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Second Generation Bioethanol from Arabica Coffee Waste Processing at Smallholder Plantation in Ijen Plateau Region of East Java

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Abstract

Bioethanol is an innovative solution that is environmentally friendly and able to reduce pollution by agricultural wastes. It has high oxygen content and burns more completely than gasoline. The research was aimed to utilize coffee wastes for producing a value added products and to reduce environmental pollution burden as well as to evaluate the potential for bioethanol production at probable optimum conditions using *Saccharomyces cerevisiae*. This process allows a yield of 77.29 % of bioethanol with respect to the theoretical value, which can be a viable alternative for obtaining second-generation biofuels in rural areas and for coffee smallholder plantation. The bioethanol production cost was assessed from waste coffee processing. In substantial amounts therefore, coffee pulp can be utilized as a potential raw material in bioethanol production in Ijen plateau region of East Java.. Bioethanol production cost was IDR 6 000 $\cdot$ L^{-1} or USD 0.48 $\cdot$ L^{-1}. Based on these facts, compared to food crops coffee pulp which is an agricultural waste is a promising alternative feedstock for second generation bioethanol production.
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Keywords: Agricultural waste; bioethanol; biorefinery; coffee pulp; fermentation; *Saccharomyces cerevisiae*; second-generation biofuels

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Nomenclature

L	liter	**min**	minute
G	gram	**mL**	mililiter
GC	gas chromatography	**h**	hour
GHG	green house gas	**million**	10^9, Giga – G.
d	day	**bar**	a metric (but not SI) unit of pressure. 1 bar equal to 100 000 Pa.
rpm	revolution per minute, 1hertz is equal to 60 rpm	**NPV**	Net present value
IDR	Indonesian Rupiah	**PB**	Payback period
USD	United States Dollar	**IRR**	Internal rate of return
B-C ratio	Benefit-cost ratio		

1. Introduction

Recently, numbers of attempts have been made to use these residues for energy or value-added compounds production, as strategies to reduce their toxicity levels, while adding value to them. The present article provides an overview regarding coffee and its main industrial residues. In a first part, the composition of beans and their processing, as well as data about the coffee world production and exportation, are presented. In the sequence, the characteristics, chemical composition, and application of the main coffee industry residues are reviewed.. Based on these data, it was concluded that coffee may be considered as one of the most valuable primary products in world trade[1]. It is concluded that coffee considered as crucial to the economies and politics in developing countries which created many jobs for million of people like in cultivation, processing, trading and marketing areas[1]. As a consequence of this big market, the reuse of the main coffee industry residues is of large importance from environmental and economical viewpoints[2].

Nowadays, energy plays a central role in the global economy. Changes in energy costs have significant effects on economic growth. Increasing oil prices, rising energy demands and concerns over global warming have encouraged many countries to develop bioethanol[3]. By the increasing energy prices and depleting natural deposits of fossil fuel, many countries have been looking for alternative energy sources. Renewable fuel such as biodiesel and bioethanol has received a considerable attention recently due to the occurrence of oil depletion, global warming and the greenhouse effect.

Bioethanol is a good renewable energy which is one of the most promising energy sources[4]. Renewable fuel produced from agricultural commodities may reduce our dependence on fossil fuel and mitigate GHG emissions. However, the new efforts to produce biofuels by intensification and expansion of crop plantations have also resulted in environmental degradation, biodiversity losses, and other negative impacts[5]. In 2008, nearly 33.3 millions hectares were used to produce biofuels, and their co-products, and biofuel production is expected to increase to 170 % by 2020[6].

Although biofuel production remains small (only 6 % of the total energy demand), it is significant in relation to the current levels of agricultural production[7]. The potential environmental and social implications of the sustainable growth and use of biofuel must be recognized and deal with. For example, reducing greenhouse gas (GHG) emissions are among the explicit goals of some policy measures which have been taken to support biofuel production[8]. They also claim that any negative impacts on land, water and biodiversity are to be considered simply as side-effects of the agricultural production of coffee in general. Despite this, the Indonesian government nevertheless supports the continued production of biofuels from agriculture wastes. This is because the negative impacts of biofuel feedstock depend on how it is produced and processed, the scale of production and the resulting changes in land-use. Added to this is the impact of economic value-factors for the users. Therefore, the aim of this work was to study the suitable hydrolysis condition of coffee pulp with diluted sulphuric acid and distilled water, and determining the influence of acid concentration and retention times. Also to evaluate the feasibility of bioethanol production by fermentation of coffee pulp by using commercial bakery yeast such as *Saccharomyces cereviciae*.

2. Material and methods

2.1 Method

2.1.1 Material and equipment

Material for producing bioethanol is waste of liquid coffee processing which was obtained from smallholder plantation in Ijen plateau region, in East Java province of Indonesia. Other material is *Saccharomyces cerevisiae*, NPK fertilizer. Equipments are fermentor, distillation apparatus, refractometer, pH meter and gas chromatography (GC)

2.1.2 Preparation

The pulp was oven-dried at 60 °C for 48 h (to moisture content of 15 %), grinded by coffee grinder and sieved. The samples were stored in hermetically closed plastic containers at room temperature, until required for treatments.

2.1.3 Fermentation process

Waste water with total 10 L was put in the fermentation place then put in some urea and NPK fertilizer for 15-15-20 for 50 g. Then the yeast (*Saccharomyces cerevisiae*) was added 40 g to 80 g depend on the variation. Then the yeast was mixed and saved until 1 d, 2 d, and 3 d.

2.1.4 Distillation process

The waste of coffee then was distillated with temperature 78 °C. The distillate was examined using refractometer and then bioethanol was measured by using gas chromatography.

2.2. Analytical methods

All the fermented solutions were centrifuged at 10 000 rpm for 5 min to separate supernatant. After centrifugation, the supernatant was filtered and then analyzed for ethanol concentration by gas chromatography.

2.2.1. Determination of sugar content

The amount of sugar in the hydrolyzed samples was determined by Fehling method. 50 mL of hydrolyzed sample solution was dissolved in 10 mL of distilled water and 2 mL of concentrated HCl (hydrochloric acid) was added and boiled. The obtained sample was neutralized with NaOH (sodium hydroxide) and the solution was made up to a volume of 300 mL and taken into the burette. The 5 mL of Fehling A and 5 ml of Fehling B were taken and mixed with 90 mL of distilled water in 250 mL erlenmeyer flask and Methylene blue indicator was added. The solution in the flask was titrated with burette solution in boiling conditions until disappearance of blue colour and the volume at which brick red colour observed were recorded.

2.2.2 Gas chromatographic determination of bioethanol

The bioethanol concentration was determined by gas chromatography Gas chromatography (DANI GC 1000) equipped with flame ionization detector (FID) was employed for the separation and quantification of ethanol. A fused silica capillary column (30 m, 0.32 mm) coated with 95 % methylpolysiloxane (stationary phase) was fitted into the instrument to provide on column injection. The injector and detector temperature were maintained at 210 °C and 250 °C, respectively. The oven temperature was started from 50 °C, one minute hold time with heating rate of 30 °C per minute to 155 °C. Nitrogen was used as carrier gas at a flow rate of 0.5 bar and for Hydrogen at 0.65 bar was adjusted. The concentration of ethanol in the samples was determined using isopropanol as internal standard.

3. Results and discussion

3.1 Extraction of coffee mucilage and pulp

Table 1 was elucidated the weights of the materials of large amount of water which was added to the process, significantly reducing the soluble solid content that is initially present in the bean. This fact represents a major disadvantage in the subsequent fermentation process, requiring the highest possible amount of concentrated sugars in the sample. The weight of the materials reveal that the large amount of water is added to the process, significantly reducing the soluble solid content that significantly reducing the soluble solid content that is initially present in the bean small portion. This fact represents a major disadvantage in the subsequent fermentation process, requiring the highest possible amount of concentrated sugars in the sample.

Table 1.Weighing of the material from the plantation

Material	Out (kg)	In total (kg)
Coffee bean	0	100
Pulp	41.25	0
Mucilage	45	0
Bean covered in skin	39.80	0
Water	0	26.05
Total weight	126.05	126.05

Table 2 elucidated the number of mucilage, pulp and pulp mixed with mucilage. The research result ~~**is**~~ was correlated with analysis and acidity which were tabulated in Table 3 and Table 4, respectively.

Table 2. Number of mucilage, pulp and pulp mixed with mucilage

Parameter	% (Dry basis)	% (Wet basis)
Humidity	-	90.92
Raw material	100	9.13
Protein	10.47	0.61
Fats	0.96	0.03
Ash	9.39	0.26
Fibre	27.21	0.75
Total Carbohydrates	79.16	8.24

Table 3. Content of mucilage and pulp juice

Sample	Acidity (% acid)
Mucilage	0.09
Pulp juice	0.12

Table 4**.** Effect of acid hydrolysis on raw materials

Sample	Un-hydrolyzed	Hydrolyzed
	ATR (%)	ATR (%)
Pulp juice	4.48	6.68
Mucilage	4.24	6.44
Pulp juice and mucilage	4.24	6.44

Table 3 presents similar values of acidity within the range of the ones evaluated for the pulp of ripe and overripe coffee fruit. The increase in ATR (total reducing sugar content) that resulted from the acid hydrolysis for mucilage. After having obtained the raw materials, it was observed that their decomposition occurred immediately after processing. The effect of hydrolysis on the juice was elucidated in Table 4. The data showed an increase of more than 50 % in the initial content of total reducing sugars for the sample. The acid hydrolysis of polymers, which was not available for the yeast, increases the content of fermentable sugars. According to Lee et al[8], the acid hydrolysis of pectic substances contained in the mucilage, such as protopectin, increases the total sugar content. Fermentation periods conduct between 1 d, 2 d and 3 d. Bioethanol content is produced from every variable is not same. In the coffee bean content much chemistry material, for example saccharin. The sugar content in the coffee bean is available in the skin and mucilage of the coffee bean. Mesocarp is part of coffee bean with has sugar and high water content. Composition redaction of sugar from mesocarp reaches 12.14 % of dry weight. Part of other coffee bean mucilage which is place between the inside coffee bean and the skin of coffee bean and content sugar 4.1 %. Fermentation which was done on the coffee beans has purpose for breakdown mucilage which has stick in the skin. Time of fermentation and yeast doses have great impact on the fermentation process.

Table 5. Result of bioethanol from liquid waste of coffee processing

Time (days)	Mass of yeast	Content (%)	Bioethanol concentration (%)
1	0	1.8	6.4
	40	1.6	53.1
	80	1.8	51.4
2	0	1.8	17.1
	40	1.2	57.8
	80	1.8	60.2
3	0	0.5	5.4
	40	0.6	51.4
	80	0.9	51.4

Fermentation periods conduct between 1 d, 2 d and 3 d. Bioethanol content was produced from every variable is not same. In the coffee bean content much chemistry material, for example saccharin. The sugar content in the coffee bean is available in the skin and mucilage of the coffee bean. Mesocarp is part of coffee bean with has sugar and high water content. Liquid waste on the coffee processing produces high pollution level. The main components of the liquid waste are organic material which is come from depulping and skin of coffee bean. The majority value of material organic in the liquid waste content were COD 50 000 mg $\cdot$ L^{-1} and BOD reaches 20 000 mg $\cdot$ L^{-1}. Temperature was mean factor which affected the life and growth of organism. The bean which was fermented changed the skin and the temperature will be increase during fermentation.

Based on the results fermentation will be stopped when the fermentation has conducted for 75 h (3 d). The results obtained in this study have demonstrated that efficient ethanol production from coffee pulp is possible. Coffee pulp hydrolysis without the addition of dilute sulphuric acid proved more efficient ethanol yield than with dilute sulphuric acid. The production of ethanol from coffee pulp is a significant finding that can constitute a valuable way of using derivative products from coffee beans at farm level. Expanding bioethanol production could entail diverting valuable cropland from producing cereal crops needed to feed people to producing cereal crops for bioethanol factories.

3.2 Economic assessment

The bioethanol production cost was assessed from waste coffee processing. Bioethanol production cost was IDR 6 000 $\cdot$ L^{-1} or USD 0.48 $\cdot$ L^{-1} [9]. The net present value (NPV) of the bioethanol production investment in Ijen mountain was greater than zero, which indicates that the investment project for bioethanol production is economically feasible. The NPV was determined by the amount of investment and the net revenue in the business. The benefit cost ratio (B/C-ratio) of 1.02 was positive, indicating that the investment in the production of bioethanol production is economically profitable. The payback period (PB) of the investment was 9.97 yr^{-1}. The internal rate of return (IRR) of the bioethanol production project was 8.96 %. Since the IRR was higher than the bank interest, the production may be assessed as economically viable.

4. Conclusion

Bioethanol was obtained from wort made from affordable raw materials such as coffee juice and mucilage, baker's yeast and panela. It was necessary to carry out an acid hydrolysis to increase the fermentable sugars content in the wort, and to apply inoculum for efficient performance of the fermentation. This process allows a yield of 77.29 % of bioethanol with respect to the theoretical value, which can be a viable alternative for obtaining second-generation biofuels in rural areas and for coffee smallholder plantation. The bioethanol production cost was assessed from waste coffee processing. Bioethanol production cost was IDR $6\ 000 \cdot L^{-1}$ or USD $0.48 \cdot L^{-1}$. The production of bioethanol from coffee waste was economically viable. Based on these facts, compared to food crops coffee pulp which is an agricultural waste was a promising alternative feedstock for bioethanol production. The use of this waste as an alternative can also reduces the environmental impacts arising from dumping of the waste directly to the nearby rivers and could also contribute to the solution of fossil fuel substitution in plantation area. Considering the remarkable potential of bioethanol that can be produced from coffee pulp further improvement is still needed for maximum results especially in the fermentation processes.

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