Investigation of Forage Sorghum (*Sorghum bicolor* L.) Genotypes for Yield and Yield Components

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Abstract

The objective of this study was to evaluate the genetic variability of forage sorghum genotypes and to estimate genotypic, phenotypic, and environmental correlations with path and stability analysis. The experiments were conducted in Antalya and Konya locations of Turkey during 2014-2015 years by using 48 selected forage sorghum lines and 4 sorghum varieties. Experimental design was the randomized complete block, with three replications. Significant variations were recorded for all the characters among the genotypes. The highest plant height has been optained from 355.2 cm and 300.1 cm in Antalya and Konya location respectively. Days to 50% flowering ranged from 64.8-101.3 days in Antalya and 69.0-111.2 days in Konya. The highest forage yield was observed in Line-22 with 99.1 tha^{-1} in Antalya and in Line-41 with 75.5 tha^{-1} in Konya. Forage yield was significantly and highly positively correlated with hay yield (r = 0.9851**), plant leaf ratio (r=0.3478*) and stalk yield (r=0.9901**). Path analysis revealed the plant stalk ratio direct positive effect on forage yield. On the other hand, plant stalk yield had negative direct effect through forage yield. According to results of the stability analysis, Line-1, 3, 5, 13, 21, 40, 42 and 44 were the most stable varieties.

Introduction

Sorghum (*Sorghum bicolor* L.) is a very important crop under rainfed areas because of its drought tolerance capability while still maintaining high productivity (Turner *et al.*, 2016). Sorghum has highly variable genetic resources and many germplasms that allows the breeding and development of new varieties adapted to different ecological regions around the world (Zhang *et al.*, 2010; Tariq *et al.*, 2012). Sorghum production and utilization is widespread in the world, it is estimated that total sorghum harvesting area is approximately 42.0 million hectares in the world (FAO, 2018). While the demand for sorghum production increases in the world, the production in Turkey is insufficient. Sorghum is grown on 1790 ha in our country (TUIK, 2018). There are various reasons why sorghum is not widespread enough. The most important reason that stands out is the lack of sufficient sorghum varieties. Breeders seek to develop new varieties that are highly efficient and compatible with every environment. The desired variety is one that would be adapted to a wide range of growing conditions in a given production area. In other word, the cultivars need to be tolerant to different stress conditions and high yield performance when production conditions become more favorable (Al-Naggar *et al.* 2018). In this respect, plant breeders should purpose to improve new cultivars that are adapted to various environmental conditions. Because of wide adaptation capacities of sorghum there are potentiality develop stable and high-yielding genotypes for different environments. Plant breeders utilize that investigation of the variability existing in a population, in order to new varieties improvement.

Many researches have been studies on sorghum in different regions of Turkey. In this study, plant height was observed 185.4-476.3 cm by Uzun *et al.* (2017), Coban and Acar (2018), Kara *et al.* (2019), Keskin *et al.* (2018), Yıldız *et al.* (2018), Kaplan *et al.* (2019), Demir (2020), and Aydinsakir *et al.* (2021a). Forage yield of sorghum was measured 6.9-34.2 t ha^{-1} by Cigdem and Uzun (2005), Yuksel, (2006), Karadag and Ozkurt (2013), Uygur (2012), Ozkose *et al.* (2015). Furthermore, Oten (2017) reported that the Mediterranean region is suitable for the cultivation of various forage crops due to the soil structure and climate. Ozkose *et al.* (2015) stated that sorghum cultivation for silage is very limited in Konya; however, applying the appropriate regional varieties of agricultural production techniques in a good

Table 1 - Variance analysis related to plant height, days to 50% flowering,forage yield, hay yield, plant stalk ratio, plant leaf ratio and stalk yield in 2014-2015

	Plant height (cm)	Days to %50 flowering (Day)	Forage yield (t ha^{-1})	Hay yield (t ha^{-1})	Plant stalk ratio (%)	Plant leaf ratio (%)	Stalk Yield (t ha^{-1})
Years							
2014	266.6	88.3	50.6	13.8	20.3	79.7	40.7
2015	253.2	88.4	42.3	11.5	19.1	80. 9	34.3
Locations							
Antalya (2014)	284.9	75.4	57.7	15.8	19.5	80.5	46.4
Antalya (2015)	248.3	101.2	43.6	11.8	21.2	78.8	34.9
Konya (2014)	271.1	95.7	42.8	11.8	20.7	79.2	34.1
Konya (2015)	235.4	81.2	41.7	11.3	17.4	82.6	34.6
				ANOVA			
Y	**	ns	**	**	**	**	**
L	**	**	**	**	**	**	**
G	**	**	**	**	**	**	**
Y × L	**	**	**	**	**	**	**
Y × G	**	**	**	**	**	**	**
G × L	**	**	**	**	**	**	**
Y × G × L	**	**	**	**	**	**	**

**: P≤0.01, ns: non-significant Y: Year, L: Locations, G:Genotypes

way with this, efficiency and production can reach the desired levels. Many researchers have been working with sorghum in Turkey, however, studies on the adaptation of sorghum in different envorimentand the other featuresvery limited, especially regarding the characteristics that influence yield production. The study of determining the relationship between yield and yield components of sorghum leads to greater efficiency and reliability when combined with other analyses, such as correlations, path and stabilty analysis. Thus, the objective of this study was to know interrelationship with yield utilizing the correlation, path and stability analysis for selected forage sorghum.

Material and methods

Germplasm

A sorghum set, total of 561 sorghum genotypes, collected around the world was evaluated for different aims in Tukey's agro-ecological conditions in 2013. Detailed information about the germplasm was given in the previous studies by Guden *et al.* (2019) and Guden *et al.* (2021). The collection consists of 309 genotypes provided by the United States Department of Agriculture, Agricultural Research Service (USDA), 242 genotypes provided from India (ICRISAT), 9 varieties developed by Bati Akdeniz Agricultural Research Institute, Antalya-Turkey (BATEM) and 1 variety belonging to Uludag University, Turkey. This collection was tested in Antalya (Turkey) ecological conditions in 2013 and 48 genotypes were selected based on potential forage performances and breeder recommendations. In this study forage performance of the selected 48 sorghum genotypes from the sorghum collection were assessed. The country origine and information about the germplasm was presented in supplementary file Table 1.

Experimental site and design

The field trials of this study were carried out at 2 locations and 2 years (2014 and 2015). First location is namely Konya in Middle Anatolian Region; second location is namely Antalya in Mediterranean Region. Experimental materials were sown on May 06, 2014, May 04 2015 in Antalya and on May 20, 2014, May 25 2015 in Konya. Two locations experiments were grown in randomized complete block design in three replications. Each experimental plot consisted of four row, 5 m length and 0.70 m inter-row. Therefore, the experimental plot area for each genotype was 14 m^2. Data was taken on the number of days to 50% flowering, forage yield, hay yield, ratio of plant stalk, plant leaf ratio and yield of stalk. In the study five randomly selected plants were used for recording the observations on measurable characters, however, days to 50% flowering dates were recorded as individual plots. Statistical analysis of obtained data was analyzed by using the SAS general linear model procedure (SAS, 1998) and means were compared using Duncan's test at the p=0.05 probabi-

Table 2 - Plant height, days to 50% flowering, forage yield and hay yield values obtained in 2014-2015

Line/Variety	Plant height(cm)		Days to 50% flowering(Day)		Forage yield(t ha^{-1})		Hay yield(t ha^{-1})	
	Antalya	Konya	Antalya	Konya	Antalya	Konya	Antalya	Konya
Line-1	285.6 hl*	239.0 rt	81.7 nq	102.3 be	67.2 de*	67.5 b	20.8 bd	19.2 ab
Line-2	231.9 v	194.2 AB	86.5 kl	100.2 dg	38.7 pr	41.8 n	10.9 tv	10.8 kn
Line-3	306.8 be	270.4 fh	79.8 ps	91.3 ln	77.7 c	56.1 eh	20.0 ce	15.1 fh
Line-4	293.6 ej	276.8 dg	82.7 mp	88.2 nq	42.1np	56.0 eh	10.8 tv	15.0 gh
Lime-5	269.1 mr	233.8 tu	93.0 eh	96.0 hj	84.8 b	73.2 a	22.5 b	19.3 ab
Line-7	288.7 gk	278.1 df	77.3 sv	77.7 vx	50.2 hk	36.0 qs	14. 2 ım	9.9 mp
Line-8	295.6 dj	247.9 nr	97.0 cd	111.2 a	54.1 fh	51.0 ıj	14.4 hl	13.9 hı
Line-9	272.6 lq	245.6 ps	94.8 df	96.5 hj	38.7 pr	42.8 mn	10.6 uv	11.9 jl
Line-10	352.7 a	257.7 ın	85.0 ln	84.3 rs	71.0 d	35.2 qt	18.4 ef	9.4 oq
Line-11	284.1 ım	236.6 su	92.2 eı	87.0 or	71.3 d	40.7 np	19.3 de	10.8 ko
Line-13	287.9 gk	261.8 hk	84.2 lo	92.5 km	47.8 jm	46.9 kl	12.9 lr	12.9 ıj
Line-14	261.4 ps	249.6 nq	81.5 or	94.7 ıl	53.1 fı	66.6 b	15.3 gj	19.3 ab
Line-15	241.6 tv	223.3 vx	75.5 ux	77.0 wx	47.8 ım	45.9 km	12.5 nt	11.8 jl
Line-16	255.9 rt	244. 1 qs	77.7 sv	89.2 mo	77.8 c	53.3 hı	19.7 ce	14.6 gh
Line-17	289.8 fk	267.3 gı	86.8 jl	101.2 df	49.5 hl	53.7 gı	13.8 ıo	14.3 gı
Line-18	274.8 kp	255.5 kp	89.2 ık	101.7 ce	55.8 fg	57.4 eg	16.1 gh	14.8 gh
Line-19	267.9 nr	267.4 fh	79.5 qt	93.5 jl	49.2 hl	48.1 jk	14.7 hk	13.9 hı
Line-22	344.1 a	219.9 xy	98.0 bc	100.2 dg	99.1 a	62.8 cd	24.5 a	16.7 ce
Line-23	316.9 b	271.0 eh	76.8 sv	79.8 tw	52.1 fj	37.3 pr	13.9 ın	8.3 qs
Line-24	262.6 ps	260.2 ım	93.2 eh	101.2 df	34.5 qt	57.8 ef	86.9 wy	14.6 gh
Line-25	287.2 hl	257.9 ın	73.2 xy	75.7 xy	46.2 kn	37.9 oq	12.7 lr	10.5 lo
Line-26	256.9 rs	256.7 jo	84.5 lo	97.0 gı	52.1 fj	56.2 eh	15.6 gı	15.4 eg
Line-27	309.9 bd	265.7 hj	100.5 ab	95.8 hk	52.2 fj	34.9 qu	14.2 ım	10.2 mo
Line-28	267.7 nr	251.5 lq	86.8 jl	95.8 hk	42.6 mp	41.2 no	12.1 ou	11.9 jk
Line-29	264.4 ps	220.8 wx	78.5 ru	82.5 su	42.2 np	23.3 xy	12.9 lr	6.7 tw
Line-30	236.9 v	228.0 ux	68.7 z	72.5 y	27.9 uv	19.2 zA	8.2 xy	5.0 xy
Line-31	313.4 bc	279.7 cf	85.3 lm	97.7 gı	41.2 np	16.9 A	12.0 pu	449. 7 y
Line-32	230.1 v	264.9 hk	74.8 vx	73.0 y	26.5 v	18.0 zA	7.8 y	5.3 wy
Line-33	307.4 be	250.6 mq	92.2 eı	102.5 be	45.9 kn	46.2 km	13.7 jp	13.0 ıj
Line-35	269.8 mr	246.9 or	77.3 sv	85.8 os	41.9 np	48.4 jk	11.3 qu	13.7 hı
Line-36	258.0 qs	204.1 zA	90.3 hı	104.8 bc	44.3 lo	55.8 fh	13.4 kq	15.0 gh
Line-37	313.0 bc	230.5 tw	90.8 gı	84.7 rs	46.1 kn	43.4 ln	11.9 qu	11.3 km
Line-38	265.6 os	245.8 or	64.8 A	69.0 z	42.5 mp	20.9 yz	11.9 u	6.8 ux
Line-39	352.6 a	265.6 hk	92.2 eı	85.7 ps	65.6 e	23.9 xy	19.5 ce	6.4 tx
Line-40	300.1 ch	248.1 nr	89.8 ıj	93.5 jl	76.8 c	27.0 wx	21.1 bc	7.6 rt
Lime-41	304.6 bf	284.4 cd	93.7 eg	98.0 fı	63.6 e	75.5 a	16.8 fg	20.2 a
Line-42	282.7 ın	271.1 eh	97.7 bd	101.3 df	49.1hl	65.0 bc	12.9 lr	17.5 cd
Line-43	258.4 qs	220.8 wx	91.3 gı	105.7 b	63.8 e	62.1 cd	18.4 ef	16.7 ce
Line-44	295.6 dı	283.0 cd	89.8 ıj	101.5 ce	78.3 c	67.4 b	19.9 ce	18.0 bc
Line-45	259.5 qs	251.5 lq	92.0 fı	99.2 eh	56.4 f	59.7 de	15.4 gj	16.5 df
Line-46	261.6 ps	210.4 yz	93.0 eh	96.0 hj	33.5 rt	24.4 xy	10.1 yw	7.2 sv
Line-47	275.4 kp	261.4 hl	93.0 eh	84.8 qs	37.5 ps	37.8 oq	10.9 sv	10.3 mo
Line-48	305.4 be	280.8 ce	77.8 sv	82.8 st	50.6 gk	33.9 ru	13.3 kq	8.7 pr
Line-49	305.4 be	289.4 bc	95.2 ce	103.2 bd	44.6 lo	46.3 km	12.3 ou	13.7 hı
Line-50	280.4 jo	300.1 a	101.3 a	105.2 b	52.1 fj	53.8 gı	13.2 kq	14.6 gh
Line-51	302.6 bg	222.1 vx	97.2 cd	92.3 lm	48.0 ıl	31.2 uv	13.3 kq	8.1 qs
Line-52	262.5 ps	189.9 bc	82.2 nq	88.3 np	30.0 tv	28.4 vw	7.7 y	7.3 rv
Line-53	355.2 a	297.6 ab	76.5 tw	89.2 mo	49.5 hl	23.9 xy	13.7 jp	6.1 vx
Rox	239.9 uv	199.4 AB	70.7 yz	80.8 tv	32.3 su	33.5 su	8.2 xy	8.4 qs
E.Sumac	252.3 su	219.6 xy	69.3 z	79.2 uw	45.5 kn	31.6 tv	12.6 ms	8.3 qs
Leoti	266.4 os	230.6 tw	73.5 wy	77.5 vx	37.9 pr	31.9 tv	9.8 vx	7.6 ru
Nes	266.9 os	231.7 tv	75.3 vx	80.0 tw	39.5 oq	34.8 qu	11.3 rv	9.5 nq

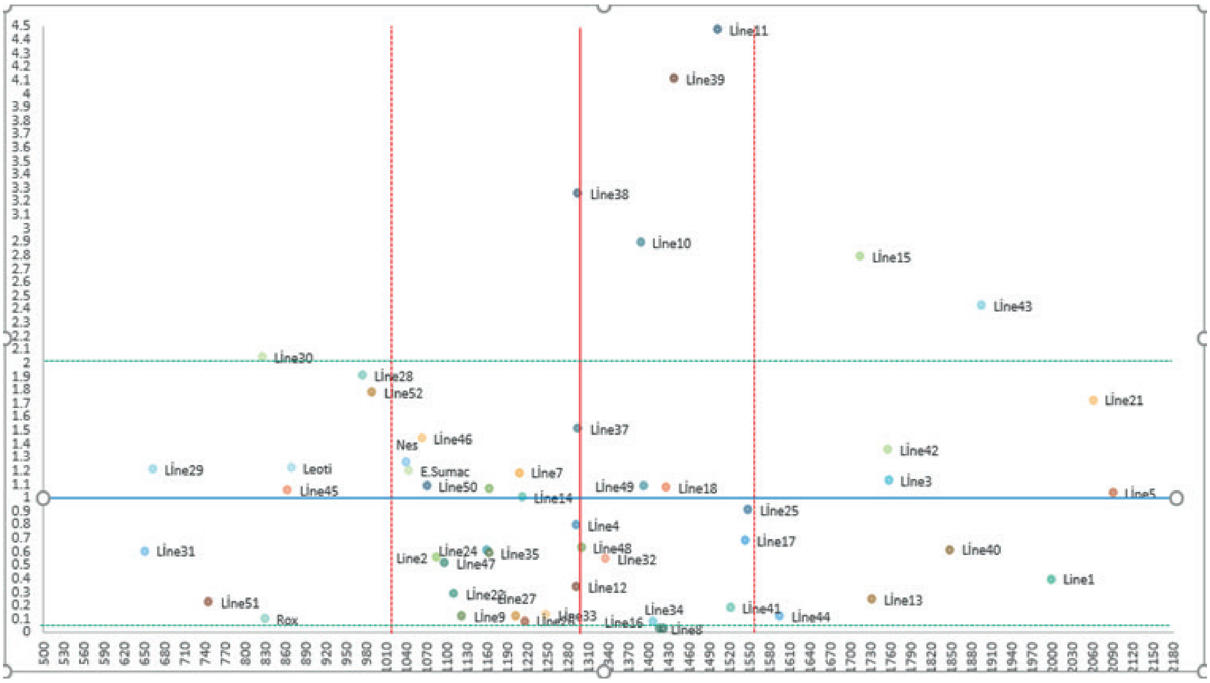

Fig. 1 - Stability analysis of the sorghum genotypes under study

lity level. Analysis of variance, correlation and path coefficient was done using standard method suggested by Duzgunes *et al.* (1987). Stability analysis was done according to Duzdemir and Akdag (2014).

Climate and soil

Climatic conditions and soil properties of the two locations are presented in supplementary files as Table 2 and Table 3. According to the data, in Antalya location, which is one of the trial areas; the total precipitation amount of the period (May-November) in which the experiment was conducted in 2014 was 253.2 mm, and 245.0 mm in 2015. The amount of long-term precipitation was determined as 367.9 mm during the trial period in Antalya. In Konya location; total precipitation was 167.0 mm in 2014, 170.0 mm in 2015 and long-term precipitation 154.0 mm. It is seen that the temperature values for the May-November period of 2014 in Antalya location, varied between 14.0-28.4°C (average 22.9°C), and 2015 between 15.7-28.6°C (average 23.3°C). The temperature values of the period in which the experiment was conducted varied between 14.0 and 28.2°C, and the average temperature value was 22.7°C. In Konya location in 2014, the average temperature values of the period (May-November) were 5.1–25.1°C (average 17.2°C), 2015 May-November period temperature values varied between 7.4–24.6°C (average 17.5°C). As shown, there were no climatically affected conditions for sorghum during the experiment. The soil type was characterized as silty clayey with pH of 8.6 in Antalya and clayey loamy with pH of 7.9. Both areas are known for cultivation of sorghum (*Sorghum bicolor*) and according to analiysis of soil there was not unfavorable environment.

Results and Discussion

Statistical analysis

Except from year that concernig day to %50 flowering, the analysis of variance for combined years and locations for all characters showed that there were highly significant ($P \leq 0.01$) differences among the investigated characters. There wassignificant difference between years(Y), locations (L), and genotypes (G). Through the analysis of variance, there were significant difference between Y×G, Y×L, G×L and Y×G×L height interactions. Therefore, year, location means were given Table 1, genotypes means on location basis and combined data analysis were given in Tables 2 and 3. Additionally, the correlations and path analysis results which shows the relationships among the traits are given in Table 4 and Table 5.

Plant height

It was also plant height and days to 50% flowering varied according to years depending on changing climate conditions. Environmental factors such as precipitation and temperature especially during the development period of plant's played very important role on plant height and days to 50% flowering. Under normal

Table 3 - Pant stalk ratio, plant leaf ratio and stalk yield values obtained in 2014 and 2015

Line/Variety	Pant stalk ratio (%)		Plant leaf ratio (%)		Stalk yield (t ha^{-1})	
	Antalya	Konya	Antalya	Konya	Antalya	Konya
Line-1	21.2 fh*	19.6 ım	77.8 sv	80.5 os	52.0 rg	54.3 bc
Line-2	21.4 fg	19.1 jn	78.6 pt	80.9 nr	30.4 zB	33.5 ln
Line-3	16.5 q	13.9 xA	83.5 bf	86.0 ad	64.9 bc	48.5 d
Line-4	16.6 qv	13.4 yA	83.4 bg	86.7 ac	35.1 ty	47.9 d
Lime-5	18.7 lp	16.1 qv	81.3 gn	83.9 gk	69.2 ab	62.1 a
Line-7	16.9 pu	17.6 nr	83.1 bh	82.4 jn	41.8 kp	29.7 oq
Line-8	14.2 w	20.2 ıj	85.8 a	79.9 rs	46.5 hj	40.8 gı
Line-9	18.7 lp	15.4 tx	81.3 fm	84.6 dh	31.6 yA	36.3 jl
Line-10	16.3 rv	19.5 ım	83.7 ae	80.5 os	59.7 de	28.3 q
Line-11	21.7 fg	19.7 ık	78.4 qu	80.3 qs	56.4 ef	32.7 mo
Line-13	18.4 mq	25.6 bc	81.6 el	74.4 yz	39.1 ot	34.8 kn
Line-14	19.3 jo	17.4 ns	80.8 ıp	82.6 ın	42.9 jo	54.8 bc
Line-15	21.1 fj	14.3 wA	78. 9 ot	85.7 ae	38.0 pu	39.2 hj
Line-16	15.4 tw	13.1 zA	84.6 ac	86.9 ab	65.8 b	46.3 de
Line-17	17.3 or	17.3 ns	82.7 cı	82.7 ın	40.9 lr	44.4 ef
Line-18	19.4 ın	17.0 ot	80.6 ıp	82.9 hm	45.0 ıl	47.8 d
Line-19	19.5 hn	13.8 xA	80.5 ıq	86.2 ad	39.8 ns	41.4 fh
Line-22	15.8 sw	17.4 ns	84.2 ad	82.7 ın	83.5 a	51.9 c
Line-23	20.8 gk	24.3 ce	79.2 ms	75.7wy	41.0 lq	28.8 q
Line-24	16.7 qu	16.7 pu	83.7 ae	83.3 gl	28.9 AC	48.1 d
Line-25	17.7 ns	15.0 uy	82.4 dj	84.9 cg	38.2 pu	32.2 np
Line-26	14. 7 vw	14.5 vA	85.3 ab	85.5 af	44.5 jm	48.1 d
Line-27	15.8 sw	17.2 os	84.3 ad	82.8 ım	43.9 jn	29.0 pq
Line-28	18.5 mq	15.8 sw	81.5 el	84.2 eı	34.7 tz	34.7 kn
Line-29	23.0 df	22.0 fh	76.9 tw	77.9 tv	32.6 wA	18.6 uv
Line-30	27.1 b	26.5 b	72.9 y	73.5 z	20.5 E	14.3 w
Line-31	18.7 lp	30.2 a	81.3 fm	69.8 A	33.7 vz	11.8 w
Line-32	23.9 de	28.5 a	76.2 vx	71.5 A	20.2 E	13.0 w
Line-33	18.4 mq	15.4 tx	79.9 kr	84.6 dh	36.7 qw	39.1 hj
Line-35	19.3 ın	14.3 vA	80.7 ıp	85.7 af	34.1 uz	41.5 fh
Line-36	14.9 uw	14.7 vz	85.1 ab	85.3 bf	37.6 pv	47.7 de
Line-37	22.1 eg	17.9 lp	77.9 rv	82.1 lp	36.0 sy	35.6 km
Line-38	19.7 hm	15.9 rw	80.4 jq	84.1 ej	34.4 uz	17.7 v
Line-39	24.9 cd	19.6 ıl	75.1 wy	80.4 ps	49.4 gı	19.3 uv
Line-40	35.5 s	22.9 ef	64.5 z	77.0 vw	49.9 gh	21.0 tu
Lime-41	16.7 qu	18.1 kp	83.3 bg	81.9 lq	52.8 eg	61.8 a
Line-42	20.5 gl	19.5 ım	79. 5 ls	80.5 os	38.3 pu	52.5 bc
Line-43	18.9 ko	25.1 bd	81.0 ho	74.9 xz	51.6 g	45.9 de
Line-44	22.4 eg	17.8 mq	77.6 sv	82.2 ko	60.8 cd	55.2 b
Line-45	19.4 ın	21.2 gı	80.6 ıp	78.8 su	45.6 hk	47.0 de
Line-46	22.3 eg	22.9 eg	77.8 sv	77.1 uw	25.9 BD	18.7 uv
Line-47	24.8 cd	23.67 df	75.2 wx	76.3 vx	28.5 AC	28.2 q
Line-48	19.3 ıo	19.1 jn	80.7 ıp	80.9 nr	40.8 lr	27.6 qr
Line-49	15.4 tw	18.5 jo	84.7 ac	81.5 mr	37.9 pv	37.7 ık
Line-50	21.9 eg	20.9 hı	78.1 rv	79.1 st	40.5 mr	42.5 fg
Line-51	23. 8 de	21.1 hı	76.2 ux	78.9 st	36.5 rx	24.9 rs
L,ne-52	21.9 eg	18.5 jp	78.1 rv	81.5 lr	23.4 DE	23.2 st
Line-53	25.9 bc	25.7 bc	74.1 xy	74.3 yz	36.6 qw	17.8 uv
Rox	20.9 gk	15.8 rw	79.1 nt	84.2 ej	25.7 CD	28.2 q
E.Sumac	18.1 mr	15.3 tx	81.9 ek	84.7 dh	37.3 qv	26.8 qr
Leoti	15.4 tw	12.8 A	84.6 ac	87.2 a	32.2 xA	27.9 qr
Nes	21.2 fı	15.9 rw	78.8 ot	84.1 ej	31.6 yA	29.3 pq

*The means in the same column with same letters are in the same group

Table 4 - Correlation matrix for different traits in forage sorghum

Parameters	Plant height	Days to 50% flowering	Forage yield	Hay yield	Plant stalk ratio	Plant leaf ratio	Stalk yield
Plant height	1						
Days to 50% flowering	0.2301	1					
Forage yield	0.2532	0.5180**	1				
Hay yield	0.2407	0.5404**	0.9851**	1			
Plant stalk ratio	0.0710	-0.0701	-0.3514*	-0.3308*	1		
Plant leaf ratio	-0.0733	0.0655	0.3478*	0.3244*	-0.9992**	1	
Stalk yield	0.2300	0.4914**	0.9901**	0.9714**	-0.4691**	0.4660**	1

*The means in the same column with same letters are in the same group

growing conditions, plant height provide more biological yield per unit area, in high yield plants such as sorghum. Therefore, plant height is very important criteria for selection in breeding program. Years and locations in terms of plant height were significantly different. In Antalya location, while it was found 284.9 cm in first year, 248.3 cm in second year. In Konya location, while it was found 271.0 cm in first year, 235.4 cm in second year. The variation among the plant heights were more pronounced in the first year of the study (Table 1). Four genotypes showed hight performance in Antalya location with 352.7 cm (Line-10),344.1 cm (Line-22), 352.6 cm (Line-39) and 355.2 cm (Line-53), two genotypes were preferred with 300.08 cm (Line-50) and297.56 (Line-53) in Konya location (Table 2). For plant height, similar results were reported by Demir, (2020)(250.80-476.30 cm), Kaplan *et al.* (2019) (203.0-255.3 cm), Coban and Acar (2018) (228.6-262.7 cm), Yıldız *et al.* (2018) (243.5 cm), Kara *et al.* (2019) (185.4-281.0 cm), Keskin *et al.* (2018) (197.1-299.4 cm),Uzun *et al.* (2017) (189.0-330.7 cm), Getachew *et al.* (2016) (180.0-300.0 cm) Karadag and Ozkurt (2013) (183.9-224.2 cm), Geren and Kavut (2008) (337.2 cm); Gunes and Acar (2005) (260.9-284.8 cm), Tsuchihashi and Goto (2005) (279.0-360.0 cm), Balabanli and Turk, (2005) (178.0 ve 222.2 cm).

Days to 50% flowering

The minimum number of days to flowering was observed in Line-38 with 64.8 days in Antalya location and 69.0 days in Konya location. As seen in the Table 1 demonstrate significant differences in first year and the second year both in Antalya (75.4-101.2 days) and in Konya (81.2-95.7days). The data demonstrate that there were clearly differences from location to location among genotypes in days to flowering. The latest flowering day was 101.3 (Line-50) days in Antalya and 111.2 (Line-8) days in Konya location (Table 2).Similar results have been reported in the past by other researchers; 77.7-108.0 day (Demir, 2020),87.1-92.8 day (Avcı *et al.*,2018), 69.0-88.0 day (Reddy *et al.*, 2005) and 73.0-77.0 day (Samarth *et al.*, 2018).

Forage yield

Mean performance of sorghum genotypes in this study for forage yield and hay yield components characters were given in (Table 2). Results showed that 50.6 t ha^{-1} and 42.3t ha^{-1} forage yields were obtained in the first and second year, respectively (Table 2). When the locations are compared in terms of forage yield, it is seen that the total forage yield in Antalya location (101.3t ha^{-1}) is higher than Konya (84.6t ha^{-1}). It can be said that the yield difference between the two locations is due to other environmental conditions, especially soil properties. Although the location averages have values close to each other, the most forage yield determineted Line-22 with 99.1 t ha^{-1} in Antalya location and Line-5 with 73.2 t ha^{-1} in Konya location. Various studies have been reported for sorghum forage yield in the literature. Forage yield was reported 74.3 t ha^{-1} by Akbudak *et al.* (2004),73.3 t ha^{-1} by Cecen *et al.* (2005), 45.5-64.3 t ha^{-1} by Balabanli and Turk (2005), 49.4-66.5 t ha^{-1} by Yuksel (2006), 62.9-76.1 t ha^{-1} byKaradas (2008), 21.2-47.6 t ha^{-1} by Karadag and Ozkurt (2013),38.1-45.4 t ha^{-1} by Jahansouz *et al.* (2014), and 33.5-54.5 t ha^{-1} by Nejad *et al.* (2014).

Hay yield

Performance of sorghum genotypes with regard to hay yield were given in (Table 2). Hay yields were foundbetween 11.5 t ha^{-1} - 13.8 t ha^{-1} parallel as in forage yield sin the first and second year, respectively. The highest hay yield among genotypes in Antalya location; as Line-22 (24.5 t ha^{-1}) and in Konya location;

Table 5 - Path coefficients and percentage rate of effects for forage yield components in sorghum genotypes

	Indirect effect					
1*	0.0004/0.0837%**	0.0000/-0.0096%	0.0002/0.0164%	0.0000/-0.0244%	0.0000/0.0062%	0.0002/0.0152%
2	0.0001/0.0184%	-0.0043/-5.6679%	-0.0003/-0.0269%	0.0000/0.0043%	0.0007/0.1502%	-0.0002/-0.0200%
3	0.0601/13.2176%	0.0086/11.2762%	0.1362/13.2681%	-0.0072/-11.0371%	0.0267/5.8009%	0.1312/12.2270%
4	0.0000/0.0002%	0.0000/0.0000%	0.0000/0.0001%	0.0000/-0.0383%	0.0000/0.0004%	0.0000/0.0001%
5	-0.0091/-2.0004%	0.0192/25.0493%	-0.0237/-2.3067%	0.0088/13.5993%	-0.1209/-26.3063%	-0.0419/-3.9028%
6	0.3853/84.6796%	0.0445/57.9970%	0.8662/84.3818%	-0.0489/-75.2966%	0.3114/67.7360%	0.8994/83.8348%
	R 2 = 0,995906723502536					

*1-Plant height 2-Days to 50% flowering 3-Hay yield 4-Plant leaf ratio 5-Plant stalk ratio 6- Stalk yield
**The bold and diagonal under line numbers is direct effects of any trait on forage yield.

as Line-1 (19.2 t ha^{-1}), Line-5 (19.3 t ha^{-1}), Line-14 (19.3 t ha^{-1}) and Line-41 (20.2 t ha^{-1}) were determined. The researchers pointed out that result related to similar hay yield;Cecen *et al.* (2005), Balabanli and Turk (2005), Cigdem and Uzun (2005), Yuksel (2006), Uygur (2012), Karadag and Ozkurt (2013), and Aydinsakir *et al.* (2021b) as 6.5-11.4, 12.0-16.7, 6.9-9.7, 12.6-17.8, 9.6-16.6, 9.4-19.2, 7.8-26.4t ha^{-1}, respectively.

Plant stalk ratio, plant leaf ratio and stalk yield

Plant morphology and the proportion of morphological parts in the total material affect nutrient content, feed consumption and digestibility. For this reason, it is important to know the ratio of the morphological parts of the sorghum plant grown for silage in total weight. According to the analysis of variance; ratio of plant stalk, plant leaf ratio and stalk yield have been found statistically significant differences (P≤0.01). Plant stalk ratio and plant leaf ratio of genotypes have been determined as 20.3-79.7% in 2014 and 19.1-80.9% in 2015 respectvely. As a matter of fact, plant leaf ratio increases as the plant stalk ratio decreases (Table 3). The highest value for plant stalk ratio observed was 35.5% (Line-40) in Antalya and 30.2 %-28.5% (Line-31 and 32) in Konya, followed plant leaf ratio given with value of 85.8%-83.7%-84.6%-84.2%-83.7%-85.3%-84.3%-85.1%-84.7% (Line-8, 10, 16, 22, 24, 26, 27, 36, 49 and Leoti) in Antalya and 86.7%-85.7%- 86.9%-86.2%-85.5% (Line-4, 15, 16, 19, 26, 35 and 32) in Konya (Table 3). Results of obtained this study related plant leaf ratio were consistent with Acar *et al.*, (2000) 15.5-25.2%, Ozkose *et al.*, (2015) 19.3-38.1 %, Coban and Acar (2018) 11. 7-20.3%, Yıldız *et al.*, (2018) 8.9-12.9%, and Demir (2020) 6.2-20.9%. For plant stalk ratio was also reported in previous studies that Acar *et al.*, (2000) 74.7-82.0%, Ozkose *et al.*, (2015) 61.9-80.7%, Daniel *et al.*, (2017) 85.1-88.3%, Coban and Acar (2018) 79.7-89.3%, Yıldız *et al.*, (2018) 52.4 -69.7%, and Demir (2020) 74.7-91.5%.

In the present study, there has been a difference between years in terms of stalk yield. In the first year of the trial, the mean stalk yield (40.7t ha^{-1}) was high compared to the second year (34.3 t ha^{-1}). This result is thought to be caused by high forage yield in first year. While the stalk yield was found 46.4 t ha^{-1} in the first year, 34.9 t ha^{-1} in the second year in Antalya and was obtained 34.1 t ha^{-1} in the first year and 34.6 t ha^{-1} in the second year in Konya (Table 1). Meanwhile the lowest combined values had recorded for stalk yield with value of 20.5 t ha^{-1} (Line-30) followed by 20.2 t ha^{-1} (Line-32) in Antalya and 14.3t ha^{-1}- 11.8 t ha^{-1}- 13.0 t ha^{-1} (Line-30, 31, 32, repectively) in Konya (Table 3). Previously study, the stalk yield was concluded by Tsuchihashi and Goto (2004) with 47.9-65.9 t ha^{-1} and Demir, (2020) with 75.5-144.3 t ha^{-1}. This study showed that the findings obtained in stalk yield were in agreement with the results of Tsuchihashi and Goto (2004) however, less than the findings of Demir (2020).

Correlation analysis

Regarding correlations between different characters, forage yield was significantly and highly positive correlated with hay yield (r = 0.9851**), plant leaf ratio (r=0.3478*) and stalk yield (r=0.9901**) (Table4). Among the traits the highst significant negative correlation coefficient was observed among the plant leaf ratio and plant stalk ratio with (r=-0.9992**). This meant that variations in the plant leaf ratio were not affect significant differences in ratio of plant stalk. Some positive and significant relationship also existed in between the forage yield and the number of days to 50% flowering (r=0.5180**), hay yield and days to 50% flowering (r=0.5404**), plant leaf ratio and stalk yield (r=0.4660**), hay yield and stalk yield (r=0.9714**). Previous studies in sorghum have also reported a high positive correlation between yield and various yield compenents similarly to our results (Moyer *et al.*, 2003; Iyanar and Khan, 2005; Sukhchain and Singh, 2008; Prakash *et al.*, 2010; and Warkad *et al.*, 2010).

Path analysis

Knowledge, on the correlations between characters is obligatory, to develop selection of characters. However, selection depending on correlations among characters can impropriety in the selection strategy when develop a new variety. For this reasons, a path analysis which investigates direct and indirect effects of a group of main variable. The results of the path analysis that made by considering the forage yieldas the dependent variable and the other characters as the independent variable are given in Table 5. While the plant stalk ratio was found the highest negative direct effect, stalk yield was found the highest positive direct effect on forage yield. The plant stalk ratio that presented a low direct effect on forage yield, therefore, must be considered during indirect selection for forage yield. Our results confirmed the result of Adugna (2007), Rohman *et al.*, (2006), and Jain *et al.* (2010).

Stability analysis

Yield stability is one of the biggest problem facing plant breeders in developing greatly adopted varieties with superior yield in breeding programmes. The analysis of variance for stability was performed for all characters on the 48 forage sorghum lines and 4 varieties under this study. Stability parameters were estimated for forage yield by using the model described by Duzdemir and Akdag (2014). As a result of the statistical analysis, when the genotype × environment interaction is important refer to stability analysis in order to determine the genotypes with the desired characteristic. According to stability analysis results Line-1, 3, 5, 13, 21, 40, 42 and 44 were with stand lines that fit well in all environments. Line-15 and Line-43 were in the group that adapts to the good environment (Figure 1). Lines-10, 11, 38 and 39 were in the same group that adapts to an average environment. Varieties of E. Sumac and Nes and Lines - 2, 4, 7, 9, 12, 14, 16, 17, 18, 22, 23, 24, 25, 26, 27, 32, 33, 34, 35, 37, 41, 46, 47, 48, 49 and 50 have an average adaptation to all environments. Line-8 has average adapted to the bad environment. Leoti and Rox varieties with 28, 29, 30, 31, 45, 51, 52 lines have bad adaptation to all environments. Although the low performance of the cultivars in different environments seems to be an unfavorable situation, it is due to the high yield of selected genotypes. That is, the control varieties behaved as expected.

Conclusions

In the present study, the obtained data indicated that there were large variations in forty-eight selected sorghum lines and four sorghum varieties under both environmental conditions. The maximum and minimum data have revealed the importance of the variation. Posive correlation was determined not only between forage yield and stalk yield but also between hay yield and forage yield. According to path analysis the plant stalk ratio had highest negative direct effect and stalk yield had the highest positive direct effect on forage yield. Correlation and path analysis results indicated that the forage yield and stalk yield are important characters in defining the performances of the genotypes. Hence stalk yield and forage yield may be considered as selection criteria for sorghum breeding programmes. Eventually, the results of the stability analysis showed that Line-1, 3, 5, 13, 21, 40, 42 and 44 were found as withstand lines in all environments.

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References

Acar R, Akbudak A, Sade B, 2000. The determination of yield and some yield components of sorghum-sudan grass hybrid cultivars for silage production in Konya ecological conditions, Selcuk Journal of Agriculture Sciences 16: 88-95.

Adugna A, 2007. Assessment of yield stability in sorghum. African Crop Science Journal 15:83-92.

Akbudak A, Sade B, Acar R, 2004. The effects of cutting periods and nitrogen applications on yield and some properties of sorghum (*Sorghum bicolor* L.) x sudane grass (Sorghum sudanense L.). Journal of Herbal Research, 1:1-10.

Al-Naggar AMM, Abd El-Salam RM, Hovny MRA, Walaa Yaseen YS, 2018. Genotype × environment interaction and stability of *Sorghum bicolor* lines for some agronomic and yield traits in Egypt. Asian Journal of Agricultural and Horticultural Research 1:1-14.

Avcı S, Ileri O, Kaya MD, 2018. Effects of seeding rates on yield, yield components and seed germination characteristics of sorghum. Suleyman Demirel University Journal of Natural and Applied Sciences 22:979-985.

Aydinsakir K, Erdurmus C, 2021a. Influence of different drip ırrigation methods and ırrigation levels on sweet sorghum. Fresenius

Environmental Bulletin 30:1465-475.
Aydinsakir K, Buyuktas D, Dinç N, Erdurmus C, Bayram E, Yegin AB, 2021b. Yield and bioethanol productivity of sorghum under surface and subsurface drip irrigation. Agricultural Water Management 243, 106452. doi:10.1016/j.agwat. 2020.106452.
Balabanli C, Turk M, 2005. A research on determination of yield and quality characteristics of sorghum, sudan grass hybrid and cultivars in Ispartaecological conditions. Suleyman Demirel University Journal of Natural and Applied Sciences 9:1-5.
Cecen S, Oten M, Erdurmus C, 2005. Assesment of sorghum (*Sorghum bicolor* L.), sudan grass (*Sorghum sudanense* L.) and corn (*Zea mays* L.) as second crop in the Coastal Region of West Mediterranean Belt of Turkey. Mediterranean Agricultural Sciences 18:337-341.
CigdemI, Uzun F, 2005. Forage sorghum and sorghum-sudan grass hybrids. Journal of Agricultural Faculty of OndokuzMayıs University20:66-72.
Coban U, Acar R, 2018. Effects of different seed beds on the yield and quality characteristics of the sorghum sudan grass varieties. Journal of Bahri Dagdas Crop Research 7:32-38.
Daniel EE, Ajit KM, Mark LJr, Danielle DB, Umakanta J, Gerald JW, Archie LW, 2017. Evaluation of three cultivars of sweet sorghum as feedstocks for ethanol production in the Southeast United States. Article No~e004902. 1-18.
Demir D, 2020. Determination of yield and yield characteristics of some late maturated sweet sorghum (*Sorghum bicolor* var. saccharatum (L.) Mohlenbr.) genotypes under main crop conditions of Harran plain Harran University Graduate School of Natural and Applied Sciences, Master Thesis, 80p.
Duzdemir O, Akdag C, 2007. Determination of genotype by environment interactions of some chickpea (*Cicer arietinum* L.) varieties. Journal of Agricultural Faculty of Gaziosmanpasa University 24:27-34.
Duzgunes O, Kesici T, Gunduz F, 1987. Research and Trial Methods. Ankara University Faculty of Agriculture, Publication number: 1021 Textbook 295 Ankara.
FAO, 2018. Agricultural Statistics Database. Food and Agriculture Organization of United Nations, http://www.fao.org/faostat/en/data/QC Accessed date: 02 February 2017.
Geren H, Kavut YT, 2008. A research on the comparison of some sorghum species grown under second crop conditions with corn in terms of yield and silage quality. Ege University Faculty of Agriculture Journal 46:9-16.
Getachew GDH, Putnam CD, PetersEJD, 2016. Potential of sorghum as an alternative to corn forage. American Journal of Plant Sciences 7:1106-1121.
Guden B, Yol E, Ikten C, Erdurmus C, Uzun B. 2019. Molecular and morphological evidence for resistance to sugar cane aphid (Melanaphissacchari) in sweet sorghum [*Sorghum bicolor* (L.) Moench]. 3 Biotech 9:245.
Guden, B., Erdurmus, C., Erdal, S., Uzun, B. 2020. Evaluation of sweet sorghum genotypes for bioethanol yield and related traits. Biofuls Bioproducts & Biorefining, 15 (2): 545-562
Gunes A, Acar R, 2005. The determination of growing possibilities of sorghum-sudan grass cultivars as second crop under karaman ecolojical conditions, Selcuk Journal of Agriculture Sciences 19:8-15.
Iyanar K, Khan AKF, 2005. Correlation and path analysis in multicut fodder sorghum. Annals of Agricultural Research 26:228-230.
Jahansouz RM, Afshar RK, Heidari A, Hashemi M, 2014. Evaluation of yield and quality of sorghum and millet as alternative forage crops to corn under normal and deficit iriigation regimes. Jordan Journal of Agricultural Sciences 10:699-715.
Jain SK, Elangovan M, Patel NV,2010. Correlation and path coefficient analysis for agronomical traits in forage sorghum (*Sorghum bicolor* (L.) Moench). Indian Journal of Plant Genetic Resources 23:15-18.
Kara E, Surmen M, Erdogan H, 2019. The effects of solid biogas residue applications on forage yield and quality in sorghum and sorghum x sudan ensehybrid plants. International Journal of Agriculture and Wildlife Science (IJAWS) 5:355-361.
Karadag Y, Ozkurt M, 2014. Effect of different row spacings on the yield and quality of silage sorghum (*Sorghum Bicolor* (L). Moench) cultivars to be second crop grown. Journal of Agricultural Faculty of Gaziosmanpasa University 31:19-24.
Karadas S, 2008. Determination to yield and some yield component of sorgum sudan grass as second crops in different row spacing, Selçuk University Graduate School of Natural and Applied Sciences Department of Field Crops (Master Thesis), 18-42.
Keskin B, Akdeniz H, Temel S, Eren B, 2018.

Determination of agricultural characteristics of some silage sorghum and sudangrass varieties grown as second product. Yuzuncu Yil Universitesi Journal of Agricultural Sciences 28:412-418.

Moyer JL, Fritz JO, Higgins JJ, 2003. Relationship among forage yield and quality factors of hay-type sorghums. Crop Management doi:10.1094/CM-2003-1209-01-RS.

Nejad MM, Nejad TS,Shokohfar AR, 2014. The effects of deficit irrigation and auxin on the forage yield sorghum. International Journal of Biosciences 4:167-176.

Oten M,2017. The effects of dıfferent sowing tıme and harvesting height on hydrocyanic acıd content in some silage sorghum (*Sorghum bicolor* L.) varieties. Turkish Journal of Field Crops 22:211-217.

Ozkose A, Mulayim M, Acar R, 2015. Effect of row spacing on some yield and yield components of silage sorghum cultivars in Konya Conditions. Selcuk Journal of Agriculture Sciences 2:10-18.

Ozkurt M, 2013. Effect of different row spacings on some morphological and agronomic characteristics for silage sorghum (*Sorghum bicolar* (L.) Moench) cultivars as second crop for Tokat Ecological Conditions Gaziosmanpasa University Institute for Applied Sciences Department of Field Crops (Master Thesis), 57p.

Prakash R, Ganesamurthy K, Nirmalakumari A, Nagarajan P,2010. Correlation and path analysis in sorghum (*Sorghum bicolor* L. Moench) Electronic Journal of Plant Breeding 1:315-318.

Reddy BVS, Ramesh S, Reddy PS, Ramaiah B, Salımath PM, Kachapur R, 2005. Sweet sorghum-a potential alternate raw material for bio-ethanol and bioenergy. International Sorghum and Millets Newsletter 46:79-86.

Rohman MM, Miah MA, Kadır M, Uddın MS,2006. Stability analysis in sorghum, Bangladesh Journal of Agricultural Research 31:645-65.

Samarth AG, More DR, Hashmil, 2018. Studies on physico-chemical properties and nutritional profile of sweet sorghum. International Journal of Chemical Studies, 6:2826-2828.

SAS Institute, 1998. INC SAS/STAT users' guide release 7.0. Cary. NC. USA.

Sukhchain S, Singh K, 2008. Association analysis among vegetative traits in forage sorghum (*Sorghum bicolor*). Range Management and Agroforestry 29:147-148.

Tariq AS, Z Akram, GhulamS, Muhammad G, Khalid S, Khan M, ShahidI, Talat M, 2012. Character association and inheritance studies of different sorghum genotypes for fodder yield and quality under irrigated and rainfed conditions. African Journal of Biotechnology 11:9189-9195.

Tsuchihashi N, GotoY, 2004. Cultivation of sweet sorghum (*Sorghum bicolor* (L.) Moench) and determination of its harvest time to make use as the raw material for fermantation, practiced during rainy season in dry land of Indonesia. Plant Production Science 7:442-448.

TUIK, 2018. Agriculture statistics summary of 2017, Turkish Statistical Institute. http://www.tuik.gov.tr/, Accessed date:12.05.2018.

Turner MF, Heuberger AL, Kirkwood JS, Collins CC, Wolfrum EJ, Broeckling CD, Prenni JE, John CE, 2016. Non-targeted metabolomics in diverse sorghum breeding lines indicates primary and secondary metabolite profiles are associated with plant biomass accumulation and photosynthesis. Frontiers in Plant Science 7:953. DOI: 10.3389/fpls.2016.00953 2.

Uygur E, 2012. Determining of adaptation ability of some sorghum cultivar for silage as second crop in Tokatecolical conditions. Gaziosmanpasa University, Graduate School of Natural and Applied Sciences Department of Field Crops (Master Thesis), 47p.

Uzun F, Garipoglu A, Ocak N,2017. Water use efficiency, yield, and nutritional quality of maize and sorghum cultivars as influenced by irrigation in a shallow soil. Anadolu Journal of Agricultural Sciences 32:358-366.

Warkad YN, Tidke RT, Maske NM, Kharde AV, Potdukhe NR, 2010. Character association and path analysis in sorghum [*Sorghum bicolor* (L.) Moench]. International Journal of Agricultural Science 6:100-104.

Yıldız D, KaplanM, Temizgul R, Kardes YM,2018. The effects of different selenium doses on sorghum grain yield and quality. Mediterranean Agricultural Sciences 31:149-153.

Yuksel O, 2006. Effect of various nitrogen fertilizer doses on yield and some quality attributes of sorghum x sudan grass (*Sorghum bicolor* (L.) Moench x Sorghum sudanense (Piper) Stapf) hybrids. Institute of Natural Sciences, Master's Thesis, 42p.

Zhang CG,Ge XL, HeT, 2010. The productive potentials of sweet sorghum ethanol in China. Applied Energy 7:2360-2368.

Table S1 - The PI numbers and country origine of the selected sorghum germplasm

Line/Variety	Line Number	Origin	Line Number	Line Number	Origin
Line-1	PI 144134	South africa, kwazulu	Line-31	IS 4092	Hindistan
Line-2	PI 154988	Switzerland	Line-32	IS 7957	Nijerya
Line-3	PI 170787	Turkey	Line-33	IS 9113	Kenya
Line-4	PI 175919	Turkey	Line-35	IS 15744	Kamerun
Lime-5	PI 196049	Ethiopia	Line-36	IS 18039	Hindistan
Line-7	PI 217691	Sudan	Line-37	IS 20632	USA
Line-8	PI 218112	Pakistan	Line-38	IS 20679	USA
Line-9	PI 255239	Meksika	Line-39	IS 20697	USA
Line-10	PI 273465	Nijerya	Line-40	IS 20816	USA
Line-11	PI 273969	Ethiopia	Lime-41	IS 24453	Güney Afrika
Line-13	PI 586541	-----	Line-42	IS 26222	Togo
Line-14	PI 641807	-----	Line-43	IS 26484	Benin
Line-15	PI 641810	-----	Line-44	IS 29187	Switzerland
Line-16	PI 641815	-----	Line-45	IS 29233	Switzerland
Line-17	PI 641817	-----	Line-46	IS 29358	Lesotho
Line-18	PI 641821	-----	Line-47	IS 29441	Lesotho
Line-19	PI 641834	-----	Line-48	IS 29468	Lesotho
Line-22	PI 651495	USA	Line-49	IS 29565	Lesotho
Line-23	PI 155746	Malawi	Line-50	IS 29654	Çin
Line-24	PI 330128	Ethiopia	Line-51	IS 29714	Zimbabwe
Line-25	PI 646858	Hindistan	L,ne-52	IS 29733	Zimbabwe
Line-26	IS 602	USA	Line-53	IS 30466	Çin
Line-27	IS 1212	Güney Africa	Rox	Variety	Turkey
Line-28	IS 2389	Afganistan	E.Sumac	Variety	Turkey
Line-29	IS 2902	Nijerya	Leoti	Variety	Turkey
Line-30	IS 3121	Kenya	Nes	Variety	Turkey

Table S2 -Climatic data at study area for long-term and experimental years

Month	Antalya						Konya					
	T	P	T	P	T	P	T	P	T	P	T	P
	2014	2014	2015	2015	LT	LT	2014	2014	2015	2015	LT	LT
May	20.2	27.2	21.3	46.0	20.1	29.9	15.4	26.0	15.7	53.2	15.7	43.3
June	25.3	0.0	23.8	5.0	25.1	9.7	19.7	31.4	18.7	39.6	20.2	24.3
July	27.5	0.0	27.7	1.0	28.2	2.9	25.1	3.0	24.0	8.6	23.6	6.6
August	28.4	5.4	28.6	0.0	27.8	2.9	25.0	4.6	24.6	17.2	23.1	5.3
September	25.0	20.0	25.0	33.3	24.3	12.9	18.2	31.4	22.0	31.4	18.6	11.8
October	20.1	120.2	21.1	102.8	19.4	77.4	12.2	37.0	9.8	14.2	12.4	30.1
November	14.0	39.4	15.7	34.9	14.0	179.4	5.1	33.6	7.4	5.8	6.1	32.6
Mean/ Total	22.9	212.2	23.3	223.0	22.7	315.1	17.2	167.0	17.5	170.0	17.1	154.0

T: Temperature, P: Precipitation, LT: Long-term

Table S3 -Some physical and chemical properties of trial areas

Soil properties	Antalya	Konya
pH (pH in soil saturated with water(1:2.5))	8.6	7.9
Lime (%)	24.8	17.8
EC (µS cm^{-1})	197.0	117.0
Texture class	silty clayey	Clayey loamy
Organic matter (%)	1.88	1.51
P (mg kg^{-1})	28.0	23.4
K (mg kg^{-1})	212.0	395.0
Ca (mg kg^{-1})	3687.0	5005.0
Mg (mg kg^{-1})	583.0	538.0
Fe (mg kg^{-1})	5.40	5.97
Mn (mg kg^{-1})	6.50	4.04
Zn (mg kg^{-1})	0.2	0.2
Cu (mg kg^{-1})	1.96	0.96