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Varieties of sweet sorghum Super-1 and Super-2 and its equipment for bioethanol in Indonesia

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Abstract. The demands for alternative sources of energy are currently growing because people now are more aware of the many negative impacts fossil fuel gives to the environment. Plant based renewable energy provides potential sources of energy with advantages of cleaner fuel effect and capability of integration with food crop production. Sorghum have been considered to be a highly potential source of food, feed and fuel, especially sweet stalk sorghum that posses both functions as source of food from its grain and fuel made from its stalk juice. Sorghum varieties are well known to have excellent adaptability in marginal areas, especially drought prone areas where other food crops are unable to thrive. The current paper aimed to share ongoing research on many functional uses of sweet stalk sorghum varieties released at Indonesian Cereals Research Institute (ICERI). Among many varieties that had been released were two sweet stalk sorghum varieties SUPER-1 and SUPER-2 released in 2013 that stands out in biomass yield and bioethanol production. Based on various researches conducted at different location and planting season, yield potential of biomass ranged at 30 - 40 t/ha with higher yield occurred during dry season. Stalk juice sugar content in brix were found to be higher in dry season ranged at 13.6 % to 18.4 %, and the amount of juice stalk was obtained at about 30-50 % from total biomass yield. Furthermore, bioethanol production from stalk juice after fermentation was at the range of 8 to 10 % from total stalk juice volume. Modification of processing equipment of bioethanol have also been carried out and was able to increased the concentration of ethanol being distilled from 85% -92% to 90% -95%. Another result obtained was able to decreased fermentation time from 14-21 days to 6-10 days. Furthermore, the yield of ethanol from juice was also from an average of 4.95% to 6.75%.

1. Introduction

Sorghum is a cereal type of plat that has multiple functions, it could be used as food, feed and in recent trend it also use as a source of ethanol (fuel). The potential of utilizing sorghum as a main source for ethanol production has drawn many research and studies performed in many Indonesian research institutions. In Indonesia especially, production of ethanol mainly utilize sugarcane molasses and maize kernel as its raw materials. And the demand from the consumer to use ethanol as the new source of renewable energy grows rapidly more than the supply can fulfill [1]. Consequently, with the increasing of demand, ethanol production will be utilizing more toward sustainable raw materials that do not compete with major commodities such as food crop both in term of land use and supply of materials. It is also important not to risk national food security in deciding which crop that is suitable as a source of ethanol. According to Schaffert *et al*. [2], crisis of fuel oil occurred in 1970 was the reason that caused sweet stalk sorghum began to be used for ethanol to substitute fuel oil. And in the last few years sweet sorghum has increasingly been used to produce free-fermentation sugar, which could potentially derived to substitute fuel oil, food, feed and various other product [3]. Because of these advantages, sorghum is the crop that has promising feature as a source of biofuel, food and feed. The function of sweet stalk sorghum is equal to what sugarcane offer, because it contains high sugar content which can produce ethanol through fermentation process [4].

Sweet sorghum (*Sorghum bicolor* [L.] Moench), which later can be divided into grain sorghum and sweet stalk sorghum are highly water efficient crop that requires low amount of water intake for its biomass growth and grain production. It can be cultivated on marginal land, mainly drought prone areas where other crops cannot survive [5]. The morphology of sweet sorghum is relatively different from grain sorghum, which is generally have taller plant height and possess high biomass [6]. Furthermore, stalk of sweet sorghum produce juice that has high sugar content, which can be use as a main source of ethanol production [7,8], whereas grain of sorghum can also be used as raw materials for food, feed and functional food [9]. Beside for bioethanol, sorghum grain and juice can also be use to produce other kind of industrial products such as bioplastic, beverages and also syrup.

Factors affecting biomass and juice yield are genetic of the varieties and the environment of the cultivation areas. Sweet stalk sorghum have higher biomass than grain sorghum, however yield of biomass also depend on the precipitation rate during anthesis and drought stage [10]. Another factor that can influence sweet sorghum is growing season, where longer growing season in temperate climate can affect and improve biomass and stalk juice yield [11]. Brix content of stalk juice is strongly controlled by the genetic each varieties posses. The amount of Nitrogen fertilizer added does not significantly affect brix content of sweet sorghum [10]. Beside genetic, factor that likely affects level of brix content is water consumption which can either be by rain precipitation of by irrigation during cultivation [12].

Among many varieties that have been released by Indonesian Department of Agriculture, almost all of those varieties were grain sorghum aimed for food. However recent release of Super-1 and Super-2 inbred varieties in 2013 were the first sweet stalk sorghum ever release in Indonesia. These varieties specifically breed, select and aimed to become potential source of bioethanol. Nevertheless, its grain can still be utilizes as a food source and the remains of the stalk biomass (bagasse) can be use as silage for cattle feed or compos manure.

Researches on the utilization of sorghum for biofuel in the form of bioethanol have been intensively carried out by Indonesian Cereals Research Institute (ICERI) as one of their mandate crop. Various data used in this review were mainly obtained from several research conducted at ICERI, ranges from research on grain yield, biomass potential and sorghum juice brix content for bioethanol.

2. Results and analysis

2.1. *Prospect of Sweet Stalk Sorghum Varieties Super-1 and Super-2 used for Bioethanol*

The quality feature of sorghum that suitable to be use for bioethanol production is determined by its high sugar content in stalk or the amount of carbohydrate in grain. Whereas the protein content in grain and lignocellulosic in the stalk is an added value [13]. However, the most secure and practical parts to produce ethanol is to use the juice from the stalk. The grain can be used for food, while bagasse containing cellulose can be used for silage (fodder) or compost. Higher rate of ethanol production derived from stalk juice is determined by the amount of stalk biomass weight, stalk juice volume and sugar content.

Among many parts of sorghum plant, the stalk gives highest contribution to produce juice as raw material for bioethanol [14]. Stalk biomass production of sorghum in average ranged between 30-50 t/ha, and leaf biomass gained 20-40 t/ha. To produce 1 liter of bioethanol requires 22-25 kg sorghum stalk [13]. Result of research conducted at Indonesian Cereals Research Institute in 2006 showed that ethanol production from stalk juice ranges between 415-2.576 l/ha. This result was similar to what had been done by Sumaryono [9] which gained 2.300 l/ha bioethanol. Another study carried out by Singgih [15] and Pabendon *et al.* [16] stated that ethanol production was determined by the production of biomass and sugar content of the stalk.

Sorghum is a food crop that has high response in its growth and yield due changes in climate, especially in Indonesia that have two main seasons, which are rainy season (MH) and dry season (MK). Response of Super-1 and Super-2 varieties is presented in Figure 1, it shows production potential of stalk biomass from both varieties was higher in dry season compare to rainy season. Even though average yield of biomass gained in dry season of Super-1 (25.20 t/ha) and Super-2 (28.75 t/ha) were relatively below their potential, nevertheless the true potential of these variety ranges from 38.7 t/ha and 39.30 t/ha. Lower biomass yield in rainy season can be resulted from high leaching of fertilizer applied, which eventually reduced N uptake available for plant [10]. Juice volume was relatively higher in rainy season for Super-1, while juice yield of Super-2 gained similar result in both seasons. Sugar content in brix was higher in dry season than rainy in both Super-1 (15.10 %), and Super-2 (13.90 %). Study also obtained data that during dry season, brix percentage tends to increase at 17 – 21 % in both varieties. Similar finding occurred in sugarcane where sugar level in stalk decreased during rainy season. Furthermore, ethanol production was higher in dry season compare to rainy, and ethanol yield obtained higher in Super-1 (1.199,33 l/ha) while Super-2 at 1.187,92 l/ha. Similar study obtained by Smith and Buxton [17] in non-irrigated sorghum sugar concentration increased versus irrigated location. Furthermore, Pabendon *et al*. [18] also reported that stalk biomass, brix level in stalk juice had high correlation to sweet sorghum ethanol production.

Sorghum plant is sensitive to photoperiodism or relative length of day and night. Sorghum requires at least 12 hours to trigger the internal mechanism that initiate growth, reproduction, flowering and seed development [19]. This is because sorghum is a type of plant that has high efficiency to convert CO_2 to become sugar compare to other crop such as sugarcane or maize.

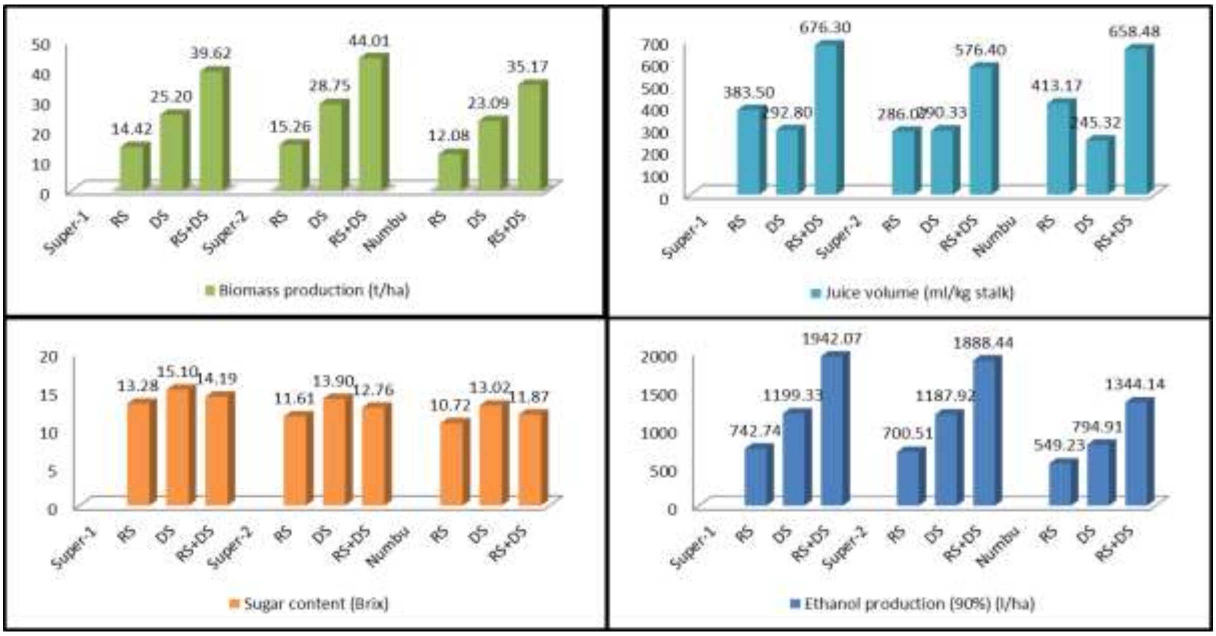


Figure 1. Diagram of average yield stalk biomass, juice volume, brix percentage and ethanol production of sweet stalk sorghum Super-1, Super-2 and control variety Numbu . RS : Rainy Season; DS : Dry Season; RS + DS : Rainy Season + Dry Season.

The grain of Super-1 and Super-2 can be use as functional food, therefore there are advantages in added value by cultivating sweet sorghum. Because not only the main purpose of bioethanol production can be achieved, addel value of obtaining food security can also be achieved. At Indonesian Cereals Research Institute (ICERI), the grain of Super-1 and Super-2 are commonly consumed as "sorghum rice" and can be made into other kind delicacies such as cookies and cakes. Average grain yield in Figure 2 showed that during dry season the grain yield was higher compare to rainy season, and Super-2 variety obtained higher yield than Super-1. One weakness of Super-2 is its susceptibility to sorghum anthracnose disease, which can infect on the stalk and affect the quality and quantity of stalk juice. However, this disease is specific to small region so in order to develop Super-2 in vast area requires vigilant selection of location.

In general the direction in developing both sweet sorghum varieties are mostly suitable in arid and dry climate region, because in addition to higher ethanol and grain yield in both quantity and quality, it can also avoid the high percentage of pest (Aphids) and anthracnose infection. Another reason is that to prevent the decrease of sugar content in stalk, it is best cultivating when the generative growth of plant occurred during dry season. Because with higher amount of rainfall, usually sugar content decrease below 10 % Brix, whereas cultivating at dry season can increase sugar content at value of 18-21 % Brix.

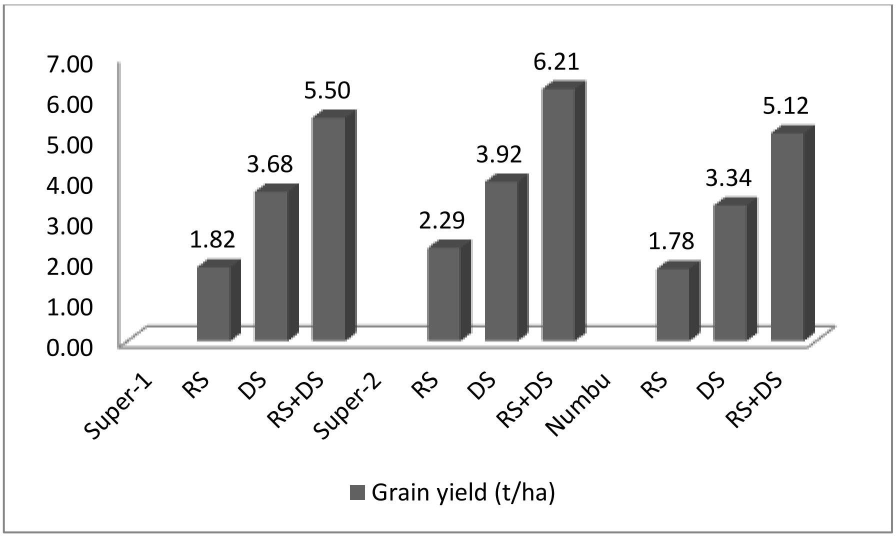


Figure 2. Diagram of average grain yield of sweet sorghum Super-1, Super-2 and control variety Numbu. RS : Rainy Season; DS : Dry Season; RS + DS : Rainy Season + Dry Season.

2.2. *The Potential in Developing Super-1 and Super-2 Varieties as a Source of Sustainable Energy*
Sweet sorghum is special type of plant that can efficiently convert CO_2 to become sugar compare to sugarcane and maize, and this is the reason why sorghum is potential to be use as a source of bioenergy, food and feed. To fulfill the demand of raw materials in bioethanol industry, consequently planting areas of sweet sorghum are suppose to cultivate throughout the year on vast areas, and preferably not to interfere areas that are use for major food crops. In the areas susceptible to drought of frequently get waterlogged, sorghum plant can still be cultivated. Therefore, there are large opportunities to increase sorghum production through land extensification of agriculture. According to Trikoesoemaningtyas and Suwarto [20], the possibility and potential of sweet sorghum to be develop in marginal areas are still vastly open, both in wet climate areas (Sumatera, Kalimantan, Sulawesi and Papua) and dry climate areas (Nusa Tenggara Timur, Sulawesi Tenggara, and parts of Sumatera and Java). Dry climate areas that have land topography waving slope (slope < 8 %) are also suitable for sorghum plantation. Previous data showed that Super-1 and Super-2 varieties are suitable and

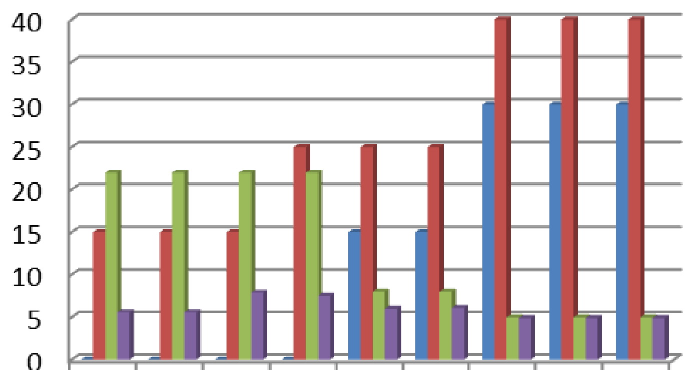
excellent to be developed in dry areas. Bennet and Anex [21] stated that juice production from sweet sorghum that is sustainable can be performed by on-farm method.

Another advantage of cultivating sorghum is its ability to grow new shoot (ratoon) from previously harvested stalk, and the shoot will grow into new plant that can be harvested for the second time [22,23]. According to Tsuchihashi and Goto [24], sorghum plant can be harvested twice or third times which include primer plant and its ratoon. Therefore, it can supply the demand for raw materials for carbohydrate, green fodder or bioethanol in sustainable ways. By utilizing the high ability of ratoon in sorghum plant, cultivating sorghum can increase in its efficiency because it can reduce labor cost, planting time, land tillage, seed usage and energy. Cultivation sorghum by ratoon system has been carried out in India, Hawaii, Australia, Philippine, Indonesia, USA, and Africa [25,26]. In ratoon system, cultivation of sorghum started by planting seed for first harvest, followed by maintaining ratoon plant through second and third harvest, which is a cultivation system that can meet the demand of sustainable raw materials for biomass or seed.

Study of ratoon ability perfomed by Effendi *et al.* [27] in rainy season on several sorghum genotypes showed that Super-2 and Super-1 had low ratoon ability, with ratoon percentage at 33-44 % and also low brix *percentage* in stalk (9 %). However, in order to understand the effect of ratoon in dry season there should be another study performs on those two varieties.

2.3. *Sweet Sorghum Processing Machine Modification*

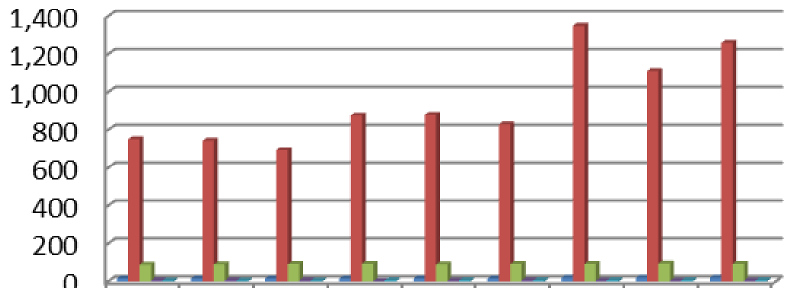
Simple mechanical device that was manufactured to produce ethanol currently was able to obtained ethanol at 1.850-2.500 liters with alcohol percentage of around 85-92 %. The period time of fermentation roughly 14 – 21 days by adding only bread yeast (*Saccharomyces cerevisiae*). The amount of ethanol produced was highly related and affected by the method being used to ferment stalk juice [28-32]. And the hours needed for distillation usually take about 9-10 hours. Modification applied on ethanol processing machine was aimed to increase ethanol productivity and quality, such as effort in increasing ethanol percentage at 90 – 95 % with less fermentation period (4-6 days) and shorter distillation time. Modification that performed were include changing fermentation process from mechanically into fully automated, it was done by stirring the juice from previous manual stirring every 3 days for 5-10 minutes to become automated stirrer attached on to the machine. Result of the modification showed that by stirring for 24 hours at stirring speed of 30 rpm, fermentation period was able to decrease from 22 days to only 5 days with remaining percentage of brix at 4.9 – 6.2 % (Figure 2).



	1	2	3	4	5	6	7	8	9
Rotation speed (rpm)	0	0	0	0	15	15	30	30	30
Juice volume (L)	15	15	15	25	25	25	40	40	40
Fermentation time (days)	22	22	22	22	8	8	5	5	5
Brix final level (%)	5.6	5.6	7.9	7.5	6.0	6.1	4.9	4.9	4.9

Figure 3. Fermentation period of sweet stalk sorghum based on stirring speed level.

Result of ethanol distillation showed that there was an increase in ethanol percentage at >90%. The time period and volume of ethanol obtained cannot be known with certainty because the volumes of stalk juice were lower compare to previous research at 40 liters. Therefore, the modification will still in progress in order to gain expected and optimum results



	1	2	3	4	5	6	7	8	9
Fermented stalk juice (L)	15	15	15	15	15	15	20	20	20
Ethanol volume (ml)	750	743	694	875	880	830	1,350	1,110	1,260
Ethanol (%)	89	90	92	93	90	92	92	94	93
Distillation time (hr)	5.35	5.45	5.15	3.00	4.00	5.35	4.45	4.05	4.20
Brix final level (%)	5.00	4.95	4.63	5.83	5.87	5.53	6.75	5.55	6.30

Figure 4. Ethanol production by distillation of stalk juice after modification; No. 1-3, distillation results before modification

2.4. *Challenges in developing Super-1 and Super-2 Varieties*

Challenges in developing these sweet sorghum varieties consist of cultivation technology aspect, post harvest technology and market and demand guarantee. Other challenges are dissemination and socialization of both varieties as a source of renewable energy. Even though cultivation technology of specific location for sorghum is not yet available, nevertheless number of sweet stalk sorghum varieties is still needed to be increase, especially sorghum for bioenergy. Major challenges that constraint sustainability of renewable energy is the guarantee of market demand, and raw material supply, so that farmers would be interested in cultivating sorghum. Market for sorghum both for grain and biomass is not yet conducive at regional or national level. Moreover, dissemination of information about sorghum potential and training in the social economy of sorghum farming at farmer level is not yet intensive. One problem often become constrain is the availability of seed in term of variety, amount, quality, time and location is low. Even when in time that many farmers are willing to cultivate and grow sorghum.

In developing sorghum for bioindustry, close connection are required between government policies, farmer producer, and other industry related starting from research (technology assembly), development (technological transfer), production (provision of production means), agribusiness practitioner (collecting, storing, marketing and processing), and utilization of goods. Supporting data on sweet sorghum demand for bioethanol production cannot appropriately presented because the productivity of sweet sorghum in Indonesia fluctuate between seasons, and also is yet to become national priority. This is due to several reasons such as : (a). Sorghum market is still very limited, and the reality on the field shows that sorghum has not been widely known to the public; (b). Sorghum cultivation is highly influence by current issues and trend occurred in public; (c). Level of planting areas have not yet achieve stable number because there is no guarantee of utilizing sorghum for specific purposes; and (d). Whenever issues and trend of alternative biofuel are brought up, farmers are very eager to cultivate sorghum. However, when the price of fuel oil decrease and bioenergy issues become less discussed, the farmer become harder to sell their sorghum products. This is the reason they would be reluctant to grow sorghum for the next season.

The reality found on the field showed that sorghum plant has yet publicly known by the people, especially farmers. One of many factor that cause underdeveloped sweet sorghum is that sorghum market is still very limited to small number of regions. Farmers will be interested in developing sweet sorghum if there are other benefits that can be obtained, such as utilizing sorghum grain for food or functional food. However, some areas have long known as the center for sorghum production in Indonesia, these districts of sorghum producer are presented in Table 1.

Table 1. Province and district of sorghum producer in Indonesia based on Directorate General of Food Crop, Department of Agriculture (2007)

Province	District of sorghum development
West Java	Indramayu, Cirebon, Kuningan, Ciamis, Garut, Cianjur dan Sukabumi
Central Jawa	Tegal, Kebumen, Kendal, Demak, Grobogan, Boyolali, Sukoharjo dan Wonogiri
DI. Yogyakarta	Kulon Progo, Sleman, Bantul dan Gunung Kidul
East Java	Pacitan, Bojonegoro, Tuban, Lamongan, Bangkalan, Pamekasan, Sampang, Sumenep, Pasuruan, Probolinggo, Malang dan Lumajang
West Nusa Tenggara	Lombok Tengah, Sumbawa, Dompu dan Bima
East Nusa Tenggara	Sumba Barat, Sumba Timur, Manggarai, Ngada, Ende, Sikka, Flores Timur, Lembata, Alor, Timor Tengah Utara, Kupang, Belu, Timor Tengah Selatan dan Rote Ndao

Areas in East Nusa Tenggara (NTT) with dry climate and many other drought prone and marginal areas in NTT are highly potential to develop sorghum, especially Super-1 and Super-2 which are suitable varieties for dry climate. By developing sorghum in these particular areas, source of renewable energy, food and feed can be fulfill in NTT, hence requires priority.

3. Conclusion

Sweet stalk sorghum potential for bioethanol production was proven to be highly suitable to be develop in many parts of Indonesia. Breeding varieties of Super-1 and Super-2 was an effort to socialize and disseminate sweet stalk sorghum for its multiple functions for food, feed and fuel. From various researches conducted at ICERI the results obtained were high biomass yield of both varieties in two different seasons, and both varieties was able to thrive and gained more yield during dry season. This is an indication that both varieties are excellent crop to be cultivated in drought prone areas of Indonesia especially in East Nusa Tenggara. Brix content of sweet sorghum was strongly influence by genetic, however environment factor of water intake affect sugar content of stalk juice. During the dry season result obtained brix content was higher compared to rainy season. On the contrary, the amount of stalk juice was relatively higher in rainy season for Super-1 as compare to dry season. Machine modification during fermentation through addition of stirring component effectively increased fermentation from 22 days to only 5 days. Furthermore, distilled ethanol was improved with purity percentage > 90 %, this mean higher efficiency occurred during distillation.

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