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Şanlıurfa Ekolojik Koşullarında Farklı Tatlı Sorgum (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.) Genotiplerinin Lignoselülozik Biyoetanol Verimleri

Ayşegül EFENDİOĞLU ÇELİK[1*], Mine AKSOY[2], Mahmut DOK[1], Kadir AYDIN[3], Celal YÜCEL[4]

Öne Çıkanlar:
- Çalışmada 21 farklı tatlı sorgum genotipi kullanıldı
- Herbir genotipin lignoselülozik biyoetanol verimi belirlendi
- En yüksek lignoselülozik biyoetanol verimi UNL-Hybrid-3 genotipinden elde edildi

Anahtar Kelimeler:
- Yenilenebilir enerji
- Selüloz
- Tatlı sorgum
- Posa

ÖZET:

Yenilenebilir enerji kaynağı olarak birim alanda yüksek biyokütle verimine sahip olan, birinci derecede gıda amaçlı olarak tüketilmeyen veya çok amaçlı olarak kullanılabilen ürünlerin kullanımı gıda güvenliği açısından büyük önem arz etmektedir. Bu amaçla, tuzlu-alkali topraklarda yetişebilen, kuraklığa ve kısa süreli su baskınlarına toleranslı, geniş adaptasyon yeteneğine sahip olan tatlı sorgum bitkisi lignoselülozik biyoetanol hammaddesi olarak son yıllarda oldukça önem kazanmıştır. Bu çalışmanın amacı, tohumu yurtiçi ve yurtdışı kaynaklardan temin edilen, Şanlıurfa ili ekolojisinde ikinci ürün koşullarında yetiştirilen 21 farklı tatlı sorgum (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.) genotipinin lignoselülozik biyoetanol verimini teorik olarak belirlemektir. Çalışmada lignoselülozik biyoetanol hammaddesi olarak bitki özsuyu alınan tatlı sorgum posaları kullanılmıştır. Posaların selüloz ve hemiselüloz içeriği belirlenmiş ve biyoetanole dönüşüm oranlarından faydalanılarak dekara elde edilebilecek lignoselülozik biyoetanol miktarı hesaplanmıştır. Elde edilen verilere göre en yüksek verim UNL-Hybrid-3 (805.5 L/da), Theis (766.5 L/da), Smith (698.1 L/da) genotiplerinden elde edilmiştir. Benzinin oktanını artırmak, sera gazı emisyonu ve benzin ithalatını azaltmak gibi sorunları çözmek için, Şanlıurfa ekolojik koşullarında bu üç genotipin lignoselülozik biyoetanol üretimi amaçlı olarak yetiştirilmesi ve yaygınlaştırılması önerilmektedir.

Lignocellulosic Bioethanol Efficiency of Different Sweet Sorghum (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.) Genotypes in Şanlıurfa Ecological Conditions

Highlights:
- 21 different sweet sorghum genotypes were used in the study
- Lignocellulosic bioethanol yield of each genotype was determined
- The highest lignocellulosic bioethanol yield was obtained from the UNL-Hybrid-3 genotype

Keywords:
- Renewable energy
- Cellulose
- Sweet sorghum
- Pulp

ABSTRACT:

The use of products with high biomass yield per unit area as a renewable energy source, which are not consumed primarily for food purposes or can be used for multi-purposes, is of great importance in terms of food safety. For this purpose, sweet sorghum plant, which can grow in salty-alkaline soils, tolerant to drought and short-term floods, and has wide adaptability, has gained importance as a lignocellulosic bioethanol raw material in recent years. The aim of this study is to theoretically determine the lignocellulosic bioethanol yield of 21 different sweet sorghum (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.) genotypes grown under second crop conditions in the ecology of Şanlıurfa province, obtained from domestic and foreign sources. In the study, sweet sorghum pulp from plant sap was used as lignocellulosic bioethanol raw material. The cellulose and hemicellulose contents of the pulp were determined and the amount of lignocellulosic bioethanol that could be obtained per decare was calculated by using the bioethanol conversion rates. According to the data obtained, the highest yield was obtained from UNL-Hybrid-3 (805.5 L/da), Theis (766.5 L/da), Smith (698.1 L/da) genotypes. In order to solve problems such as increasing the octane of gasoline, reducing greenhouse gas emissions and gasoline imports, it is recommended that these three genotypes be cultivated and disseminated for lignocellulosic bioethanol production in Şanlıurfa ecological conditions.

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INTRODUCTION

Today, increasing energy consumption in parallel with economic growth and the use of fossil fuels cause an increase in greenhouse gas emissions and climate change. For this purpose, researchers in our country as well as in all countries of the world have focused on renewable and sustainable energy sources for the production of alternative biofuels based on biomass. Biofuels, such as bioethanol, biomethanol, biodiesel biomethane, etc., can be obtained from biomass. Studies have shown that biofuel products create fewer greenhouse gas emissions than fossil fuels and are effective in controlling global warming (Lal, 2008). Bioethanol, which is a good alternative especially for the transportation sector, is planned to completely replace fossil fuels in the future (Kaplan et al., 2009).

Unlike fossil fuels, bioethanol is an alternative biofuel that can be produced by fermentation of sugar from plants containing starch (first generation raw material) or lignocellulose (second generation raw material) and can be used alone or mixed with gasoline (Balat & Balat, 2009). Sugary, starchy and cellulose containing plants and residues such as sugar beet, sugar cane, corn, wheat, sweet sorghum, potatoes, woody and agricultural wastes are used in bioethanol production (Buresova & Hrivna, 2011).

In terms of food safety, it is of great importance that the plants to be used for energy purposes are plants that are not used as food raw materials, are easily and abundantly available, and have high biomass yield. Sweet sorghum, which has high biomass yield, drought tolerance and wide adaptability, has started to take place in the country's agriculture due to its lower cultivation cost and advantages in bioethanol production. In addition, sweet sorghum is seen as a valuable energy plant due to the non-structural carbohydrates (sucrose, glucose and fructose) and structural carbohydrates (cellulose and hemicellulose) contained in its pulp (Aksoy et al., 2023).

Sweet sorghum (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.) is a grassy plant with high photosynthetic activity due to being a C4 plant belonging to the Poaceae family (Shinde et al., 2013). In this respect, sweet sorghum is a promising or important plant for low-cost bioethanol production that can be used for many purposes (Wang & Liu, 2009). Obtaining must from the stalks of sweet sorghum for bioethanol production, making energy production and plastic production from the rest of the stalk, using the grain for human food, animal feed, ethanol production, making its pulp and green leaves an excellent feed, organic fertilizer, cellulosic raw material in industry, food, Its importance is increasing day by day as it has many uses such as sugar and pulp (Miller & Creelman, 1980; Almodares et al., 1999, Negro et al., 1999; Chiaramonti et al., 2004; Gnansounous et al., 2005; Reddy et al., 2005; Zhao et al., 2009; Nahar, 2011; Almodares et al., 2013). Sweet sorghum is also called “smart crop” in international literature because it has many uses (Kumar et al., 2010).

Sweet sorghum, which has wide adaptability, has the potential for rapid growth, high sugar accumulation and high biomass production (Reddy & Sanjana, 2003). The use of both the juice and pulp of sweet sorghum in bioethanol production increases the bioethanol productivity per unit area (Dolciotti et al., 1998).

Sweet sorghum stalks contain 43.6%-58.2% soluble sucrose, glucose and fructose (Amaducci et al., 2004) and 22.6-47.8% insoluble cellulose and hemicellulose (Dolciotti et al. 1998). When the sorghum plant is considered as a whole, it contains 12.4% cellulose, 10.2% hemicellulose, 4.8% lignin, 55% sucrose, 3.2% glucose and 0.3% ash (Billa et al., 1997).

The lignocellulosic residue remaining after the fermentable sap is separated from sweet sorghum contains significant amounts of polymeric carbohydrates (cellulose and hemicellulose). These polysaccharides can be hydrolyzed to sugars and then to second generation bioethanol by fermentation. In a study conducted in 2014, it was reported that sorghum pulp contains 27-48% cellulose, 19-24%

hemicellulose and 9-32% lignin, and lignocellulosic bioethanol can be obtained with a yield of 69.49% when optimum conditions are met (Yu et al. 2014). Guimaraes et al. (2014) determined the yield values of cellulose, hemicellulose, lignin and theoretical ethanol as 21.4%-49.1%, 18.4%-34.8%, 1.8-11.5% and 221-412 L/ton, respectively, in their modeling study with 957 sweet sorghum plants consisting of 100 hybrids.

Korpos et al. (2008) reported that 8-10 tons of fresh grass were taken from sweet sorghum in Hungarian conditions, and after pressing and extracting the sap, 4-5 tons/da of lignocellulosic raw material was obtained. In the same study, it was reported that a total of 829 L of bioethanol would be obtained, 373 L from the plant sap and 456 L from the pulp.

This study aims to determine the chemical composition of the pulp obtained from 21 different sweet sorghum genotypes grown as a secondary crop in Şanlıurfa province conditions and the genotypes from which lignocellulosic bioethanol will be obtained with the highest yield. Thus, it is to contribute to the economy by bringing high-efficiency alternative energy sources to the country's agriculture and to prevent harmful gas emissions by using clean energy.

MATERIALS AND METHODS

Materials

In the study, 21 different sweet sorghum genotypes, whose seeds were obtained from different domestic and foreign sources, were used (**Table 1**).

Table 1. Sweet sorghum genotype names used in the study

No	Genotype Name	No	Genotype Name	No	Genotype Name
1	Corina[a]	8	Ramada[a]	15	UNL-hybrid -3[a]
2	Cowley[a]	9	Rio[a]	16	Williams[a]
3	Grass1[a]	10	Roma[a]	17	Wray[a]
4	M81-E[a]	11	Smith[a]	18	No91(653411,Taiwan)[b]
5	N98[a]	12	Theis[a]	19	No5 (144134, USDA South Africa)[b]
6	Nebraska sugarcane[a]	13	Topper 76[a]	20	No41 (156890, USDA Zaira) [b]
7	P1579753[a]	14	Tracy[a]	21	Gülşeker (Türkiye)[c]

[a]: Nebraska University-Prof. Dr. Ismail Dweikat-USA
[b]: Bati Akdeniz Agricultural Research Institute, Antalya-Türkiye
[c]: Uludağ University, Bursa-Türkiye

Method

Field experiments of the study were carried out at the GAP Agricultural Research Institute, Talat Demirören Research Station in Şanlıurfa province, and laboratory studies were carried out at the Energy Agriculture Research Center Laboratory within the Black Sea Agricultural Research Institute.

The research station where the study was conducted is at 36º 42' north latitude, 38º 58' east longitude, and its altitude is 410 m above sea level (Anonymous, 2020). The physical and chemical analysis of soil samples taken from 0-15 and 15-30 cm depth of the experiment field were carried out in the Laboratory of Plant Nutrition and Soil Department of Çukurova University Faculty of Agriculture (Table 2). The soils in this area are with alluvial parent material, flat and almost flat slopes, and deep profiles. Typical red profiles have a clayey texture and the entire profile is very calcareous. The soils are with A, B, C horizons, pH between 7.3 and 7.8, low organic matter content and high cation exchange capacity. Cation exchange capacity increases towards the lower layers depending on the clay content (Dinç et al. 1988).

Table 2: Some physical and chemical properties of the soil experiment area

Years	Depth (cm)	pH	EC 1:2.5	N (%)	OC (%)	P (mg/kg)	$CaCO_3$ (%)	Sand (%)	Silt (%)	Clay (%)	Texture Class
2016	0-15	7.68	0.34	0.08	0.40	0.45	46.6	29	27	44	C
	15- 30	7.65	0.30	0.06	0.34	0.39	44.5	28	27	45	C
2017	0-15	7.70	0.37	0.07	0.50	0.50	47.0	30	26	44	C
	15- 30	7.74	0.36	0.05	0.40	0.41	45.5	29	26	45	C

Although Şanlıurfa falls into the continental climate region, the influence of the Mediterranean climate is observed. Summers are dry and hot, and winters are mild. During the summer season, Basra is mostly under the influence of the dry and hot tropical air mass settled in the low pressure center. Daytime temperature rises above 40 ºC. Too low relative humidity increases evaporation (Atalay and Mortan, 2006).

After harvesting 21 sweet sorghum genotypes grown in Şanlıurfa province conditions in 2016 and 2017, sorghum stems from which leaves and inflorescences were taken were squeezed and the sap was taken.

500 g wet sample was taken from each genotype pulp to represent the whole and dried and ground in a drying cabinet at 65-70 ºC until it reaches a constant weight. Neutral detergent fiber (NDF=cellulose+hemicellulose+lignin), acid detergent fiber (ADF=cellulose+lignin) and acid detergent lignin (ADL=lignin) contents of the prepared samples were determined using ANKOM 200 Fiber Analyzer device (Kutlu, 2008). Then, using the conversion rates in the literature, the amount of lignocellulosic bioethanol to be obtained from 1 ton of raw material from the percentages of ADF, NDF and ADL was calculated theoretically. In Table 3 and Table 4, the conversion rates used to calculate the amount of lignocellulosic bioethanol to be obtained from 1 ton of raw material (based on the cellulose and hemicellulose content of the raw material) are given step by step (Badger, 2002).

In addition, the theoretical lignocellulosic bioethanol yields per decare were calculated in liters by taking into account the dry matter yields per decare of sweet sorghum genotypes.

Table 3. Bioethanol efficiency of glucose

Dry Raw Material	1 ton (1000 kg)
Cellulose Content	x 0.45
Cellulose Conversion and Recovery Efficiency	x 0.76
Stoichiometric Bioethanol Yield	x 0.51
Fermentation Efficiency of Glucose	x 0.75
Bioethanol Efficiency of Glucose	131 kg = 151 L bioethanol

Table 4. Bioethanol efficiency of xylose

Dry Raw Material	1ton (1000 kg)
Hemicellulose Content	x 0.29
Hemicellulose Conversion and Recovery Efficiency	x 0.90
Stoichiometric Bioethanol Yield	x 0.51
Fermentation Efficiency of Xylose	x 0.50
Bioethanol Efficiency of Xylose	66 kg bioethanol = 76 L bioethanol

All the data obtained were subjected to a combined analysis of variance according to the randomized blocks experimental design using the JUMP software package and the averages were compared according to the multiple comparisons Tukey test (Yurtsever, 1984).

RESULTS AND DISCUSSION

Cellulose and Hemicellulose Contents of Sweet Sorghum Pulp

Cellulose and hemicellulose, which are the main polysaccharides of biomass, affect the efficiency of enzymatic hydrolysis and the amount of ethanol obtained accordingly. For this reason, in the study, cellulose and hemicellulose contents of different sweet sorghum genotypes pulp grown in Şanlıurfa province conditions in 2016 and 2017 were determined on the basis of dry matter. The obtained values and variance analysis results are given in Table 5 and Table 6 comparatively.

Table 5. Cellulose contents of the pulp of sweet sorghum genotypes grown in Şanlıurfa province conditions.

Genotype Name	Cellulose (%)		
	2016	**2017**	**Average**
Corina	36.88 efg	34.61 de	35.74 efg
Cowley	36.61 efg	33.08 fg	34.84 ghı
Grass1	**40.27 a**	35.36 cd	37.81 bc
M81-E	36.06 gh	34.01 ef	35.04 fgh
N98	33.38 j	39.26 a	36.32 de
Nebraska sugarcane	33.24 j	33.02 fg	33.13 j
P1579753	39.06 abc	35.36 cd	37.21 cd
Ramada	34.01 ıj	36.34 c	35.18 fgh
Rio	34.04 ıj	35.91 c	34.97 gh
Roma	37.89 cde	30.78 ı	34.34 hı
Smith	37.30 d-g	32.75 gh	35.03 gh
Theis	37.60 def	33.89 efg	35.74 efg
Topper 76	**31.75 k**	**30.72 ı**	**31.23 k**
Tracy	37.26 d-g	33.20 fg	35.23 fgh
UNL-hybrid-3	40.14 a	35.43 cd	37.79 bc
Williams	36.23 fgh	31.78 hı	34.01 ıj
Wray	35.08 hı	36.22 c	35.65 efg
No91	36.54 efg	35.35 cd	35.94 ef
No5	39.68 ab	31.13 ı	35.40 efg
No41	39.02 abc	37.87 b	38.45 ab
Gülşeker	38.46 bcd	**39.81 a**	**39.14 a**
Average	**36.69**	**34.57**	
CV (%)			1.41
F genotype			**
F year			**
F genotype×year interaction			**

** There is a statistically significant difference between genotypes at the P≤0.01 level

According to the results of the analysis of variance, a statistically significant difference was found at the P≤0.01 level between the genotype, year and genotype×year interaction in terms of cellulose content (Table 5). According to the results of the combined two-year analysis, the cellulose content of sweet sorghum pulp varies between 30.72-40.27%. The highest cellulose content was obtained in the Grassi genotype (40.27%) in the first year of the study, and the lowest cellulose content was obtained in the Topper 76 genotype (30.72%) in the second year of the study. Although the average cellulose content varied between 31.23% and 39.14%, the lowest was observed in the Topper 76 genotype and the highest in the Gülşeker genotype. Considering the year averages, the cellulose content in the first year of the study (36.69%) was found to be higher than in the second year (34.57%).

According to the results of the analysis of variance in the hemicellulose content, a statistically significant difference was found at the P≤0.01 level between the genotype, year and genotype×year interaction (Table 6). According to the results of the two-year combined analysis, the hemicellulose content of sweet sorghum pulp was determined to vary between 18.34-24.90%. The highest hemicellulose content was obtained in the No41 genotype (24.90%) in the second year of the study, and the lowest hemicellulose content was obtained in the Ramada genotype (18.34%) in the second year of the study. Although the average hemicellulose content varied between 19.70-23.51%, the lowest content was observed in the Ramada genotype, and the highest content was observed in the No41 genotype.

Table 6. Hemicellulose contents of the pulp of sweet sorghum genotypes grown in Şanlıurfa province conditions.

Genotype Name	Hemicellulose (%)		
	2016	**2017**	**Average**
Corina	22.11 bc	19.89 fgh	21.00 d-h
Cowley	22.22 bc	18.99 gh	20.61 e-h
Grass1	**24.34 a**	21.44 c-f	22.89 ab
M81-E	20.92 b-e	22.70 bcd	21.81 b-e
N98	21.21 b-e	21.67 c-f	21.44 c-g
Nebraska sugarcane	20.03 de	21.58 c-f	20.80 d-h
P1579753	24.19 a	21.43 c-f	22.81 abc
Ramada	21.06 b-e	**18.34 h**	**19.70 h**
Rio	22.56 ab	20.77 d-g	21.67 b-f
Roma	22.31 bc	19.98 fgh	21.15d-g
Smith	20.63 cde	20.03 e-h	20.33 fgh
Theis	21.40 bcd	24.51 ab	22.96 ab
Topper 76	21.41 bcd	18.91 gh	20.16 gh
Tracy	21.26 b-e	19.71 fgh	20.48e-h
UNL-hybrid-3	21.38 bcd	20.23 e-h	20.80 d-h
Williams	21.47 bcd	19.60 fgh	20.53 e-h
Wray	20.80 b-e	23.32 abc	22.06 bcd
No91	20.95 b-e	23.43 abc	22.19 a-d
No5	22.59 ab	21.63 c-f	22.11 a-d
No41	22.12 bc	**24.90 a**	**23.51 a**
Gülşeker	**19.50 e**	22.19 cde	20.85 d-h
Average	**21.64**	**21.20**	
CV (%)			3.58
F genotype			**
F year			**
F genotype×year interaction			**

** There is a statistically significant difference between genotypes at the $P \leq 0.01$ level

Han et al. (2013) conducted a study to determine the cellulose and hemicellulose contents of the stalk and pulp of the sweet sorghum plant for ethanol production potential. In the study, the cellulose content for Dale, M81-E, Topper and Theis varieties was 30.5%, 32.1%, 33.1% and 34.4%, respectively, and the hemicellulose content; respectively, 23.9%, 26.4%, 27.0% and 27.8%. In this study, cellulose and hemicellulose contents of M81-E, Topper and Theis cultivars grown in Şanlıurfa province conditions were similar.

Marx et al. (2014), in their study on bioethanol production from sweet sorghum pulp using microwave irradiation, determined the cellulose and hemicellulose contents of sweet sorghum pulp as 36.60% and 22.96%, respectively. Umagiliyage et al. (2015) found the cellulose and hemicellulose contents of sweet sorghum pulp to be 36.9±1.6% and 17.8±0.6%, respectively, in their study on improving the enzymatic hydrolysis of sweet sorghum pulp. Barcelona et al. (2016), in their study on ethanol production from sweet sorghum, determined the cellulose and hemicellulose contents of sweet sorghum pulp as 40.4±2.6% and 20.0±2.5%, respectively.

In the study conducted with six hybrid sorghum biomass in two different regions of Minas Gerais State for the production of lignocellulosic bioethanol; It has been determined that the average cellulose content of the hybrids varies between 35.81% and 39.07%, and the average hemicellulose content varies between 25.34-28.91% (Almeida et al., 2019).

When the average cellulose and hemicellulose contents of the studied sorghum genotypes were examined, it was observed that similar results were obtained with the studies.

Theoretical Lignocellulosic Bioethanol Yield of Sweet Sorghum Pulp

The theoretical lignocellulosic bioethanol yield values and multiple comparisons of the pulp obtained from different sweet sorghum genotypes grown in Şanlıurfa province conditions in 2016 and 2017 are given in Table 7.

According to the results of the analysis of variance in the theoretical lignocellulosic bioethanol yield, a statistically significant difference was found at the P≤0.01 level between the genotype, year and genotype×year interaction (Table 7). According to the combined two-year analysis, it was determined that the theoretical lignocellulosic bioethanol yield ranged between 168.2-219.2 L/ton raw material. The highest theoretical lignocellulosic bioethanol yield was obtained in Grassi genotype in the first year of the study, and the lowest yield was obtained from Topper genotype in the second year of the study.

Table 7. Theoretical lignocellulosic bioethanol yields of pulp of sweet sorghum genotypes grown in Şanlıurfa province conditions.

Genotype Name	Theoretical Lignocellulosic Bioethanol Yield (L/ton raw material)		
	2016	**2017**	**Average**
Corina	200.2 efg	185.4 f	192.8 f-ı
Cowley	199.5 efg	177.1 hı	188.3 jkl
Grassi	**219.2 a**	192.6 cd	205.9 b
M81-E	193.7 hıj	191.3 cde	192.5 ghı
N98	184.7 lm	207.7 a	196.2 c-f
Nebraska sugarcane	180.7 mn	184.4 fg	182.6 m
P1579753	214.3 ab	192.6 cd	203.5 b
Ramada	186.6 kl	187.3 ef	186.9 kl
Rio	191.0 ıjk	192.7 cd	191.9 hıj
Roma	204.5 de	171.5 jk	188.0 kl
Smith	197.4 fgh	178.9 hı	188.2 kl
Theis	200.8 ef	196.1 bc	198.5 cd
Topper 76	**179.3 n**	**168.2 k**	**173.7 n**
Tracy	199.1 fg	179.7gh	189.4 ıjk
UNL-hybrid-3	210.1 bc	189.4 def	199.7 c
Williams	195.9 f-ı	174.1 ıj	185.0 lm
Wray	189.7 jkl	201.3 b	195.5 d-g
No91	195.6 ghı	198.4 b	197.0 cde
No5	211.9 bc	177.6 hı	194.8 e-h
No41	208.1 cd	**212.0 a**	**210.0 a**
Gülşeker	198.4 fgh	211.2 a	204.8 b
Average	**198.1**	**189.0**	
CV (%)			1.03
F genotype			**
F year			**
F genotype×year interaction			**

** There is a statistically significant difference between genotypes at the P≤0.01 level

The average variety ranged between 173.7-210.0 L/ton raw material and the lowest value was in Topper 76 genotype, followed by Nebraska sugarcane and Williams genotypes, respectively.

Considering the year averages, while the theoretical average lignocellulosic bioethanol yield was 198.1 L/ton raw material in 2016, it was found to be 189.0 L/ton raw material in 2017.

In the study, the theoretical lignocellulosic bioethanol yield per decare (L/da) was calculated by considering the dry matter yields per decare of sweet sorghum genotypes and given in Table 8 with multiple comparisons.

According to the results of the analysis of variance, a statistically significant difference at the level of P≤0.01 was found between genotype, year, genotype×year interaction in terms of theoretical lignocellulosic bioethanol yield per decare. According to the two-year pooled analyzes, the theoretical lignocellulosic bioethanol yield ranged from 414.9 to 834.3 L/da. The highest theoretical lignocellulosic bioethanol yield was obtained in the UNL-hybrid-3 genotype in the first year of the study, and the lowest in the N98 genotype in the first year of the study. The genotype average ranged between 474.7-805.5 L/da, and the lowest yield was observed in Williams genotype, while the highest yield was observed in UNL-hybrid-3 genotype. Considering the year averages, it was determined that the average theoretical lignocellulosic bioethanol yield in the first year of the study was 622.9 L/da, and the yield in the second year was 575.5 L/da.

Table 8. Theoretical lignocellulosic bioethanol yields of the pulp of sweet sorghum genotypes grown in Şanlıurfa province conditions (based on dry matter).

Genotype Name	**Theoretical Lignocellulosic Bioethanol Yield (L/da)**		
	2016	**2017**	**Average**
Corina	592.7 b-g	537.4 c-g	565.1 d-h
Cowley	580.9 b-g	542.3 c-f	561.6 d-h
Grassi	673.0 a-e	558.5 c-f	615.7 cde
M81-E	686.9 a-d	583.9 b-e	635.4 cde
N98	**414.9 g**	597.1 bcd	506.0 fgh
Nebraska sugarcane	443.7 fg	553.5 c-f	498.6 gh
P1579753	769.2 ab	529.6 d-g	649.4 cde
Ramada	584.7 b-g	632.0 bc	608.3 c-f
Rio	552.9 c-g	592.6 bcd	572.7 d-h
Roma	633.3 b-f	519.0 d-g	576.2 d-h
Smith	725.1 abc	671.0 b	698.1 abc
Theis	755.7 ab	**777.2 a**	766.5 ab
Topper 76	664.7 a-e	538.2 c-f	601.5 c-g
Tracy	554.0 c-g	530.0 d-g	542.0 e-h
UNL-hybrid-3	**834.3 a**	776.7 a	**805.5 a**
Williams	479.3 efg	470.2 fg	**474.7 h**
Wray	478.0 efg	493.6 efg	485.8 h
No91	755.3 ab	580.3 b-e	667.8 bcd
No5	659.4 a-e	**439.6 g**	549.5 e-h
No41	717.5 a-d	556.5 c-f	637.0 cde
Gülşeker	525.0 d-g	607.4 bcd	566.2 d-h
Average	**622.9**	**575.5**	
CV (%)			9.92
F genotype			**
F year			**
F genotype×year interaction			**

**There is a statistically significant difference between genotypes at the P≤0.01 level

In a study conducted with six sweet sorghum cultivars planted in the Pacific coastal plains of Guatemala, the average bioethanol yield was found to be 220 g bioethanol/kg on dry matter basis and 2465 L bioethanol per hectare (Cifuentes et al., 2014). In another study, it was tried to determine the amount of bioethanol obtained from the biomass of three sorghum cultivars (Rona 1, Santos, Sucrosorgo 506) grown as the main crop and second crop in central and eastern Europe with a temperate climate.

As a result of the study, it was determined that the amount of bioethanol that could be obtained from the main product was higher than the second product, and the highest average bioethanol yield was obtained from Sucrosorgo 506 variety (22.84 m^3/ha) in the second year of the study (Batog et al., 2020).

Frankowski et al. (2022) reported that the amount of lignocellulosic bioethanol obtained in their study with five different types of sweet sorghum pulp in Polish conditions varied between 2.89-9.48 m^3/ha. In another study conducted in Ukraine, it was reported that 11.4 m^3 of bioethanol will be obtained per hectare from sweet sorghum pulp (Rakhmetova et al., 2020).

In this study, the highest theoretical lignocellulosic bioethanol yield was obtained from the UNL-hybrid-3 genotype as 805.5 L/da.

CONCLUSION

The addition of bioethanol to gasoline as an octane-increasing additive or its use as an alternative contributes to meeting the energy need, but it is important because it reduces environmental pollution and contributes to the country's economy. Research and adaptation studies should be focused on agricultural products that are low in cultivation cost for bioethanol production, have high unit area yield and are not used directly as human and animal food.

In this study, which was carried out to determine the genotypes of sweet sorghum plant suitable for the conditions of Şanlıurfa province, with high yield and biofuel potential; It has been determined that the adaptation ability of the plant to the region is high. It has been determined that sweet sorghum is a plant that can be used both as an energy plant and in animal nutrition since a high amount of biomass is obtained from the sweet sorghum plant.

As a result of the 2-year study conducted in Şanlıurfa province conditions, it was observed that the theoretical lignocellulosic bioethanol yield of different sweet sorghum genotypes pulp varied between 474.7-805.5 L/da. It was calculated that Smith, Theis, UNL Hybrid-3 genotypes among the studied genotypes had the highest lignocellulosic bioethanol yield and 698.1 L, 766.5 L and 805.5 L lignocellulosic bioethanol could be obtained per decare, respectively. It has been concluded that the varieties in question are suitable for the region and that they can be grown in large areas. In addition, within the scope of the study, the potential for energy use of sweet sorghum plant, which has a wide variety of uses, was also evaluated. Considering all the analyzes made, it was seen that the bioethanol obtained from the sweet sorghum plant can be considered as a source of bioethanol that can be obtained directly from the stems or from the pulp remaining after the must is taken. As a result, it has been determined that the sweet sorghum plant has the potential as an environmentally friendly, sustainable, renewable source of both liquid and solid biofuels and can be a raw material source in the production of alternative fuels to fossil fuels.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

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