Mass Balance analysis of Bioethanol Production from Sweet Sorghum (Sorghum bicolor)

Muhammad Lauda1*, Nadiya Rahmawati1, Wayda Rahma Putri Fajar1, Aliya Ramadhani1, Rahmah Amirah June1, Meiti Pratiwi1, Jenny Rizkiana1,2

1 Bioenergy Engineering and Chemurgy, Faculty of Industrial Technology, Bandung Institute of Technology, Indonesia
2 Chemical Engineering, Faculty of Industrial Technology, Bandung Institute of Technology, Indonesia

Abstract. Current fossil fuel reserves cannot keep up with the world's need for fuel, leading to a global energy crisis. The issue raises attention to renewable energy sources. Indonesia has committed to using 15% bioethanol in gasoline mixture by 2025, as outlined in Presidential Decree No. 5 of 2006. This article discusses past studies on sweet sorghum plants in their use as a raw material for bioethanol production from various aspects. The study shows that sweet sorghum juice has a high potential to be converted into bioethanol due to its high sugar content. Pretreated sweet sorghum seeds and bagasse also have great potential to be converted into bioethanol due to their rich oligomer and polymer sugar content. The main challenge of producing bioethanol from sweet sorghum is the low economic competitiveness of utilizing sweet sorghum as an energy crop compared to using sweet sorghum as a food crop. The present study focuses on the mass balance analysis of bioethanol production from sweet sorghum. It is expected that the results of the present study may give a preliminary overview of the bioethanol production potential from sweet sorghum.

1. Introduction

Bioethanol is a widely-used substitute for gasoline due to its compatibility with gasoline engines and high octane number, reaching 109. The mixture of bioethanol and gasoline has a higher octane number than pure gasoline and can prevent knocking in the engine [1]. Historically, bioethanol has been produced through the fermentation process from various substrates. The first generation of bioethanol uses sugar or starch from food crops, such as sugarcane and corn, as substrate. Brazil and the United States have successfully developed the first generation of bioethanol. Brazil uses sugarcane, while the United States uses corn as raw material for bioethanol production. Unlike the first generation, second-generation bioethanol uses lignocellulose as a fermentation substrate; the presence of a long carbon chain necessitates pretreatment of the substrate before fermenting the sugar in the initial material. Second-generation bioethanol can be made from biomass waste, which is easier to obtain than food crops [2].

Even though Indonesia has never been included in FAO’s list of sorghum producers, exporters, and importers, it does not mean sorghum does not thrive in Indonesia. Sorghum was first planted in Indonesia before 1970 when Indonesia was still prone to food shortages and national food security had not been achieved yet [3]. Unfortunately, in Indonesia’s status quo, sorghum has not been appropriately managed because it is seen as a low-grade crop among farmers [3]. Indonesia’s highest sorghum producers in
2011 – based on harvested area and production yield – are Central Java, East Java, Yogyakarta, West Nusa Tenggara, and East Nusa Tenggara [4].

Sorghum production is closely related to sorghum productivity per hectare. Productivity is influenced by the sorghum variety as well as soil conditions and the environment in which sorghum grows. Sweet sorghum plants have a high level of productivity in Indonesia. In 2011, the production of sweet sorghum in Indonesia reached 7,695 tonnes [5].

Sweet sorghum has stems containing sugar-rich juice, bagasse waste containing lignocellulose, and seeds containing starch. The juice, bagasse, and sorghum seeds can all be used as raw material for bioethanol production [6]. The sugar content of sweet sorghum juice is approximately 11.8% while the lignocellulose content of bagasse waste sorghum is approximately 13% [7]. This study focuses on reviewing current knowledge and comparing the mass balance of ethanol production from various parts of the sweet sorghum plant to provide an overview of the potential of sweet sorghum to be used as a bioethanol feedstock.

2. Bioethanol production process review

Bioethanol can be derived from sweet sorghum juice, seed starch, and bagasse cellulosic material. Each raw material requires a different conversion process to be bioethanol.

2.1. Bioethanol production from sweet sorghum juice

The processing of converting sweet sorghum juice into bioethanol consists of several steps that have been summarized into a flowchart in Figure 1.

![Figure 1. The block flow diagram of bioethanol production from sweet sorghum juice [8].](image)

2.1.1. Juice extraction. Sweet sorghum juice extraction is done by crushing and squeezing the sweet sorghum stem using a crushing mill [9]. The process produces bagasse as a by-product. The extracted juice is separated from impurities through clarification and filtration processes. Sweet sorghum juice is very susceptible to bacterial contamination [10], so it must be protected from bacterial contamination.
by heating and concentrating the sugar solution. Heating is carried out to a temperature of 100°C to kill microbes [11]. Sugar concentrate is made by passing the solution through an evaporator. Then, the juice is fermented at 16-18° Brix. When not in use, it should be stored at a minimum of 65° Brix[9]. A preserving technique alternative is to keep the juice at -20°C [12].

2.1.2. Fermentation. In conventional industrial practices, fermentation is carried out with Saccharomyces cerevisiae’s help due to its ability to produce high ethanol yields (93% theoretical yield) and its resistance to fermentation inhibitors [13]. The alternative fermentation agent commonly used is Zymomonas mobilis. Z. mobilis has a higher ethanol theoretical yield than S. cerevisiae, reaching a value of 97%. However, Z. mobilis is only useful in fermenting D-glucose. The performance of Z. mobilis in D-fructose and sucrose fermentation is not as good as D-glucose fermentation. Thus it is not very effective in fermenting molasses, sorghum, or starchy materials [14]. A different research reports that a 96-hour fermentation with Escherichia coli produced higher fermentation results (95% theoretical yield) than S. cerevisiae (90% theoretical yield). This trend has exceptions to varieties with juice that has high sucrose content due to E. coli’s low effectiveness in sucrose fermentation [15].

2.2. Bioethanol production from sweet sorghum seeds
The starch content in sorghum seeds is higher, at 61%, than the sugar content in sweet sorghum juice, making the seeds’ bioethanol potential higher than juice. Starch can be hydrolyzed and converted to fermentable sugar. The processes of producing bioethanol from sweet sorghum seeds include grinding, liquefaction, saccharification, fermentation, and purification. Solid waste from the fermentation process can be dried and used as animal feed. Figure 2 displays a block diagram of the bioethanol production process from sweet sorghum seeds.

![Block Diagram](image)

**Figure 2.** The block flow diagram of bioethanol production from sweet sorghum seeds [8].
2.2.1. Grinding. Sweet sorghum seeds consist of 60–77% starch [16]. Sweet sorghum seeds need to be ground to increase the contact area with water, enzymes, and microbes. The most common grinding method is dry milling − grinding without the addition of water − with a hammer mill. Wet milling − a grinding process in which sorghum seeds are soaked in water beforehand − can also reduce friction on the mill. In bioethanol production, dry milling is more commonly used because the equipment is simpler, cheaper, and the process requires less time [8]. The sweet sorghum particle size must be small enough to ensure water binding, heat transfer, and enzymatic reactions occur sufficiently. Research examining sweet sorghum seed particle size in the range of 0.3–0.7 mm shows that smaller particle size results in better bioethanol production [17].

2.2.2. Liquefaction. Ground sorghum seeds are soaked in water with a specific ratio of solids to liquids. The sorghum suspension is heated to 90°C. Then the acidity is adjusted before adding the enzyme α-amylase and/or β-amylase. Soaking and heating are done to dissolve the starch and to disrupt the structure of the seeds. This action can enhance the performance of enzymes starch hydrolysis (liquefaction). Liquefaction performance is measured by the sugar yield from starch hydrolysis. Around 86.4% of starch was successfully hydrolyzed using α-amylase enzyme at 90°C for 2 hours with a solid to liquid ratio of 1:7 g/ml. This study found that the higher the concentration of solids, the lower hydrolysis efficiency becomes, although a higher mass of sugar is obtained [17].

2.2.3. Saccharification. Saccharification is the process of converting dextrins obtained from liquefaction to simple sugar (glucose). Saccharification is generally done by adding the enzyme glucoamylase obtained from Aspergillus sp. to a starch solution. Factors affecting saccharification include temperature, saccharification duration, enzyme concentration, and dissolved solids concentration. A conversion rate of 90% can be achieved with saccharification using glucoamylase at 45°C and pH 5 for 24 hours [18]. Other studies report similar results, with 84.6% efficiency of liquefaction followed by saccharification using glucoamylase at pH 4.5 and temperature 55°C for 2 hours with a solid to liquid ratio of 1:7 [17]. Hydrolysis using amyloglucosidase enzyme obtained a 98% saccharification rate after 9 hours of processing time with an enzyme concentration of 0.4%, while lower enzyme concentrations took longer to achieve the same results [19]. These three studies show the correlation of reaction conditions with the yield of sugar. These studies suggest that the optimum saccharification temperature is in the range of 45–60°C, saccharification duration is generally directly proportional to the sugar yield, the concentration of dissolved solids is inversely proportional to the efficiency of saccharification, and the concentration of enzyme is proportional to saccharification rate.

2.2.4. Fermentation. Hydrolyzate (sugars obtained from starch hydrolysis) is converted into ethanol through the fermentation process. Sweet sorghum seed fermentation is similar to sweet sorghum juice fermentation.

2.3. Bioethanol production from sweet sorghum bagasse
Sweet sorghum bagasse is a lignocellulosic by-product of sweet sorghum juice extraction. Before converting it into ethanol, bagasse components need to be separated. Cellulose in bagasse is hydrolyzed into sugar, which is used to produce bioethanol. The block flow diagram of the bioethanol production process from sweet sorghum bagasse is presented in Figure 3.
2.3.1. Pretreatment. Pretreatment of sweet sorghum bagasse can be divided into mechanical, physical, and chemical pretreatment. Physical and chemical pretreatment (or called pretreatment) makes biomass more easily digested by enzymes by separating lignin, hemicellulose, and cellulose. In contrast, mechanical pretreatment is done to increase the surface area so that enzymes can penetrate the fibers and reach the polymer and oligomer sugars in the fiber, such as cellulose, more easily [20]. Typically, bagasse chips 10–20 mm in size are ground to reach 0.2–2 mm in size [21]. Despite the benefits of decreasing bagasse particle size, this process has the disadvantage of higher energy consumption [22].

2.3.2. Cellulose hydrolysis. The pretreated bagasse is separated into liquid and solid phases. The liquid phase is a mixture of lignin and xylose. After lignin is separated, xylose can be fermented directly into bioethanol [23]. The solid phase (consists mainly of cellulose) must undergo a hydrolysis process first because cellulose cannot be fermented directly by the fermentation agents. Starch hydrolysis can be carried out with dilute acids or enzymes. The hydrolysis agent more commonly used is enzymes because, even though the unit price of enzymes is high, enzymes have high effectiveness and do not need detoxification step after the primary hydrolysis process. Acid hydrolysis results need to be detoxified with alkali pre-fermentation to accommodate the microbial agents, which have their optimum pH. Cellulase enzymes (which consist of endoglucanase, exoglucanase, and β-glucosidase) can be combined with xylanase for maximum hydrolysis results [24].

2.3.3. Bagasse fermentation. Sweet sorghum bagasse hydrolyzate contains glucose and xylose. Glucose can be fermented into bioethanol by biological agents S. cerevisiae and/or Z. mobilis. Xylose can be fermented by several wild type microbes such as Scheffersomyces stipitis and Thermoanaerobacter ethanolicus, as well as recombinant microbes such as E. coli ATCC 11303 (pLOI297). Genetic engineering is required to enable S. cerevisiae and Z. mobilis to digest xylose [8,25]. An alternative use for xylose is as a growth medium for cellulase-producing microbes.
2.4. Bioethanol purification

Crude sweet sorghum fermentation product usually has an ethanol concentration of 5–12% v/v. Purification of bioethanol cannot be done by conventional distillation because water and ethanol form an azeotropic solution at 95% ethanol concentration. In contrast, ethanol for fuel purposes is required to have a purity of at least 99.5%. Some separation technologies such as azeotropic distillation, molecular sieve adsorption, and extractive distillation have been tested. All three of these technologies have been used commercially to produce anhydrous ethanol [12]. Extractive distillation with ethylene glycol solvent and reflux value of $R = 0.5$ can purify ethanol up to 99.5% [26]. Zeolite 3A molecular sieve technology can absorb water in ethanol, even in azeotropic solution [27]. Azeotropic distillation with benzene as a separating agent is able to produce ethanol with a purity of 99.3% [28].

2.5. Sweet sorghum-based bioethanol production alternatives

Research shows that sweet sorghum juice, seeds, and bagasse from the same plant can be used as bioethanol production raw material, although with different yields. Utilization of all parts of sweet sorghum plants can increase the yield of bioethanol per land area. Alternative uses of sweet sorghum plant parts are described in Figure 4.

![Figure 4](image_url)

**Figure 4.** Sweet sorghum utilization as bioethanol production raw material routes: A) using all sweet sorghum plant components and B) using sweet sorghum juice and seeds.

3. Discussions

3.1. Sweet sorghum bioethanol yield

A comparative investigation of bioethanol yield from juice and bagasse of several sweet sorghum varieties has been conducted. GK-Coba, MN-4508, and SS-301 varieties stem juice was fermented with a mixture of *S. cerevisiae* and *Z. mobilis* cultures at 30°C for 48 hours. Bagasse from the same plant is hydrolyzed with dilute acid and fermented under similar conditions. SS-301 variety produces the highest bioethanol for both parts of the plant. However, bioethanol yield from bagasse is lower because the sugar concentration obtained from bagasse hydrolysis is lower than the juice [29]. The utilization of sweet sorghum bagasse and juice is summarized in the sorghum utilization chart in Figure 5.
Ethanol can be derived from sweet sorghum juice, bagasse, and seeds. Each component of the sweet sorghum plant has different compositions. The ethanol yield of sweet sorghum seeds and juice data are available in a literature reference [31], but the ethanol yield from the sweet sorghum bagasse needs to be predicted with several assumptions: hydrolysis of glucans by cellulase produces 90% theoretical glucose yield, hydrolysis of xylan by xylanase has 75% theoretical xylose yield, and ethanol is produced from all sugars with the yield of 0.45 g ethanol/g sugar [31].

**Table 1.** Theoretical bioethanol yield from sweet sorghum (kg/ha, dry basis) [7].

| Variable          | Sweet sorghum |
|-------------------|---------------|
| Raw material      | 1.000         |
| Juice             | 719           |
| Fiber             | 130           |
| **Sugars**        |               |
| Sugar from juice  | 85            |
| Glucose from cellulose | 64    |
| Xylose from hemicellulose | 40 |
| **Ethanol**       |               |
| Ethanol from juice| 43            |
| Ethanol from cellulose | 33     |
| Ethanol from hemicellulose | 20  |
| Total ethanol     | 97            |
Table 2. Predicted bioethanol yield, converted into post-distillation volume [32].

| Genotype          | Predicted yield of bioethanol from juice (l/ha) | Predicted yield of bioethanol from bagasse (l/ha) | Predicted yield of bioethanol from seeds (l/ha) | Predicted yield of bioethanol from juice and bagasse (l/ha) | Predicted yield of bioethanol from seeds and bagasse (l/ha) | Predicted yield of bioethanol from juice, seeds, and bagasse (l/ha) |
|-------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------------------------|
| Watar Hammu Putih| 3,570                                         | 3,294                                         | 721                                           | 6,864                                                   | 4,290                                                     | 4,015                                                         | 7,585                                                        |
| 4-183A            | 3,005                                         | 3,337                                         | 942                                           | 6,342                                                   | 3,948                                                     | 4,279                                                         | 7,284                                                        |
| 5-193C            | 2,547                                         | 3,703                                         | 684                                           | 6,250                                                   | 3,231                                                     | 4,387                                                         | 6,934                                                        |
| 15011A            | 2,989                                         | 4,583                                         | 1,020                                         | 7,572                                                   | 4,009                                                     | 5,603                                                         | 8,592                                                        |
| 15019B            | 1,772                                         | 2,547                                         | 745                                           | 4,319                                                   | 2,517                                                     | 3,292                                                         | 5,064                                                        |
| 15011B            | 3,033                                         | 3,486                                         | 649                                           | 6,520                                                   | 3,682                                                     | 4,135                                                         | 7,168                                                        |
| 15131B            | 2,160                                         | 2,518                                         | 725                                           | 4,678                                                   | 2,885                                                     | 3,243                                                         | 5,403                                                        |
| 15020A            | 1,566                                         | 2,028                                         | 1,288                                         | 3,594                                                   | 2,854                                                     | 3,316                                                         | 4,882                                                        |
| 1090A             | 2,439                                         | 2,314                                         | 1,190                                         | 4,753                                                   | 3,629                                                     | 3,504                                                         | 5,943                                                        |
| 15105B            | 2,631                                         | 2,926                                         | 914                                           | 5,557                                                   | 3,545                                                     | 3,840                                                         | 6,471                                                        |
| 15021A            | 3,909                                         | 4,175                                         | 1,243                                         | 8,084                                                   | 5,153                                                     | 5,418                                                         | 9,327                                                        |
| Selayar hitam     | 2,812                                         | 3,505                                         | 864                                           | 6,318                                                   | 3,676                                                     | 4,369                                                         | 7,182                                                        |
| Numbu             | 2,272                                         | 3,311                                         | 697                                           | 5,583                                                   | 2,969                                                     | 4,008                                                         | 6,280                                                        |
| Sorghum hitam     | 2,961                                         | 3,517                                         | 859                                           | 6,478                                                   | 3,820                                                     | 4,377                                                         | 7,337                                                        |
| Average           | 2,690                                         | 3,232                                         | 896                                           | 5,922                                                   | 3,586                                                     | 4,128                                                         | 6,818                                                        |

Ethanol yield from fermented juice, bagasse, and sorghum seeds differs between each variety and genotype. Of the 11 genotypes and three sweet sorghum local varieties in Table 2, Watar Hammu Putih and 15021A genotypes have the highest ethanol yields: 7,139 l/ha and 7,819 l/ha respectively, while the average ethanol yield is only 5,381 l/ha. The yield of stem biomass has a range of 12.99–33.47 t/ha. Watar Hammu Putih and 15021A genotypes have higher stem yields than other genotypes: 29.98 t/ha and 33.47 t/ha, respectively. Besides having a high stem biomass yield, Watar Hammu Putih and 15021A have higher sugar content in their stem juice than other genotypes: 12.33% and 12.67%, respectively. The high stem yield and sugar content in the Watar Hammu Putih and 15021A genotypes result in both genotypes having high ethanol yield [6,12].

Watar Hammu Putih, 15011B, and 15021A genotypes have the highest bagasse yields of 5.43 t/ha, 5.55 t/ha, and 7.10 t/ha respectively. Ethanol yield from fermented bagasse ranges from 4,0561 l/ha to 9,166 l/ha with an average of 6,463 l/ha. Genotypes 5-193C, 15011A, and 15021A has the highest ethanol yields of 7,406 l/ha, 9,166 l/ha, and 8,349 l/ha respectively. The high ethanol yield in genotype 15021A is due to the high yield of bagasse per unit area. However, the high ethanol yield in genotypes 5-193C and 15011A is due to the high volume of ethanol obtained per kg of bagasse. Genotype 5-193C has an ethanol yield of 11.9% and ethanol volume per kg bagasse of 1.79 ml, while genotype 15011A has an ethanol yield of 14.2% and ethanol volume per kg bagasse of 2.13 ml. These figures are higher than the average ethanol yield and the volume of ethanol per kg bagasse, which is 11.2% and 1.68 ml [32].
Sweet sorghum seeds yield ranges from 1.59–2.64 t/ha with an average of 2.05 t/ha, while the yield of ethanol from sweet sorghum seeds ranges from 1.297–2.577 l/ha with an average of 1.792 l/ha. The productivity of ethanol from sweet sorghum seeds is influenced by the tannin and starch content in the seeds. Sorghum seeds with high glucose levels and low tannin levels tend to have high ethanol yield. High tannin level inhibits the process of glucose fermentation; thus seeds with low tannin levels are preferred. Genotypes 15020A is one of the genotypes with a low tannin level (0.04%). Conversely, genotype 15020A has the highest ethanol yield (2.577 l/ha). Nevertheless, the tannin level is not the only deciding factor. Despite having higher tannin content (0.82%), 15011A has high seed yield and glucose levels in its seeds, so the fermentation of the seeds still produces a relatively high ethanol volume [32].

The fermentation substrate may consist of a mixture of raw materials. In all possible combinations of three parts of sorghum crop, except bagasse-and-seed mixture, genotype 15021A has the highest ethanol yield among all genotypes listed in Table 2. This is due to genotype 15021A having high stem biomass yield, juice sugar content, bagasse yield, and seed starch content altogether. Meanwhile, for the mixture of bagasse and seeds, genotype 15011A has the highest ethanol yield. This is due to genotype 15011A having high seed yield, seed starch level, and ethanol volume per kg of bagasse [32].

Table 3. Sweet sorghum products price comparison [33,34,35,36,37,38].

| Product                | Price/Unit | Raw material price | Value-add |
|------------------------|------------|--------------------|-----------|
| Fuel grade bioethanol  | $0.89/kg  | $0.16/kg sorghum seed; $0.24/kg sorghum stem | 445%      |
| Sorghum seed flour     | $0.51/kg  | $0.16/kg sorghum seed | 318%      |
| Sorghum seed flake     | $1.05/kg  | $0.16/kg sorghum seed | 656%      |
| Sweet sorghum syrup    | $2.46/kg  | $0.24/kg sorghum stem | 1025%     |

b2020 wholesale price.

3.2. Economic added-value comparison between sweet sorghum as food and sweet sorghum as bioethanol feedstock

Before sweet sorghum was considered an energy crop, sweet sorghum had been cultivated as a food and feed crop. Sorghum seeds can be flaked into cereal and also processed into flour, which is an ingredient of various foods. The nutritional content of sorghum seeds is superior compared to other cereals such as wheat or rice. High minerals and protein content is a big advantage of eating sorghum seeds. Sweet sorghum juice contains a lot of sugar, so it has great potentials to be made into syrup, sugar, and alcoholic drinks. Additionally, sorghum seeds are commonly added to animal feed as a protein supplement. However the dose is limited because sorghum seeds contain lots of tannins that can interfere with nutrient absorption. Air-dried sorghum leaves and sorghum bagasse have high cellulose content, which makes them popular animal feeds. The nutrient content of sorghum leaves is equivalent to that of napier grass and sugarcane shoots, two types of plants commonly used as animal feed [39]. The potential of sweet sorghum as an energy crop is changing market demand for sweet sorghum. Table 3 presents the comparison of sweet sorghum economic values as food and as an energy crop. Table 3 shows that the sorghum economic value as a feedstock for bioethanol is small, compared to the value of sweet sorghum as food. This is one of the challenges of utilizing sorghum as a renewable energy source. The value-add of sorghum as an energy source can be increased if bioethanol’s selling price is increased, but this is not a simple task since the government controls the energy price.

4. Conclusion

As one of the bioethanol-producing plants utilized as a renewable energy source, sweet sorghum has enormous potential for further development. Bioethanol can be produced by processing sweet sorghum juice, seeds, and bagasse from the same plant. In this review, two alternative routes have been compared to see the profitability of sweet sorghum as a source of bioethanol. The comparison is also made between
sweet sorghum genotypes to see which variety produces the highest bioethanol. Although value-add comparison gives a rough estimate of economic viability, more accurate assumptions in economic aspects such as capital cost, utility cost, and labor cost are needed to make a better estimate of development feasibility. Besides, the development of sweet sorghum as a feedstock for bioethanol must be supported by the Indonesian government, especially the development of a superior variety of sweet sorghum.

References

[1] Hunwartzen I 1982 Modification of CFR Test Engine Unit to Determine Octane Numbers of Pure Alcohols and Gasoline-Alcohol Blends SAE Technical Paper Series

[2] Lennartsson P R, Erlandsson P, Taherzadeh M J 2014 Integration of the first and second generation bioethanol processes and the importance of by-products Bioresour Technol 165(C) 3-8

[3] Subagio H and Aqil M 2013 Pengembangan Produksi Sorgum Di Indonesia Pros. Semin. Nas. Inov. Teknol. Pertan. 199–214

[4] Balai Penelitian dan Pengembangan Pertanian Sorgum http://inaagrimap.litbang.pertanian.go.id/index.php/sentra-produksi/tanaman-pangan/sorgum

[5] Direktorat Budi Daya Serealia 2012 Kebijakan direktorat jenderal tanaman pangan dalam pengembangan komoditas jagung, sorgum dan gandum (Jakarta: Direktorat Jenderal Tanaman Pangan–Kementan RI)

[6] Yulita R and Risda 2006 Pengembangan sorghum di Indonesia (Jakarta: Direktorat Budi Daya Serealia, Ditjen Tanaman Pangan)

[7] Kim M and Day D F 2011 Composition of sugar cane, energy cane, and sweet sorghum suitable for ethanol production at Louisiana sugar mills J. Ind. Microbiol. Biotechnol. 38 803–7

[8] Ray R C, Uppuluri K B, Trilokesh C and Lareo C 2019 Sweet Sorghum for Bioethanol Production: Scope, Technology, and Economics (Elsevier Inc.)

[9] Almodares A and Hadi M R 2009 Production of bioethanol from sweet sorghum: A review African J. Agric. Res. 4 772–80

[10] Davila-Gomez F J, Chuck-Hernandez C, Perez-Carrillo E, Rooney W L and Serna-Saldivar S O 2011 Evaluation of bioethanol production from five different varieties of sweet and forage sorghums (Sorghum bicolor (L) Moench). Ind Crops Prod. 33 611-6

[11] Quintero J A, Montoya M I, Sánchez O J, Giraldo O H and Cardona C A 2007 Fuel ethanol production from sugarcane and corn: Comparative analysis for a Colombian case Energy 33 385-99

[12] Ebrahimiaqda E and Ogden K L 2017 Simulation and Cost Analysis of Distillation and Purification Step in Production of Anhydrous Ethanol from Sweet Sorghum ACS Sustain Chem Eng. 5 6854–62

[13] Ratnavathi C V., Patil J V. and Chavan U D 2016 Sorghum Biochemistry: An Industrial Perspective

[14] Bai F W, Anderson W A and Moo-Young M 2008 Ethanol fermentation technologies from sugar and starch feedstocks Biotechnol Adv. 26 89-105

[15] Castro E, Nieves I U, Rondón V, et al 2017 Potential for ethanol production from different sorghum cultivars Ind Crops Prod. 109(September) 367-73

[16] Watson S A 1984 Corn and sorghum starches: Production. in: Whistler R L, Bemiller J N, and Paschall E F, ed. Starch: Chemistry and technology. 2nd ed. (New York, NY: Academic Press)

[17] Barcelos C A, Maeda R N, Santa Anna L M M and Pereira N 2016 Sweet sorghum as a whole-crop feedstock for ethanol production Biomass and Bioenergy 94 46–56

[18] Aggarwal N K, Nigam P, Singh D and Yadav B S 2001 Process optimization for the production of sugar for the bioethanol industry from sorghum, a non-conventional source of starch. World J Microb Biot. 17 411-5

[19] Du Preez J C, de Jong F, Botes P J and Lategan P M 1985 Fermentation alcohol from grain
sorghum starch *Biomass* 8 101-17

[20] Hamelinck C N, Van Hooijdonk G and Faaij A P C 2005 Ethanol from lignocellulosic biomass: Techno-economic performance in short-, middle- and long-term *Biomass and Bioenergy* 28 384–410

[21] Sun Y and Cheng J 2002 Hydrolysis of lignocellulosic materials for ethanol production: A review *Bioresour. Technol.* 83 1–11

[22] Taylor J, Zhang K and Wang D 2019 *Chapter 13 - Industrial and Nonfood Applications* (AACC)

[23] Sipos B, Réczezy J and Somorai Z 2009 Sweet Sorghum as Feedstock for Ethanol Production: Enzymatic Hydrolysis of Steam-Pretreated Bagasse *Appl Biochem Biotechnol.* 151 151–62

[24] McIntosh S and Vancov T 2010 Enhanced enzyme saccharification of Sorghum bicolor straw using dilute alkali pretreatment *Bioresour Technol.* 101 6718-27

[25] McMillan J D 1993 Xylose Fermenta to Ethanol : A R. *Natl Renew Energy Lab.* NREL/TP-42(January) 51

[26] Meirelles A, Weiss S and Herfurth H 1992 Ethanol dehydration by extractive distillation. *J Chem Technol Biotechnol.* 53 181-8

[27] Carmo M J and Gubulin J C 1997 Ethanol-water adsorption on commercial 3A zeolites: kinetic and thermodynamic data *Brazilian J Chem Eng.* 14 217-24

[28] Sipos B, Réczey J and Somorai Z 2009 Sweet Sorghum as Feedstock for Ethanol Production: Enzymatic Hydrolysis of Steam-Pretreated Bagasse *Appl Biochem Biotechnol.* 151 151–62

[29] Khalil S R A, Abdelhafez A A and Amer E A M 2015 Evaluation of bioethanol production from juice and bagasse of some sweet sorghum varieties *Ann. Agric. Sci.* 60 317–24

[30] Prasad S, Singh A and Joshi H C 2007 Ethanol production from sweet sorghum syrup for utilization as automotive fuel in India *Energy Fuels* 21 2415-20

[31] P. Nghiem N, Montanti J and B. Johnston D 2016 Sorghum as a renewable feedstock for production of fuels and industrial chemicals *AIMS Bioeng.* 3 75–91

[32] Pabendon M B and Sarungallo R S 2015 Pemanfaatan Nira Batang, Bagas, dan Biji Sorgum Manis sebagai Bahan Baku Bioetanol 31 180–7

[33] Index Mundi. Sorghum Monthly Price Sep 2019 – Mar 2020. https://www.indexmundi.com/commodities/?commodity=sorghum.

[34] Diver S and Sampson J 2003 Sorghum Syrup (ATTRA)

[35] Harga Indeks Pasar (HIP) Bahan Bakar Nabati (BBN) Bulan April 2020. Direktorat Jenderal EBTKE. http://ebtke.esdm.go.id/post/2020/03/17/2512/harga.indeks.pasar.hip.bahan.bakar.nabati.bbn.bulan.april.2020. Published 17 March 2020.

[36] Shi-Zhong L Meeting the Demands of Food, Feed, and Energy by Sweet Sorghum. Presented on: FAO Technical Consultation on-How to Make Integrated Food Energy Systems Work and Benefit Small-Scale Farmers and Rural Communities in a Climate-Friendly Way; 14-15 July 2010; Roma http://www.fao.org/bioenergy/26369-0887fe6c2880f4aa44c69d0a48457cb6e.pdf.

[37] Sorghum Flour. Indiamart. https://www.indiamart.com/proddetail/sorghum-flour-4634341491.html

[38] Jowar Flakes, Packaging Type: HDPE Bag. Indiamart. https://www.indiamart.com/proddetail/jowar-flakes-18580843988.html

[39] Biba M A 2011 Prospek Pengembangan Sorgum untuk Ketahanan Pangan dan Energi *Iptek Tanam. Pangan* 6 257–69