Original Research Article

Bio-Fuel Potential of Some Sweet Sorghum Genotypes [*Sorghum bicolor* (L.) Moench *ssp. saccharatum*]

ABSTRACT

The fossil energy sources used in the world are gradually decreasing and limited. Fossil fuels cause environmental pollution, and the unit price is constantly increasing. For this reason, demand for cheaper and renewable energy sources that do not pollute the environment is increasing day by day. The sweet sorghum plant has attracted attention in recent years with its high biomass yield, sugar content and bioethanol yield. In this study, it was aimed to determine the bio-fuel potential of some sweet sorghum genotypes in semi-arid climatic conditions. The experiment was set up in randomized complete block design with 4 replicates. Research was carried out in 2015 under Harran Plain (36^{o} 42' N and 38^{o} 58' E) second crop conditions, Sanliurfa, Turkey**.** In the study 49 genotypes of sweet sorghum were used. Stalk yield, juice yield, syrup yield, brix, sugar yield and theoretical ethanol yield were determined in the study. Significant differences were found between the genotypes for tested characteristics ($P \leq 0.01$). Stalk yield ranged from 7110.0 kg da^{-1} to 24262.5 da^{-1}, juice yield from 2550.0 L da^{-1} to 12187.5 L da^{-1}, syrup yield from 291.4 L da^{-1} to 2242.5 L da^{-1}. Also, brix value varied between %7.0 and %18.87, sugar yield between 247.7 da^{-1} and 1906.1 da^{-1}, Theoretical ethanol yield between 131.9 L da^{-1} and 1014.8 L da^{-1}. Considering to stalk yield, juice and syrup yield, brix, sugar yield and theoretical ethanol yield; Nebraska sugar, Topper 76, Smith, M81E and Corina genotypes were found as the best. As a result of research, 21 genotypes with better performance than the others were selected for further studies.

Keywords: Sweet sorghum, stalk yield, juice yield, sugar yield, brix, bio-fuel, ethanol

1. INTRODUCTION

Fossil energy resources are limited in the world and is depleting dramatically day by day to meet the ever-increasing energy demands globally. Also, fossil fuels are causing environmental pollution. For this reason, it is necessary to focus on clean, environmentally friendly, renewable biofuels sources. Biofuels are sustainable and renewable source of energy derived from organic matter in the form of biomass. Biofuels can be derived from plant as well as animal biomass. Plants grown for biofuel purposes have potential to reduce the net greenhouse gas emissions. Crop plants are one of the best sources of renewable energy which can be used as feedstock for biofuel production. Sweet sorghum has a very good potential as an alternative feed stock for ethanol production.

Also, sweet sorghum provides grain and stem that can be used for sugar, alcohol, syrup, fodder, fuel, bedding, roofing, fencing, paper and chewing. Sweet sorghum juices usually contain approximately 16–18% fermentable sugar, which can be directly fermented into ethanol by yeast. Technical challenges of using sweet sorghum for biofuels are a short harvest period for highest sugar content and fast sugar degradation during storage [1].

Sweet Sorghum plant [*Sorghum bicolor* (L.) Moench *ssp. saccharatum*] is one of many types of cultivated sorghum. Sweet sorghum is a multipurpose crop providing food, feed, fiber, and fuel across a range of agroecosystems [2]. Sweet sorghum is a crop well adapted to environmental conditions ranging from tropical to temperate conditions within 40°N and 40°S of the equator [3]. It grows as a perennial in dry and hot places in the world. But sweet sorghum is adapted to widely differing climatic and soil conditions. It also grows well in temperate climates.

It tolerates drought and high-temperature stress better than many crops and has the capability of remaining dormant during the driest periods [4]. Its waxy leaves and deep roots are better suited for dry and hot climates. It also has a high tolerance to salt, biotic and abiotic stresses. Sweet sorghum requires less fertilizer and water to produce significant biomass. It is a C4 crop with low input requirements and accumulates high levels of sugars in its stalks. Sorghum plants are very flexible and can be planted after many crops.

Sweet sorghum has different uses area. The grain can be used as a gluten-free human food product, an animal feed, or processed into ethanol. The stalk has a high concentration of fermentable sugars and can be used as a feedstock for ethanol production. The residual fiber (bagasse) from sweet sorghum can be used to produce electricity, paper, cattle fodder and the crop itself could be used for silage if needed.

Ethanol can be produced from any sugary or starchy material. But for drier climates, there is a need to produce bio-energy from more water efficient crops, such as sweet sorghum. Sweet sorghum is a very efficient source of bio-energy. Sweet sorghum has been recognized widely as potential alternative source of bio-fuel because of its high fermentable sugar content in the stalk. Sweet sorghum can be used the production of biofuels in three ways. The stalk and seed are used directly for biomass energy, lignocellulosic biofuel production and their high sugar content allows them to be fermented to make ethanol [5]. Sorghum biomass is burned by fast pyrolysis to produce syngas, bio-oil, and charcoal. Sweet sorghum juice contains sucrose, fructose, and glucose which can easily be made into ethanol. Sweet sorghum-based ethanol is sulfur-free and cleaner than molasses-based ethanol, when mixed with gasoline.

The objectives of the study are to determine the bio-fuel potential of some sweet sorghum genotypes in semi-arid climatic conditions.

2. MATERIAL AND METHODS

This study was conducted in 2015 second crop conditions, Sanliurfa, Turkey. The experimental field is located in Harran Plain (36^o 42$'$ N and 38^o 58$'$ E) where the climate varies from arid to semi-arid. Table 1. provides the climatic data obtained from Sanliurfa City Meteorological Station. As can be seen from Table 1. that the weather is hot and dry in the months of June, July and August where maximum temperatures were all above 40 ^{o}C while the relative humidity was below 50%. Rainfall was very low from June to August in 2015.

Table 1. Monthly some climatic data during 2015 sweet sorghum growth period in Sanliurfa[†].

Meteorological observations	Months							
	May	June	July	Aug.	Sept.	October	November	December
Min.Temp. ^{0}C	11.8	16.7	21.4	22.1	18.7	12.7	6.8	0.5
Max.Temp. ^{0}C	36.9	38.4	42.8	43.1	40.4	33.0	24.3	20.0
Average Temp. ^{0}C	22.8	27.7	33.2	31.5	29.8	21.6	14.0	8.6
Average Humidity (%)	38.0	35.3	26.5	37.4	30.5	50.5	48.1	50.8
Rainfall (mm)	10.3	0.7	0.2	-	-	58.8	7.9	25.3

Sunshine Duration (hour)	10.4	12.1	12.4	11.1	9.0	6.0	6.1	4.6

†Data collected from the Sanliurfa Meteorological Station

The soil of the research field was slightly alkaline, high in lime and very low in salt contents. Organic matter was low. Field capacity of the soil was 33.8% on dry basis, permanent wilting point was 22.6% and bulk density was 1.41 g cm^{-3}. Some physical and chemical properties of research soil were given in Table 2.

Table 2. Some physical and chemical properties of research soil

Deep (cm)	Org. Mat. (%)	Total Salt (%)	pH	$CaCo_3$ (%)	P_2O_5 Kg da^{-1}	K_2O Kg da^{-1}	N %	C %	C:N	Texture (%)		
										Sand	Clay	Silt
0-15	0.66	0.098	7.65	48.17	3.6	99.3	0.06	0.38	6.53	2.42	15.12	82.46
15-30	0.68	0.086	7.64	46.88	3.9	93.8	0.06	0.40	6.55	5.50	8.41	86.08

Forty-nine sweet sorghum genotypes (*Sorghum bicolor* (L.) Moench *ssp. saccharatum*) were used as crop material.

Land was ploughed and cultivated then prepared for planting with a single pass of a disk-harrow. The experiment was laid out in a randomize block design with four replications. Each plot area was 14 m^2 (5 m x 2.8 m) and consisted of four rows of 5 m in length. The plants were grown 70 cm apart between the rows with 15 cm spacing in each row.

The seeds were sown in second part of June at a 50-60 mm depth. At sowing, 50 kg ha^{-1} of pure N, P and K, as a 15-15-15 composed fertilizer, was applied to each plot; this was followed by 50 kg ha^{-1} of pure N as urea when the plants reached 30-40 cm in height. Irrigation water was first applied to all the plots using a sprinkler irrigation system. After the emergence of plants, plots were irrigated equally by the furrow irrigation system.

The stalks of sweet sorghum were crushed to extract juice using a three-roller crusher. During the squeezing juice volume was measured as mL with graded plastic tube. Total soluble solids of the juice (Brix) were measured immediately after squeezing from the stalks using a hand-held refractometer (Atago Co., Ltd., Japan).

Just as syrup yield was calculated by multiplying the juice yield by brix, sugar yield was calculated by multiplying the syrup yield by 0.85 as due to fermentation efficiency for juice previously done [6]. Theoretical ethanol yield was calculated using given equation. EtOH = [(total sugar/5.68) x 3.78] x 0.8 [7, 8, 9]. Bunphan et al. [9] emphases that theoretical ethanol yields estimated from this equation were very close to actual yields for sweet sorghum.

All tested characteristics were measured from two rows in the middle of each plot. Every harvested plot area was 7 m^2 (5 m x 1.4 m) and consisted of two rows of 5 m in length. Rows outside each parcel are left as edge effects.

An analysis-of-variance (ANOVA) was performed using Jump statistical package program to evaluate statistically differences between results. Means of the data obtained from research were compared using Duncan test at P≤0.05.

3. RESULTS AND DISCUSSION

3.1. Stalk Yield (kg da^{-1})

According to variance analyses, stalk yield was significant (P≤0.01). As seen from table 3. that stalk yield values were ranged from 7110.0 kg da^{-1} (Norkan) to 24262.5 kg da^{-1} (Topper 76). Some of the genotypes such as Topper 76, USDA-Zaira, Nebraska sugar, Corina, Smith, Theis and M81E gave higher stalk yield than other genotypes. Stalk yield is one of the crucial characteristics for getting plant juice. The more stalk yield means that the more plant juice. Some researchers reported different stem yields values such as 6743 kg da^{-1} in Keller variety [10]. It's also reported that stem yields were varied between 4790 and 6593 kg da^{-1} in Wray, Keller and Rio genotypes [11]. Other researchers stated that stem yield ranged between 4100 and 5200 kg da^{-1} [12], between 3235 and 6285 kg da^{-1} [13], and between 7440.0 and 13950.0 kg da^{-1} [14].

2.1. Juice Yield (L da^{-1})

There were statistically significant differences among tested sweet sorghum genotypes for juice yield (P≤0.01). The highest juice yield value was obtained from Nebraska sugar genotype (12187.5 L da^{-1}) whereas the lowest values were seen at USDA-Sudan genotype (2550.0 L da^{-1}). Juice yield was higher at Nebraska sugar, USDA-Zaira, Corina, Topper 76 and Gulseker genotypes. Similar finding reported that juice yield was between 12100 and 18500 L da^{-1} [11], between 3525.0 L da-1 and 6150.0 L da^{-1} [14]. As long as juice yield is high, syrup yield and sugar yield increases. Because of that higher juice yield is desired for biofuel production.

2.3. Syrup Yield (L da^{-1})

In performed variance analyses, syrup yield was found significant (P≤0.01). Syrup yield values were varied from 291.4 L da^{-1} to 2242.5 L da^{-1}. The highest syrup yield value was obtained from Nebraska sugar genotype whereas the lowest values were seen at USDA-Uganda genotype. Nebraska sugar, M81E, Theis, Smith, Topper 76 and UNL-Hiybrid-3 genotypes gave higher syrup yield than others. Syrup yield was calculated by multiplying juice yield by brix value. Provided that juice yield and brix value is high, syrup yield will increase.

Table 3. Stalk yield, juice yield and syrup yield values of sweet sorghum genotypes

Genotypes	Stalk yield (kg da^{-1})**	Juice yield (L da^{-1})**	Syrup yield (L da^{-1})**
Blue Ribben	13305.0 ı-o	6600.0 ı-r	899.4 h-r
Brandes	14317.5 h-n	4725.0 o-w	715.1 m-t
Colman	12472.5 ı-q	6450.0 ı-s	864.0 ı-s
Corina	22507.5 abc	10875.0 abc	1591.9 b-e
Cowley	18900.0 b-h	8100.0 d-k	1304.6 b-ı
Dale	14647.5 g-m	7950.0 d-l	963.9 g-q
Early Folger	8475.0 o-r	3768.8 s-w	381.6 rst
Grassi	21262.5 a-e	9675.0 a-g	1455.8 b-g
H. Sugarcane	8175.0 o-r	4237.5 q-w	306.0 t
Hasting	12997.5 ı-p	7462.5 e-n	1077.0 e-p
Honey	9562.5 m-r	4987.5 n-w	504.8 q-t
M81-E	20400.0 a-f	10050.0 a-e	1648.7 bcd
Mennonita	10987.5 l-r	4312.5 p-w	686.6 n-t

N98	14617.5 g-m	6825.0 h-r	1267.9 b-k
Nebraska sugar	22635.0 abc	12187.5 a*	2242.5 a
Norkan	7110.0 r	3787.5 s-w	410.3 rst
P1579753	16350.0 e-k	5587.5 k-u	969.8 g-q
Ramada	17010.0 d-ı	6870.0 h-q	1150.0 d-o
Rex	8565.0 o-r	4462.5 p-w	518.3 q-t
Rio	16357.5 e-k	7012.5 g-p	1222.9 c-m
Roma	16395.0 e-k	7762.5 d-m	1269.8 b-k
Rox Orange	11617.5 j-r	5287.5 l-v	742.1 l-t
Simon	8625.0 o-r	4387.5 p-w	667.3 o-t
Smith	22050.0 a-d	9412.5 b-h	1768.1 ab
Snow Flakes	10830.0 l-r	5437.5 k-u	864.4 ı-s
Sugar Drip	11280.0 kr	5700.0 j-u	775.5 j-t
Theis	21750.0 a-d	9037.5 b-ı	1389.0 b-h
Topper 76	24262.5 a*	10275.0 a-d	1707.4 bc
Tracy	19800.0 a-g	7950.0 d-l	1287.8 b-j
UNL-hybrid -3	22050.0 a-d	9825.0 a-f	1571.6 b-f
UNL-hybrid -4	15810.0 f-l	5737.5 j-u	965.6 g-q
White Orn	17632.5 c-ı	8400.0 c-j	1053.4 f-p
Waconia-L	10575.0 l-r	4800.0 n-w	759.4 k-t
Williams	14107.5 h-n	7237.5 f-o	1199.8 c-n
Wray	14025.0 h-u	6300.0 j-s	1189.5 c-n
USDA-China	10957.5 l-r	4350.0 p-w	572.6 p-t
USDA-Taiwan	17475.0 c-ı	7950.0 d-l	1241.6 c-l
USDA-S. Africa	16770.0 d-j	5925.0 j-t	871.3 h-s
USDA-Sudan	9750.0 m-r	2550.0 w	356.3 st
USDA-Uganda	7605.0 qr	4125.0 rw	291.4 t
USDA-Malavi	9945.0 m-r	2700.0 vw	417.2 rst
USDA-Zaira	23145.0 ab	11287.5 ab	1432.1 b-g
USDA-Kenya	9172.5 n-r	4950.0 n-w	459.8 q-t
USDA-Uganda	11640.0 j-r	3337.5 t-w	403.3 rst
USDA-Turkey	11475.0 j-r	3187.5 uvw	473.1 q-t
USDA-India	11190.0 k-r	5137.5 m-w	826.1 ı-s
Gulseker	17790.0 c-ı	10156.5 a-e	1495.5 b-f
Rox	7800.0 pqr	3262.5 t-w	431.6 rst
ICRISAT-S. Africa	10050.0 m-r	5167.5 m-w	698.0 n-t
Average	14412.86	6480.87	966.56

†There is no statistical difference among values annotated with the same letter P≤0.05.

** : denotes P≤0.01,

1 kg da^{-1} = 0.01 Mg ha^{-1}

Table 4. Brix, sugar yield and theoretical ethanol yield values of sweet sorghum genotypes

Genotypes	Brix (%)**	Sugar yield (kg da^{-1})**	T. Ethanol yield (L da^{-1})**
Blue Ribben	13.62 g-p+	764.5 g-q	407.0 g-q
Brandes	15.12 d-n	607.9 k-t	323.6 k-t
Colman	13.37 ı-p	734.4 h-s	391.0 h-s
Corina	14.62 e-o	1353.1 bcd	720.4 bcd
Cowley	16.00 a-l	1108.9 b-h	590.4 b-h
Dale	12.12 n-r	819.4 f-p	436.2 f-p
Early Folger	10.00 qrs	324.3 rst	172.7 rst
Grassi	15.05 d-n	1237.4 b-f	658.8 b-f
H. Sugarcane	7.25 s	260.1 t	138.5 t
Hasting	14.45 e-o	915.5 e-o	487.4 e-o
Honey	10.00 qrs	429.1 p-t	228.4 p-t

M81-E	16.37 a-j	1401.4 bcd	746.1 bcd
Mennonita	15.92 a-l	583.6 m-t	310.7 m-t
N98	18.62 abc	1077.7 b-ı	573.8 b-ı
Nebraska sugar	18.37 a-d	1906.1 a	1014.8 a
Norkan	10.75 pqr	348.7 q-t	185.7 q-t
P1579753	17.25 a-f	824.3 f-p	438.9 f-p
Ramada	16.75 a-h	977.5 d-n	520.4 d-n
Rex	11.62 o-r	440.5 p-t	234.5 p-t
Rio	17.45 a-e	1039.4 c-k	553.4 c-k
Roma	16.37 a-j	1079.3 b-ı	574.6 b-ı
Rox Orange	13.95 f-p	630.8 j-t	335.8 j-t
Simon	15.20 d-n	567.2 n-t	302.0 n-t
Smith	18.75 ab	1502.9 ab	800.1 ab
Snow Flakes	15.87 a-l	734.7 h-s	391.2 h-s
Sugar Drip	13.62 g-p	659.2 ı-t	350.9 ı-t
Theis	15.37 c-n	1180.7 b-g	628.6 b-g
Topper 76	16.62 a-ı	1451.3 bc	772.7 bc
Tracy	16.25 a-k	1094.6 b-h	582.8 b-h
UNL-hybrid -3	12.87 l-q	1075.5 b-ı	572.6 b-ı
UNL-hybrid -4	16.87 a-g	820.8 f-p	437.0 f-p
White Orn	12.50 m-r	895.4 e-o	476.7 e-o
Waconia-L	15.75 a-m	645.5 ı-t	343.6 ı-t
Williams	16.62 a-ı	1019.8 c-l	543.0 c-l
Wray	18.87 a*	1011.1 d-m	538.3 d-m
USDA-China	13.00 k-q	486.7 o-t	259.1 o-t
USDA-Taiwan	15.62 a-m	1055.4 c-j	561.9 c-j
USDA-S. Africa	14.87 e-o	740.6 h-r	394.3 h-r
USDA-Sudan	13.87 g-p	302.8 s-t	161.2 st
USDA-Uganda	7.00 s	247.7 t	131.9 t
USDA-Malavi	15.50 b-m	354.6 q-t	188.8 q-t
USDA-Zaira	12.50 m-r	1217.3 b-f	648.1 b-f
USDA-Kenya	9.25 rs	390.8 p-t	208.1 p-t
USDA-Uganda	12.12 n-r	342.8 q-t	182.5 q-t
USDA-Turkey	14.87 e-o	402.1 p-t	214.1 p-t
USDA-India	15.62 a-m	702.2 h-s	373.9 h-s
Gulseker	14.75 e-o	1271.2 b-e	676.8 b-e
Rox	13.25 j-q	366.9 q-t	195.3 q-t
ICRISAT-S. Africa	13.50 h-p	593.3 l-t	315.9 l-t
Average	14.41	816.26	434.57

†There is no statistical difference among values annotated with the same letter P≤0.05.

** : denotes P≤0.01,

1 kg da^{-1} = 0.01 Mg ha^{-1}

2.4. Brix Value (%)

As seen from table 4 that brix value was significant (P≤0.01). Brix values varied from 7.0% to 18.87%. The highest brix value was seen at Wray genotype whereas the lowest brix value was found at USDA-Uganda genotype. The highest brix values were obtained from Cowley, M81E, N98, Nebraska sugar, P1579753, Rio and Wray genotypes. Similar results were obtained by some researchers. Studies conducted on sweet sorghum have shown that brix values ranged from 11.4% to 15.6% [10], from 16.0% to 22.7% [11] and from 14.2% to 17.1% [12], from 13.50% to 18.25% [14]. Similar brix values were reported as %8-17 [15], %

6.2-20.7 [16] and %12.5-17 [17]. Brix is soluble dry matter in liquids, in that, the value of brix refers to the amount of sugar in plant juice. When the brix augmented, sugar yield increase.

2.5. Sugar Yield (kg da^{-1})

Differences among tested sweet sorghum genotypes for sugar yield was significant (P≤0.01). Sugar yield ranged between 247.7 kg da^{-1} (USDA-Uganda) and 1906.1 kg da^{-1} (Nebraska Sugar). Sugar yields were higher at Nebraska Sugar, Smith, Gulseker, M81E and Corina genotypes. Studies conducted on sweet sorghum have shown that sugar yield ranged from 286 to 401 kg da^{-1} in sweet sorghum varieties (Wray, Keller, Rio) [11], from 240 to 290 kg da^{-1} [12] and 1320 kg da^{-1} [18]. Sugar is the most important substance for getting ethanol. Sugar in plant juice convert to ethanol via fermentation. Sugar amount affect directly amount of ethanol. The more sugar in the plant juice means that, the more ethanol.

2.6. Theoretical Ethanol Yield (L da^{-1})

According to variance analyses theoretical ethanol yield was significant (P≤0.01). Theoretical ethanol yield was the highest in Nebraska sugar genotype as 1014.8 L da^{-1} whereas the lowest ethanol yield was seen at USDA-Uganda genotype as 131.9 L da^{-1}. Nebraska sugar, Topper 76, Smith, Cowley, Grassi and Corina genotypes gave higher ethanol yield than others. Ethanol yield was reported as 768.2 L da^{-1} [18] and 924-1051 L da^{-1} [19], 214.3 to 464.5 L da^{-1} [14] in sweet sorghum. Different ethanol yield values were reported by some researchers. Smith and Buxton [20] stated that 600 L da^{-1} ethanol yield was found in Iowa. Ethanol yield values reported as 125- 562.5 L da^{-1} by Li [21] and 81.16-345.85 L da^{-1} by Teetor et al. [22].

Obviously, the higher the sugar content in the stalks, the higher the potential ethanol yield. An important quality factor is the sugar content of the syrup, because the sugars (total soluble solids) are fermented into ethanol. This ethanol can be used as a blending substance with fossil fuel to produce biofuel. The main requirement for first generation bio-ethanol production is a Brix of 16% and above [23].

4. CONCLUSION

Based on the research results; sweet sorghum stalk yield ranged from 7110.0 kg da^{-1} (Norkan) to 24262.5 kg da^{-1} (Topper 76). The highest juice yield value (12187.5 L da^{-1}), syrup yield (2242.5 L da^{-1}), sugar yield (1906.1 kg da^{-1}) and theoretical ethanol yield (1014.8 L da^{-1}) obtained from Nebraska sugar genotype. Considering to stalk yield, juice and syrup yield, brix, sugar yield and theoretical ethanol yield; Nebraska sugar, Topper 76, Smith, M81E and Corina genotypes were found as the best.

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