

Evaluation of Sorghum Biorefinery Concepts for Bioethanol Production

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In the field of sustainable biorefinery concepts, sorghum receives increasing attention as a raw material. Main advantages of various sorghum types are fast growth as well as efficient nutrient and water utilization. When considering the competition between food and energy crop production, sorghum could be part of a sustainable solution. Through convenient crop rotation, sorghum could be grown as a catch crop with good harvest results. This could constitute an advantage as opposed to classical crops like maize or wheat whose utilization as energy feedstock directly competes with food production.

In this study, four process variants will be compared. First, a conventional bioenergy production which was considered as a benchmark scenario, and in addition three new variants of sorghum biorefinery concepts.

The reference variant consisted of two conventional pathways. Here we considered a conventional biogas and a bioethanol plant with maize as a raw material. Because the necessary data for comparison was already available, this scenario served as a benchmark for the other process variants.

The first new concept utilizes a grain sorghum type which exhibits rather high starch content. The grains and straw are separated during the harvest, and processed separately. While the straw is ensiled and fed into biogas production, the starch rich grains are used in a fermentation process with ethanol as the end product. The unfermented residue can be processed to DDSSG, a valuable fodder for livestock or feed a biogas process to generate energy.

A sugar rich sweet sorghum variant serves as raw material for the third scenario. In this case, the whole plant is stabilized after the harvest, and consecutively fed to a whole plant fermentation to produce ethanol. The residue could again be used for biogas production.

The last process scenario we considered is similar to the previous one, with the distinction, that the sugar juice, which is mainly stored in the plant stem, is separated from the remaining plant prior to ethanol fermentation.

Ethanol potentials for all crops were calculated according to the appropriate process scheme. It was found that some sorghum variants yield comparable ethanol potentials.

1. Introduction

Sorghum gained attention over the years as an alternative to conventional crops, since similar biomass yields can be achieved as multiple authors have shown (Geng et al., 1989, Amaducci, 2004). Several sorghum variants were investigated in field tests in 2011 by Theuretzbacher et al. (2012) where a tremendous potential for energy production was found. It was also suggested that, depending on the sorghum variant, a different path of plant utilization should be followed. In this study, two major types were considered. First, a sugar type, that builds up a sugar rich juice in the stem during growth, but only insignificant amounts of grain. Second, a starch type that forms grain, which contains starch. To account for the large differences in plant development between these types, three process schemes have been developed. According to process and sorghum variant, the potential ethanol yield was calculated. As a benchmark, the traditional feedstocks maize and wheat are used.

2. Methods

For the calculation of the potential ethanol yield, the harvest results and compositional analysis of the previously mentioned field tests in 2011 were used.

Ethanol potential was calculated from C6-sugars according to Eq.(1). Taking molecular weights into account, 1 kg of sugar yields 0.51 kg ethanol and 0.49 kg of CO₂. A conversion rate of 0.9 (Wang et al., 2008) was used.



In the case of the starch type, the starch must first be hydrolysed to sugars in order to be fermentable by the yeast. For the conversion, Eq.(2) was used with a yield of 100 %.



2.1 Feedstock

Three sorghum variants were used in this comparison. A starch variant called Chopper (C), and the sugar variants Sugargraze 1 (SG1) and Sugargraze 2 (SG2). Several harvests of the crops were conducted over in the vegetation period (data not shown), but only the harvest with the highest sugar yield was taken into account for this comparison. Harvest data for maize and wheat were taken from the Austrian Field Crop Harvest Report 2011 (Bader and Kriesel, 2011). Harvest, sugar and starch yields are shown in Table 1.

Table 1: Harvest data

Crop	Dry Matter Yield t.ha ⁻¹	Sugar content %	Starch content %	Sugar yield t.ha ⁻¹	Starch yield t.ha ⁻¹
SG1	18.5	24.1		4.5	
SG2	11.7	16.9		2.0	
C grain	10.2		63.7		6.5
Maize grain	5.1		69		3.5
Wheat grain	9.3		66		6.1

2.2 Process Variants

The following process schemes were taken into account: A Conventional Biogas- and bioethanol plant, one for starch rich sorghum, where grains and straw are used separately, a whole plant fermentation process for sugar rich sorghum, and a squeezing variant for sugar rich sorghum.

The Benchmark variant, which is a conventional Biogas- and Bioethanol plant, which are not coupled in any way (Figure 1). Since the biogas production lies outside the scope of this study, it is not calculated in any of the process variants. On the right side, the classic bioethanol production pathway is shown. After delivery and storage of the raw material, it undergoes comminution and mashing. The starch is then liquefied, hydrolised to sugars and fermented to ethanol. These three steps can of course be carried out sequentially or simultaneously. Here the alcohol production is based only on Eq.(1) and Eq.(2), so this difference has no influence on the outcome of this study. Ethanol is enriched by continuous distillation and further purified if needed.

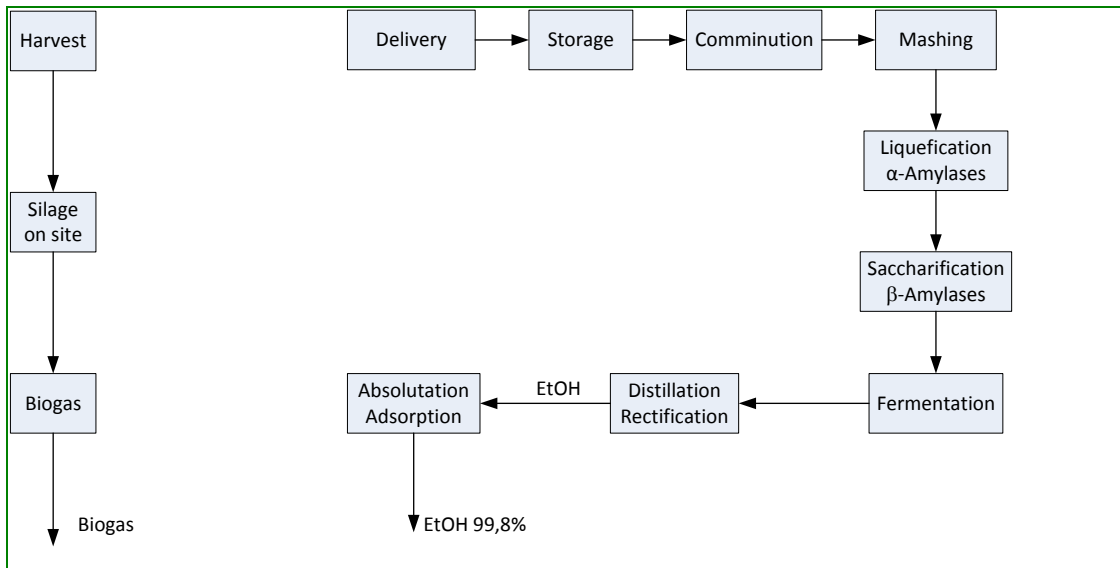


Figure 1: Benchmark variant – conventional Biogas- and Bioethanol production (Variant 1)

The second process variant utilizes a starch rich sorghum variant. After harvesting, the grain is separated from the rest of the plant and both fractions used separately. The remaining plant is silage and can be used for biogas production. The grains are dried, depending on moisture content to guarantee that it is suitable for storage. The Pathway for the grains follows then the conventional bioethanol production with mashing, liquefication and hydrolisation of the starch, fermentation and purification of the ethanol. To utilize the distillation residue, it can be dried to produce DDGS, a valuable fodder for livestock. Alternatively, the residue could be used as substrate in a biogas production process (Figure 3).

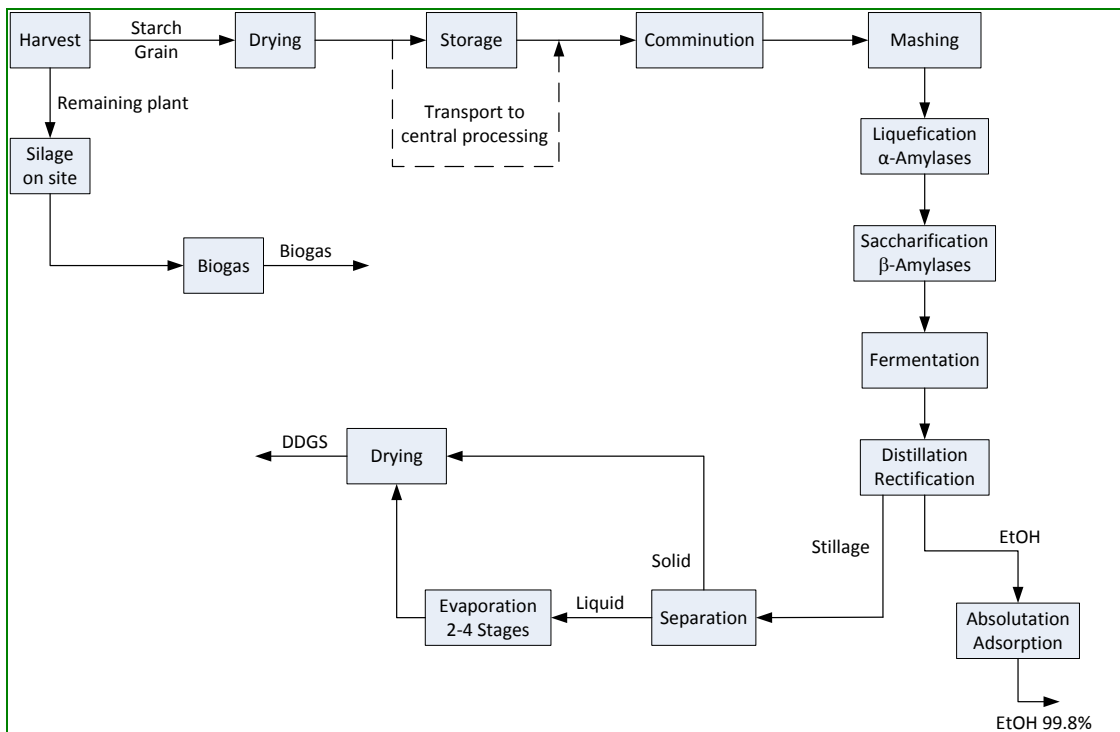


Figure 2: Utilization of a starch rich sorghum variant (Variant 2)

The next two variants are designed for sugar building sorghum variants. The feasibility of both depends upon a stabilising step just after or during harvesting of the crop. This step is imperative, because the plant

builds up sugar juice in the stem during growth. At the harvest, the stem is cut, and so the juice can flow out freely and is exposed to the surroundings. The sugar is then available to microorganisms, which can convert the sugar into undesirable compounds. To prevent this, the stabilizing step should start as soon as possible to minimize sugar losses.

Process variant number three is shown in Figure 3. After stabilization and size reduction, the whole plant is fed into a fermenter. Since not all components of the plant can be fermented, a solid fraction will remain that has to be separated prior to ethanol purification. The separated solids are washed and the washing fraction is fed to the distillation unit to increase ethanol yields. The washed solids and the distillation residue are utilised for biogas production.

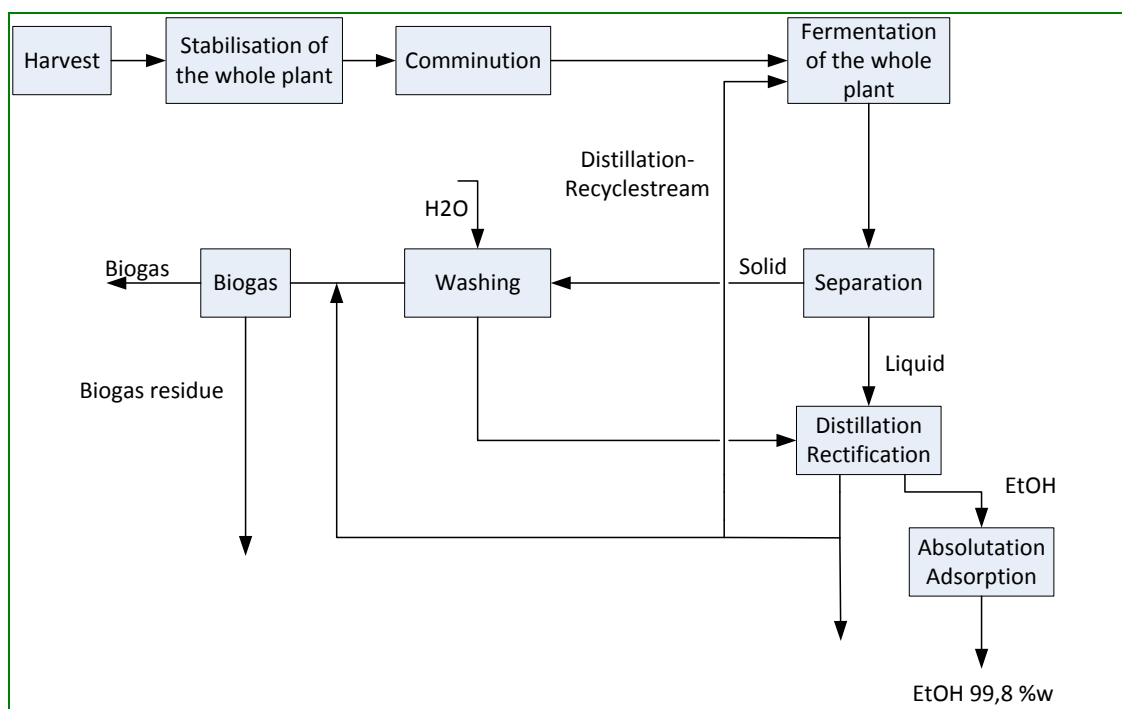


Figure 3: Whole plant fermentation of a sugar rich sorghum variant (Variant 3)

The last variant uses the sugar juice in a different way. After stabilization of the whole plant and size reduction, the plants are squeezed to obtain the sugar juice. The press cake then undergoes a washing step to increase the sugar yield. The two liquid fractions are combined and fed into a fermenter, where the sugars are converted to ethanol. The washed press cake is used for biogas production. The process scheme is shown in Figure 4.

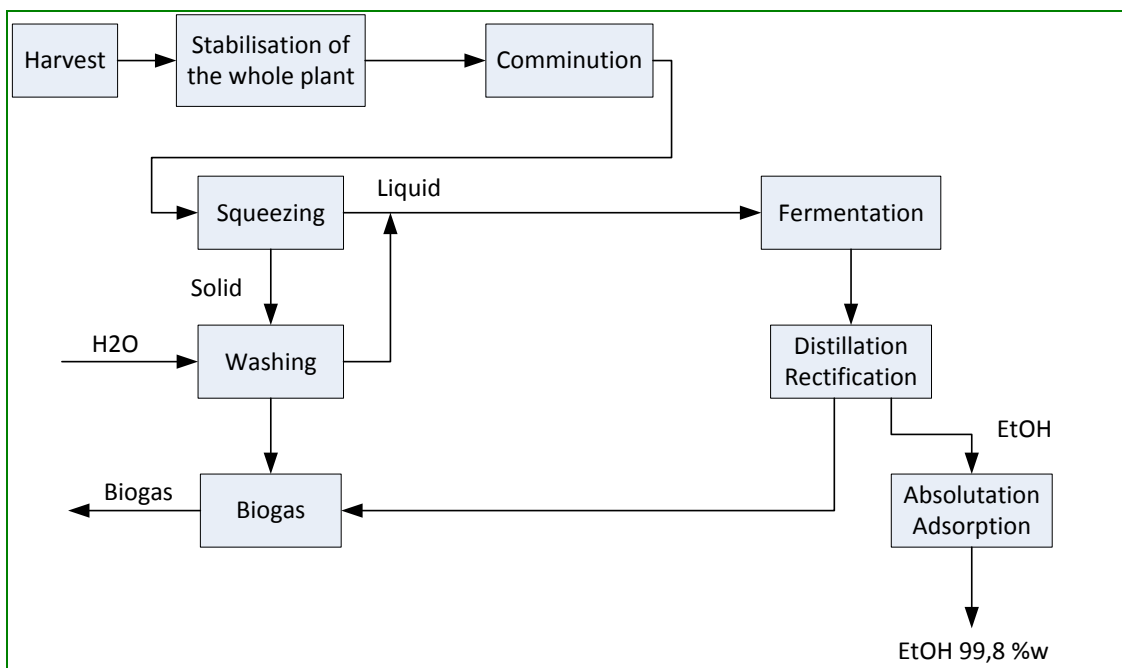


Figure 4: Sugar juice fermentation with a sugar rich sorghum variant (Variant 4)

3. Results

The potential bioethanol production was calculated according to the process variants and harvest data in Table 1. For the benchmark process, ethanol yields of $1.8 \text{ t}\cdot\text{ha}^{-1}$ for wheat grain and $3.1 \text{ t}\cdot\text{ha}^{-1}$ for maize grain were calculated. The sorghum variants perform mostly well in comparison. For the Sugargraze 1 variant, an ethanol potential of $2.1 \text{ t}\cdot\text{ha}^{-1}$ was calculated. The Sugargraze 2 variant did not perform very well as only $0.9 \text{ t}\cdot\text{ha}^{-1}$ of ethanol were estimated. The chopper variant on the other hand outperformed all the other crops in this comparison. The calculated ethanol potential reached $3.3 \text{ t}\cdot\text{ha}^{-1}$. The results are presented in Table 2 and Figure 5.

Table 2: Ethanol potential

Crop	Process variant	Ethanol potential $\text{t}\cdot\text{ha}^{-1}$
SG1	3, 4	2.1
SG2	3, 4	0.9
C grain	2	3.3
Maize grain	1	3.1
Wheat grain	1	1.8

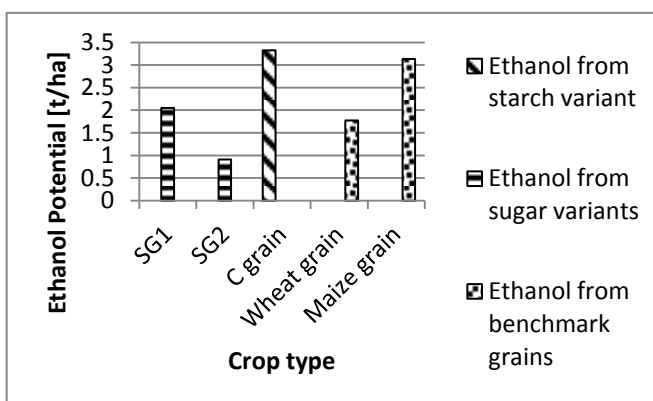


Figure 5: Ethanol potentials for several crops

While SG2 is outperformed by all other crops. The SG1 and C variants reach the potential ethanol yields off the benchmark crops wheat and maize.

4. Conclusions

The results show, that sorghum varieties can compete with conventional energy crops in terms of bioethanol production. The potential energy production is still higher, because in this study, only the ethanol pathways were considered. The production of biogas from the remaining plant parts which was not considered here, is expected to increase the total energy potential significantly which is part of ongoing research. Furthermore, process simulation of the presented variants will be conducted to optimize utilization of sorghum varieties for energy production.

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