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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Assessment of Variation in Seed Yield and Related Traits of F3 Sweet Sorghum Population

F3 Şeker Sorgum Popülasyonunda Dane Verimi ve İlgili Özelliklerdeki Varyasyonun Değerlendirilmesi

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Abstract

Sweet sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereals in the world. It contributes significantly to food security, sustainable agriculture, and renewable energy production as a low input crop. It is also grown for its sugar, bioenergy, human food, and livestock feed with high seed yield and biomass. The objective of this study was to evaluate the variation in seed yield and related traits, including thousand seed weight (TSW), seed yield (SY), seed length (SL), and width (SW) of the F3 sweet sorghum population (183 genotypes and two parents) in two different locations in Türkiye namely, Antalya (lowland) and Konya (highland). The results revealed that TSW ranged from 12.03 to 48.25 g with an average of 21.57 g in the lowland and 11.75 to 27.30 g with a mean of 20.43 g in the highland. The highest average value of SY was recorded as 3469.6 kg ha^{-1} in highland and 2435.1 kg ha^{-1} in lowland. The average SL value was identified 3.64 and 3.83 mm for lowland and highland, respectively, with a genotype-environment interaction was insignificant. The two locations average value of SW was 2.89, ranging from 2.07 (210) to 4.13 mm (271) and the highest value was identified in the genotype 20 (2.95 mm) in highland. The combination of the results from both locations indicated that the highest values of TSW, SY, SL, and SW were observed in genotypes 348 (34.98 g), 109 (4346.6 kg ha^{-1}), 275 (4.36 mm), and 345 (3.38 mm), respectively. An important environmental variation was also observed in TSW, SY, SL and SW. The study showed a significant and positive correlation with a value of 0.32 between SW and SL, as well as a comparatively lower positive correlation of 0.14 between SW and TSW. Our results demonstrated the importance of the influence of the environment on different genotypes, thus enabling assessment and the efficient use of sorghum.

Keywords: Seed length, Seed width, Seed yield, Sweet sorghum, Thousand seed weight

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Öz

Şeker sorgumu (*Sorghum bicolor* L. Moench) dünyanın en önemli tahıllarından biridir. Gıda güvenliğine, sürdürülebilir tarıma ve yenilenebilir enerji üretimine önemli ölçüde katkı sağlamaktadır. Aynı zamanda şekeri, biyoenerjisi, insan gıdası ve hayvan yemi olarak yüksek tane verimi ve biyokütlesi için yetiştirilmektedir. Bu çalışmanın amacı, Türkiye'de Antalya (ova) ve Konya (yayla) olmak üzere iki farklı lokasyonda F3 şeker sorgum popülasyonunda (183 genotip ve 2 ebeveyn) bin dane ağırlığı (TSW), dane verimi (SY), dane uzunluğu (SL) ve genişliği (SW) gibi özelliklerden oluşan dane verimi ve ilişkili özelliklerdeki varyasyonu değerlendirmektir. Sonuçlar, TSW'nin ovadaki ortalaması 21.57 g olup 12.03 ila 48.25 g arasında değiştiği ve yaylada ortalama 20.43 g olup 11.75 ila 27.30 g arasında belirlenmiştir. En yüksek SY ortalama değeri ovada 2435.1 kg ha^{-1} iken yaylada 3469.6 kg ha^{-1} olarak kaydedilmiştir. Ortalama SL değeri ova ve yayla için sırasıyla 3.64 ve 3.83 mm olup, genotip-çevre interaksiyonu her iki lokasyon için de önemsiz olmuştur. Iki lokasyonun SW ortalama değeri 2.89 olup, 2.07 (210) ile 4.13 mm (271) arasında değişmekte ve en yüksek değeri ise genotip 20 (2.95 mm)'de yaylada görüşülmüştür. Her iki lokasyondan elde edilen sonuçlarda, en yüksek TSW, SY, SL ve SW değerlerinin sırasıyla 348 (34.98 g), 109 (4346.6 kg ha^{-1}), 275 (4.36 mm) ve 345 (3.38 mm) genotiplerinde belirlenmiştir. TSW, SY, SL ve SW'de önemli bir çevre varyasyonu da gözlenmiştir. Çalışma, SW ve SL arasında 0.32 değerinde önemli ve pozitif bir korelasyonun olduğunu ve SW ile TSW arasında 0.14'lük düşük bir pozitif korelasyon olduğunu göstermiştir. Sonuçlarımız, çevrenin farklı genotipler üzerindeki etkisinin önemini göstermiş, böylece sorgumun değerlendirilmesi ve verimli bir şekilde kullanılmasına olanak sağlamıştır.

Anahtar Kelimeler: Dane uzunluğu, Dane genişliği, Dane verimi, Şeker sorgumu, Bin dane ağırlığı

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a highly self- pollinated C4 and diploid (2n = 20) annual crop of the Poaceae family (Cliford et al., 1990; El-Awady et al., 2008). It is cultivated in semi-arid and arid areas in Africa, Asia, and Central America (Ramatoulaye et al., 2016). It adapts to different environmental and agronomic conditions, can perform well in regions with low rainfall (Getachew et al., 2016), and can tolerate higher temperatures and drought (van Oosterom et al., 2021; Polat et al., 2024; Sarshad et al., 2021). Sorghum is one of the most important cereals in the world, with an annual production estimated at 57.58 million tons from 40.7 million ha in 2022 (Anonymous, 2024), ranking it fifth after wheat, rice, maize, and barley (Bakari et al., 2023; Arslan et al., 2017). It is mainly grown for its seeds, sugar, fodder, and bioenergy production (Bakari et al., 2023). Moreover, sorghum is used for human and animal nutrition (Ramatoulaye et al., 2016) because it contains an important source of vitamins, minerals, proteins, antioxidants, and starch (Chhikara et al., 2018).

Seed yield, which is determined by seed number per unit area, the average seed weight, and a thousand seed weights (Borrell et al., 1999; Gambín and Borrás, 2012; Sadras, 2007), is a highly important trait that is strongly influenced by environmental conditions (Singh et al., 2014). Thousand seed weight (TSW), which is one of the important yield components, varies between 25 and 38 g (Taylor and Emmambux, 2008; Fromme et al., 2018). This component is a crucial parameter for seed quality, which impacts sprouting, plant performance, seedling growth, and seed yield potential (Afshari et al., 2011). TWS, which is influenced by ecological factors such as precipitation, temperature, humidity, etc. (Rahman et al., 2009) is one of the main purposes of plant breeding (Conley and John, 2013). A study conducted by Zhang et al. (2023) reported that TSW is an important indicator of seed size and filling characteristics. Moreover, seed shape contributes significantly to the TSW (Cui et al., 2011).

In cereal crops, seed shape is a very important agronomic characteristic because it is directly/indirectly related to the quality and quantity of seed production (Ayoub et al., 2002; Ohsawa et al., 1998). Moreover, assessments and correlations between seed shape and size are also necessary to optimize yield or seed quality (Cervantes et al., 2016). Seed size is closely associated with physical form, ecology, and domestication (Zhao et al., 2022). Seed size components such as seed length and width also considerably affect seed yield (Li et al., 2013; Liu et al., 2016). The sorghum seed has a flattened form with a length and width of around 4.0 mm and 3.5 mm, respectively (Ma, 1975). Seed length generally corresponds to the longest axis of the seed, while the width is the second longest axis, perpendicular or almost perpendicular to the length axis (ISMA, 2019). They can be affected by different environmental factors (Erdal et al., 2017).

The comprehension and evaluation of seed yield and related traits in sorghum is a significant step toward the breeding of cultivars. It is important to evaluate genotypes for seed yield and related traits in different environments to understand variation and effectively utilize sorghum genotypes. Therefore, in two different locations, the F3 population consisting of 183 F3 genotypes developed from the cross of Erdurmus and Ogretmenoglu cultivars was evaluated along with their two parents.

2. Materials and Methods

2.1. Genetic materials

The F3 population developed from the cross of Erdurmus (♀) and Ogretmenoglu (♂) cultivars, with 183 F3 genotypes and two parents were used for this study. The parents are registered at WMARI (Western Mediterranean Agricultural Research Institute of Türkiye) are contrasting for yield and other agronomic traits (Guden et al., 2020). Erdurmus is a sweet sorghum cultivar with high brix and sap content, high plant height and seed yield. While Ogretmenoglu is a grain sorghum cultivar characterized by its short height and a seed yield that can reach 5000 kg ha^{-1}.

The parents were crossed in 2016 under greenhouse conditions in Akdeniz University (36°53'N, 38°30'E and altitude of 15 m), and the F1 plant was selfed in the following year in the experimental fields of Akdeniz University. In 2018, the F2 seeds obtained were grown at the WMARI, Antalya, Turkey and were advanced to F3.

2.2 Experimental site and design

The F3 seeds were cultivated during the 2019 growing season in two different agro-ecological regions of Türkiye, which were WMARI in Antalya (lowland) and at the Soil Water and Deserting Control Research Institute in Konya (highland). The lowland was located at 36˚52'N and 30˚50'E, 41 m above sea level, and has an area that is characterized by an alkali soil with a basic pH of 8.6, clay (with a lime value of 24.8%), organic matter, magnesium, and iron (1.88%, 6.50 mg kg^{-1}, and 5.40 mg kg^{-1}, respectively). The highland location (37˚ 48 N and 32˚ 30' E, 1072 m above sea level) has a soil typically alkali with a pH of 7.2, clay soils with an organic matter value of 1.57%, 8.52 mg kg^{-1} of magnesium available, and 8.74 mg kg^{-1} of iron available (*Table 1*). Climatic data for rainfall and temperature for two locations during the growing period are detailed in *Figure 1*. In this period, the highest temperatures were registered in August, in lowland and the lowest in September, in highland. Rainfall was more abundant in the lowland than the highland during this growing period. The long-term averages (1953-2019) were significantly similar in both environments. The field trials of the F3 genotypes were conducted using a randomized complete blocks design with three replications. The F3 seeds were sown in two rows 5 m long, with 70 cm between rows and 15 cm between plants. Before seed germination, chemical fertilizers (60 kg ha^{-1} N and 60 kg ha^{-1} P2O5) were applied at both environments. Once the plants reached a height of 50 cm, a second application of 60 kg ha^{-1} N was performed.

Table 1. Soil properties of the experimental locations

Properties	Highland	Lowland
EC (µS/cm)	640	197.0
pH	7.2	8.6
Organic matter (%)	1,57	1.88
Fe (mg kg^{-1})	8.74	5.40
Cu (mg kg^{-1})	1.41	1.96
Zn (mg kg^{-1})	0.4	0.2
Mn (mg kg^{-1})	8.52	6.50

2.3. Phenotypic evaluations

Three plants from each plot were randomly chosen and measured for yield related components at two locations in the F3 population of sorghum. After manual harvesting, seeds were dried and stored at +4 °C. Seed length (SL) and width (SW) were measured with a digital caliper and LCD Stainless Electronic Ruler Micrometer (Clockwise Tools DCLR-0605 Electronic Digital Caliper). The length of the seed was determined by measuring the longest axis of the seed. The width of seed was measured from the second longest axis, perpendicular or almost perpendicular to the length axis. Seed yield (SY) was determined by weighing using a precision graduated balance and calculated in kg $ha^{-1.}$ Thousand seed weight (TSW) was calculated by counting 100 seeds manually, weighing them with an electronic balance and multiplied by 10.

2.4. Statistical analysis

Analysis of variance (ANOVA) and correlation analysis were determined using SAS version 9.0 (SAS Institute, 2003).

3. Results and Discussion

The assessment of characteristics for various sweet sorghum F3 genotypes in different environments and comprehending the variation are crucial to optimize their utilization in production regions. Their growth, development and performance are influenced by the environment (Aruna et al., 2021; Gasura et al., 2015). In this study, the two environments, highland and lowland, were very different, with temperatures and rainfall higher in the lowland than in the highland (*Figure 1*). These meteorological factors supported the effect of the environment, which was statistically significant for all traits (*Table 2*).

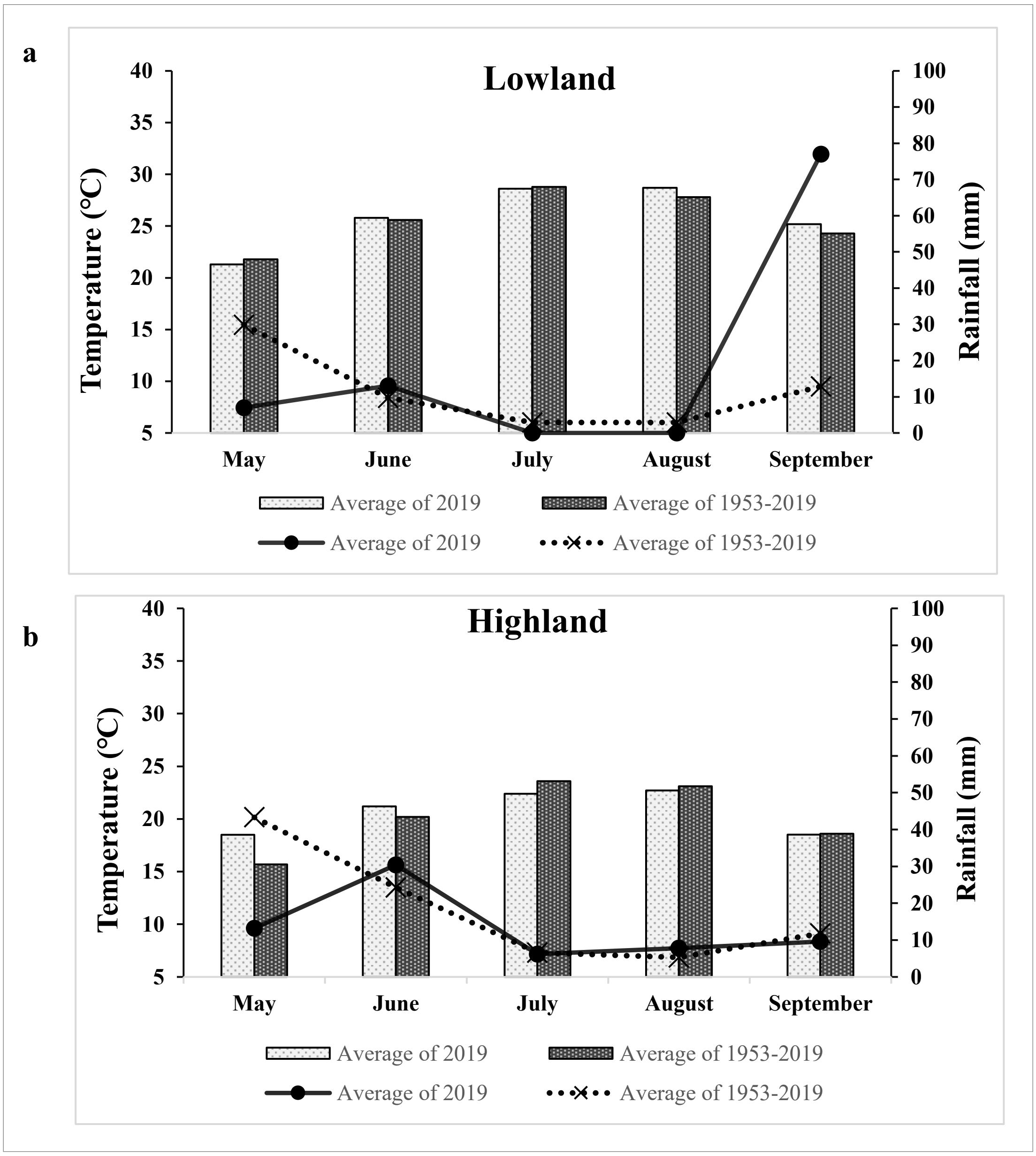

Figure 1. The average monthly rainfall (mm) and temperature (°C) values of the study areas (a) Lowland and (b) Highland

Table 2. Phenotypic variation for the traits studied in the F3 population

Traits	Lowland					Highland					Across the Environments				
	Min	Max	Mean	CV (%)	δg^2	Min	Max	Mean	CV (%)	δg^2	Mean	CV (%)	δg^2	δE^2	δgxE^2
TSW (g)	10.00	49.65	21.57	26.79	2.01**	10.50	33.50	20.43	11.74	3.68**	21.00	21.06	2.20**	18.45**	2.31**
SY (kg ha^{-1})	261.90	8280.7	2435.1	38.97	1.67**	374.3	7057.1	3469.6	27.30	1.51**	2952.3	32.11	1.81**	330.29**	1.37**
SL (mm)	1.27	5.58	3.64	16.38	1.22	2.43	5.32	3.83	9.53	1.14	3.73	13.23	1.31**	41.93**	1.09
SW (mm)	0.97	4.69	2.89	30.74	0.40	1.66	3.72	2.42	11.03	1.33*	2.66	24.69	0.56	140.01**	0.37

*. **: Statistically significant at $p \leq 0.05$ and $p \leq 0.01$ significance level, respectively; **CV**: Coefficient of variation; **$\delta^2 g$** : Genotypic variance; **δE^2** : Environment variance; **δgxE^2** : Genotype by environment interaction for two locations; **TSW**: Thousand seed weight; **SL**: Seed length; **SW**: Seed width; **SY**: Seed yield**.**

TSW is one of the crucial factors in both the selection process and the evaluation of yield, regardless of the influence of various environments (Conley and John, 2013). Moreover, it is an important indicator for assessing seed quality and crop productivity potential (Gavazzi and Sangiorgio, 2017). The individual analysis of variance conducted in each environment revealed that the combined F3 population and parents, where there was a genotype effect ($p \leq 0.01$) of the population, exhibited a high level of significance ($p \leq 0.01$) for TSW in both environments (*Table 2*). Significant differences in TSW were observed in this population, ranging from 12.03 to 48.25 with a mean of 21.57 g and 11.75 to 27.30 with a mean of 20.43 g for lowland and highland, respectively. Various studies reported that the TSW of sorghum ranged between 25-38 g (Fromme et al., 2018; Taylor and Emmambux, 2008) and 24.3-34.4 g (Gul and Saruhan, 2005; Nema et al., 1987), in comparison with the results obtained from the research conducted in both locations, which indicated the TSW between 11.75 and 48.25 g (*Figure 2*). These results were almost similar for Allam et al. (2018), which indicated that TSW varied from 12.67 to 34.66 g, and higher for Boumessila (1980), who obtained results ranging between 10.75 and 29.13 g in different locations, and for Koffi et al. (2011), who found that the TSW ranged from 8.2 to 27.4 g. The mean values observed in lowland were higher than in highland, with a significant variation ($p \leq 0.01$) among the different genotypes for TSW. These differences showed a high impact of the environment of production (Aruna et al., 2015). The highest TWS was identified as 48.25 and 27.30 g from genotypes 348 and 335 for lowland and highland, respectively. Twenty-nine (31, 42, 77, 79, 87, 92, 97, 126, 145, 147, 150, 164, 221, 238, 239, 245, 258, 259, 264, 276, 282, 321, 341, 345, 347, 348, 372, 401 and 424) and eighteen (15, 16, 32, 45, 57, 83, 96, 127, 134, 181, 295, 296, 214, 287, 289, 335, 366 and 397) F3 genotypes demonstrated significant TSW compared to the superior female parent (Erdurmus) for lowland and highland, respectively. These results are similar with Rahimi et al. (2010), who also demonstrated a significant variation between parents and genotypes.

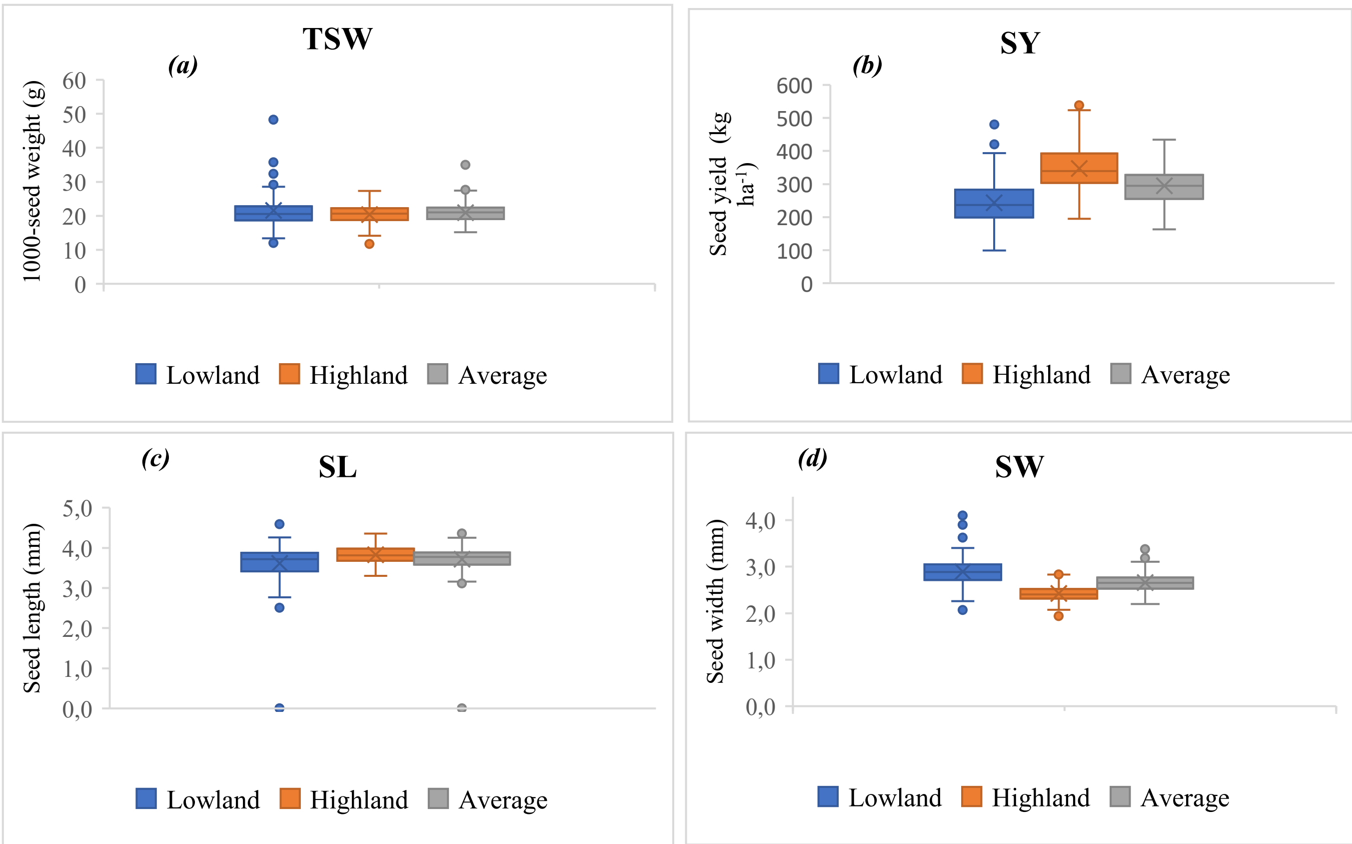

***Figure 2.** Statistical analysis of (a) thousand seed weight, (b) seed yield, (c) seed length and (d) seed width according to the locations*

SY is a crucial indicator of agronomic productivity in sorghum. Statistical analysis showed a significant difference ($p \leq 0.01$) in SY between genotypes at different locations and within the combined F3 population. SY varied from 992.0 (267) to 4802.1 (120) and from 1954.0 (01;59) to 5428.7 kg ha^{-1} (57) for lowland and highland, respectively. The highest average value was recorded in highland (3469.6) compared to lowland (2435.1 kg ha^{-1}).

These different values demonstrated the influence of the environment on yield (Aruna et al., 2015). The average of the two locations was 2952.3 (*Table 2*), with the highest SY value found in genotype 109 (4346.6 kg ha^{-1}). These results were confirmed by Avci et al. (2018), who, after three years of research, demonstrated that the Aldari cultivar produces 3430 kg ha^{-1} of SY. Moreover, they were significantly lower than those of Akgun and Acar (2008), which found SY values between 7870.0-8770.0 kg ha^{-1}. Genotypes and environment interaction were statistically significant ($p \leq 0.01$) in both locations, indicating an important effect on sorghum SY (Gasura et al., 2015).

Despite the wide range of variations observed for SL in the different environments, there were no statistically significant variations found within the F3 population when comparing genotypes from the two locations. This restricted variation showed SL values ranging from 2.51 (210) to 4.59 (275) for lowland and highland, respectively, and from 3.30 (303) to 4.35 mm (132) when combining both locations. They were similar to those obtained by Taylor and Emmambux (2008), which was 4 mm. According to Vignier (1945), SL ranged between 4 and 4.7 mm, differing from that obtained by GISD (2024), which ranged between 4.0 and 6.6 mm. Genotype-environment interaction was insignificant in both locations (*Table 2*) but was important for genotypic and environmental variance. This interaction requires observations of this principal component over time (Priyadarshan, 2019). However, other factors, such as environmental conditions, could be more influential in explaining the differences in the trait (Zakir, 2018; Qian et al., 2023).

SW is one of the important seed characterization traits. The study found significant differences ($P < 0.05$) in SW among F3 genotypes in the highland location with a mean of 2.42 ranging between 1.94 and 2.95 mm (*Table S1*), while in the lowland location, there was no significant variation between SW genotypes. The highest SW was achieved in 20 (2.95 mm), followed by 88 (2.84 mm), 200 (2.82 mm) in the highland. While in the lowland location, there was no significant variation among the genotypes for SW. The average value was 2.89, ranging from 2.07 (210) to 4.13 mm (271). The results from highland were similar with GISD (2024), which showed that SW were 2.0-2.6 mm. Other studies conducted by Ma (1975), and by Schober and Bean (2008) in different conditions indicated that SW values were 3.5 and 2 mm, respectively. Environmental variance was an important factor which influenced significantly ($p \leq 0.01$) different locations. Environmental conditions are explained by this difference (Zakir, 2018; Qian et al., 2023; Erdal et al., 2017). However, there was no variation and significant interaction between the genotypes and their production environment in both locations.

A combined analysis across two environments for the F3 population and parents showed that the overall means were identified as 21.00 g, 2952.3 kg ha^{-1}, 3.73 mm, and 2.66 mm for TSW, SY, SL, and SW, respectively. The highest values of TSW, SL, and SW were observed for genotypes 348, 275, and 271, respectively in lowland. While for SY, it was observed for genotype 109 in highland (*Table S1*). Twenty-three, one hundred and fifty-two, sixty-nine and one hundred and forty-five genotypes exhibited greater values than the superior female parent (Erdurmus) for TSW, SY, SL, and SW, respectively across two environments. Of those, two genotypes (282 and 345) exhibited values that surpassed those of the superior parent across all traits. They indicated the performance of some genotypes as in wheat compared to the superior parent for all the traits and environments assessed (Azam et al., 2013; Kumar et al., 2014).

The correlation analysis revealed significant and positive relationships between SW and TSW, SY and TSW, SY and SL, as well as between SW and SL, with correlation coefficients of 0.14, 0.11, 0.12 and 0.32, respectively (*Table 3*). The average TSW had a non-significant ($p > 0.05$) correlation with SL. Also, there was a significant and negative correlation between SY and SW (-0.13). This indicates the impact of climate and environment on genotypes (Williams et al., 2008). These different reactions affect the variation of the yield and yield components between accessions in identical or different conditions (Daba et al., 2015; Kim et al., 2014). The stability and adaptability of genotypes represent an essential factor for the selection of cultivars according to cultivation conditions (Zakir, 2018).

Table 3. Pearson correlation coefficients between traits across two environments

Traits	TSW	SL	SW
SL	0.05		
SW	0.14**	0.32**	
SY	0.11**	0.12**	-0.13**

TSW: thousand seed weight; SL: seed length; SW: seed width; SY: seed yield.
** represent significance $p \leq 0.001$

4. Conclusion

This research assessed the variation of seed yield and related traits (TSW, SY, SL and SW) of 183 genotypes of the F3 population of sorghum in two different locations in Türkiye. Statistically, significant differences between TSW and SY were observed in the population, while there was no importance for SL. For the SW, significant variations were only identified among F3 genotypes in the highland. Genotypes 282 and 345 showed higher values than the superior parent for TSW, SL and SW in both locations. However, twenty-three, one hundred and fifty-two, sixty-nine and one hundred and forty-five genotypes were superior to the higher female parent (Erdurmus) for TSW, SY, SL and SW, respectively. After a suitable degree of purification, the potential varieties candidates selected could be used for seed production.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Uzun, B., Yol, E.; Design: Uzun, B., Yol, E.; Data Collection or Processing: Kiemde, O., Guden, B.; Statistical Analyses: Guden, B.; Literature Search: Kiemde, O.; Writing, Review and Editing: Kiemde, O., Guden, B., Uzun, B., Yol, E.

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Table S1. Mean of the seed yield and related traits in F_3 population

Genotip NO	Lowland				Highland				Across the Environments			
	TSW	SL	SW	SY	TSW	SL	SW	SY	TSW	SL	SW	SY
01	19.38	2.91	2.71	1311.11	16.26	3.74	2.12	1953.97	17.82	3.33	2.42	1632.54
03	21.73	3.86	3.07	2007.94	21.00	3.79	2.40	3826.19	21.37	3.83	2.74	2917.06
05	18.10	3.44	2.78	1811.27	21.46	3.53	2.50	4104.13	19.78	3.49	2.64	2957.70
10	13.78	3.26	2.59	3150.79	17.13	3.71	2.52	2965.32	15.46	3.49	2.56	3058.06
13	21.48	4.03	3.01	2209.52	22.05	4.20	2.33	4229.44	21.77	4.12	2.67	3219.48
14	15.96	3.43	2.83	2414.29	21.93	3.77	2.45	3651.35	18.95	3.60	2.64	3032.82
15	21.76	3.98	3.31	2187.30	24.10	3.91	2.27	3735.63	22.93	3.95	2.79	2961.47
16	20.30	4.09	3.16	2633.33	23.86	4.18	2.48	4815.48	22.08	4.14	2.82	3724.40
17	22.43	4.05	3.10	2261.90	19.50	3.95	2.43	2381.59	20.97	4.00	2.77	2321.75
18	18.25	3.95	2.89	1766.67	18.86	4.00	2.37	3467.78	18.56	3.98	2.63	2617.22
20	19.56	3.65	2.73	1876.19	23.30	4.02	2.95	3961.03	21.43	3.84	2.84	2918.61
21	24.08	3.62	3.21	1765.08	21.90	3.67	2.53	3991.90	22.99	3.65	2.87	2878.49
31	25.00	3.42	2.70	2141.27	18.56	3.57	2.29	2739.44	21.78	3.50	2.50	2440.36
32	20.78	3.86	2.91	1904.76	24.00	3.87	2.38	3147.86	22.39	3.87	2.65	2526.31
33	26.08	3.68	3.04	2984.92	21.80	3.66	2.45	3858.41	23.94	3.67	2.75	3421.67
34	23.93	3.82	2.95	2906.35	22.56	3.84	2.34	3924.60	23.25	3.83	2.65	3415.48
35	17.56	4.04	3.05	1691.27	19.85	4.03	2.55	2136.27	18.71	4.04	2.80	1913.77
37	20.51	4.05	3.19	2535.71	20.13	3.91	2.51	3294.52	20.32	3.98	2.85	2915.12
39	20.91	3.53	2.80	2577.78	21.10	3.41	2.50	3680.79	21.01	3.47	2.65	3129.29
40	22.6	3.23	2.38	2974.60	23.03	3.70	2.46	3260.08	22.82	3.47	2.42	3117.34
42	27.85	3.52	2.71	3761.90	20.05	3.63	2.47	4717.14	23.95	3.58	2.59	4239.52
44	16.05	3.83	2.86	1792.06	18.30	3.53	2.15	2913.73	17.18	3.68	2.51	2352.90
45	20.58	3.15	2.52	2602.38	24.40	3.67	2.25	3301.35	22.49	3.41	2.39	3048.53
48	23.21	3.76	3.01	1985.71	21.56	3.91	2.34	3556.67	22.39	3.84	2.68	2643.53
49	15.53	4.02	2.80	1942.86	22.50	3.75	2.68	3194.29	19.02	3.89	2.74	2749.76

Table S1 (Continued)

50	12.03	3.98	2.55	2355.56	21.20	3.56	2.07	4120.95	16.62	3.77	2.31	2774.92
55	20.11	3.56	2.97	2380.95	21.40	3.99	2.51	3416.43	20.76	3.78	2.74	3250.95
56	20.96	2.76	2.27	2784.13	21.20	3.62	2.37	3952.78	21.08	3.19	2.32	3100.28
57	20.06	4.26	3.39	2469.84	26.96	3.86	2.68	5428.65	23.51	4.06	3.04	3211.31
59	24.56	4.19	2.83	2561.90	20.93	3.86	2.47	1954.0	22.75	4.03	2.65	3995.28
61	21.40	4.14	3.04	2272.22	22.43	3.80	2.26	2792.86	21.92	3.97	2.65	2532.54
63	16.05	3.76	2.92	1793.65	18.80	3.82	2.32	3675.32	17.43	3.79	2.62	2734.48
65	16.25	4.19	2.20	1922.22	22.05	3.60	2.18	5231.43	19.15	3.90	2.19	3576.83
67	15.26	3.67	2.65	1122.22	17.43	3.61	2.47	2410.00	16.35	3.64	2.56	1766.11
68	20.18	3.72	2.81	1526.19	19.30	3.80	2.35	3457.54	19.74	3.76	2.58	2491.87
71	19.62	3.19	2.69	1633.33	18.73	3.58	2.46	3114.37	19.18	3.39	2.58	2373.85
72	24.42	3.54	2.93	1559.37	19.85	3.50	2.39	2986.51	22.14	3.52	2.66	2272.94
74	21.18	3.70	3.09	1722.22	19.60	3.96	2.40	2739.84	20.39	3.83	2.75	2231.03
77	36.50	3.82	3.13	1629.37	18.33	3.85	2.19	3926.35	27.42	3.84	2.66	2777.86
78	18.75	4.17	3.27	2366.67	20.95	3.67	2.65	3495.71	19.85	3.92	2.96	2931.19
79	30.13	2.80	2.39	2164.29	19.00	3.91	2.32	3772.94	24.57	3.36	2.36	2968.61
83	18.68	3.65	2.87	3190.48	24.60	3.73	2.17	4841.59	21.64	3.69	2.52	4016.03
85	21.40	3.89	3.23	2807.94	18.15	3.74	2.58	2076.90	19.78	3.82	2.91	2442.42
87	26.98	3.58	2.79	3939.63	19.45	4.12	2.23	4566.75	23.22	3.85	2.51	4253.19
88	19.75	3.76	3.33	2653.67	19.13	3.73	2.84	2983.25	19.44	3.75	3.09	2818.46
89	17.00	3.71	2.84	4431.04	20.43	3.94	2.38	2798.49	18.72	3.83	2.61	3614.77
92	28.45	3.64	3.04	2532.43	16.70	3.37	2.26	4500.16	22.58	3.51	2.65	3516.29
94	17.97	3.47	2.84	1605.56	17.76	3.50	2.47	3493.25	17.87	3.49	2.66	2549.40
96	22.45	3.81	3.25	2836.23	23.43	4.24	2.78	3615.79	22.94	4.03	3.02	3226.01
97	35.92	3.88	2.94	3000.00	18.20	3.78	2.70	2635.71	27.06	3.83	2.82	2817.86
98	18.70	2.78	2.49	2548.35	19.50	3.55	2.37	4509.05	19.10	3.17	2.43	3528.70
100	22.12	3.40	3.22	3582.11	18.75	4.17	2.49	3700.79	20.44	3.79	2.86	3641.45

Table S1 (Continued)

109	19.60	4.04	3.35	4362.44	24.26	3.71	2.68	4330.79	21.93	3.88	3.02	4346.62
115	18.20	3.50	3.20	2500.40	20.30	4.12	2.26	4315.32	19.25	3.81	2.73	3407.86
119	19.98	3.58	2.92	2048.57	22.30	3.74	2.31	3178.97	21.14	3.66	2.62	2613.77
120	21.70	3.68	3.34	4802.05	19.26	3.89	2.62	3456.98	20.48	3.79	2.98	4129.52
121	21.41	3.79	2.73	2105.56	18.33	3.62	2.26	2559.92	19.87	3.71	2.50	2332.74
125	21.57	3.72	2.90	2749.13	21.30	3.74	2.40	3127.06	21.44	3.73	2.65	2938.10
126	25.01	3.38	2.71	2039.29	20.83	3.83	2.11	3619.52	22.92	3.61	2.41	2829.40
127	23.81	4.01	2.86	2822.30	24.56	4.21	2.45	4931.03	24.19	4.11	2.66	3876.67
130	21.78	4.10	2.97	2641.43	21.75	3.96	2.52	3544.76	21.77	4.03	2.75	3093.10
132	22.43	3.90	2.91	2582.06	21.05	4.35	2.68	4263.33	21.74	4.13	2.80	3422.70
133	18.70	3.04	2.36	2197.54	18.66	3.75	2.44	2878.81	18.68	3.40	2.40	2538.17
134	20.40	3.84	2.97	2928.10	26.96	3.94	2.35	3414.05	23.68	3.89	2.66	3171.07
136	21.91	3.60	2.70	2090.16	20.65	3.81	2.32	2964.76	21.28	3.71	2.51	2527.46
137	20.98	3.00	2.39	2194.52	20.66	3.98	2.29	3533.33	20.82	3.49	2.34	2863.93
138	18.36	3.58	2.95	2183.49	20.65	4.02	2.69	3726.35	19.51	3.80	2.82	2954.92
140	20.18	3.76	3.03	1871.27	21.40	3.95	2.57	3899.37	20.79	3.86	2.80	2885.32
141	19.83	3.67	3.04	2065.08	22.20	4.12	2.43	4000.48	21.02	3.90	2.74	3032.78
143	18.50	3.71	3.06	2642.78	18.90	3.72	2.43	3567.70	18.70	3.72	2.75	3105.24
145	27.03	3.02	2.57	2592.22	20.26	3.68	2.46	4054.29	23.65	3.35	2.52	3323.25
147	28.18	3.12	2.49	2332.70	20.90	3.75	2.45	2992.62	24.54	3.44	2.47	2662.66
149	18.68	3.62	2.91	2296.03	21.46	3.72	2.23	3414.92	20.07	3.67	2.57	2855.48
150	30.23	3.91	2.60	2948.41	20.05	3.90	2.64	4209.05	25.14	3.91	2.62	3578.73
156	20.18	3.85	3.01	2427.94	22.45	3.57	2.40	3890.56	21.32	3.71	2.71	3159.25
158	19.16	3.69	2.85	3231.11	19.43	3.47	2.20	3347.06	19.30	3.58	2.53	3289.09
162	19.30	4.08	2.81	2472.54	22.20	4.11	2.37	3584.21	20.75	4.10	2.59	3028.37
163	20.68	3.95	2.87	2133.65	20.46	3.63	2.48	4118.57	20.57	3.79	2.68	3126.11

Table S1 (Continued)

164	35.80	3.77	3.02	2261.75	19.50	3.88	2.35	4468.57	27.65	3.83	2.69	3365.16
169	18.51	3.82	2.82	2117.70	11.75	3.49	2.39	2982.86	15.13	3.66	2.61	2550.28
171	20.83	3.73	2.73	2373.57	15.16	3.47	2.48	2554.76	18.00	3.60	2.61	2464.17
172	23.86	3.09	2.41	1776.43	21.06	3.79	2.31	4348.33	22.46	3.44	2.36	3062.38
174	19.60	3.07	2.74	3319.92	21.80	3.87	2.34	3456.19	20.70	3.47	2.54	3388.06
175	21.21	3.81	2.87	2696.83	22.20	4.10	2.39	3824.84	21.71	3.96	2.63	3260.83
176	20.48	3.94	3.09	1722.30	21.60	3.69	2.46	2809.29	21.04	3.82	2.78	2265.79
177	20.61	3.05	2.38	2720.24	18.53	3.72	2.38	3393.02	19.57	3.39	2.38	3056.63
179	20.36	3.72	2.89	2239.60	21.45	4.15	2.80	3137.70	20.91	3.94	2.85	2688.65
181	19.63	3.83	3.00	2217.86	24.30	3.87	2.54	2913.89	21.97	3.85	2.77	2565.87
183	18.67	3.72	2.88	3160.48	18.30	3.93	2.27	2412.22	18.49	3.83	2.58	2786.35
184	20.95	4.04	3.03	3208.73	20.95	3.67	2.37	5189.84	20.95	3.86	2.70	4199.29
185	17.11	3.67	2.60	1214.29	19.86	3.55	2.25	3295.79	18.49	3.61	2.43	2255.04
190	22.83	4.11	3.17	3557.46	21.70	3.73	2.35	4755.24	22.27	3.92	2.76	4156.35
195	14.90	3.69	2.93	1267.14	18.83	3.38	2.35	2591.75	16.87	3.54	2.64	1929.44
197	17.21	3.73	2.98	1729.21	15.55	3.72	2.40	3215.56	16.38	3.73	2.69	2472.38
200	17.57	3.59	2.90	1130.79	19.00	3.91	2.82	3246.43	18.29	3.75	2.86	2188.61
202	23.41	3.75	2.86	3233.73	23.20	4.15	2.53	4012.06	23.31	3.95	2.70	3622.90
203	22.68	3.79	2.76	3070.71	21.30	3.81	2.62	3184.84	21.99	3.80	2.69	3127.78
205	21.33	2.84	3.31	3304.44	24.93	4.12	2.57	3336.90	23.13	3.48	2.94	3320.67
206	19.28	3.71	2.80	3157.86	23.43	3.93	2.43	4243.10	21.36	3.82	2.62	3700.48
210	22.65	2.51	2.07	2553.73	22.36	3.72	2.56	3347.30	22.51	3.12	2.32	2950.52
213	20.45	3.05	2.48	2691.27	19.83	4.00	2.68	4162.06	20.14	3.53	2.58	3426.67
214	19.51	3.73	2.95	1277.54	24.73	3.62	2.35	3244.92	22.12	3.68	2.65	2261.23
217	21.50	3.75	3.12	2441.19	20.70	3.97	2.51	3447.86	21.10	3.86	2.82	2944.52
221	27.43	3.86	2.91	2711.75	22.23	3.95	2.21	3267.62	24.83	3.91	2.56	2989.68
222	18.45	2.89	2.44	2154.68	18.20	3.42	2.46	2965.71	18.33	3.16	2.45	2560.20

Table S1 (Continued)

223	15.77	3.72	2.82	1158.97	14.63	3.68	2.15	2837.38	15.20	3.70	2.49	1998.17
225	19.10	2.79	2.72	2108.25	17.96	3.91	2.26	4003.97	18.53	3.35	2.49	3056.11
228	18.58	3.65	2.93	2321.75	20.30	3.90	2.51	3810.95	19.44	3.78	2.72	3066.35
229	17.95	3.14	2.96	2073.25	23.00	3.91	2.19	3368.65	20.48	3.53	2.58	2720.95
233	18.50	3.95	3.02	4203.65	17.10	3.53	2.16	3518.57	17.80	3.74	2.59	3861.11
235	19.05	3.77	2.76	2338.57	18.90	3.84	2.39	3517.22	18.98	3.81	2.58	2927.90
238	28.35	4.23	2.81	2319.13	22.90	4.13	2.33	3127.78	25.63	4.18	2.57	2723.45
239	30.08	3.80	2.96	1887.14	21.20	4.07	2.31	2883.65	25.64	3.94	2.64	2385.40
245	34.42	4.04	2.69	3679.92	17.60	3.65	1.94	2335.24	26.01	3.85	2.32	3007.58
246	21.17	3.81	3.09	3061.63	21.90	3.98	2.76	3217.38	21.54	3.90	2.93	3139.50
251	22.82	3.88	3.15	3365.37	20.10	3.80	2.48	2981.43	21.46	3.84	2.82	3173.40
257	21.22	3.87	2.95	4245.03	21.00	3.93	2.74	3290.40	21.11	3.90	2.85	3767.71
258	33.35	3.30	3.19	3609.01	19.65	3.92	2.54	3390.48	26.50	3.61	2.87	3499.75
259	29.15	2.92	2.67	3393.26	15.90	4.23	2.31	2218.17	22.53	3.58	2.49	2805.72
260	20.00	3.33	2.90	1380.95	14.10	3.75	2.71	3175.71	17.05	3.54	2.81	2278.33
262	15.95	3.63	3.62	1429.21	18.20	3.73	2.22	3384.92	17.08	3.68	2.92	2407.06
264	32.30	3.21	2.64	4244.30	19.23	4.07	2.41	3182.06	25.77	3.64	2.53	3713.18
265	20.40	3.68	2.81	3508.02	22.36	4.03	2.20	3409.44	21.38	3.86	2.51	3458.73
267	18.48	3.40	2.80	991.98	20.23	3.35	2.24	3744.21	19.36	3.38	2.52	2368.10
268	15.27	3.39	2.80	2241.15	22.30	3.32	2.64	4427.14	18.79	3.36	2.72	3334.15
269	20.50	3.52	3.33	2000.71	22.55	3.76	2.29	2142.38	21.53	3.64	2.81	2071.55
271	21.60	4.01	4.13	2408.10	16.30	3.59	2.50	3918.81	18.95	3.80	3.32	3163.45
275	16.96	4.59	2.71	2099.84	23.20	4.13	2.35	4182.46	20.08	4.36	2.53	3141.15
276	28.50	2.88	2.51	1774.92	19.33	3.49	2.38	3297.70	23.92	3.19	2.45	2536.31
279	19.20	3.92	3.16	2170.32	20.90	3.79	2.33	4017.86	20.05	3.86	2.75	3094.09
282	32.87	3.74	2.74	3175.87	18.55	3.94	2.74	3675.08	25.71	3.84	2.74	3425.48
286	20.48	2.97	2.41	2424.92	19.40	4.08	2.21	3202.54	19.94	3.53	2.31	2813.73

Table S1 (Continued)

287	16.57	3.63	3.04	1931.83	25.56	3.99	2.52	4341.98	21.07	3.81	2.78	3136.91
288	20.21	4.00	2.97	2112.78	20.93	3.76	2.29	3327.38	20.57	3.88	2.63	2720.08
289	17.52	3.93	2.93	2331.73	24.00	4.27	2.37	3360.40	20.76	4.10	2.65	2846.06
290	23.11	3.80	2.80	2846.43	14.70	3.73	2.51	2757.54	18.91	3.77	2.66	2801.98
293	20.52	3.66	2.98	2456.51	22.90	4.05	2.51	3437.38	21.71	3.86	2.75	2946.94
295	19.95	3.71	3.10	2616.11	23.63	4.28	2.39	3925.40	21.79	4.00	2.75	3270.75
296	21.97	3.82	2.71	2578.57	22.90	3.65	2.49	3364.52	22.44	3.74	2.60	2971.55
297	20.07	2.67	2.57	2777.86	15.45	3.78	2.17	3111.11	17.76	3.23	2.37	2944.48
302	21.40	3.67	3.05	2765.71	16.15	3.48	2.07	2749.60	18.78	3.58	2.56	2757.66
303	24.05	3.82	3.65	2545.95	23.10	3.30	2.82	3145.00	23.58	3.56	3.24	2845.48
305	19.22	3.36	2.78	2251.83	14.75	3.71	2.13	2186.98	16.99	3.54	2.46	2219.40
309	19.60	2.92	2.32	2858.81	17.60	3.56	2.12	3336.67	18.60	3.24	2.22	3097.74
310	21.20	4.10	3.12	2074.13	23.10	4.10	2.69	4188.73	22.15	4.10	2.91	3131.43
318	20.98	3.73	2.70	2578.49	22.30	4.06	2.50	3555.24	21.64	3.90	2.60	3066.87
321	25.00	3.81	3.69	1700.24	19.76	3.64	2.67	3263.17	22.38	3.73	3.18	2481.71
329	13.40	3.94	3.90	1417.62	21.90	3.76	2.61	3158.89	17.65	3.85	3.26	2288.25
333	23.20	2.81	2.80	1258.33	16.45	3.87	2.67	2531.27	19.83	3.34	2.74	1894.80
334	18.10	3.90	3.09	2936.43	18.00	3.73	2.29	4199.44	18.05	3.82	2.69	3567.94
335	18.50	3.69	2.88	1350.32	27.30	3.75	2.32	3480.16	22.90	3.72	2.60	2415.24
337	17.21	3.76	2.74	1370.71	14.70	3.72	2.40	3063.81	15.96	3.74	2.57	2217.26
338	23.61	3.05	2.44	2264.68	21.30	3.71	2.65	3338.81	22.46	3.38	2.55	2801.75
341	28.45	4.11	2.83	3375.56	17.50	3.94	2.36	2296.75	22.98	4.03	2.60	2836.15
345	25.16	4.12	4.10	3186.90	22.60	3.67	2.65	4320.24	23.88	3.90	3.38	3753.57
347	29.17	3.93	3.22	2044.29	16.40	3.80	2.33	5382.54	22.79	3.87	2.78	3713.41
348	48.25	3.41	3.40	2606.43	21.70	3.95	2.37	3998.57	34.98	3.68	2.89	3302.50
351	18.50	3.67	3.02	2032.46	22.10	4.19	2.51	4800.32	20.30	3.93	2.77	3416.39
352	22.75	3.69	3.70	3188.33	20.25	3.79	2.50	3154.52	21.50	3.74	3.10	3171.43

Table S1 (Continued)

354	18.10	3.31	2.63	2414.21	21.46	4.04	2.58	4268.81	19.78	3.68	2.61	3341.51
363	20.06	3.84	2.64	2386.11	17.95	3.68	2.08	2558.10	19.01	3.76	2.36	2472.10
365	21.32	3.65	2.91	3238.10	21.80	4.13	2.34	2163.97	21.56	3.89	2.63	2701.03
366	19.01	2.91	2.25	1446.51	25.20	4.34	2.47	4091.51	22.11	3.63	2.36	2769.01
367	20.66	3.21	2.47	1676.75	18.10	4.12	2.30	3027.14	19.38	3.67	2.39	2351.94
370	19.23	3.17	2.47	2029.21	23.26	4.00	2.62	3435.16	21.25	3.59	2.55	2732.18
371	17.73	2.84	2.19	2099.44	19.10	3.77	2.42	3014.21	18.42	3.31	2.31	2556.83
372	29.96	3.00	2.30	2992.86	22.66	3.84	2.18	3853.89	26.31	3.42	2.24	3423.37
375	19.78	3.52	2.68	1728.49	20.76	3.81	2.44	2757.46	20.27	3.67	2.56	2242.98
385	25.08	4.22	2.91	3081.59	23.56	3.85	2.33	3983.41	24.32	4.04	2.62	3532.50
386	22.53	4.09	3.18	2021.11	15.75	3.54	2.33	2593.97	19.14	3.82	2.76	2307.54
387	21.01	3.59	2.86	2543.10	20.05	4.14	2.45	2967.70	20.53	3.87	2.66	2755.40
388	17.45	3.42	2.83	3855.09	17.76	3.57	2.63	3404.21	17.61	3.50	2.73	3629.65
393	22.41	3.48	2.97	2948.49	20.40	3.54	2.44	3449.05	21.41	3.51	2.71	3198.77
396	23.28	3.86	2.81	3637.54	20.70	4.24	2.68	3040.87	21.99	4.05	2.75	3339.21
397	19.25	3.86	2.92	2662.54	25.16	4.28	2.68	4656.27	22.21	4.07	2.80	3659.40
398	22.11	3.98	3.12	2816.11	20.60	4.08	2.64	3306.03	21.36	4.03	2.88	3061.07
399	17.65	3.35	2.70	2160.32	20.40	3.85	2.39	3298.97	19.03	3.60	2.55	2729.64
401	26.86	3.96	3.22	2132.62	19.43	3.58	2.53	2881.03	23.15	3.77	2.88	2506.83
403	21.13	3.96	2.94	2181.11	17.93	3.66	2.33	3267.06	19.53	3.81	2.64	2724.09
404	17.00	3.74	2.87	1741.03	15.95	4.04	2.32	3400.08	16.48	3.89	2.60	2570.56
420	18.07	3.75	2.55	2798.57	17.43	3.96	2.12	3202.46	17.75	3.86	2.34	3000.52
424	28.30	4.19	2.15	1712.14	20.23	4.31	2.23	2488.25	24.27	4.25	2.19	2100.20
426	16.55	3.51	2.84	1774.05	17.50	3.54	2.16	3349.13	17.03	3.53	2.50	2561.59
Erdurmus	24.00	3.82	2.77	1751.35	23.30	3.83	2.24	3153.33	23.65	3.83	2.51	2452.34
Ogretmenoglu	22.30	3.72	3.05	2430.23	19.30	3.72	2.30	2348.10	20.80	3.72	2.68	2389.16
Means	21.57	3.64	2.89	2435.10	20.43	3.83	2.42	3469.60	21.00	3.73	2.66	2952.30

*. **: Statistically significant at P = 0.05 and P = 0.01 significance level, respectively; **TSW**: Thousand Seed Weight; **SL**: Seed Length; **SW**: Seed Width; **SY**: Seed yield;