah sugar palm (10). Third, the high production of palm sap has not been able to be balanced with widespread and maximum utilization. This is because most of the palm sap is used by the community in making palm sugar (5), (11). In some places, the use of palm sap even causes problems because it is not suitable for its intended use. They use palm sap as a raw material for traditional liquor which of course affects public security and order (12).

Apart from making sugar, palm sap is also used as a raw material for bioethanol production through a fermentation process (13). The most important stage of bioethanol production is the fermentation process. This is because many factors influence the product produced at the fermentation stage, such as the type and concentration of yeast, acidity (pH) of the raw material, temperature, and fermentation time. This research is aimed to identify the potential of palm sap in Gorontalo as a raw material for making bioethanol.

2. METHODS

This research mainly used sugar palm sap from several different places. This was intended to know and identify its initial characteristics in terms of their availability in nature.

2.1 Identify Potential Products

This identification was intended to find out data on the type of product that was the object of research. Identification was carried out through literature searches from various sources/references, including statistical data presented online by the central statistics agency. Additionally, samples were taken from several points that have high potential value based on statistical data and are easy to reach.

2.2 Materials and Tools

The tools used in this research were beakers, measuring cups, digital scales, baths, stirring rods, pycnometers, pH meters, mortars and pestles, hot plates, distillation equipment sets, alcohol meters, and gas chromatographs. The ingredients used are palm sap and yeast.

2.3 Methods

2.3.1 Physical properties of Sugar palm sap

Characterization of palm sap includes physical properties and carbohydrate content. Physical properties include pH and density. The pH of palm sap is measured using a pH meter, while the density is measured using a pycnometer. Testing carbohydrate content using titration method.

2.3.2 Pasteurization

Pasteurization (another name for sterilization) is intended to kill pathogenic microbes in sap (14), (15). Palm sap is heated at a temperature of less than 100 ^{o}C (14), (16), (17), (18). In this study, pasteurization was carried out at a temperature of 50-60 ^{o}C for 10 minutes.

2.3.3 Fermentation

Fermentation of palm sap was carried out at room temperature for 72 hours with a yeast and palm sap ratio of 0.03 gr/mL. The fermented palm juice is characterized in terms of pH, sugar (carbohydrate) content, density, and ethanol content.

2.3.4 Distillation

The fermented palm sap is distilled using a distillation equipment set. Distillation of palm sap takes place at a temperature of 78-80 ^{o}C. This temperature is the boiling point range of ethanol. The distillate resulting from the distillation process is characterized in terms of pH and density.

3. RESULT AND DISCUSSION

3.1 Potential of Sugar Palm Sap as a Feedstock for Bioethanol Production

In statistical data, the largest potential for sugar palm plants in Gorontalo Province is in Bone Bolango Regency from 2015-2017 with a percentage of 60% of the area of sugar palm plants in Gorontalo Province (19), (20) as presented in Figure 1. Moreover, serious attention to the development of sugar palm potency leads the regency government of Bone Bolango to publish Regulation No. 43 in 2014 concerning the guidelines for developing Core Industrial Competencies for Bone Bolango in 2014-2018. This regulation was issued based on the regulation of Indonesia Ministry of Industry Number 86/M-IND/PER/12/2013, where the regulation states that sugar palm is one of the Core Commodities for Regional Industries. One of the purposes to issue the regulation is to increase the additional value of palm derivative products, including palm sap fermented products. The area of sugar palm plantations in 2020-2022 tends to be stable. It is around 857.3 hectares, with an average planting area of 535 hectares (21). The number of sugar palm trees in Community Forest Areas can reach around eight trees with a potential productivity percentage of 51.65% (22). The low rate is because the area not only grows palm trees but also various forms of plants, including large trees whose wood is used. This condition is different if the area is a plantation area, where one hectare can reach 95-98 trees (23). Based on this data, there will be around 50.8-52.4 thousand palm trees in the mature category in 2022. Based on the parameters in Table 1, palm sap production in 2022 reach 6.3 million liters of palm sap.

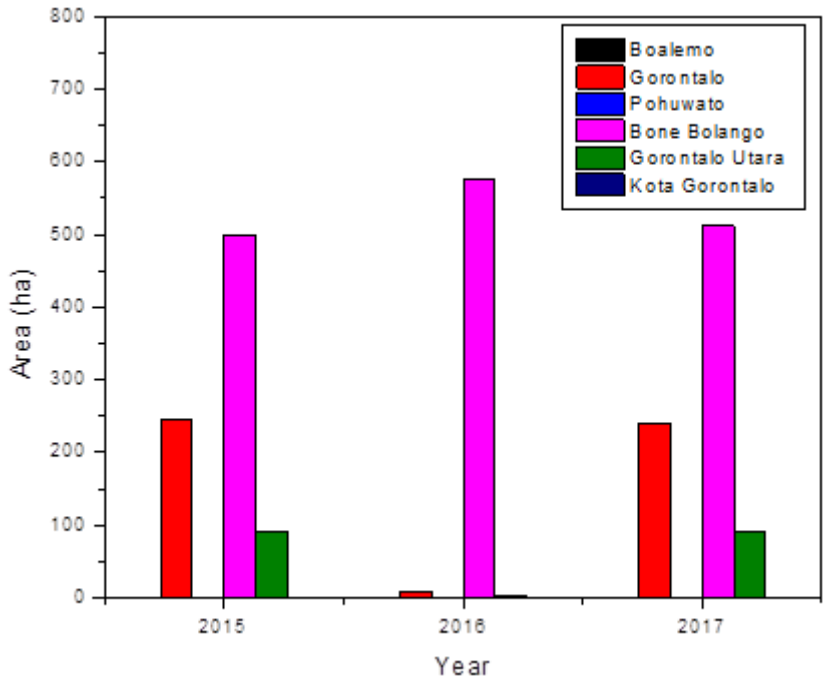

Figure 1. Sugar palm area in Gorontalo Province 2015-2017

Table 1. Parameters of Tapping

No	Parameters	Value	References
1.	Age at start of tapping (years)	6-7	(24), (25)
2.	Volume per day	10-20	(24)
3.	The productive age of tapping	7-20	(26), (27)

However, in 2022 the area decrease by around 60% of the total area in Bone Bolango Regency due to the construction of the Bulango Ulu Dam which covers two sub-districts, Bulango Ulu and Bulango Utara Districts (20). However, the potency of sugar palm still outpaces in Bone Bolango Regency area due to the addition of 5000 trees. If the growth percentage of sugar palm plants is 58.45% (28), then at the age when palm trees begin tapping there are around 2.9 thousand categories of producing plants. This condition occurs in the projected years 2022 to 2042 which is referred to as productive age, namely during the 20-year age range. After the age of 20 years, productivity decreases. This is similar to the results of previous research that after the age of 20 years (age range 21-30) productivity decreases to 61.85% (27) with the amount of decline as presented in Figure 2. Apart from age, the quantity of palm sap production is also influenced by the type of flower, where palm sap is generally tapped from male flowers. Tapping palm sap from female flowers is often of poor quality and quantity (29).

3.2 Characteristics of Sugar Palm Sap

Palm sap resulting from tapping in two different places has a characteristic white, slightly purple, cloudy/pale color accompanied by foam (Figure 2), pH = 3.1-3.2, density 0.96 gr/ml, has a distinctive smell, and has a sugar content of 1.51%. Elsewhere, palm sap has a pH = 4.05-4.32 (30). Palm sap which has a low pH (very acidic) can be caused by the independent fermentation process from alcohol to acid with the help of *Acetobacter sp* bacteria (31). These changes are chemical reactions illustrated in equation 1 (31), where ethanol (C_2H_5OH) undergoes oxidation to become acetic acid (CH_3COOH):

$$C_2H_5OH_{(l)} + O_{2(g)} \rightarrow CH_3COOH_{(l)} + H_2O_{(l)} \quad (1)$$

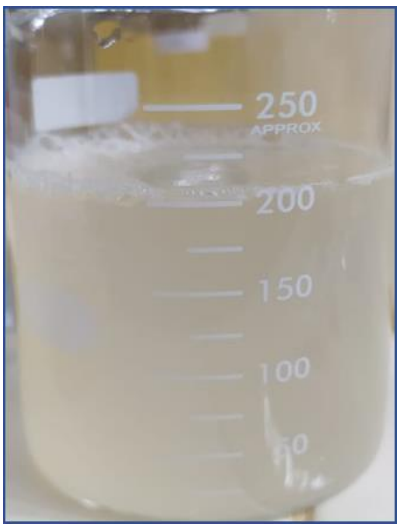

Figure 2. Sugar palm sap one day after tapping

The mutation of characteristics of palm sap when it is stored for several days without any process are not only chemical but also physical. Palm sap which was initially purple/bright colored changed to white (Figure 3). In addition, the pH changed from 3.1 to 2.8. This means that changes in pH affect color changes, where a decrease in pH causes

a color change from dark to light (32). Palm sap that has a pH < 6 usually looks cloudier than one with a pH > 6 (33). Palm sap from tapping has a carbohydrate (sugar) content of 1.51%. In some places, palm sap has a sugar content of 12.04%, slightly higher than coconut sap and Siwalan (*Borassus flabellifer*) sap (17). Genjah sugar palm contains reducing sugar of 1.02% (3). Low sugar levels indicate a chemical change from sugar to acetic acid. The quality of palm sap is greatly influenced by several factors, both internal and external. Internal factors can include plant type, flower age, natural fermentation, and tapping process. Meanwhile, external factors include lack of nutrition, wind, rain, soil fertility, and drought (34), (35). Additionally, cleanliness, sanitation facilities, and equipment are also part of the factors that influence the quality of palm sap (36).

Figure 3. Color change of palm sap

3.3 Fermentation Process

The fermentation process is influenced by many factors and these factors sometimes have different results at each location where the raw materials are taken. Optimum conditions for the fermentation process generally occur for 72 hours (37), but in some places, fermentation can be carried out for more than 72 hours. The test results showed that fermented palm sap had carbohydrate content and ethanol content of 1.51% and 63.96% respectively with a density of around 0.97 gr/mL. The fermentation process increases the pH from 3.1 to 3.5 with a yellow to brown palm sap color (Figure 4). The characteristics of palm sap before and after fermentation can be seen in Table 2.

Table 2. Differences Between Palm Sap Before and After Fermentation

No	Parameters	Values	
		Before	After
1.	Fermentation time (hour)	0	72
2.	Density (gr/ml)	0.96	0.97
3.	pH	2.8-3.1	3.4-3.5
4.	Colour	Cloudy white – purplish clear	Cloudy brown
5.	Carbohydrate contents (%)	1,51	1.51
6.	Ethanol contents (%)	-	63.96
7.	Foam	That's pretty much it at the top of the container	Not enough

Figure 4. Fermentation process of Palm sap

3.4 Distillation of Palm Sap after Fermentation

Distillation is a process of separating substances based on the difference in boiling points of the substances being separated. Distillation of palm sap to produce distillate (bioethanol) is carried out at temperatures ranging from 78-80 ^{o}C for 3 hours 30 minutes. This temperature range is the boiling point area of ethanol which allows it to be used to separate it from the mixture. The results of the distillation process of fermented palm juice can be seen in Table 3.

Table 3. Results of Distillation Process

No	Volume of Palm Sap (mL)	Volume of Distillate (mL)	Percentage (% v/v)
1	100	5,00	5,00
2	100	5,50	5,50
3	100	8,00	8,00
4	150	13,00	8,70
5	150	15,00	10,00
	Average	9,30	7,44

Table 1 shows that the results obtained were an average of 7.44% v/v from fermented palm sap feedstocks. This value is still higher compared to several previous studies. The results of research conducted by Da Suka (2020) show that 45 liters produce 1 bottle of class 1 Sopi (liquid ethanol). If it is assumed that 1 bottle is 600 mL (aqua bottle), then only around 1.33% of the distillate will be obtained. Other research reveals that increasing the temperature in the distillation process to 90-92 ^{o}C can increase the amount (volume) of distillate. However, increasing temperature has an effect on reducing the levels of ethanol produced (38).

The low results obtained can be influenced by the very high acidity level of palm sap. An inappropriate pH value affects the quality of bioethanol, where pH < 4 has the potential for the formation of acetic acid as shown chemically in equation 1. Meanwhile, pH > 5 is a condition that has the potential for the formation of butyric acid (39). The fermentation process also has an effect on the characteristics of bioethanol products (37), (40). Several efforts can be made to ensure that the pH of the juice matches what is required in optimizing the fermentation process by adding NaOH (41). The distilled bioethanol has a clear color (Figure 5) with a density of 0.91 gr/mL. Other research shows that bioethanol has a density ranging from 0.79-0.84 gr/mL with a tendency to decrease in density as the fermentation process takes longer (42). The results of other research show that ethanol content of 91.86% has a density of around 0.83 gr/mL (43). The difference in density shows the difference in the level of ethanol produced.

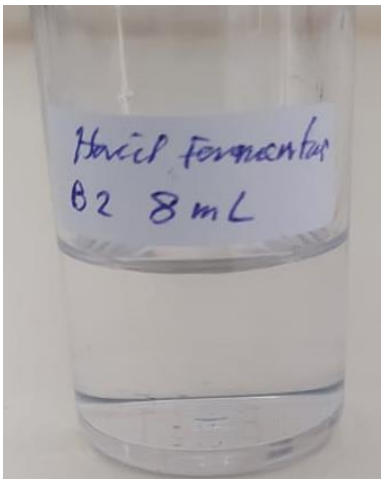

Figure 5. Distilled Bioethanol

4. CONCLUSION

The large land area in Gorontalo Province, especially in several districts where sugar palm trees grow indicates that this tree is a potential natural resource. This potential will have high economic value when palm sap from tapping is not only used to make sugar but also as a raw material for making bioethanol. This is proven by research results that bioethanol obtained from the distillation process can reach an average of 7.44% v/v. This result can be improved by paying attention to the factors that play a role in increasing it, especially at the fermentation stage. The acidity level of the raw material during fermentation greatly influences the bioethanol produced.

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