Available online at www.sciencedirect.com

jmr&t Journal of Materials Research and Technology

journal homepage: www.elsevier.com/locate/jmrt

Original Article

Enhancement of bioethanol production from palm sap (*Arenga pinnata* (Wurmb) Merr) through optimization of *Saccharomyces cerevisiae* as an inoculum

Ansar [a,**], *Nazaruddin* [b], *Atri Dewi Azis* [c], *Ahmad Fudholi* [d,e,*]

[a] *Department of Agricultural Engineering, Faculty of Food Technology and Agroindustries, University of Mataram, Indonesia*

[b] *Department of Food Science and Technology, Faculty of Food Technology and Agroindustries, University of Mataram, Indonesia*

[c] *Department of English Education, Faculty of Teacher Training and Education, University of Mataram, Indonesia*

[d] *Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia*

[e] *Research Centre for Electrical Power and Mechatronics, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia*

ARTICLE INFO

Article history:
Received 18 August 2020
Accepted 24 June 2021
Available online 1 July 2021

Keywords:
Palm sap
Bioethanol
Fermentation
Distillation
Inoculum

ABSTRACT

Availability of fossil fuels is increasingly limited, so the search for alternative fuels is important. In accordance with the current scenario, bioenergy research emphasizes the bioethanol production from plants that are abundant and available throughout the year, such as palm sap. The palm sap is a type of palm tree that grows in tropical forests, particularly in South Asia and Southeast Asia. More than 3000 species of palm exist, and they are categorised as multipurpose trees because they can be used as raw materials for various products, such as sugar, fermented drinks, syrup, palm wine, vinegar, alcohol and bioethanol. This study was aimed to examine bioethanol production from palm sap through optimization of *Saccharomyces cerevisiae* as an inoculum. The research sample was obtained from local farmers in Pusuk, Lombok Island, West Nusa Tenggara, and Indonesia. The research parameters included the pH change, colour, and ethanol content. The results showed that the pH change of the palm sap during storage was caused by the growth of microorganisms to produce organic acids by releasing hydrogen ions. As pH decreased, L* and b* values also decreased significantly, but not significantly change in a* values was observed. Glucose changed to ethanol during fermentation. The higher the percentage of inoculum used, the higher the volume of ethanol obtained. The bioethanol content of palm sap prior to fermentation was 32.3%, and it increased to 75.6% after 24 hours of incubation.

* Corresponding author.
** Corresponding author.
E-mail addresses: ansar72@unram.ac.id (Ansar), a.fudholi@gmail.com (A. Fudholi).
https://doi.org/10.1016/j.jmrt.2021.06.085

1. Introduction

Palm sap (*Arenga pinnata* (Wurmb) Merr) is a type of palm tree that grows in tropical forests, particularly in South Asia and Southeast Asia [1–3]. More than 3000 species of palm exist, and they are categorised as multipurpose trees because they can be used as raw materials for various products, such as sugar, fermented drinks, syrup, palm wine, vinegar, alcohol and bioethanol [4,5].

Some parts of the palm tree are used to meet human needs; for example, the fruit can be used for cocktails or desserts; and the fibre is used to make ropes, filters, brooms and roofs [6]. Starch, the inner part of the tree, is the raw material for noodle production. Young leaves can be consumed as a salad or cooked as an ingredient for soups. Stems (wood) can be processed for the manufacture of furniture, and roots are used as traditional medicine because they are believed to dissolve bladder stone [7].

The national palm tree cultivation programme for industrial purposes has been implemented since 2007 in Indonesia [8,9]. The land area for palm cultivation in Indonesia is approximately 60,482 ha, and its potential for sap production can reach 303.76 million litres per year [10]. If production is 50% of the total population, then sap production can reach 210.600 L/ha/year [11]. Every 10 L of sap can produce an average of 3.5 L of ethanol [12]. Accordingly, 1 ha of palm trees can produces of 73,710 L of ethanol. If production is adequate, then the potential of biofuel from palm sap can reach 2 million kilolitres per year. Thus, biofuel exhibits considerable potential and must be developed.

The quality of palm sap is determined by the pH value [13]. The palm sap with a pH value of 6–7 is considered good quality for use in ethanol production [14]. However, new palm sap tapped with neutral pH is easily damaged; hence, the sap must be processed immediately after harvesting [15–17]. *Saccharomyces cerevisiae* microorganisms in palm sap can trigger an acidic reaction [18,19]. This condition poses a challenge to maintaining sap quality at neutral pH.

The bioethanol production from renewable raw materials has attracted attention today because it can be used as an alternative fuel [20,21]. Bioethanol is the most popular biofuel because it is environmentally friendly [22]. Bioethanol production for the first generation in general still uses food as raw material [23,24]. The second generation of bioethanol has replaced it by using biomass as a feedstocks [25,26]. The second generation technology has encouraged the development of bioethanol production with lower production costs and better environmental impact [27,28]. Palm sap is the most promising bioethanol raw material for bioethanol production because it is available throughout the year and is abundant [29,30].

The success factors to the bioethanol production from the palm sap include initial treatment, fermentation method, and refining [31,32]. Busic et al. [33] asserted that the most influential factor in obtaining bioethanol content from the palm sugar is tapping and distribution during processing because palm sugar is easily damaged by environmental conditions. Kismurtono [34] also explained that the bioethanol content produced from fermented palm sap is strongly influenced by the quality of raw materials used [35–37]. Meanwhile, according to Sebayang et al. [38], the purity of ethanol can be increased through a distillation process using zeolite as an adsorbent. Bioethanol production from the banana stems for power generation applications is very profitable economically and environmentally friendly [39].

The bioethanol production from the palm sap is a relatively new technology [40]. Bioethanol has the potential as a vehicle fuel because it has a high calorific value [41]. This high calorific value results in a long burning time [42]. Fuel substitution requires an ethanol level above 95% [43]. In the current study, anaerobic fermentation is performed to produce ethanol at levels that can be used as substitutes for environment-friendly fuels [44,45].

The research focusing on the processing of palm sap into bioethanol has been conducted by researchers, like [46], but the bioethanol content obtained is still less than 95%, so it cannot be used as a substitute for vehicle fuel. Thus, it is still important to do research to produce bioethanol that can be used as an environmentally friendly substitute for biofuels. These research use a method of fermentation and multilevel distillation to produce biofuels that can be used as biofuel substitutes that are environmentally friendly. Anaerobic fermentation method uses microbial culture made from a mixture of palm sap and *S. cerevisiae* as an inoculum [47,48]. The increase of ethanol yield up to 99.5% was done by stratified distillation [49–51]. Based on the arguments above, the purpose of this study was enhancement of bioethanol production from palm sap through optimization of *S. cerevisiae* as an inoculum. This research is very important as information to the bioethanol industry to develop palm sap as a raw material for making biofuels.

2. Materials and methods

2.1. Samples and tools

The raw material used was palm sap obtained from farmers in Pusuk, Lombok Island, West Nusa Tenggara Province, Indonesia. To accelerate the growth of the culture, microbes are used. Cerevisiae as additional nutrition in preparing inoculum. The tools used were fermenters, distillation system, pH meter and Hunter Lab.

2.2. Preparation of palm sap

The palm sap was heated approximately 50–60 °C for 10 min to produce glucose and to destroy bacteria that were not beneficial for fermentation. Thereafter, the palm sap culture was stored for 24 h to decrease the temperature to 28 °C [52].

2.3. Preparation of inoculum culture

To prepare the inoculum culture, 500 mL of palm sap was heated at 60 °C for 10–15 min and then cooled at the room temperature. After cooling, the palm sap was inoculated with *Saccharomyces cerevisiae* and bread yeast. Then, it was incubated at 30 °C for 24 h to be used as microbial culture. This culture was mixed with NPK as an additional nutrient to accelerate microbial growth.

2.4. pH testing

Determination of pH is done by measuring the temperature of the sample first. Then the temperature of the pH meter was turned on, adjusted, and allowed to stabilize for 15–30 min. The electrodes were rinsed with distilled water and dried using a tissue. The electrode is dipped into the sample until the scale reading is stable [53].

2.5. Colour testing

The change in palm sap colour was recorded in clean plastic bottles at different time intervals (ASTM D 1500-03). The colours were analysed qualitatively and quantitatively using Adobe Photoshop. The colour value of Adobe Photoshop was set to L* a* b* by using the following equation [54]:

$$L^* = \frac{Lightness}{255} \times 100 \quad (1)$$

$$a^* = \frac{240a}{255} - 120 \quad (2)$$

$$b^* = \frac{240b}{255} - 120 \quad (3)$$

where, $L^* = 0$ (black), $L^* = 100$ (white), a^* ($-a$ = greenness, $+a$ = redness) and b^* ($-b$ = blueness, $+b$ = yellowness).

2.6. Fermentation process

The palm sap was anaerobically fermented in the bottles at room temperature [55]. The palm sugar was added to the inoculum in varying concentrations of 5, 7, 10, 12, and 15% (v/v). The culture was incubated for 48, 60, and 72 h at 30 °C. The fermentation process was performed with different volume concentrations of the palm sap, inoculum and microbes as shown in the Table 1. Reaction was accelerated by stirring the culture every 6 h for 5 min. The fermentation results were centrifuged at a spinning speed of 10,000 rpm for 10 min at 30 °C. The parameter observed was ethanol content.

2.7. Distillation process

The water and ethanol were separated via distillation using a vacuum system with a pressure of less than 1 atm and the temperature range of 140–150 °C (ASTM D 86-04b) [56]. The fraction with the lowest boiling point can evaporate firstly and will be at the top of the column, whilst the fraction with a high boiling point will remain at the bottom of the column.

Table 1 – Treatment of fermentation methods.

Treatment	Volume of palm sap (%)	Volume of inoculum (%)	Nutrient (%)
F1	95	5	15
F2	93	7	15
F3	90	10	15
F4	88	12	15
F5	85	15	15

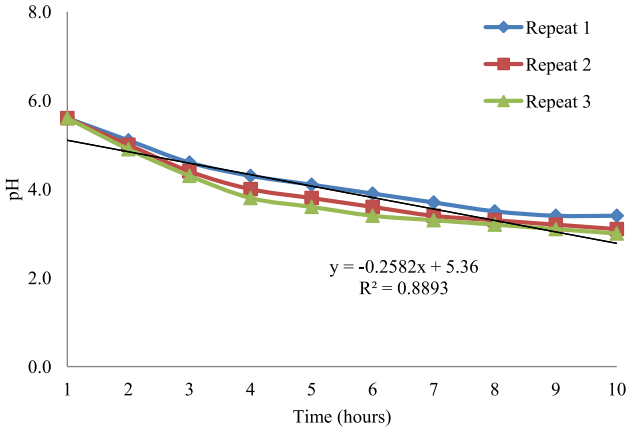

Fig. 1 – The pH change with storage time variation.

2.8. Measuring ethanol content

Ethanol content was measured using the pycnometer method [57]. Firstly, a sample of 100 mL was placed in a distillation flask. Then, 100 mL of distilled water was added and distilled at 80 °C. The distillate was stored in an Erlenmeyer flask to a volume of 50 mL. The distillate was then inserted into a pycnometer to meet the pycnometer. Excess distillates at the top of the capillary tube were cleaned. The pycnometer containing the distillate was weighed, and the weight was recorded. The same procedure was performed on distilled water for comparison. The results of ethanol density calculations were converted using ethanol specific gravity conversion tables. Ethanol density was calculated using the Eqs. (1–3) [58]:

$$F = g\left(m_b - \frac{\rho_{a-m_b}}{\rho_b}\right) \quad (4)$$

where, subscript b is the bottle, a is air, ρ is density, m is mass, and g is acceleration due to gravity.

2.9. Viscosity measurement

The viscosity sample was measured using a gravity capillary viscometer in the temperature range of 20–30 °C (ASTM D 88-94). The mathematical viscosity equation can be written [59]:

$$F = \eta A \frac{V}{L} \quad (5)$$

where, F is force on the surface of the liquid, η is coefficient of fluid viscosity (Ns/m^2), A is liquid area (m^2), V is moving wall velocity (m/s), and L is distance of the two surfaces (m).

2.10. Measurement of calorific value

The calorific value of combustion was measured using a bomb calorimeter type IKA C-5000 (ASTM D 2014-96) [60]. The reaction that occurs in the bomb calorimeter can produce heat which is absorbed by the water and the bomb, so that no heat is wasted into the air. The calorific value of combustion can be written as:

$$r_{reaction} = -\left(q_{air} + q_{bomb}\right) \quad (6)$$

Table 2 – Comparison of the pH and colour values of L* a* b* results.

Varieties of palm sap	pH	Colour interval			Ref.	Tools
		L*	a*	b*		
Borassus flabellifer Linn	4.19–5.23	61.49–87.53	1.46–3.52	12.41-19-31	[17]	Hunter Lab Color flex
A. Pinnata Merr	4.883–6.387	44.5–54.8	1.2–1.6	6.5–9.8	[69]	Minolta Reader
Phoenix dactylifera L.	6.86 ± 0.05	72.01 ± 0.07	0.64 ± 0.02	15.04 ± 0.02	[70]	Lovibond Tintometer PFX 195
Palm sap	4.8–7.1	47.3–56.0	7.6–8.7	34.0–46.0	This study	Chroma Meter-CR-400)

The amount of heat absorbed by water can be calculated using the Eq. (7):

$$Q_{water} = m \cdot c \cdot \Delta T \quad (7)$$

where, m is mass of water (g), c is heat type of water (J/kg°C), and ΔT is temperature change (°C).

The amount of heat absorbed by the bomb calorie meter can be calculated using the Eq. (8):

$$q_{water} = c_{bomb} \cdot \Delta T \quad (8)$$

where, c_{bomb} is heat capacity of bomb (J/g°C) and ΔT is temperature change (°C).

2.11. Data analysis

The research data were analysed using one-way analysis of variance [61]. If the F-count value is greater than the F-table, then a significant difference exists. Statistical significance between sample treatments was defined at $p < 0.05$. Mean differences were evaluated with Duncan's Multiple Range Test (DMRT), which was analysed using SPSS for Windows version 16.0.

3. Results and discussion

3.1. The pH content

The pH value of palm sap used in this study was 5.6, but the value decreased after storage (Fig. 1). Based on the Fig. 1 was showed that the pH of palm sap decreases during storage due to the interaction between palm sap and environmental air and the subsequent fermentation process. A similar finding was reported by Elijah et al. [62] that the decrease in the pH of palm sap is caused by acid fermentation in alcohol. Devi et al. [63] also explained that palm sap naturally contains microbes that can produce amylase enzymes, which eventually become alcohol.

The palm sap is highly sensitive to environmental temperature and it easily damaged. The most easily detected damage indicator is pH value. Some researchers have also reported that the pH of palm sap drops from 7.41 to 6.02 after 20 h of storage [18], from 6.70 to 6.34 [15]. The trend of decreasing pH in this study was apparently lower than those reported by previous researchers. Other researchers have also reported changes in pH along with the length of storage time, such as sweet sorghum sap from pH 5.16 changing to 4.34 in 48 h of storage [64], sugarcane with pH changed from 5.30 to 4.50 in 96 h [65]. The change in the pH of palm sap is also related to the activity of microorganisms. The growth of microorganisms that can rapidly reduce pH by producing organic acids. When acid increases, pH decreases. When acids release hydrogen ions, vegetative cell bacteria can multiply well under low acid conditions. The decrease in pH by lactic acid bacteria in palm sap has also been reported by Manel et al. [66].

Temperature is an extremely influential factor in the pH decrease of palm sap. In the current study, a high storage temperature indicated a considerable decrease rate in pH presumably because changes in sugar levels to acidic levels accelerate at high temperature. Ansar et al. [67] reported that palm sap stored at 40 °C exhibits a higher decrease in pH compared with palm sap stored at 29 °C. The lowest decrease in pH value of palm sap is obtained at a storage temperature of 10 °C. Lasekan and Abbas [68] have also reported that palm sap stored at 28 °C has decreased pH faster than that stored at 15 °C.

3.2. Changes in colour (L* a* b* values)

The results show that the L* value decreased significantly ($p < 0.05$) from 56.0 to 47.3, and the b* value decreased significantly ($p < 0.05$) from 8.7 to 7.6. By contrast, no significant change was observed in the value of a* ($p > 0.05$) during storage. These results indicate that when pH decreases, the colour values (L* and b*) of palm sap change with storage time length. It has been reported also by Manel et al. [66] that the

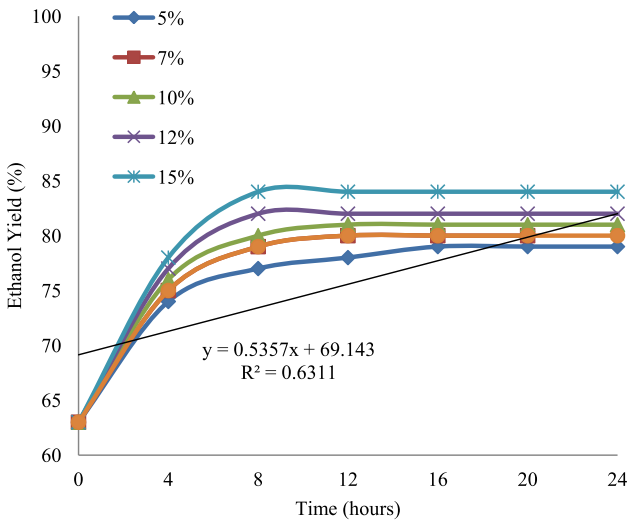

Fig. 2 – Profile of ethanol concentration during anaerobic fermentation at varying inoculum concentrations.

Table 3 – Analysis of variance.

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	10624.13	2	5312.07	368.89	1.68E-11	3.88
Within groups	172.8	12	14.4			
Total	10796.93	14				

palm colour changed from the original palm colour (pure) into milk white during the fermentation process.

The effect of colour change during storage before fermentation can be used as an indicator of palm sap quality. The results of the current study exhibit that pH value contains a function of lightness (L*) and yellowness (a*) but is not correlated with redness (b*). This finding agrees with the results of Victor and Orsat [69] that a high pH causes *A. pinnata* to appear more transparent, whereas a low pH causes the palm sap to appear cloudy. Comparison of the pH and colour values of L* a* b* results of this study with some previous studies are shown in the Table 2.

3.3. *Ethanol content*

Fermentation can convert glucose in the palm sap into ethanol due to the reduced glucose levels in ethanol. This finding agrees with the results of Mustafa et al. [71] and Trivedi et al. [72]. The higher the percentage of inoculum used, the higher the ethanol content obtained (Fig. 2). The ethanol content of palm sap prior to fermentation was 32.3%, and it increased to 75.6% after 24 h of fermentation.

The analysis variance results showed that the F-count value is greater (368.893) than the F-table (3.885). Thus, inoculum concentration significantly affects ($p < 0.05$) ethanol yield. The DMRT analysis determines that inoculum concentration variation significantly influences the obtained ethanol content. The higher the inoculum concentration, the higher the obtained ethanol content. This result was consistent with that of Mojovic et al. [73] that the content of fermented ethanol depends on the quality of sap used and the type of microbes for the inoculum.

The result of analysis of variance was known that the value of F-count is greater (368.89) than F-table (3.88) (Table 3), so it can be explained that inoculum concentration variation of significantly affect ($P < 0.05$) to ethanol yield was obtained.

The time of fermentation (incubation period) also significantly influences the ethanol yield formed. The longer the fermentation time, the higher the ethanol yield obtained. The same results have been revealed by Oguri et al. [36] who explain that the longer the fermentation process, the chances of ethanol to formed is also higher. The result of this fermentation is still a mixture of ethanol and water, so it must be separated by the distillation method. The same thing has been revealed by Hashem and Darwish [74] who state that the fermentation process usually requires an incubation period of 12–72 h and depends on the number and type of microorganisms used to initiate fermentation.

In order to increase the ethanol content of fermented products, distillation was carried out to obtain higher ethanol levels. The distillation process was carried out with a vacuum system. In this system the fraction that has the lowest boiling point will experience evaporation first. In this study, the maximum yield obtained was still low at around 75.6%. This is allegedly because the raw materials used have been contaminated before fermentation. The same thing has been reported by Amigun and Musango [75] that the obtaining process of ethanol yield highly depends on raw materials and environmental conditions at the time of tapping.

4. Conclusion

Changes in the pH value of palm sap after tapping are caused by the growth of microorganisms that produce organic acids by releasing hydrogen ions. As the pH decreased, the values of L* and b* also decreased significantly, but there was no significant change in the values of a*. Palm juice converts glucose into ethanol during fermentation. The higher the percentage of inoculum used, the higher the ethanol yield volume. The ethanol content of palm sap before distillation was 32.3% and increased to 75.6% after distillation. The physicochemical properties of bioethanol still need to be studied comprehensively by conducting trials on various types of motorized vehicles.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors gratefully acknowledge the Ministry of Research, Technology, and Higher Education and the Republic of Indonesia for awarding the PTUPT Research Grant (No. 065/SP2H/LT/DRPM/2019). The authors also thank the Dean of Faculty of Food Technology and Agroindustries, University of Mataram for all supporting facilities used in this research.

REFERENCES

[1] Ansar, Putra GD, Abdullah SH, Siahaya MS. Effect of NPK and starter concentration variation on ethanol content result of palm sap fermentation and distillation. Teknotan J 2019;13(1):35–8.
[2] Ali A, Sanuddin AB, Ezzeddin S. The effect of aging on *Arenga pinnata* fiber-reinforced epoxy composite. Mater Des 2010;31(7):3550–4.
[3] Fahrizal F, Abubakar Y, Muzaifa M, Muslim M. The effects of temperature and length of fermentation on bioethanol production from arenga plant (*Arenga pinnata* MERR). Int J Adv Sci Eng Inf Technol 2013;3(3):244.
[4] Yamada H, Tanaka R, Sulaiman O, Hashim R, Hamid ZA, Kosugi A, et al. Old oil palm trunk: a promising source of sugars for bioethanol production. Biomass Bioenergy 2010;34(4):1608–13.
[5] Sahari J, Sapuan SM, Zainudin ES, Maleque MA. Sugar palm tree: a versatile plant and novel source for biofibres,

biomatrices, and biocomposites. Polym Renew Resour 2012;3(2):61–77.
[6] Li W, Fu H, Yu L, Cracknell A. Deep learning based oil palm tree detection and counting for high-resolution remote sensing images. Rem Sens 2017;9(1):22.
[7] Sahari J, Sapuan SM, Zainudin ES, Malequ MA. Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree. Mater Des 2013;49:285–9.
[8] Giesen W. Utilising non-timber forest products to conserve Indonesia's peat swamp forests and reduce carbon emissions. J Indone Nat Hist 2015;3(2):17–26.
[9] Krishna VV, Kubitza C. Impact of oil palm expansion on the provision of private and community goods in rural Indonesia. Ecol Econ 2021;179:106829.
[10] Effendi DS. Prospect of aren tree development (*Arenga pinnata* merr) to supporting bioethanol need in Indonesia. Perspektif 2010;9(1):36–46.
[11] Ansar Sukmawaty, Abdullah SH, Nazaruddin, Safitri E. Physical and chemical properties of mixture fuels (MF) between palm sap (*Arenga pinnata* merr) bioethanol and premium. ACS Omega 2020;75(1):1–9.
[12] Alisjahbana AS, Busch JM. Forestry, forest fires, and climate change in Indonesia. Bull Indones Econ Stud 2017;53(2):111–36.
[13] Ho CW, Aida WW, Maskat MY, Osman H. Changes in volatile compounds of aren palm (*Arenga pinnata*) during the heating process for production of palm sugar. Food Chem 2006;102(4):1156–62.
[14] Tan L, Sun ZY, Okamoto S, Takaki M, Morimura S, Kida K, et al. Production of ethanol from raw juice and thick juice of sugar beet by continuous ethanol fermentation with flocculating yeast strain KF-7. Biomass Bioenergy 2015;81(1):256–72.
[15] Bekmuradov V, Luk G, Luon R. Comparative ethanol productivities of two different recombinant fermenting strains on source-separated organic waste. Int J Eng Res Appl 2014;4(1):77–82.
[16] Ho CW, Aida WW, Maskat MY, Osman H. Effect of thermal processing of aren palm on the physico-chemical composition of traditional palm sugar. Pakistan J Biol Sci 2008;11(7):989–95.
[17] Naknean P, Meenune M, Roudaut G. Characterization of aren palm harvested in songkhla Province, southern Thailand. Int Food Res J 2010;17(3):977–86.
[18] Idiata DJ, Iyasele JU. Waste to wealth: production of bioethanol from pineapple waste. J Multidiscip Eng Sci Tech (JMEST) 2014;1(4):282–7.
[19] Ishak MR, Sapuan SM, Leman Z, Rahman MA, Anwar UM, Siregar JP. Sugar palm (*Arenga pinnata*): its fibres, polymers and composites. Carbohydr Polym 2013;91(2):699–710.
[20] Baeyens J, Kang Q, Appels L, Dewil R, Lv Y, Tan T. Challenges and opportunities in improving the production of bioethanol. Prog Energy Combust Sci 2015;47:60–88.
[21] Ishola MM, Jahandideh A, Haidarian B, Brandberg T, Taherzadeh MJ. Simultaneous saccharification, filtration and fermentation (SSFF): a novel method for bioethanol production from lignocellulosic biomass. Bioresour Technol 2013;133:68–73.
[22] Sakamoto T, Hasunuma T, Hori Y, Yamada R, Kondo A. Direct ethanol production from hemicellulosic materials of rice straw by use of an engineered yeast strain codisplaying three types of hemicellulolytic enzymes on the surface of xylose-utilizing *Saccharomyces cerevisiae* cells. J Biotechnol 2012;158(4):203–10.
[23] Chen H, Qiu W. Key technologies for bioethanol production from lignocellulose. Biotechnol Adv 2010;28:556–62.
[24] Zhao L, Zhang X, Xu J, Ou X, Chang S, Wu M. Techno-economic analysis of bioethanol production from lignocellulosic biomass in China: dilute-acid pretreatment and enzymatic hydrolysis of corn stover. Energies 2015;8(5):4096–117.
[25] Aditiya HB, Mahlia TI, Chong WT, Nur H, Sebayang AH. Second generation bioethanol production: a critical review. Renew Sustain Energy Rev 2016;66:631–53.
[26] Fernandes MC, Ferro MD, Paulino AC, Mendes JS, Gravitis J, Evtuguin DV, et al. Enzymatic saccharification and bioethanol production from *Cynara cardunculus* pretreated by steam explosion. Bioresour Technol 2015;186:309–31.
[27] Vohra M, Manwar J, Manmode R, Padgilwar S, Patil S. Bioethanol production: feedstock and current technologies. J Environ Chem Eng 2014;2(1):573–84.
[28] Binod P, Sindhu R, Singhania RR, Vikram S, Devi L, Nagalakshmi S, et al. Bioethanol production from rice straw: an overview. Bioresour Technol 2010;101:4767–74.
[29] Ilyas RA, Sapuan SM, Ibrahim R, Abral H, Ishak MR, Zainudin ES, et al. Effect of sugar palm nanofibrillated cellulose concentrations on morphological, mechanical and physical properties of biodegradable films based on agro-waste sugar palm (*Arenga pinnata* (Wurmb.) Merr) starch. J Mater Res Technol 2019;8(5):4819–30.
[30] Mohd Izwan S, Sapuan SM, Zuhri MM, Mohamed AR. Effects of benzoyl treatment on NaOH treated sugar palm fiber: tensile, thermal, and morphological properties. J Mater Res Technol 2020;9(3):5805–14.
[31] Zhang Q, Weng C, Huang H, Achal V, Wang D. Optimization of bioethanol production using whole plant of water hyacinth as substrate in simultaneous saccharification and fermentation process. Front Microbiol 2016;6(1):1–9.
[32] Pavlecic M, Rezic T, Ivancic Santek M, Horvat P, Santek B. Bioethanol production from raw sugar beet cossettes in horizontal rotating tubular bioreactor. Bioproc Biosyst Eng 2017;40(11):1679–88.
[33] Bušić A, Marđetko N, Kundas S, Morzak G, Belskaya H, Ivančić Šantek M, et al. Bioethanol production from renewable raw materials and its separation and purification: a review. Food Technol Biotechnol 2018;56(3):289–311.
[34] Kismurtono M. Fed-batch alcoholic fermentation of palm juice (*Arenga pinnata* Merr): influence of the feeding rate on yeast, yield and productivity. Int J Eng Technol 2012;2(5):795–9.
[35] Oyeleke SB, Jibrin NM. Production of bioethanol from Guinea cornhusk and millet husk. Afr J Microbiol Res 2009;3(4):147–52.
[36] Oguri E, Takimura O, Matsushika A, Inoue H, Sawayama S. Bioethanol production by pichia stipitis from enzymatic hydrolysates of corncob-based spent mushroom substrate. Food Sci Technol Res 2011;17(4):267–72.
[37] Anam S, Tabbssum MR, Rashid U, Ibrahim M, Gill SS, Mehmood MA, Anam S, Tabbssum MR, Rashid U, Ibrahim M, Gill SS, Mehmood MA. Marine macro algae ulva: a potential feed-stock for bioethanol and biogas production. Asian J Agric Biol 2013;1(3):155–63.
[38] Sebayang AH, Hasan MH, Chyuan OH, Dharma S, Bahar AH, Kusumo F. Enzymatic hydrolysis using ultrasound for bioethanol production from durian (*Durio zibethinus*) seeds as potential biofuel. Chem Eng Trans 2017;56.
[39] Hossain N, Razali AN, Mahlia TI, Chowdhury T, Chowdhury H, Ong HC, et al. Experimental investigation, techno-economic analysis and environmental impact of bioethanol production from banana stem. Energies 2019;12(20):3947.
[40] Tamunaidu P, Matsui N, Okimori Y, Saka S. Nipa (*Nypa fruticans*) sap as a potential feedstock for ethanol production. Biomass Bioenergy 2013;52(1):96–102.

[41] Aditiya HB, Chong WT, Mahlia TI, Sebayang AH, Berawi MA, Nur H. Second generation bioethanol potential from selected Malaysia's biodiversity biomasses: a review. Waste Manag 2016;47:46–61.
[42] Nurfahmi, Mofijur M, Ong HC, Jan BM, Kusumo F, Sebayang AH, et al. Production process and optimization of solid bioethanol from empty fruit bunches of palm oil using response surface methodology. Processes 2019;7(10):715.
[43] Thatoi H, Dash PK, Mohapatra S, Swain MR. Bioethanol production from tuber crops using fermentation technology: a Review. Int J Sustain Energy 2014;35(5):443–68.
[44] Hossain N, Mahlia TI. Progress in physicochemical parameters of microalgae cultivation for biofuel production. Crit Rev Biotechnol 2019;39:835–59.
[45] Ho SH, Huang SW, Chen CY, Hasunuma T, Kondo A, Chang JS. Bioethanol production using carbohydrate-rich microalgae biomass as feedstock. Bioresour Technol 2013;135:191–8.
[46] Herrmann R, Jumbe C, Bruentrup M, Osabuohien E. Competition between biofuel feedstock and food production: empirical evidence from sugarcane outgrower settings in Malawi. Biomass Bioenergy 2017;56(1):1–12.
[47] Rizza LS, Smachetti MS, Nascimento MD, Salerno GL, Curatti L. Bioprospecting for native microalgae as an alternative source of sugars for the production of bioethanol. Algal Res 2017;22(3):140–7.
[48] Sarkar N, Ghosh SK, Bannerjee S, Aikat K. Bioethanol production from agricultural wastes: an overview. Renew Energy 2012;37(1):19–27.
[49] Dave N, Selvaraj R, Varadavenkatesan T, Vinayagam R. A critical review on production of bioethanol from macroalgal biomass. Algal Res 2019;42(9):1–14.
[50] Ingale S, Joshi SJ, Gupte A. Production of bioethanol using agricultural waste: banana pseudo stem. Braz J Microbiol 2014;45:885–92.
[51] Quintero JA, Cardona CA. Process simulation of fuel ethanol production from lignocellulosics using aspen plus. Ind Eng Chem Res 2011;50(10):6205–12.
[52] Danmaliki GI, Auwal MM, Shamsuddeen AA, Usman BJ. Bioethanol production from banana peel. J Environ Sci Toxicol Food Technol 2016;10(6):56–62.
[53] Hwang JH, Kabra AN, Ji MK, Choi J, El-Dalatony MM, Jeon BH. Enhancement of continuous fermentative bioethanol production using combined treatment of mixed microalgal biomass. Algal Res 2016;17:14–20.
[54] Yam KL, Papadakis SE. A simple digital imaging method for measuring and analyzing color of food surfaces. J Food Eng 2004;61(1):137–42.
[55] Iglesias A, Pascoal A, Choupina AB, Carvalho CA, Feás X, Estevinho LM. Developments in the fermentation process and quality improvement strategies for mead production. Molecules 2014;19(8):12577–90.
[56] Gerbaud V, Rodriguez-Donis I, Hegely L, Lang P, Denes F, You XQ. Review of extractive distillation. Process design, operation, optimization and control. Chem Eng Res Des 2019;141:229–71.
[57] Sadagopan M, Malaga K, Nagy A. Modified pycnometer method to measure the water absorption of crushed concrete aggregates. J Sustain Cem-Based Mater 2020;9(5):259–69.
[58] Nishimura H, Tan L, Sun ZY, Tang YQ, Kida K, Morimura S. Efficient production of ethanol from waste paper and the biochemical methane potential of stillage eluted from ethanol fermentation. Waste Manag 2016;48(2):644–51. 48(2).
[59] Niemeyer KE, Daly SR, Cannella WJ, Hagen CL. A novel fuel performance index for low-temperature combustion engines based on operating envelopes in light-duty driving cycle simulations. J Eng Gas Turbines Power 2015;137:101601.
[60] Yu X, Zhou CR, Han XW, Li GP. Study on thermodynamic properties of glyphosate by oxygen-bomb calorimeter and DSC. J Therm Anal Calorim 2013;111:943–9.
[61] Ansar, Nazaruddin, Azis AD. Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (*Passiflora edulis* sims) extract. In: International symposium on agriculture and biosystem enginnering. Makassar; 2019.
[62] Elijah I, Ohimain PE, Tuwon, Ekiemene A. Traditional fermentation and distillation of raffia aren palm for the production of bioethanol in Bayelsa State, Nigeria. J Technol Innovat Renew Energy 2012;1(2):131–41.
[63] Devi MG, Purwito A, Husni A. Globular embryo induction of sugar palm (*Arenga pinnata* (Wurmb) Merr.). Int J Biosci Biochem Bioinform 2014;4(1):60–6.
[64] Lingle ST, Rukavina H, Boykin D. Post-harvest changes in sweet sorghum II: pH, acidity, protein, starch, and mannitol. Bioenergy Res 2013;6(1):178–87.
[65] Saxena P, Srivastava RP, Sharma ML. Impact of cut to crush delay and biochemical changes in sugarcane. Aust J Crop Sci 2010;4(9):692–9.
[66] Manel Z, Sana M, Nedia K, Moktar H, Ali F. Microbiological analysis and screening of lactic acid bacteria from Tunisia. Afr J Microbiol Res 2011;5(19):2929–35.
[67] Ansar, Nazaruddin, Azis AD. Effect of temperature and time storage to pH and color changes of aren palm (*Arenga Pinnata* MERR) after tapping. J Lampung Agric Eng 2019;8(1):40–8.
[68] Lasekan O, Abbas KA. Flavor chemistry of palm toddy and palm juice: a review. Trends Food Sci Technol 2010;21(10):494–501.
[69] Victor I, Orsat V. Characterization of *Arenga pinnata* (palm) sugar. Sugar Technol 2018;20(1):105–9.
[70] Ben Thabet I, Besbes S, Masmoudi M, Attia H. Compositional, physical, antioxidant and sensory characteristics of novel syrup from date palm (*Phoenix dactylifera* L.). Food Sci Technol Int 2009;15:583–90.
[71] Mustafa B, Havva B, Cahide O. Progress in bioethanol processing. Prog Energy Combust Sci 2008;34(1):551–73.
[72] Trivedi N, Reddy CK, Radulovich R, Jha B. Solid state fermentation (SSF)-derived cellulase for saccharification of the green seaweed Ulva for bioethanol production. Algal Research 2015;9(1):48–54.
[73] Mojovic L, Pejin D, Grujic O, Markov S, Pejin J, Rakin M, et al. Progress in the production of bioethanol on starch-based feedstock. Chem Ind Chem Eng Q 2009;15(4):211–26.
[74] Hashem M, Darwish S. Production of bioethanol and associated by products from potato in very high gravity fermentation. Biotechnol Lett 2011;29(1):233–6.
[75] Amigun B, Musango JK. An analysis of potential feedstock and location for biodiesel production in Southern Africa. Int J Sustain Energy 2011;30:S35–58.