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Quantification of Bioethanol Derived from Selected Renewable Coconut Raw Materials Using Simple Fermentation-Distillation Process

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ABSTRACT

Coconut (Cocos nucifera L.) is a major crop in the Philippines which entails a large volume of young coconut water (YCW), mature coconut water (MCW), young coconut husk juice (YCHJ), and coconut sap (CS) can be produced all year. The growing demand of bioethanol as a fuel blend to gasoline paves the way to the search for feedstock that can contribute to the bioethanol need of the country. YCW is normally processed as a refreshment product but due to the large volume of consumption, young coconut water is normally discarded. Moreover, MCW is considered as waste in the market after the extraction of coconut meat. The young coconut husk is considered waste and can be processed as a potential source of bioethanol. The coconut sap was explored considering the number of coconut trees in the country. The initial sugar concentration of the YCW, MCW, CS, and YCHJ are 4.39 $\pm$ 0.3, 3.76 $\pm$ 0.44 , 9.51 $\pm$ 1.86, and 4.85 $\pm$ 0.65 ^{0}Bx, respectively. The fermentation process was done for 72 hours using Saccharomyces cerevisiae as the fermenting yeast. The obtained bioethanol yields for YCW, MCW, YCHJ, and CS were 31.67, 15.71, 16.89, and 64.42 mL of ethanol per liter of their raw materials, respectively. The highest bioethanol yield was obtained using the CS and a lower energy is required in the process because of its high initial sugar concentration. The production cost was computed for each raw material that was shown to be higher compared to the bioethanol price index of Php 81.68 per liter using sugarcane molasses as feedstock.

Keywords: Bioethanol, Coconut sap, Coconut water, Husk.

1. INTRODUCTION

Coconut (Cocos nucifera L.) is a major export commodity in the Philippines. The total production (metric tons) of coconut in the Philippines is 14.72 million (nut terms) in 2021 [1]. Ample products can be derived from the different parts of the coconut tree such as rope from coconut coir fiber, broomsticks from coconut midribs, charcoal from the coconut shell, vinegar and sugar from coconut flower, coconut meat and water from the nut, etc. The volume of coconut water from young and mature coconut, the young coconut husk juice extracts, and the coconut sap is proportional to the coconut production. The current study aimed to seek the potential feedstock for the production of bioethanol based on the abundance of the feedstock available. The young coconut husk, coconut sap, and coconut water are seen to be a promising feedstock. Coconut husk contains 28 % cellulose, 38 % hemicellulose, and 32.8 % lignin [2]. Coconut water is the liquid extracted from mature and young coconuts. The sugars available for young coconut water are 5.23 g/100 g (total sugars), 0.06 g/100g (sucrose), 2.61 g/100g (glucose), and 2.55 g/100g (fructose), whereas those available for mature coconut water are 3.42 g/100 g (total sugars), 0.51 g/100g (sucrose), 1.48 g/100g (glucose), and 1.43 g/100g (fructose) [3]. The coconut sap is extracted

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from the unopened spadixof the coconut tree by means of slicing and bounding it with a string. The total soluble sugars and carbohydrate contents of coconut sap are 12.40 $\pm$ 1.14 and 13.53 $\pm$ 0.64 %, respectively [4]. The young coconut husk extracts contain 6 - 7 g of sucrose/ 100 g of solution [5].

Bioethanol demand in the Philippines is increasing due to the increasing number of vehicles needed for transport as well as the increasing number of agricultural machinery needed to cope with the mechanization. A 10 % bioethanol blend to gasoline fuel is maintained in the Philippines as mandated by Republic Act 9367 also known as the Biofuel Act of 2006. It is also anticipated that the amount of bioethanol needed for blending should be doubled (20%) and is aiming to reach 85 % blending capacity by 2030 [6]. Aside from being an additive to fossil-based fuel, bioethanol is also used to produce beverages [7], used as pure bioethanol fuel for gasoline engines [8], used as bio solvent for pharmaceutical and cosmetic industries [9], etc. The work of [10], demonstrated the performance of a micro tiller and power tiller-operated hauler fed using hydrous bioethanol. Bioethanol is a promising solution for today's energy crisis [11].

Fermentation is a process used to produce ethanol from biomass materials with the aid of yeast enzymes that convert sugars and starches into ethanol [12]. The juice extracted from sugar-based feedstock can directly undergo a fermentation process to produce ethanol [6]. The aid of fermenting organisms generally fastens up the fermentation process. *Saccharomyces cerevisiae*, *Pichiastipites*, and *Zymomonas mobilis* are some of the yeast strains that are commonly used in the fermentation process [13]. Distillation is a process wherein two different liquids separate due to their difference in boiling temperatures. There are various designs of distillation systems such as multi-stage, vapor-liquid contacting systems, countercurrent, and continuous, correspondingly, all of them work on the principle that two liquid substances separate due to the difference in boiling point [14]. The main objective of the study was to determine the volume of bioethanol that can be extracted from different coconut parts (coconut sap, young coconut husk extracts, coconut water) using a simple fermentation-distillation process.

2. MATERIAL AND METHODS

2.1 Sample Collection and Preparation

Four feedstocks (Figure 1) were identified in the production of bioethanol based on its abundance and availability in the province (Bataan, Philippines). The coconut sap (CS) was collected from the unopened spadix of the coconut tree, the mature coconut water (MCW) was collected from the market where it is commonly discarded, the young coconut water (YCW) was collected from processors, and the coconut juice was extracted from the young coconut husk.

The collected coconut sap was filtered using a cloth to remove the impurities. Its initial degree brix was 13 $\pm$ 0.15 ^{0}Bx. The MCW and YCW were filtered using a cloth to remove the impurities. The impurities refer to the small particles from the coconut meat or husk for the MCW and YCW. Moreover, in the CS the impurities refer to the tiny particles of the spadix. These impurities were removed because the solid particles can clog in the filtration systems during the distillation process and it may introduce unwanted microorganisms during fermentation that might compete with the desired ethanol-producing microorganisms. Also, the weight of the solid particles will affect the volume of feedstock needed in the fermentation process.

The initial degree brix of YCW and MCW were 4.39 $\pm$ 0.3, and 3.76 $\pm$ 0.44 ^{0}Bx, respectively. The young coconut husk juice (YCHJ) has an initial degree brix of 4.85 $\pm$ 0.65 ^{0}Bx. The juice from the husks was collected by means of mechanically shredding the husk using a young coconut husks shredder with a capacity of 100.95 kg.hr^{-1}. The shredded husks were then pressed using a juice extractor with a capacity of 0.38 L.kg^{-1}. All collected samples were boiled for a period of 4 - 4.5

hours to increase the sugar concentrations into 13.92 $\pm$ 0.48, 13.71$\pm$ 1.08, and 12.88 $\pm$ 0.22 ^{0}Bx, respectively, for YCW, MCW and YCHJ. A higher sugar concentration means a shorter time needed in the boiling process.

(a) (b) (c) (d)

Figure 1: (a) coconut sap; (b) young coconut husk; (c) mature coconut; (d) young coconut.

2.2 Fermentation

Seven liters per batch of YCHJ, YCW, MCW, and CS with sugar concentrations of 13-14 ^{0}Bx was fermented in a 20 L capacity plastic container. The container is equipped with a fermentation airlock placed at the top portion of the container to allow the release of carbon dioxide as a by-product of the fermentation process and to prohibit the entry of oxygen, thus maintaining the anaerobic condition in the set-up. 500 ml of concentrated samples per type of feedstock was used for yeast activation. The *Saccharomyces cerevisiae* (red star active and instant dry yeast) was normally activated at a temperature of 30-32 ^{o}C with a continuous stirring for 5 minutes. Upon activation, the activated yeast was poured into the container. Then, the container airlock cap with water was placed at the opening of the container to achieve the anaerobic condition necessary for the production of bioethanol.Variation of the yeast ratio at 1, 1.5, and 2.0 g/L was done in the study to have baseline information about the optimum yeast necessary in fermentation of different types of feedstock. The fermentation time was set for 72 hours.

The theoretical ethanol yield was calculated using Equation 1. The expected amount of bioethanol was calculated using the density of ethanol and the maximum theoretical yield of ethanol from glucose which was 0.511 g ethanol /g sugars of bioethanol. The actual ethanol yield refers to the actual amount of bioethanol collected after the distillation of bioethanol considering that the obtained product has 95 % alcohol concentration. The fermentation efficiency was calculated using Equation 2. Moreover, the study investigated the potential of using young coconut water in addition to molasses. The molasses was diluted with young coconut water to attain the desired sugar concentration for comparison. Two factorial experiments in Completely Randomized Design were used in the analysis. Comparison among means using Least Significant Difference was used in comparing the actual ethanol yield for the YCW and Young coconut water added with molasses (YCW+M).

$$\text{Theoretical ethanol yield} = \frac{0.511\,(x)}{0.789\,(v)} \times 1000 \tag{1}$$

Where:

0.511 g ethanol/g sugars = maximum theoretical yield of ethanol from glucose
x = total soluble solids, °Brix
0.789 g/mL = density of ethanol
v = volume of fermented broth, L

$$FE = (\text{Actual yield}/\ \text{theoretical yield}) \times 100 \tag{2}$$

2.3 Distillation

The distiller used in the study has a capacity of 12 L. However, 7 liters was only used to allow airspace between the column and the feedstock level, necessary for the separation of the ethanol and feedstock. A gas stove burner using Liquefied petroleum gas (LPG) as fuel was used in the distillation process. An inlet water with a temperature of 27-29 ^{0}C was used in order to turn the ethanol in the vapor phase into the liquid phase. The outlet water had a higher temperature because it took up the heat during the condensation process necessary to turn the ethanol extracted into liquid form. The distillation time in the study ranged from 60 to 75 minutes.

3. RESULTS AND DISCUSSION

3.1 Actual and Theoretical Ethanol Yield

The actual and theoretical ethanol yield obtained in the study are shown in Table 1 and Table 2, respectively. The obtained data was based on the set seven-liter capacity of the fermenter and distiller. A higher theoretical and actual yield value was obtained using the YCW because of the higher initial sugar concentration prior to fermentation. The bioethanol reported in Table 1 and Table 2 is equivalent to hydrous bioethanol (95%). The variation in the theoretical ethanol yield was attributed to the range of the sugar concentration of the feedstock used. The YCHJ provided varying theoretical and actual ethanol yields that are directly attributed to the initial sugar concentration of the feedstock before boiling. Since the YCHJ was collected in the market, the varying initial sugar concentration is attributed to the maturity level of the collected husk. The study of [16] stated that the glucose level is significantly increasing as the coconut husk matures while other sugars present do not change.

A comparison of the actual ethanol yield of the YCW and YCW+M is shown in Table 3. It is evident in Table 1 that among the raw materials selected that undergo the boiling process, the YCW produced the highest volume of bioethanol. The result of the study revealed that the addition of young coconut water to the molasses produced a lower amount of bioethanol. Since, the young coconut water used did not undergo the boiling process, diluting the molasses to reach a 14 ^{0}Bx resulted in a lower volume of bioethanol recovered. The increase in bioethanol yield of the YCW that undergoes the boiling process is due to the reduction of water in the samples as affected by the boiling process. Statistically, the volume of bioethanol produced from the two feedstock is significantly different. Although adding YCW to the molasses produced a lower yield, it depicts that bioethanol can still be produced at a lower energy consumption compared to subjecting the coconut water to the boiling process.

Table 1: Actual ethanol yield (L) of the feedstock used in the production of bioethanol.

Yeast amount, g/L	YCW	MCW	YCHJ	CS
1.0	0.51	0.27	0.29	0.41
1.5	0.53	0.31	0.3	0.45
2.0	0.53	0.28	0.54	0.38

Table 2: Theoretical ethanol yield (L) of the feedstock used in the production of bioethanol.

Yeast amount, g/L	YCW	MCW	YCHJ	CS
1.0	0.76	0.53	0.49	0.54
1.5	0.72	0.57	0.49	0.56
2.0	0.84	0.58	0.79	0.49

Table 3: Actual ethanol yield (L) of the feedstock used in the production of bioethanol using YCW and molasses diluted with young coconut water (YCW+M).

	Yeast amount			Mean
Raw material	**1.0 g/L**	**1.5 g/L**	**2.0 g/L**	
YCW	0.51	0.53	0.53	0.52[a]
YCW+M	0.40	0.39	0.4	0.39[b]
Mean	0.46	0.46	0.47	
Grand Mean				0.46

*Means with the same letter are not significantly different.

3.2 Fermentation Efficiency

Several factors affect the fermentation process resulting in an increase or decrease in bioethanol that can be extracted for a particular feedstock. The temperature, pH, nutrient availability at specific sugar concentrations, and mixing affect the yield of the fermentation process [17]. The distillation set-up or equipment also affects the actual bioethanol that can be extracted from the feedstock. Distillation set-up without a control system in heating tends to overshoot the temperature requirement of separation of ethanol from other substances resulting in the decrease or increase in the actual ethanol yield. Table 4 shows the fermentation efficiency from this study. Based on the result of the study, the yeast amount that resulted in the highest fermentation efficiency was observed using 1.5 g/ L for the YCW (74.42 %), MCW (53.43 %), and CS (81.20%). Moreover, the YCHJ can produce a better yield when added with a yeast amount of 2 g/L having a fermentation efficiency of 68.53 %. An increase or decrease in the yeast amount resulted in a decrease in the actual ethanol yield resulting in lower fermentation efficiency as shown in Table 4. Table 4 shows that CS had the highest fermentation efficiency which depicted that a higher amount of bioethanol was extracted from the feedstock. The least fermentation efficiency was observed from the MCW due to the sugar concentration and nutrient availability. The total soluble solids obtained for MCW are lower compared to the other feedstock used in the study. Also, the sugars (glucose, fructose, and sucrose) available in the coconut water decrease towards the maturation of the coconut [18]. A lower total sugar, glucose, and fructose can be observed from MCW compared to YCW as in the previous study [3].

Table 4: Fermentation efficiency (%) of the feedstock used in the production of bioethanol.

Yeast amount, g/L	YCW	MCW	YCHJ	CS
1.0	66.91	49.73	59.46	75.14
1.5	**74.42**	**53.43**	61.18	**81.20**
2.0	62.56	48.90	**68.53**	78.57

3.3 Bioethanol Yield

The study showed that bioethanol can be extracted from the YCW, MCW, YCHJ, and CS using a simple fermentation-distillation process. The result of the study showed that the volume of bioethanol that can be derived per nut (young coconut) is 15.70 ml if each nut produces around 500 ml of coconut water. The bioethanol yield for young coconut water is 31.67 mL of ethanol per L of coconut water. The result of the study also showed that the volume of bioethanol that can be derived per nut (mature coconut) is 7.87 mL per nut. The bioethanol yield for mature coconut water is 15.71 mL of ethanol per L of coconut water. Moreover, the young coconut husk juice extracted from the young coconut husk is about 6.42 mL/kg. The bioethanol yield is 16.89 mL of ethanol per L of young coconut husk juice. The bioethanol yield for coconut sap is 64.42 mL per liter. It can be observed that the bioethanol yield for mature coconut water is lesser compared to young coconut water because of the sweetness level of the coconut. As reported by [18], the sweetness level of the coconut water decreases with the maturation of the coconuts.

The bioethanol yield refers to the bioethanol that can be extracted from the identified raw materials. The initial sugar concentration of the raw material before boiling has variations. The computation will be affected by the initial volume of feedstock used before the boiling process. A higher sugar concentration means a lower volume of feedstock is needed to attain the 13-14 degree Brix. The lower the volume of raw material required, the higher the bioethanol yield. Using the mature coconut water which has the lowest initial sugar concentration, it entails a large volume of feedstock is needed before it will reach the set sugar concentration (13-14 ^{0}Bx) prior to the fermentation process. The quality of the bioethanol yield was also affected by the heating process where the feedstock was needed to continuously heated to allow the evaporation of water thus increasing the sugar concentration. During the study, a buildup of oil was noticed in MCW after the boiling process. This happens because MCW contains a small amount of natural fats and oils. Oils and fats can coat yeast cells or form a film on the fermentation medium, potentially reducing oxygen and nutrient transfer to the yeast. The study of [19], states that oil could further change to fatty acids and other organic acids which can eventually affect the growth of microorganisms. Moreover, prolonged or excessive heating can lead to sugar degradation and reduced yields as evident in the result of the study.

3.4 Cost Per Liter

Based on the materials used in the study and the bioethanol yield, the cost per liter of bioethanol was estimated. The coconut sap and young coconut water show the highest bioethanol yield at which the cost per liter associated with its production is Php 330.86 per liter and Php 176.28 per liter, respectively. The cost per liter of MCW is Php 620.49 per liter and Php 553.28 per liter, respectively. An assumption of 20 liters of bioethanol at 95 % purity per day at 241 days per year of operation was considered in the computation of the cost of production. A higher sugar concentration will need additional energy in the boiling process which will result in a higher production cost. The computed cost per liter is higher compared to the bioethanol price index as of September to March 2023 using sugarcane molasses having a value of Php 81.68 per liter [20].

4. CONCLUSION

The study demonstrated the potential of the YCW, MCW, YCHJ, and CS for the production of bioethanol. The selection of the bioethanol was based on the possible and abundant source of feedstock to sustain the production. The simple fermentation-distillation process is attributed to directly fermenting the feedstock at a specified sugar concentration using *Saccharomyces cerevisiae*. The bioethanol yields from YCW, MCW, YCHJ, and CS were 31.67, 15.71, 16.89, and 64.42 mL/liter, respectively. The highest bioethanol yield was obtained using the coconut sap due to the high initial sugar concentration necessary for the growth of the yeast. The difference in the initial sugar concentration of the raw materials affects the bioethanol yield and quality. Prolonged or excessive heating can degrade sugars and form inhibitors that can hinder fermentation directly affecting microbial activity. The oil buildup in MCW resulted in a decline in the fermentation efficiency and affected the bioethanol yield. The study recommends the potential of biomass materials as a renewable energy resource in the production of bioethanol, however, optimization of the different processes and equipment is needed to extract the optimum value of bioethanol derived from each feedstock thus lowering its cost of production.

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REFERENCES

[1] Statista Research Department. Retrieved from: https://www.statista.com/statistics/751403/philippines-coconut-production/. (2021).
[2] Pollard, S. J. T., Fowler, G. D., Sollars, C. J., & Perry, R. Low-cost adsorbents for waste and wastewater treatment: a review. Science of the total environment, vol 116, issue 1-2 (1992) pp. 31-52.
[3] Yong, J. W., Ge, L., Ng, Y. F., & Tan, S. N. The chemical composition and biological properties of coconut (Cocos nucifera L.) water. Molecules, vol 14, issue 12 (2009) pp. 5144-5164.
[4] Asghar, M. T., Yusof, Y. A., Mokhtar, M. N., Ya'acob, M. E., Mohd. Ghazali, H., Chang, L. S., & Manaf, Y. N. Coconut (Cocos nucifera L.) sap as a potential source of sugar: Antioxidant and nutritional properties. Food science & nutrition, vol 8, issue 4 (2020) pp. 1777-1787.
[5] Siano, D. B., Caberto, M. J. P., Garcia, R. E., & Lacayanga, J. E. Development Of Bioethanol Production Process Using Young Coconut Husk Extracts As Feedstock, 5th International Conference of theInternational Commission of Agricultural and Biosystems Engineering (CIGR) (2021).
[6] Gatdula, K. M., Demafelis, R. B., & Bataller, B. G. Comparative analysis of bioethanol production from different potential biomass sources in the Philippines. In Bioethanol Technologies. IntechOpen. Retrieved from: DOI: 10.5772/intechopen.94357. (2021).
[7] Dahiya, D., & Nigam, P. S. Bioethanol synthesis for fuel or beverages from the processing of agri-food by-products and natural biomass using economical and purposely modified biocatalytic systems. Aims Energy, vol 6, Issue 6, (2018) pp. 979-992.
[8] Zabochnicka-Świątek, M., & Sławik, L. Bioethanol-production and utilization. Archivum Combustionis, vol 30, (2010) pp. 327-246.
[9] Sharif-Hossain, A. B. M. Bio-Solvent preparation from apple biomass for pharmaceutical, cosmetic and biomedical industrial application. Global Journal of Biology, Agriculture and Health Sciences, vol 4, issue 3 (2015) pp. 52-61.
[10] Belonio, A. T., Regalado, M. J. C., Rafael, M. L., Villota, K. C., & Castillo, P. R. Design and Performance Evaluation of a Variable-Feed Hydrous-Bioethanol Fuel Injector for Retrofitted Engine. Open Access Library Journal, vol 6, issue 1 (2019) pp. 1-11.
[11] Sawarkar, A. N., Kirti, N., Tagade, A., & Tekade, S. P. Bioethanol from various types of banana waste: A review. Bioresource Technology Reports, vol 18, (2022) p. 101092.
[12] Sharma, R., Garg, P., Kumar, P., Bhatia, S. K., & Kulshrestha, S. Microbial fermentation and its role in quality improvement of fermented foods. Fermentation, vol 6, issue 4 (2020) p. 106.
[13] Gonçalves, F. A., Ruiz, H. A., dos Santos, E. S., Teixeira, J. A., & de Macedo, G. R. Bioethanol production by Saccharomyces cerevisiae, Pichia stipitis and Zymomonas mobilis from delignified coconut fibre mature and lignin extraction according to biorefinery concept. Renewable energy, vol 94, (2016) pp. 353-365.
[14] P.W. Madson. Ethanol distillation: the fundamentals, The alcohol textbook. 4th Edition. ISBN 1-897676-13-1.
[15] Khoja, A. H., Yahya, S. M., Nawar, A., Ansari, A. A., & Qayyum, M. Fermentation of sugarcane molasses using Zymomonas mobilis for enhanced bioethanol production. Journal of Advanced Research in Applied Sciences and Engineering Technolog, vol 11, issue 1 (2018) pp. 31-38.
[16] van Dam, J. E., van den Oever, M. J., Keijsers, E. R., van der Putten, J. C., Anayron, C., Josol, F., & Peralta, A. (2006). Process for production of high density/high performance binderless boards from whole coconut husk: Part 2: Coconut husk morphology, composition and properties. Industrial Crops and Products, vol 24, issue 2 (2006) pp. 96-104.

[17] Mengesha, Y., Tebeje, A., & Tilahun, B. A review on factors influencing the fermentation process of teff (Eragrostis teff) and other cereal-based Ethiopian injera. International journal of food science, vol 2022, issue 1 (2022) p. 4419955.
[18] Halim, H. H., Williams Dee, E., Pak Dek, M. S., Hamid, A. A., Ngalim, A., Saari, N., & Jaafar, A. H. Ergogenic attributes of young and mature coconut (Cocos nucifera L.) water based on physical properties, sugars and electrolytes contents. International Journal of Food Properties, vol 21, issue 1, (2018) pp. 2378-2389.
[19] Gao, M., Su, W., Ma, H. Z., & Wang, Q. H. Effect of waste oil on bioethanol production from food waste. In Selected Proceedings of the Fifth International Conference on Waste Management and Technology, (2010) pp. 180-183.
[20] Sugar Regulatory Administration. Bioethanol Reference Price 2022-2023. Retrieved from: https://www.sra.gov.ph/bioethanol-reference-price/.(2023).

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