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BIOETHANOL POTENTIAL FROM WHOLE PARTS OF CASSAVA PLANT IN INDONESIA

POTENSI BIOETANOL DARI SELURUH BAGIAN TANAMAN SINGKONG DI INDONESIA

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ABSTRAK

Singkong adalah bahan baku bioetanol yang menjanjikan karena semua bagian dari tanaman singkong termasuk umbi, batang, daun, serta limbah pengolahan seperti kulit dan ampas dapat digunakan dalam produksi bioetanol. Akan tetapi, potensi total bioetanol dari seluruh bagian tanaman singkong belum dipelajari. Penelitian ini mengkaji dan menghitung rata-rata hasil bioetanol dari setiap bagian tanaman singkong, serta menghitung potensi bioetanol dari seluruh bagian tanaman singkong khususnya di Indonesia. Umbi singkong segar, batang segar, daun segar, kulit segar, dan ampas kering memiliki rata-rata hasil bioetanol masing-masing 180 L/ton, 155 L/ton, 75 L/ton, 160 L/ton, dan 390 L/ton. Jika seluruh tanaman singkong digunakan untuk memproduksi bioetanol, tanaman singkong yang menghasilkan satu ton umbi singkong segar dapat menghasilkan 400 L bioetanol. Dengan skenario total area perkebunan yang dipanen seluas 700.000 ha dan produktivitas singkong 22,5 ton/ha/tahun, potensi bioetanol dari seluruh bagian tanaman singkong di Indonesia adalah 6,3 miliar L/tahun. Akan tetapi, penggunaan seluruh bagian tanaman singkong untuk memproduksi bioetanol tidak memungkinkan secara teknis dan ekonomis, mengingat adanya pemanfaatan lain dari singkong. Potensi bioetanol dari seluruh bagian tanaman singkong dengan mempertimbangkan pemanfaatan lain adalah 2,9 miliar L/tahun. Bahkan ketika umbi singkong digunakan untuk pemanfaatan lain, bioetanol dari batang, daun, kulit, dan ampas singkong yang tidak termanfaatkan masih signifikan dan patut dipertimbangkan.

Kata kunci: bioetanol, tanaman singkong, limbah

ABSTRACT

Cassava is a promising bioethanol feedstock as all parts of cassava plant including its tuber, stem, leaves, along with processing waste such as peel and dregs can be used in bioethanol production. However, bioethanol potential from the whole parts of cassava plant has not been studied. This research reviewed and calculated the average bioethanol yield from each part of the cassava plant, and calculated bioethanol potential from the whole parts of cassava plant, especially in Indonesia. Fresh cassava tuber, fresh stem, fresh leaves, fresh peel, and dry dregs are found to have average bioethanol yield of 180 L/ton, 155 L/ton, 75 L/ton, 160 L/ton, and 390 L/ton, respectively. If the whole cassava plant were utilized for bioethanol production, cassava plants that produce a ton of fresh cassava tuber can yield 400 L bioethanol. With a scenario of total area harvested 700,000 ha and cassava productivity of 22.5 ton/ha/year, bioethanol potential from whole cassava plant in Indonesia is 6.3 billion L/year. However, using all the cassava plant for bioethanol production is impractical and uneconomical, considering other utilization of cassava. The bioethanol potential from whole parts of cassava plant after considering other use of plant becomes 2.9 billion L/year. Even when the cassava tuber is used for other utilization, bioethanol from unused cassava stem, leaves, peel, and dregs is still significant and worth considering.

Keywords: bioethanol, cassava plant, waste

INTRODUCTION

Regulation of the Minister of Energy and Mineral Resources of The Republic of Indonesia No. 12/2015 stated that by January 2020, E10 should be implemented in transportation non-public services, industry, and commercial sector. However, the regulation is currently not yet implemented because of several factors such as high bioethanol production cost compared to convetional gasoline, and insufficient feedstock supply that affects the production line. Currently, bioethanol in Indonesia is produced from molasses feedstock that has limited resources due to competition with other industries, and increasing price of molasses contributes to the final bioetannol production cost (Suryana *et al.,* 2012).

Industrialization of bioethanol requires raw material with abundant availability *(Haditjaroko et al.,* 2014). In Indonesia, cassava is potentially abundant and its availability assure the sustainability of bioethanol production. Furthermore, cassava is considered as one of the promising bioethanol feedstock. Nuwamanya *et al.* (2012) summarize

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several advantages of cassava as bioethanol feedstock such as it has high productivity and yield, requires minimum labor work, low management cost, and can grow on marginal land or degraded soils. Baeyens *et al*. (2015) calculated that bioethanol from cassava feedstock is more economical than bioethanol from corn or sugarcane. Rao (as cited in Wang, 2007) compared bioethanol potential from several crops, shown in Table 1, and the result showed that among other crops, cassava tuber has the highest bioethanol yield per hectare area per year. Additionally, the other parts of the plant, such as stem, leaves, along with processing waste such as peel and pile can also be used as bioethanol feedstock.

Indonesia has a high potential to utilize cassava as bioethanol feedstock, especially because Indonesia is one of the main cassava producing countries in the world. (FAO, 2019) recorded a total production of 16,119,020 ton cassava in 2018 with a total area of 697,384 ha, and productivity of 231,135 hg/ha, making Indonesia the sixth-largest cassava producing country in the world. Figure 1 visualized cassava production, along with area harvested and productivity in Indonesia since 1961 to 2018.

However, there is no study summarizing bioethanol potential from the whole cassava plant especially in Indonesia. Review and summary about current bioethanol potential from the whole cassava plant will provide a consideration to choose cassava as bioethanol feedstock in industrial scale, cheap bioethanol feedstock by utilizing the whole cassava plant to produce bioethanol, and therefore, increase the bioethanol yield per hectare area. Thus, this research was done to obtain bioethanol potential from the whole cassava plant and its processing waste, especially in Indonesia while considering other utilizations of cassava that may reduce availability of cassava as bioethanol feedstock.

MATERIALS AND METHODS

Calculation in this paper were made based on several data and parameters taken from different studies.

Table 1. Bioethanol potential from several crops (Wang, 2007)

Crops	Productivity (ton/ha/year)	Conversion to Bioethanol (liter/ton)	Bioethanol Yield (liter/ha/year)
Cassava tuber	40	150	6,000
Sugar cane	70	70	4,900
Sweet sorghum	35	80	2,800
Rice	5	450	2,250
Corn	5	410	2,050
Wheat	4	390	1,560

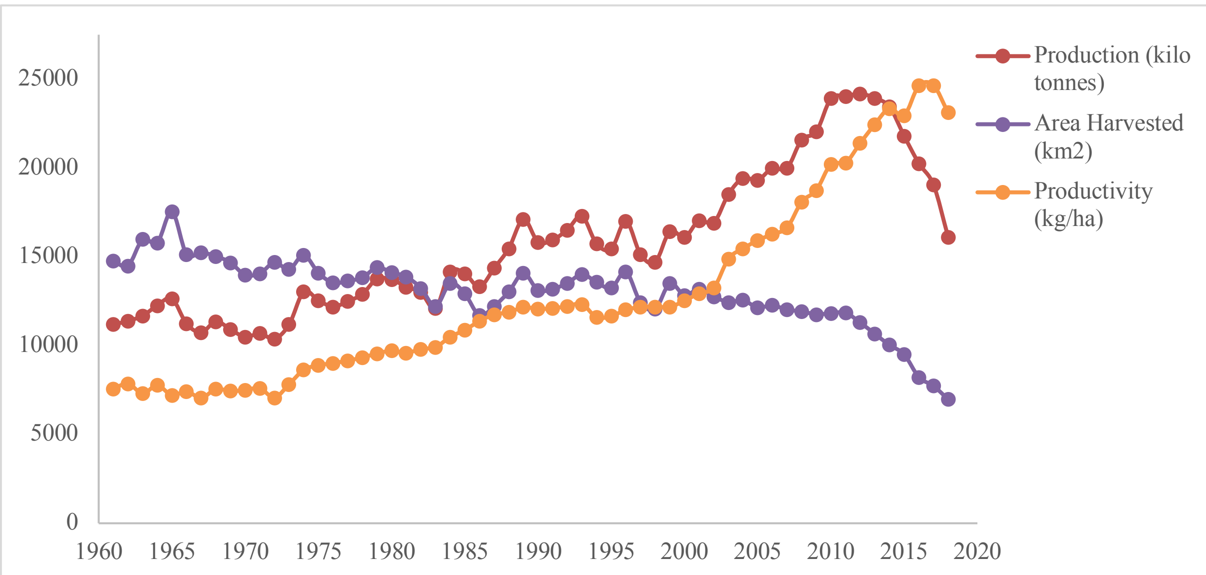

Figure 1. Production, area harvested, and productivity of cassava tuber in Indonesia (FAO, 2019)

Comparison of Bioethanol Yield from Several Studies

Several studies about bioethanol from cassava tuber, stem, leaves, peel, and pile were collected and compared on the same basis. Bioethanol yield can be expressed in many ways, e.g. mL bioethanol/g substrate, g bioethanol/g substrate, mL bioethanol/L solution, g bioethanol/L solution, etc. To have a better comparison, the bioethanol yield unit was converted into the same unit. In this study, the unit was converted into L bioethanol/ton fresh substrate for cassava tuber, stem, leaves, peel; and L bioethanol/ton dry substrate for cassava pile with several assumptions listed below. The result was then compared with the study done by Wang (2007) which state that casava tuber has bioethanol yield of 150 L/ton.

Concentration of bioethanol in the unit of g bioethanol/L solution is converted into L bioethanol/ton substrate with the following equations 1 – 5.

Calculation of Bioethanol Potential from Whole Cassava Plant

The average bioethanol yield from each part of the plant was then used to calculate bioethanol potential from the whole cassava plant by multiplying it with the mass proportion of the cassava plant. However, the mass of other parts than tuber is often not quantified, as cassava production data is expressed in terms of ton of tuber produced. Therefore, mass of other parts of the plant is calculated based on the mass percentage of the plant relative to the tuber.

$$\frac{g\ \text{bioethanol}}{1\ Liter\ final\ \text{solution}} = \frac{g\ \text{substrate}}{1\ Liter\ initial\ solution} \quad (1)$$

$$Bioethanol\ yield = \frac{g\ \text{bioethanol} \div 0.7893 \frac{g}{mL}}{g\ \text{substrate}} \quad (2)$$

$$= \frac{mL\ \text{bioethanol} \div 1{,}000 \frac{mL}{L}}{g\ \text{substrate} \div 1{,}000{,}000 \frac{g}{ton}} \quad (3)$$

$$= \frac{L\ \text{bioethanol}}{ton\ \text{substrate}} \quad (4)$$

Table 2. Parameter used for bioethanol yield convertion

Process parameter	Value	Details	References
Bioethanol density	0.7893 g/mL	Ethanol density at 20 °C	-
Fresh cassava tuber to tapioca starch convertion ratio	0.225 w/w	Starch content of the tuber 25%	Lebot (2019); Yang, El-Ensashy, and Thongchul (2013)
Fresh cassava tuber to dry chips or cassava flour conversion ratio	0.4 w/w	Drying to moisture content 14%	Lebot (2019); Yang, El-Ensashy, and Thongchu
Fresh cassava stem to dry stem conversion ratio	0.4 w/w	Drying to moisture content 10%	Mohan *et al.* (2019); Nuwamanya et al. (2012)
Fresh cassava leaves to dry leaves conversion ratio	0.3 w/w	Drying to moisture content 10%	Mohan *et al.* (2019); G. Ravindran and Ravindran (1988)
Fresh cassava peel to dry peel conversion ratio	0.4 w/w	Drying to moisture content 10%	Nuwamanya *et al.* (2012); Santosa (2004)
Final volume of fermentation broth	Initial volume of the solution when substrate was prepared	If the final volume of fermentation broth was not defined	-

Ravindran (1993) studied that cassava plant consists of approximately 45% root, 35% stem, and 20% forage, while forage composed of 45% leaf, 25% petiole, and 30% tender stem. Fresh cassava tuber is comprised of 6-15% fresh cassava peel (Grace, 1977; Sivamani and Baskar, 2015), and 10-15% dry pile (Sriroth as cited in Sivamani *et al.,* 2018; Thongkratok *et al.,* 2010). To simplify the calculation, the cassava plant is assumed to be comprised of tuber, stem, and leaves with a mass percentage of 45%, 40%, and 15%, respectively. Cassava tuber is assumed to comprise 10% fresh peel, and 15% of dry pile.

The Scenario of Cassava Plantation Conditions in Indonesia

The scenario of cassava plantation conditions in Indonesia was made based on area harvested and productivity of cassava from 2010 to 2018. Area harvested of cassava is decreasing over the year, and the total area harvested in 2018 was 697,384 ha. From 2010 to 2018, the average cassava productivity was 22.6 ton ha^{-1} $year^{-1}$, and the highest productivity was recorded in 2017 with a productivity of 24.6 ton/ha (FAO, 2019).

For the scenario of cassava plantation condition in Indonesia, the total area harvested is assumed to be 700,000 ha, nearly the same with area harvested in 2018, with cassava productivity of 22.5 ton/ha/year.

The Scenario of Cassava Utilization in Indonesia

Theoretically, it is possible to use all cassava and its plant for bioethanol production. However, it is not practical, especially in Indonesia where cassava is widely used for other utilizations. Some of the stems are used to vegetatively propagate the plant and the rest is assumed to be used for bioethanol production. All the leaves during harvesting are assumed to be used for bioethanol production. The peels and piles from cassava processing industries are also assumed used for bioethanol production.

Tuber Utilization

From 2010 to 2018, BPS recorded average cassava consumption in the household sector was 4.429 kg/capita/year (Pusat Data dan Sistem Informasi Pertanian 2012, 2015, 2018). However, Widianingsih (2016) argued that the SUSENAS result recorded by BPS-Statistics Indonesia was very low (underestimate), as this value only counted fresh cassava consumption in the household sector, while processed cassava both for food and non-food industry was not counted in the survey. Thus, this value should be added with processed cassava consumption.

Badan Pusat Statistik (2019) recorded that in 2018, Indonesia's population reached up to 265,015,300 people with an average annual growth rate of 1.33% from 2010 to 2018. With this data, it is assumed that total population in Indonesia is 272,000,000, with consumption of fresh cassava tuber in the household sector 5 kg/capita/year, added with consumption of processed cassava from 20 kg tuber/capita/year, which is around 4 times of fresh cassava tuber consumption. Other than food consumption, the rest of the tuber is used for tapioca starch. Production of tapioca starch is assumed to produce cassava peel and pile that can be collected and reprocessed into bioethanol.

Stem Utilization

Zhu *et al.* (2015) mentioned that 10-20% of cassava stem is used to vegetatively propagate the plant. For this scenario, it is assumed that 15% of the cassava stem is used to propagate the plant and the rest is used for bioethanol production.

Leaves Utilization

All the leaves during harvesting are assumed to be used for bioethanol production. Leaves for food consumption is assumed to be collected through pruning before the tuber is harvested, and pruning gives no negative effect on the productivity of the tuber.

RESULT AND DISCUSSION

Bioethanol Yield from Several Studies

Bioethanol yield from cassava tuber, stem, leaves, peel, and pile in several studies along with its average bioethanol yield are shown in Table 2 to 6. The value was taken form experiment done in other studies, then converted into L bioethanol/ton fresh substrate. Although bioethanol yield usually expressed in the form of g bioethanol/g substrate, in this study, L bioethanol/fresh substrate was taken to compare the result obtained wih study done by Wang (2007) on Table 1, which stated that cassava tuber has bioethanol yield of 150 L/ton. To convert the bioethanol yield to g bioethanol/g substrate, L bioethanol/ton fresh substrate is multiplied with bioethanol density.

On average, fresh cassava tuber, stem, leaves, peel, and dry pile have bioethanol yield of 180 L/ton, 155 L/ton, 75 L/ton, 160 L/ton, and 390 L/ton, respectively. The average value is taken for further calculation even though the range of data obtained from literature is relatively wide. The reason for taking the average is that the data obtained from literature is ranging from lab scale to pilot scale processing. Further development to actual industrial scale generally have unknown effect to yield and coversion, incomparison to smaller scale. Taking average is considered reasonable approach in compensating the actual potential of yield in industrial scale in estimating the capacity of the technology.

Table 3. Comparison of bioethanol yield from cassava tuber

Author(s)	Methods		Equivalent Bioethanol Yield* (L/ton fresh tuber)
Atthasampunna *et al.* (1987)	Enzymatic hydrolysis	Low-temperature processing High-temperature processing	185-200
Ueda *et al*. (1981)	Enzymatic hydrolysis, SLSF	Commercial *Aspergillus niger*	206.618
		Aspergillus awamori NRRL 3112	199.544
		Aspergillus niger from University of Kyushu	190.042
Yuwa-Amompitak (2010)	Enzymatic hydrolysis using *Rhizopus* sp #3Su, SSF		68.225
Ademiluyi and Mepba (2013)	Acid hydrolysis	TMS 92B/00068	240
		TMS 91/02324	220
		TMS 98/0581	204
		TMS 92B/00061	200
		TMS 98/0505	168
Wangpor *et al.* (2017)	Enzymatic hydrolysis		124.002
Average			183.786

Note: * (converted value from original finding)

Table 4. Comparison of bioethanol yield from cassava stem

Author(s)	Methods		Equivalent Bioethanol Yield* (L/ton fresh stem)
Han *et al.* (2011)	Acid pretreatment, enzymatic hydrolysis		95.654
Nuwamanya *et al.* (2012)	Chemical and enzymatic hydrolysis		104.8
Sovorawet and Kongkiattikajorn (2012)	Acid pretreatment, enzymatic hydrolysis, SHF	*S. cerevisiae* TISTR5048	201.698
		S. cerevisiae KM1195	210.313
		S. cerevisiae KM7253	199.164
		Co-culture *S. cerevisiae* TISTR5048 and *C. tropicalis* TISTR5045.	205.245
	Acid pretreatment, enzymatic hydrolysis, SSF	*S. cerevisiae* TISTR5048	182.440
		S. cerevisiae KM1195	209.806
		S. cerevisiae KM7253	188.015
		Co-culture *S. cerevisiae* TISTR5048 and *C. tropicalis* TISTR5045.	199.671
Peláez, Alfaro, and Montoya (2013)	Alkaline pretreatment, enzymatic hydrolysis derived from *Trichoderma reesei*, SSF		59.2
Klinpratoom, Ontanee, and Ruangviriyachai (2015)	2 stage chemical pretreatment using $NaOCl_2$ and NaOH, acid hydrolysis		114.404
Tanaka *et al.* (2019)	2 step acid hydrolysis, intermittent inoculation		47.511
Average			155.227

Note: * (converted value from original finding)

Table 5. Comparison of bioethanol yield from cassava leaves

Author(s)	Methods		Equivalent Bioethanol Yield* (L/ton fresh leaves)
Kongkiattikajorn (2011)	Acid pretreatment, enzymatic hydrolysis, SHF	*S. cerevisiae* TISTR5048	83.238
		S. cerevisiae KM1195	88.179
		S. cerevisiae KM7253	76.397
		Co-culture *S. cerevisiae* TISTR5048 and *C. tropicalis* TISTR5045.	84.759
	Acid pretreatment, enzymatic hydrolysis, SSF	*S. cerevisiae* TISTR5048	74.876
		S. cerevisiae KM1195	90.080
		S. cerevisiae KM7253	85.139
		Co-culture *S. cerevisiae* TISTR5048 and *C. tropicalis* TISTR5045.	87.039
Nuwamanya *et al.* (2012)	Chemical and enzymatic hydrolysis		22.6
Anbuselvi and Balamurugan (2013)	Enzymatic hydrolysis using α-amylase from barley malt		88.350
	Average		78.066

Note: * (converted value from original finding)

Table 6. Comparison of bioethanol yield from cassava peel

Author(s)	Methods		Equivalent Bioethanol Yield* (L/ton fresh peel)
Akponah and Akpomie (2011)	Acid hydrolysis using H_2SO_4 0.6 M		175.2
	Enzymatic hydrolysis	*Aspergillus niger*	105
		α-amylase	40.7
Kongkiattikajorn and Sornvoraweatn (2011)	Acid pretreatment, enzymatic hydrolysis, SSF	*S. diastaticus* 2047	211.833
		S. cerevisiae 7532	141.898
		Co-culture of *S. diastaticus* 2047 and *C. tropicalis* 5045	223.489
Oyeleke *et al.* (2012)	Enzymatic hydrolysis using *G. sepiarium* and *P. ostreatus* and fermented using *Z. mobilis* and *S. cerevisiae*		298
Abidin *et al.* (2014)	Acid hydrolysis using H_2SO_4 0.5 M		95.467
Ezebuiro and Ogugbue (2015)	Acid hydrolysis, fermentation using VCE-19 *Bacillus cereus* GBPS9		225.516
Efeovbokhan *et al.* (2019)	Acid hydrolysis using HCl 0.7 M		168
	Enzymatic hydrolysis using *A. niger* with heat pretreatment		104
	Average		162.646

Note: * (converted value from original finding)

Bioethanol Potential from Whole Cassava Plant

Bioethanol yield from whole cassava plant along with its processing waste is calculated by multiplying the average bioethanol yield with the mass of each part of the cassava plant. In general, bioethanol yield can be calculated as follows.

However, since cassava production data is expressed in terms of ton of tuber produced, the mass of other parts of the plant is often not quantified. In this study, cassava plant is assumed to be comprised of tuber, stem, and leaves with a mass percentage of 45%, 40%, and 15%, respectively. Cassava tuber is assumed to comprise 10% fresh peel, and 15% dry pile.

Equation 7 to 11 can be substituted to equation 5, and the bioethanol yield from the whole cassava plant along with its processing waste can be calculated as follows.

Table 7. Comparison of bioethanol yield from cassava pile

Author(s)		Methods	Equivalent Bioethanol Yield* (L/ton dry pile)
Kosugi *et al.* (2009)	Hydrothermal, acid pretreatment	Enzymatic hydrolysis (cellulase), fermentation *S. cerevisiae* K7G	428.228
		Enzymatic hydrolysis (cellulase, α-amylase, glucoamylase), fermentation *S. cerevisiae* K7	471.304
Li and Zhu (2011)	Enzymatic hydrolysis	*C. thermocellum* ATCC 27405	225.516
		T. aotearoense SCUT27	250.538
		Co-culture *C. thermocellum* ATCC 27405 and *T. aotearoense* SCUT27	281.579
Ndubuisi *et al.* (2018)	Enzymatic hydrolysis using *Pichia kudriavzevii*		266.059
Martinez *et al.* (2018)	Enzymatic hydrolysis	Sample A1	103.48
		Sample A2	368.21
		Sample A3	97.49
		Sample A4	461.39
Efeovbokhan *et al.* (2019)	Acid hydrolysis	IBA980505	415
		IBA950289	695
		IBA010040	470
	Enzymatic hydrolysis using *A. niger* with heat pretreatment	IBA980505	490
		IBA950289	725
		IBA010040	540
Average			393.050

Note: * (converted value from original finding)

$$\begin{aligned} \textit{Bioethanol yield from whole cassava plant} \\ &= \left(\textit{mass of fresh tuber without peel} \times 180\frac{L}{ton}\right) \\ &+ \left(\textit{mass of fresh stem} \times 155\frac{L}{ton}\right) \\ &+ \left(\textit{mass of fresh leaves} \times 75\frac{L}{ton}\right) \\ &+ \left(\textit{mass of fresh peel} \times 160\frac{L}{ton}\right) \\ &+ \left(\textit{mass of dry bagasse} \times 390\frac{L}{ton}\right) \end{aligned} \quad (5)$$

$$\textit{If } m = \textit{mass of fresh tuber harvested} \quad (6)$$

- $\textit{mass of fresh tuber without peel} = 0.9\ m$ **(7)**
- $\textit{mass of fresh stem} = \frac{0.4}{0.45}\ m$ **(8)**
- $\textit{mass of fresh leaves} = \frac{0.15}{0.45}\ m$ **(9)**
- $\textit{mass of fresh peel} = 0.1\ m$ **(10)**
- $\textit{mass of dry bagasse} = 0.15\ m$ **(11)**

$$Bioethanol\ yield\ from\ whole\ cassava\ plant = \left(0.9\ m \times 180\frac{L}{ton}\right) + \left(\frac{0.4}{0.45}m \times 155\frac{L}{ton}\right) + \left(\frac{0.15}{0.45}m \times 75\frac{L}{ton}\right) + \left(0.1\ m \times 160\frac{L}{ton}\right) + \left(0.15\ m \times 390\frac{L}{ton}\right) \quad (12)$$

$$Bioethanol\ yield\ from\ whole\ cassava\ plant = m \times 399.2778\frac{L}{ton} \approx m \times 400\frac{L}{ton} \quad (13)$$

Generally, cassava tuber is peeled before it is processed into bioethanol, therefore only 90% of the tuber mass is multiplied with average bioethanol yield 180 L/ton. The rest 10% is cassava peel and multiplied with average bioethanol yield of 160 L/ton. If processing cassava tuber into bioethanol were assumed to produce 15% dry pile that can be reprocessed into bioethanol through lignocellulosic hydrolysis and fermentation, an additional 390 L bioethanol can be produced from a ton of dry pile. From those average bioethanol yield and mass percentage assumptions, if the whole cassava plant along with its processing waste were utilized for bioethanol production, it can be predicted that cassava plants that produce a ton of cassava tuber can yield 399.28 L bioethanol or nearly 400 L bioethanol.

However, if the pile were not reprocessed into bioethanol, the bioethanol yield from whole cassava plant is reduced into 340 L and calculated as follow (Equation 14 and 15).

Whether pile is reprocessed into bioethanol or not, both bioethanol potentials are higher and significant compared to only processing cassava tuber, which based on this study yield to 180 L bioethanol/ton and based on Rao (as cited in Wang, 2007) yield to 150 L/ton. Utilizing the whole cassava plant as bioethanol feedstock produces approximately 2 times higher bioethanol yield compared to only processing cassava tuber. Thus, it is advantageous to utilize all parts of the cassava plant and its processing waste as bioethanol feedstock. Especially because cassava is harvested as an annual crop, in which the plant is harvested by uprooting the plant. Thus, during harvesting, all parts of the cassava plant are also harvested, and it produces a lot of biomass that if not utilized and treated well will become merely agricultural waste. Instead of becoming agricultural waste, the biomass can be used for bioethanol production.

However, further study should be done to investigate the economic feasibility of the overall process. Processing the whole cassava plant using different methods for each part of the plant will lead to many different processes, which require a lot of equipment and may increase the initial capital cost. Furthermore, study conducted by Mcaloon *et al.* (2000) showed that generally, bioethanol from lignocellulosic feedstock is more expensive than bioethanol from starch feedstock (corn). The highest cost contributor in bioethanol from lignocellulosic feedstock is the depreciation of capital cost which includes the equipment such as reactor tanks, whereas the highest cost contributor in bioethanol from starch feedstock is the feedstock itself.

Other than economic feasibility, net energy gain (NEG) of the process should also be investigated. Currently, distillation is the highest energy consumption in bioethanol production, which based on Lee and Pahl (1985) conventional distillation accounts for 50-80% of the energy input. Although many studies have calculated a positive net energy gain from cassava (Cheroennet and Suwanmanee, 2017; Gallegos *et al.,* 2014; Hanif *et al.,* 2017), with further development in distillation technology and other bioethanol production processes, energy input or on-site energy demand for bioethanol production can be reduced, and therefore increase the net energy gain from cassava and its plant.

With suitable methods, cassava stem, peel, and pile have comparable bioethanol yield with the tuber, where based on the average value, the bioethanol yields are 155 L/ton fresh stem, 160 L/ton fresh peel, and 390 L/ton dry pile, compared to 180 L/ton fresh tuber without peel. Cassava leaves have lower potential compared to other parts of the plant, where it produces only 75 L bioethanol/ton fresh leaves. Sivamani *et al.* (2018) mentioned that cassava leaves have lower bioethanol potential compared to other parts of the plant due to low carbohydrate and high protein content.

Wang *et al.* (2008) mentioned that starch and protein have an inverse relationship in a unit mass of grain, thus as protein increases, carbohydrate and bioethanol yield usually decrease. Additionally, small starch granules can be embedded in protein matrix, thus became ungelatinized during cooking and inaccessible to hydrolytic means.

Considering the average bioethanol yield and the mass proportion of each part relative to the fresh tuber, fresh tuber without peel contributes to the highest bioethanol yield as it has the biggest mass percentage and high bioethanol yield of 180 L/ton. Figure 2 shows the mass proportion of other parts of the plant relative to the fresh tuber, and Figure 3 shows the bioethanol yield from each part based on the baker's percentage on fresh tuber mass.

$$\begin{aligned} &\textit{Bioethanol yield from whole cassava plant without bagasse} \\ &= \left(0.9\, m \times 180 \frac{L}{ton}\right) + \left(\frac{0.4}{0.45} m \times 155 \frac{L}{ton}\right) + \left(\frac{0.15}{0.45} m \times 75 \frac{L}{ton}\right) + \left(0.1\, m \times 160 \frac{L}{ton}\right) \end{aligned} \quad (14)$$

$$\begin{aligned} &\textit{Bioethanol yield from whole cassava plant without bagasse} \\ &= m \times 340.7778 \frac{L}{ton} \\ &\approx m \times 340 \frac{L}{ton} \end{aligned} \quad (15)$$

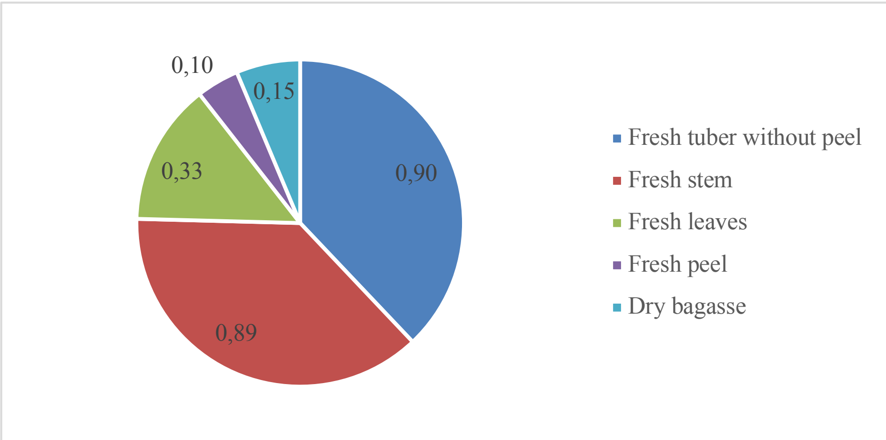

Figure 2. Mass proportion of parts of plant relative to fresh cassava tuber (kg/kg fresh tuber)

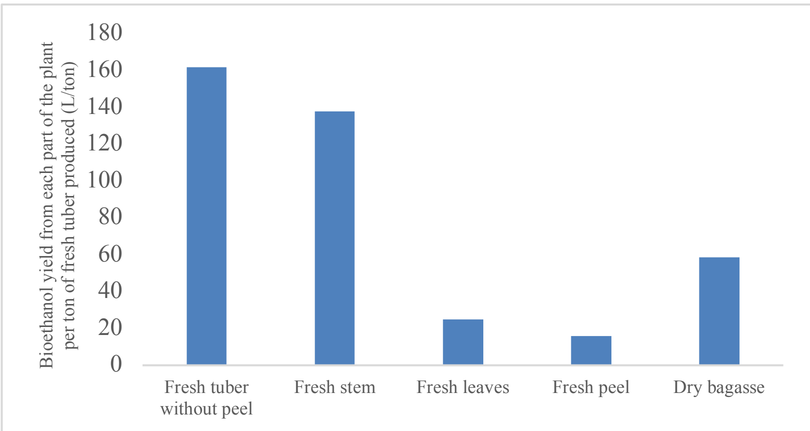

Figure 3. Bioethanol yield based on the mass proportion of other parts of the plant relative to fresh cassava tuber

Next to fresh tuber without peel, fresh stem contributes to the second-highest bioethanol yield because it has the biggest mass percentage after cassava tuber and high bioethanol yield of 155 L/ton. Fresh cassava peel contributes the least because it has the lowest mass percentage, accounts for only 10% of the tuber mass. Relative to the tuber, the fresh leaves have a bigger mass proportion compared to dry pile, however, the leaves have lower contribution because it has low bioethanol potential of 75 L/ton. Dry pile has higher contribution because it has a higher bioethanol yield of 390 L/ton.

Bioethanol Potential from Whole Cassava Plant in Indonesia

With a scenario of total area harvested 700,000 ha and cassava productivity of 22.5 ton ha^{-1} $year^{-1}$, the total production of cassava tuber in Indonesia is 15,750,000 ton per year. The total area harvested was chosen based on the area harvested in 2018, and the productivity was chosen based on the average productivity from 2010 to 2018.

Over the year, the area harvested of cassava shows a declining trend with the latest data in 2018 of 697,384 ha (FAO, 2019). It is predicted that the decline in the area harvested is related to the low selling price of the cassava. With a better price and technology, it is expected that the total area harvested will increase and consequently fulfill the domestic needs. Especially considering that the demand for cassava in Indonesia is very high, while cassava production is currently not yet able to fulfill the domestic needs, and Indonesia still has to import cassava (especially in form of starch).

On the other hand, although cassava productivity is fluctuating, it shows an increasing trend with the highest productivity was recorded in 2017 with a value of 24.65 ton/ha. From 2010 to 2018, the average productivity was 22.56 ton/ha/year (FAO, 2019). However, the average productivity of cassava in Indonesia is relatively quite low compared with the productivity that mentioned by Rao (as cited in Wang, 2007), where the productivity of cassava was mentioned to be 40 ton/ha/year. This is because cassava productivity in several provinces is very low, for example in 2013, although the productivity in Sumatra Barat was 39.766 ton/ha, the productivity in Nusa Tenggara Timur was only 10.25 ton/ha, in Papua Barat was 11.29 ton/ha, and in Kepulauan Riau was 11.93 ton/ha (Badan Pusat Statistik n.d.). To increase cassava productivity in Indonesia, the productivity in all the provinces should also be increased by planting the cassava in proper condition and choosing variety with high productivity.

With a total production of cassava tuber 15,750,000 ton/year, the mass of the whole cassava plant produced is 35,000,000 ton/year. Table 7 shows the detailed biomass along with bioethanol that can be produced. If all the plants along with the additional dry pile were used for bioethanol production, approximately 6.3 billion L of bioethanol/year can be produced.

However, the bioethanol potential of 6.3 billion L/year is not feasible, as it is impossible and impractical to use all the cassava and its plant for bioethanol production. Furthermore, the actual applications of cassava in Indonesia are not for bioethanol production. Cassava tuber is widely used for other utilizations such as food and other processed industry such as tapioca starch, *tapai*, chips, and many others. The demand for cassava tuber is very high, and with the current production condition, it is almost impossible to use tuber as bioethanol feedstock. People would prefer to process cassava into food and other processed industry because it has a better price compared to bioethanol feedstock. Other than cassava tuber, cassava stem is utilized to propagate the plant and young cassava leaves are widely eaten as food and feed due to its high protein content. Cassava peel and pile are sometimes used as feed. Other utilization of cassava should be taken into account as it limits and reduces the availability of cassava as bioethanol feedstock, and thus reduce the bioethanol potential in Indonesia.

In the scenario, it is assumed that all cassava tubers are used for either food consumption or raw material for tapioca starch. The scenario was chosen based on the fact that Indonesia still has to import a large amount of cassava, especially in the form of starch. Table 8 shows the data of total imported cassava, imported cassava starch, and total exported cassava from 2014 to 2018 in Indonesia. Exported cassava is relatively small compared to the imported cassava, and for the scenario, it is assumed that all cassava tubers produced are used to fulfill the domestic needs.

Table 8. Biomass and bioethanol potential from whole cassava plant in Indonesia

Parts of the plant	Biomass potential (ton/year)	Bioethanol potential (liter/year)
Fresh tuber without peel	14,175,000	2,551,500,000
Fresh stem	14,000,000	2,170,000,000
Fresh leaves	5,250,000	393,750,000
Fresh peel	1,575,000	252,000,000
Dry pile	2,362,500	921,375,000

Table 9. Exported and imported cassava from 2014 to 2018 in Indonesia (Badan Pusat Statistik n.d.)

Year	Total exported cassava (kg)	Total imported cassava (kg)	Cassava starch imported (kg)
2014	114,500,682.00	365,084,956.00	365,084,956.00
2015	16,775,829.20	600,163,056.00	595,951,315.00
2016	47,875,846.00	642,667,224.00	630,126,574.00
2017	21,525,152.70	388,821,935.00	385,430,814.00
2018	10,703,937.40	375,590,486.00	375,589,316.00

For food consumption of cassava tuber in the household sector, it is assumed that the consumption of fresh cassava tuber is 5 kg/capita/year, and the consumption of processed cassava is 20 kg tuber/capita/year. The value was chosen based on the average of cassava consumption in the household sector from 2010 to 2018 which was recorded through a National Survey of Socio-Economics (SUSENAS) done by BPS.

Cassava consumption in the household sector from 2010 to 2018 was ranging from 3.422 to 6.355 kg/capita/year with an average value of 4.429 kg/capita/year (Pusat Data dan Sistem Informasi Pertanian 2012, 2015, 2018). Although cassava consumption in the household sector is fluctuating, it generally shows a declining trend. Center for Agricultural Data and Information System (as cited in Widianingsih, 2016) predicted that the consumption of 12.78 kg/capita in 1993 will decreases to only 2.15 kg/capita in 2020. As Widianingsih (2016) argued that the value only shows fresh cassava consumption in the household sector, it implies that the consumption of fresh cassava tuber as a staple food is reduced and replaced by other food. Nowadays, processed cassava are more preferable compared to fresh cassava, especially because fresh cassava is highly perishable.

Based on the argument by Widianingsih (2016) that stated SUSENAS result was very low (underestimate) and it only counted fresh cassava consumption in the household sector, the assumption of fresh cassava consumption 5 kg/capita/year should be added with the processed cassava consumption. It is assumed that the consumption of processed cassava in the household sector that includes *tapai*, *gaplek*, and cassava chips is made from 20 kg tuber/capita/year. In total, it is assumed that the food consumption of cassava is 25 kg/capita/year, and with the assumption that the total population in Indonesia is 272,000,000 people, cassava tuber consumption for food in the household sector is 6,800,000 ton/year. The rest 8,950,000 ton of the tuber per year are assumed to be used in industry for starch extraction.

In the household sector, fresh cassava consumption and processing into *tapai*, *gaplek*, cassava chips produce peel as its waste. However, the peel from fresh cassava consumption and processing cassava in the household sector is assumed cannot be collected for bioethanol production as it is distributed in every household in a small amount. On the other hand, processing cassava into tapioca starch is assumed to be done on a bigger scale and the waste that includes peel and pile can be collected for bioethanol production. Thus from the extraction of 8,950,000 ton of fresh tuber per year, as much as 895,000 ton of fresh peel and 1,342,500 ton of dry pile can be collected for bioethanol production. From it, the peels can yield 143,200,000 L bioethanol, and the dry pile can yield 523,575,000 L bioethanol.

For cassava stem, it is assumed that from 14,000,000 ton of cassava stems/year, 15% of it or equals to 2,100,000 ton/year are used to vegetatively propagate the plant. Other utilization of the stem such as firewood is neglected, as it is not significant and uneconomical. The rest 11,900,000 ton/year are assumed to be used in bioethanol production. From it, 1,844,500,000 L bioethanol/year can be produced. The stem has high potential as bioethanol feedstock, as it has a high mass percentage (accounts for 40% of the plant) and high bioethanol yield of 155 L/ton fresh stem. Furthermore, other than used to propagate the plant, the stem has no significant competitive utilization.

For the leaves, it is assumed that all the fresh leaves produced during harvesting are used for bioethanol production. Leaves for food and feed consumption is assumed to be collected from pruning, done before the tuber is harvested. Sivamani et al. (2018) mentioned that pruning is done to remove unwanted leaves and it enhance the tuber production. Morgan and Choct (2016) mentioned that every hectare of cassava planting can produce up to 10 ton of dry cassava leaves. This value is very big compared to the mass of the leaves collected during harvesting. With the assumption that leaves account for 15% of the plant and a hectare of an area harvested can yield a maximum of 40 ton of cassava tuber, the fresh leaves produced are only 13.333 ton or it equals to 4 ton of dry leaves. The value mentioned by Morgan and Choct (2016) is predicted to include the leaves from pruning. Thus, from proper pruning, additional 6 ton of dry leaves or 20 ton of fresh leaves can be collected. Therefore, all the 5,250,000 ton of fresh leaves collected during harvesting can be used for bioethanol production, and from it, approximately 393,750,000 L of bioethanol per year can be produced.

Table 10. Summary of the bioethanol potential from the whole cassava plant in Indonesia before and after considering other utilization of cassava

Parts of the plant	Utilizing the whole cassava plant		Considering other utilization of cassava	
	Biomass potential (ton/year)	Bioethanol potential (liter/year)	Biomass potential (ton/year)	Bioethanol potential (liter/year)
Tuber without peel	14,175,000	2,551,500,000	-	-
Stem	14,000,000	2,170,000,000	11,900,000	1,844,500,000
Leaves	5,250,000	393,750,000	5,250,000	393,750,000
Peel	1,575,000	252,000,000	895,000	143,200,000
Dry pile	2,362,500	921,375,000	1,342,500	523,575,000
Total	**37,362,500**	**6,288,625,000**	**19,387,500**	**2,905,025,000**

Table 9 shows the summary and illustration of the bioethanol potential from the whole cassava plant in Indonesia considering other utilization of cassava, based on the scenario and assumptions mentioned above. Theoretically, it is possible to use all the 35,000,000 ton plants/year along with the additional 2,362,500 ton dry pile/year for bioethanol production, where it will yield to approximately 6.3 billion L of bioethanol/year. However, it is impractical to use all the cassava and its plant for bioethanol production, especially in Indonesia where cassava is widely utilized for food and other processed industry such as tapioca starch. Considering other utilization of cassava, it is summed that Indonesia can produce 2.9 billion L bioethanol/year from unused cassava stem, leaves, peel, and pile. It is smaller compared to 6.3 billion L bioethanol/year, but the value of 2.9 billion is more feasible and practical to implement.

The value chosen in this scenario can differ with the real conditions as cassava plantation conditions and utilization in Indonesia changes. However, this scenario gives an illustration that bioethanol from other parts of cassava plant such as stem, leaves along with cassava processing waste such as peel and pile is significant compared to only processing cassava tuber. Even when all the tuber is used for other utilization, such as for food and industry, the amount of bioethanol produced from the unused stem, leaves, peel, and pile is still significant and worth considering.

CONCLUSIONS AND RECOMENDATIONS

Conclusions

Bioethanol from other parts of the cassava plant, such as stem and leaves, along with cassava processing waste such as peel and pile are significant to increase the total bioethanol potential from the whole cassava plant. If the whole cassava plant along with its processing waste were utilized to produce bioethanol, cassava plants that produce a ton of cassava tuber can yield 400 L bioethanol. It is significant compared to only processing a ton of cassava tuber that on average will yield to 180 L bioethanol.

Theoretically, all cassava plants can be used as bioethanol feedstock. With a scenario of total area harvested 700,000 ha and cassava productivity of 22.5 ton/ha/year, bioethanol potential from whole parts of cassava plant and its processing waste in Indonesia is 6.3 billion L/year. Considering other utilization of cassava, the bioethanol potential becomes 2.9 billion L/year. Even when the tuber is used for other utilization, the amount of bioethanol produced from the unused stem, leaves, peel, and pile is still significant and worth considering.

Recomendations

More research should be conducted to find a suitable method to produce high bioethanol yield from cassava plants and its waste, especially on cassava leaves because there are only a few studies about it.

The method produces the highest bioethanol yield should be up scaled to give more accurate bioethanol yield. Then, further studies about the economic feasibility cost and net energy gain of the process should also be done.

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