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Original scientific article

YIELD AND QUALITY CHARACTERISTICS OF DURUM WHEAT GENOTYPES UNDER RAINFED CONDITIONS IN CENTRAL ANATOLIA REGION

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The study aimed to investigate the possibility of integrated assessment of durum wheat genotypes in multi-environmental trials for grain quality and yield. The most important selection parameters for durum wheat grain quality were analysed: kernel weight, test weight, kernel diameter, hardness index, kernel vitreousness, colour *L, a, b* values, grain protein content, SDS sedimentation, and modified SDS sedimentation. A wide variation was observed for all quality characteristics as well as grain yield. Variations in test weight and grain yield in different environments were significantly higher than those found among cultivars, whereas variations in hardness index, kernel vitreousness, colour *L* and *b* values, grain protein content, SDS sedimentation, and modified SDS sedimentation among cultivars were significantly higher than those found between environments. Variations in kernel weight, kernel diameter, and colour *a* value were similar for cultivars

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and environments. Heritability values of the traits in the study ranged from 0.28 for grain yield to 0.99 for the SDS sedimentation test. Significant relationships were observed among traits according to both biplot and correlation analyses. The İkizce location, where the highest mean grain yield and the lowest variation (347 kg/da, 299-412 kg/da, respectively) were obtained, might be considered the most suitable location for wheat production. Nine genotypes out of twenty-four evaluated showed good values for SDS sedimentation, colour value *b*, and grain yield and could be considered the most promising lines for selection.

Keywords: breeding, durum wheat, quality

INTRODUCTION

Durum wheat (*Triticum turgidum* ssp. *durum* Desf.) is mostly utilized for producing pasta, bulgur, and couscous, especially in the Mediterranean region (BRANDOLINI *et al.,* 2018). Pasta is one of the most important staple foods of the Mediterranean diet. Also, bulgur is widely consumed in the region, particularly in Türkiye. Both of these foods have the advantages of being affordable, easy to prepare as well as having a long shelf life (KAPLAN EVLICE, 2022). Türkiye is the second-biggest exporter of pasta in the world, coming after Italy, with 1,400,417 tonnes of pasta exported to 145 countries annually. Also, it is the leading bulgur exporter in the world with 283,027 tonnes exported to 110 countries (TRADE MAP, 2022).

Wheat breeders all over the world have primarily focused on increasing the grain yield in the last century. Grain quality was the secondary goal in wheat breeding programmes during this period (SANCHEZ-GARCIA *et al.,* 2015). Recently, wheat grain quality has gained importance due to increased interest in the end-product quality by consumers, the milling industry, and breeders (PADALINO *et al.,* 2014). Among a number of traits affecting durum wheat quality, the test weight (TW), yellow pigment content (YPC), kernel vitreousness (KV), and grain protein content (GPC) are the most important ones determining the commercial value (FU *et al.,*2018). Yellow colour, grain protein content, and gluten quality, in particular, are regarded as important quality parameters in durum wheat breeding. Grain protein content and gluten quality are related to the quality of the pasta (SISSONS, 2008), and the bright yellow-coloured pasta and bulgur are preferred by consumers (KAPLAN EVLICE and ÖZKAYA, 2019).

It is well documented that wheat grain quantity and quality are negatively correlated (MAICH *et al.,* 2017; TSENOV *et al.,* 2021). Therefore, one of the most challenging objectives in wheat breeding efforts is to achieve high-yielding genotypes with good quality parameters (BÉKÉS, 2012; TSENOV, *et al.,* 2021). While quality characteristics like protein quality and colour are mostly controlled by genetics, others, such as ash and grain protein contents, are greatly affected by environmental factors (CAFFE-TREML *et al.,* 2011; DENCIC *et al.,* 2011; SCHULTHESS *et al.,* 2013). Heritability estimation is a method utilized extensively in breeding programs to determine the effect of genetic and environmental factors on different traits. This method demonstrates how genotype (G), environment (E), and G x E interaction affect traits of interest (KAYA and AKCURA, 2014).

In breeding programs, the grain quality of wheat is determined not by a single factor but by the interaction of many (GUZMAN *et al.,* 2016). The correlation coefficient is a beneficial tool that is being utilized in breeding programs. However, it gives an incomplete account of the relative importance of direct and indirect effects on the individual factors that are involved (ZECEVIC *et al.*, 2004). Biplot analysis is an effective method that can carry out the analysis of different types of two-way data, such as genotype by trait (YAN and HOLAND, 2010). Genotype by trait biplot analysis is utilized extensively in the selection process in order to develop new cultivars in breeding programs (BRANKOVIĆ *et al.,* 2018). The biplot provides useful information by assessing genotypes on multiple traits (MOHAMMADI, 2019). It also exhibits how traits are related, which is consistent with the correlation coefficients (SCHULTHESS *et al.*, 2013).

Thus, the objectives of this study were to a) evaluate the durum wheat genotypes based on quality characteristics and grain yield (GY); b) determine the heritability of the traits; and c) reveal the relationships among the traits using biplot and correlation analyses.

MATERIALS AND METHODS

Materials

Five durum wheat cultivars (Çeşit-1252, Eminbey, Imren, Kızıltan 91, and Vehbibey) and nineteen advanced breeding lines from Durum Wheat Regional Yield Trials (Central Research Institute for Field Crops, Ankara, Türkiye), were utilized in the study. The genotypes were grown at five locations (İkizce-Ankara, Malya-Kırşehir, Polatlı-Ankara, Sarkışla-Sivas, Ulaş-Sivas) in 2020-2021 growing season under rainfed conditions.

Table 1. Monthly average temperature (°C) and total precipitation (mm) values of the locations (2020-2021)

Months	İkizce				Malya				Ulaş				Şarkışla			
	Temp*		Preci		Temp		Preci		Temp		Preci		Temp		Preci	
	20/21	LP	20/21	LP	20/21	LP	20/21	LP	20/21	LP	20/21	LP	20/21	LP	20/21	LP
October	16.8	11.5	22.2	22.7	15.5	10.6	3.0	23.0	14.2	9.8	0	37.9	13.7	11.0	4.7	24
November	5.4	5.7	3.8	29.1	3.5	4	14.0	25.7	3.3	4.8	10.0	36.1	3.4	5.2	6.2	30
December	4.7	0.9	19.2	37.7	2.8	-0.1	10.0	31	1.5	0.3	12.5	23.8	1.5	0.2	11.0	48
January	2	-0.9	59.9	36.3	2	-2.3	35.0	45	0.1	-2.7	69.0	34.8	-1	-3.1	49.9	44
February	2.8	1	13.1	34	1.2	-0.7	9.0	30.5	0.2	-1.5	27.0	29	-1.2	-1.1	2.2	34
Mart	2.6	5.1	72.2	35.7	2.7	4	72.0	31.9	2.6	3	62.8	38.2	2.3	4	46.6	41
April	9.3	9.7	35.4	40.2	10.3	8.9	13.0	28.4	9.6	8	32.5	37.7	9.9	9.3	17.9	58
May	16.5	14.4	19.2	46.9	16.3	13.9	5.0	37.9	13.8	13	46.5	54.7	14.6	13.9	10.8	47
June	15.9	18.1	51.6	35.7	17.4	17.6	8.0	28.9	15.4	15.8	45.4	47.1	16.6	17.8	27.3	35
Average	**8.4**	**7.3**	**-**	**-**	**7.9**	**6.2**	**-**	**-**	**6.7**	**5.6**	**-**	**-**	**6.6**	**6.4**	**-**	**-**
Total	**-**	**-**	**296.6**	**318**	**-**	**-**	**169**	**282**	**-**	**-**	**305.7**	**339**	**-**	**-**	**176.6**	**361**

* Temp: Monthly average temperature (°C), Preci: Monthly total precipitation LP: Long period

The trials were conducted according to Randomized Complete Block Design (RCBD) with four replications. The plot area was 6 m^2 with 6 rows of 5 m length, while the seeding rate was 500 seeds/m^2.The nitrogen and phosphorous fertilizers were applied as per recommendation, i.e., 30 kg N per hectare and 60 kg P per hectare at the time of sowing while 30 kg N per hectare was applied at tillering stage.

Monthly average temperature (°C) and total precipitation (mm) values of the locations are given at Table 1. As shown on the table, insufficient rainfall was obtained in almost all months until harvest, compared to the long-term average because of drought experienced throughout the growing season. Additionally, temperature values have remained above the average. Especially the plants that entered the winter without sufficient tillering experienced serious problems in some locations and suffered great damage due to the effect of drought. The fact that the amount of precipitation and temperature values in June were suitable for plant development increased the grain filling especially on the tillers and the average yield in the trials in İkizce, Ulaş, and Şarkışla approached normal.

Hereinafter, cultivars Çeşit-1252 and Kızıltan 91 will be referred to as Cesit and Kiziltan, respectively, in the text for convenience.

Methods

The GY was calculated from 6 m^2 plot (5m x 1.2m) and has been given as kg/da. Before physical analyses, a dockage tester (Quator, Tripette & Renaud, France) was used to clean the samples. The TW was calculated in kg/hl using the one-liter container (Seedburo Equipment Company, Chicago, IL). Hardness index (HI), kernel diameter (KD), and kernel weight (KW) were determined according to the AACC Method No: 55-31 (AACC INTERNATIONAL, 2010) using the Single Kernel Characterization System (SKCS 4100, Perten Instruments, Sweden). ICC Method No: 129 was used to determine the KV (ICC, 2008).

A small quantity of durum wheat sample was milled into meal using a Perten 3100 laboratory mill (Huddinge, Sweden) after physical analyses in order to determine the moisture and grain protein contents. Samples were also milled to flour following the AACC Method No: 26-50 (AACC INTERNATIONAL, 2010) by using a Brabender Quadrumat Junior (Duisburg, Germany). The flour samples were stored at 4°C for two weeks before use.

AACC Method No: 44-15A and 46-30 were used to determination of the moisture and grain protein contents, respectively (AACC INTERNATIONAL, 2010). The conversion factor 5.7 was used for protein analysis. The SDS sedimentation (SDSS) and modified SDS sedimentation (MSDSS) analyses were carried out according to KOKSEL *et al.* (2009). The *L*, *a*, *b* colour values according to the Hunter *Lab* colorimeter were measured using Gardner BYK (Color View, USA) equipment.

A statistical analysis software (JMP 13.2.1) was used to perform Analysis of Variance (ANOVA) and Pearson correlation coefficients (SAS Institute Inc., Cary, NC, USA). The broad-sense heritability (h^2b) was computed using the GGE-biplot software as stated by YAN and HOLLAND (2010). Using the GenStat software (17^{th} edition, VSN International Ltd., Hemel Hempstead, UK), a genotype trait biplot was created to determine the relationships among traits and genotypes.

RESULTS AND DISCUSSION

The mean, maximum, and minimum values as well as standard deviations of grain yield and some quality parameters for 24 genotypes, grown in 5 different locations, are presented in Table 2.

Table 2. Mean, minimum, maximum, and standard deviation of wheat grain yield and quality parameters for genotypes and environments

Traits* \ Values	Genotypes (*n*=24)			Environments (*n*=5)			Mean (*n*=120)	Heritability
	Min.	Max.	Std. D.	Min.	Max.	Std. D.		
TW (kg/hl)	76.2	80.5	1.1	75.0	80.7	2.3	78.4	0.91
KW (mg)	32.9	39.2	1.9	33.3	39.7	2.9	35.9	0.86
KD (mm)	2.82	3.08	0.07	2.82	3.05	0.10	2.93	0.86
HI	73.4	88.5	3.3	75.9	84.2	3.2	80.7	0.93
KV (%)	92	100	2.0	93	100	3.1	97	0.39
L	94.29	96.18	0.47	94.89	95.30	0.15	95.10	0.84
a	1.57	2.01	0.12	1.66	2.01	0.14	1.81	0.81
b	16.99	23.38	1.87	19.30	21.69	0.92	20.53	0.98
GPC (%)	12.2	14.7	0.6	12.7	13.9	0.4	13.2	0.74
SDSS (ml)	15	70	15.3	39	51	4.6	44	0.99
MSDSS (ml)	14	57	10.8	32	49	6.6	38.4	0.90
GY (kg/da)	225.3	280.9	14.4	136.7	347.3	95.2	250.6	0.28

*Traits: TW: Test weight, KW: Kernel weight, HI: Hardness index, KD: Kernel diameter, KV: Kernel vitreousness, *L*: colour *L* value, *a*: colour *a* value, *b*: colour *b* value, GPC: Grain protein content, SDSS: SDS sedimentation value, MSDSS: Modified SDS sedimentation value, GY: Grain yield. The results of TW and GPC were expressed on dry weight basis. The results of SDSS and MSDSS were expressed on 14% moisture basis.

Kernel size has an important effect on numerous compositional and qualitative characters since big and heavy kernels hold a higher amount of starchy endosperm and lesser proportions of aleurone layers and the external pericarp. The KW and TW directly affect the semolina and flour yields. Therefore, particularly the milling industry desires wheats with high KW and TW (BRANDOLINI *et al.*, 2011). In the present study, the TW and KW displayed similar variations for genotypes (76.2-80.5 kg/hl, 32.9-39.2 mg) and environments (75.0-80.7 kg/hl, 33.3-39.7 mg) with means of 78.4 kg/hl and 35.9 mg, respectively (Table 2). In another study conducted by the same author, a wider range and lower values (71.5-77.4 kg/hl) for TW and similar range (33.3-40.5 mg) for KW were found for genotypes (KAPLAN EVLICE, 2022). Nearly the same ranges were found for genotypes (2.82-3.08 mm) and environments (2.82-3.05 mm) in terms of KD in the present study (Table 2). Various results for these traits are reported in the literature, while TAGHOUTI *et al.* (2010) found the genotypic effect to be dominant for the TW, SUBIRA *et al.* (2014) and SIEBER *et al.* (2015) stated that the TW was mostly influenced by the environmental factors in Mediterranean countries. GUZMAN *et al.* (2016), on the other hand, reported that TW and KW showed great variability both in genotypes and environments. The reason for these different findings may be the result of different wheat species and cultivars, as well as environmental conditions and agronomic applications employed in these studies, which affect kernel weight, test weight, and kernel diameter.

Traditionally, durum wheat is characterized by hard and glassy-textured kernel (LAFIANDRA *et al.,* 2022). In the present study, HI and KV were found 73.4-88.5 and 92-100% for genotypes, 75.9-84.2 and 93-100% for environments, respectively. The variations for both traits in environments were slightly smaller compared to genotypes (Table 2). The hardness index had shown a high heritability (0.93). This result is expected due to grain hardness being primarily controlled by the genes at the Hardness locus, *Ha*, located on the short arm of chromosome 5D, that encodes the Puroindolines *a* and *b* (BHAVE *et al.,* 2009). However, KV had a low heritability (0.39) (Table 2) because it is prone to be affected by environmental conditions. Similarly, a moderate heritability value (0.67) for KV (SIEBER *et al.,* 2015) and a high heritability value (0.90) for HI (GUMAN *et al.,* 2016) were reported by researchers.

Colour is one of the most important quality parameters in durum wheat and affects consumer's choice of the end product (CABAS-LÜHMANN *et al.,* 2021). In the present study, colour *L* value (brightness) presented a wider variation on genotypes (94.29-96.18) than on environments (94.89-95.30). The colour *a* value (redness) ranged from 1.57 to 2.01 for genotypes and from 1.66 to 2.01 for environments. The *b* value (yellowness) had also a wider variation on genotypes (16.99-23.38) than environments (19.30-21.69). Colour *L,a,b* values presented wider variations on genotypes than on environments. The *L,a,b* colour traits which are mostly controlled by genetics, had a high heritability values (≥0.81) (Table 2). Similarly higher heritability values for colour *b* value (≥0.90) were reported by several researchers (LONGIN *et al.,* 2013; SIEBER *et al.,* 2015). Therefore, it is one of the main parameters employed for selecting the lines in durum wheat breeding programmes.

The trait GPC is one of the most important quality parameters, since it is well known that the higher grain protein content translates to higher quality durum wheat (VÁZQUEZ *et al.,* 2012). The range of values for GPC was slightly wider for genotypes (12.2-14.7%) than for environments (12.7-13.9%) and the mean GPC was found 13.2% (Table 2). Similar results were reported by BRANKOVIĆ *et al.* (2018). However, GUZMAN (2016) stated that the variation and mean value in GPC increased under heat and drought stress conditions compared to optimum conditions. Since the present study was carried out under rainfed conditions, the range of GPC in locations could be smaller than in genotypes.

Sedimentation tests indicate the quantity and quality of protein fractions that define the characteristics of gluten (CECCHINI *et al.,* 2021) and are employed by wheat breeders to select durum wheat genotypes (CLARKE *et al.,* 2010) since pasta with a firm texture and high cooking quality can be produced by using durum wheat with strong gluten and high grain protein content (DENG *et al.,* 2017). Compared to GPC, the traits SDSS and MSDSS showed greater variations; 15-70 ml and 14-57 ml for genotypes, 39-51 ml and 32-49 ml for environments, respectively (Table 2). SDSS had a higher and wider variation compared to what BRANKOVIĆ *et al.* (2018) reported for genotypes. Both SDSS and MSDSS resulted in higher heritability values (≥0.90) (Table 2). The standard deviations in SDSS were 3.3 times higher among the genotypes than the environments, showing the genetic variability within the material utilized in the study. This genotypic variation is essential to develop cultivars with good gluten quantity and quality.

MSDSS is utilized to evaluate suni-bug damage (*Eurygaster integriceps*), as well as to determine the quantity and quality of protein in wheat. The difference between SDSS and MSDSS values is an indicator of the degradation in gluten quality caused by the damage of suni-bug (KOKSEL *et al.,* 2009). Results of both sedimentation tests show that the genotypes in the present study had suni-bug damage (Table 2). Therefore, rheological and end-product quality analyses could not be performed since gluten quality was affected by the suni-bug damage.

Variation among environments (136.7-347.3 kg/da) was higher than among genotypes (225.3-280.9 kg/da) for GY as expected. The standard deviation of GY for the environment was 95.2 kg/da, while it was 14.4 kg/da for genotype (Table 2). Higher standard deviation values for environments suggest higher variability. The present study showed similar results to those reported by VAZQUEZ *et al.* (2012) who concluded that the environmental conditions dictated the variation of GY. Similarly, the environmental effect explained about from 76% to 98% of yield variability in durum wheat studies (ROYO *et al.* 2010; SUBIRA *et al.* 2014; CHAIRI *et al.* 2020). In this study, a quite low heritability value (0.28) was calculated for GY, supporting these findings (Table 2). Similarly, a low heritability value was reported by LONGIN *et al.* (2013).

In wheat breeding, GY is one of the most important parameters affecting the selection of genotypes (ROMENA *et al.,* 2022). Therefore, a more detailed explanation was provided for GY compared to TW, KW, HI, KD, KV, colour *L, a, b* values, GPC, SDSS, MSDSS. The GY variations and means for genotypes and environments are presented in Figure 1 and Table 3. The mean grain yield was observed as 250.6 kg/da in the present study. Although all genotypes presented GY of 250.6 kg/da or above at least in one environment, particularly, lines 7, 11, and 17 had yielded more than 400 kg/da at least in one location. Among the locations, the highest variability for GY was observed in Sarkışla (277-429 kg/da, mean:340 kg/da), while the lowest was found in Malya (108-160 kg/da, mean:137 kg/da). However, İkizce location with the highest mean GY and low variation (299-412 kg/da, mean 347 kg/da) can be considered the most suitable location for wheat production (Figure 1).

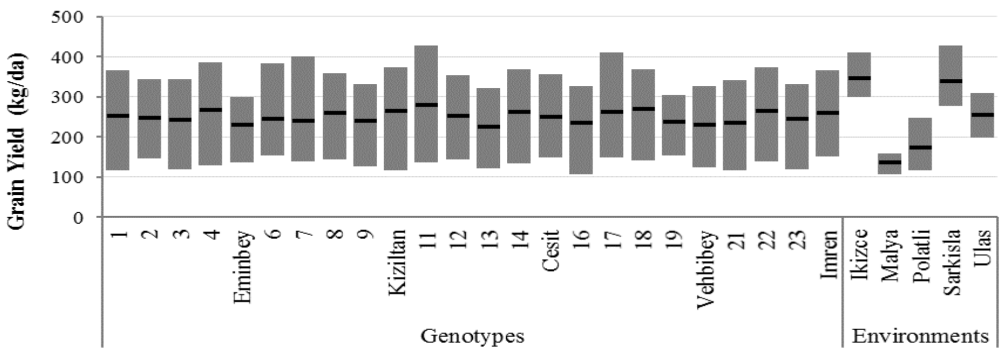

Figure 1. Grain yield ranges and means for genotypes and environments.

Table 3. Mean values of grain yield for twenty-four genotypes grown at five environments.

	Grain Yield (kg/da)	Environments					Mean Value
		İkizce	Malya	Polatlı	Sarkışla	Ulaş	
Genotypes	1	367.5±15.3^{ad}	116.0±19.1^{gh}	155.1±36.8^{dg}	359.4±18.2^{ae}	272.8±28.3^{ae}	254.1±51.6^{bf}
	2	344.3±52.9^{bg}	147.3±22.4^{ad}	175.8±33.0^{cf}	326.7±26.4^{bf}	251.0±24.3^{ag}	249.0±39.3^{bf}
	3	320.3±19.3^{dg}	120.3±20.8^{eh}	159.8±28.7^{dg}	343.7±17.6^{bf}	267.0±28.7^{af}	242.2±44.0^{dg}
	4	386.0±16.7^{ab}	128.3±18.8^{ch}	163.8±27.7^{cf}	381.7±17.0^{ac}	278.3±22.3^{ac}	267.6±53.5^{ac}
	Eminbey	299.0±14.6^{g}	136.3±17.4^{ag}	211.5±28.5^{ac}	293.4±14.5^{ef}	219.0±22.1^{eg}	231.8±30.0^{fg}
	6	382.8±13.2^{ac}	156.5±12.7^{ab}	154.8±28.8^{dg}	277.0±22.3^{f}	258.8±26.0^{af}	246.0±52.5^{cg}
	7	312.3±6.7^{eg}	140.3±15.8^{ag}	152.1±29.3^{eg}	401.7±72.3^{ab}	198.8±11.7^{g}	241.0±50.4^{dg}
	8	358.5±25.5^{af}	143.5±26.4^{af}	183.8±27.7^{be}	359.7±51.0^{ae}	259.0±14.4^{af}	260.9±44.2^{ae}
	9	330.8±16.5^{cg}	128.0±22.7^{ch}	184.1±22.5^{be}	317.7±52.7^{cf}	248.0±16.4^{bg}	241.7±38.7^{dg}
	Kiziltan	353.8±19.7^{bf}	117.8±24.2^{fh}	171.8±34.0^{cf}	374.0±83.0^{ad}	304.6±35.7^{ab}	264.4±50.8^{ad}
	11	359.3±18.9^{af}	137.5±20.2^{ag}	221.8±52.0^{ab}	429.0±80.7^{a}	256.8±32.4^{af}	280.9±51.3^{a}
	12	355.3±18.4^{bf}	145.3±7.3^{ae}	195.5±26.5^{bd}	349.4±31.7^{bf}	220.5±16.6^{dg}	253.2±42.3^{bf}
	13	321.3±19.8^{dg}	123.0±16.2^{dh}	161.1±43.1^{df}	322.4±51.7^{bf}	198.8±15.5^{g}	225.3±41.2^{g}
	14	363.8±78.3^{ae}	134.0±18.0^{bg}	134.1±26.8^{fg}	368.0±11.4^{ad}	309.4±26.2^{a}	261.8±53.2^{ad}
	Cesit	357.0±20.9^{bf}	157.3±20.6^{ab}	149.1±23.7^{eg}	306.7±78.8^{df}	284.5±17.6^{ac}	250.9±41.6^{bf}
	16	327.0±37.1^{dg}	108.0±19.6^{h}	248.4±50.2^{a}	277.0±52.5^{f}	215.3±27.0^{fg}	235.1±36.7^{fg}
	17	412.0±19.6^{a}	148.8±12.8^{ad}	172.5±37.5^{cf}	336.8±68.4^{bf}	240.0±18.7^{cg}	262.0±49.7^{ad}
	18	368.8±10.1^{ad}	141.8±20.8^{ag}	174.1±27.7^{cf}	366.4±38.0^{ae}	300.5±9.7^{ab}	270.3±47.8^{ab}
	19	305.8±5.1^{fg}	157.2±16.7^{ab}	154.5±26.9^{dg}	301.7±65.0^{df}	270.3±14.5^{af}	237.8±34.1^{eg}
	Vehbibey	327.3±10.8^{dg}	124.3±20.4^{dh}	166.5±31.0^{cf}	309.0±53.1^{cf}	229.8±25.5^{cg}	231.3±39.3^{fg}
	21	342.1±33.8^{bg}	160.0±9.7^{a}	117.8±14.4^{g}	327.4±20.4^{bf}	231.3±20.7^{cg}	235.7±44.4^{fg}
	22	349.3±14.3^{bg}	139±11.7^{ag}	180.5±31.9^{be}	374.7±87.1^{ad}	285.0±33.9^{ac}	265.7±46.1^{ac}
	23	331.8±25.3^{cg}	119.5±23.1^{eh}	204.5±36.0^{ac}	301.7±39.4^{df}	275.8±25.7^{ad}	246.6±38.1^{cg}
	Imren	360.5±19.6^{ae}	150.5±17.9^{ac}	186.1±28.0^{be}	366.4±18.2^{ae}	234.3±11.9^{cg}	259.5±44.5^{ae}
Mean Value		347.3	137.0	174.1	340.4	254.5	250.6
LSD		54.1	25.9	43.0	74.3	56.4	23.0
CV (%)		11.04	13,45	12.21	13.3	15.78	13.56
Significance		*	*	**	*	**	**

$^{a-g}$: Values in the same column with different superscripts indicate a statistically significant difference.

*, **: Significant at the 0.05 and 0.01 probability levels indicted by one and two asterisks, respectively.

The heritability of a trait determines the success of selection in breeding (DENCIC *et al.*, 2011). The heritability values for all traits are presented in Table 2, these values were ranged from 0.28 (for GY) to 0.99 (for SDSS) (Table 2). Similar heritability values were found for

SDSS (0.79) and GPC (0.78) by MICHEL *et al.*, 2017). Further, GUZMAN *et al.* (2016) reported high heritability values for TW (0.88), KW (0.97), HI (0.90), GPC (0.83), and SDSS (0.96). However, MLADENOV *et al.* (2001) recorded relatively low heritability values (0.29 for TW, 0.35 for GPC, and 0.50 for SDSS), showing that environmental effects account for a large portion of the total phenotypic variation of these traits. A relatively low heritability value for KW was also reported by HEIDARI *et al.* (2016). Similarly, because of broader environmental variance, relatively low heritability values were determined (varied from 0.32 for TKW to 0.52 for ZSV) by KAYA and AKCURA (2014).

Table 4. Correlations coefficients among traits

Traits	GY	TW	KW	HI	KD	KV	*L*	*a*	*b*	GPC	SDSS
TW	0.391**										
KW	0.583**	0.601**									
HI	-0.148	-0.299**	-0.333**								
KD	0.552**	0.669**	0.945**	-0.335**							
KV	-0.171	-0.064	-0.268**	0.062	-0.138						
L	0.041	0.302**	0.079	-0.013	0.108	0.041					
a	-0.462**	-0.193*	-0.215*	0.011	-0.251**	-0.241**	-0.277**				
b	-0.169	-0.333**	-0.210*	-0.070	-0.242**	-0.026	-0.567**	0.607**			
GPC	-0.281**	-0.035	-0.170	0.049	-0.172	0.097	-0.163	0.365**	0.068		
SDSS	-0.116	-0.293**	-0.067	0.133	-0.187*	0.047	-0.097	0.086	0.046	0.258**	
MSDSS	0.059	-0.329**	-0.009	0.063	-0.177*	0.246**	-0.042	-0.001	0.052	0.112	0.742**

Traits: GY: Grain yield, TW: Test weight, KW: Kernel weight, HI: Hardness index, KD: Kernel diameter, KV: Kernel vitreousness, *L*: colour *L* value, *a*: colour *a* value, *b*: colour *b* value, GPC: Grain protein content, SDSS: SDS sedimentation value, MSDSS: Modified SDS sedimentation value.
*, **: Significant at the 0.05 and 0.01 probability levels, respectively.

It is desirable to determine correlations among traits when several traits are involved in the evaluation of quality (MLADENOV *et al.*, 2001). In the present study, the correlation coefficients among the traits are presented in Table 4. Grain yield correlated positively with TW, KW, KD and negatively with colour *a* value and GPC. Similarly, TW showed significant positive correlations with KW, KD, colour *L* value and negative correlations with HI, colour *a* and *b* values, SDSS, and MSDSS. The trait KW presented a significant positive correlation with KD and a negative correlation with HI, KV, colour *a* and *b* values. Kernel diameter had negative correlations with HI, colour *a*, and colour *b*. There was also a negative relationship between colour *L* and *b* values. The colour *a* value correlated negatively with KV, colour *L* and positively with colour *b* value and GPC. SDSS correlated negatively with KD and positively with GPC. The trait MSDSS had a negative correlation with KD and positive correlations with KV and SDSS (Table 4). Similar to the results of the present study, positive correlations were found between GY and KW (KHAZRATKULOVA *et al.,* 2015; SASANI *et al.,* 2020; KHALID *et al.,* 2022) and between GPC and SDSS by other scientists (SASANI *et al.,* 2020). A negative association existed between GPC and GY as reported by LONGIN *et al.* (2013) and SIEBER *et al.* (2015). The negative relation between GY and GPC may be related to the impact of grain protein content, because low grain protein content may arise from high grain yield. BRANKOVIĆ *et al.* (2018) reported that higher grain yield is the result of protein dilution by non-nitrogen compounds in the wheat grain during the grain filling stage. Similarly, GUZMAN *et al.* (2016) stated that TW and KW had a negative connection with GPC due to dilution or concentration effect depending on grain size.

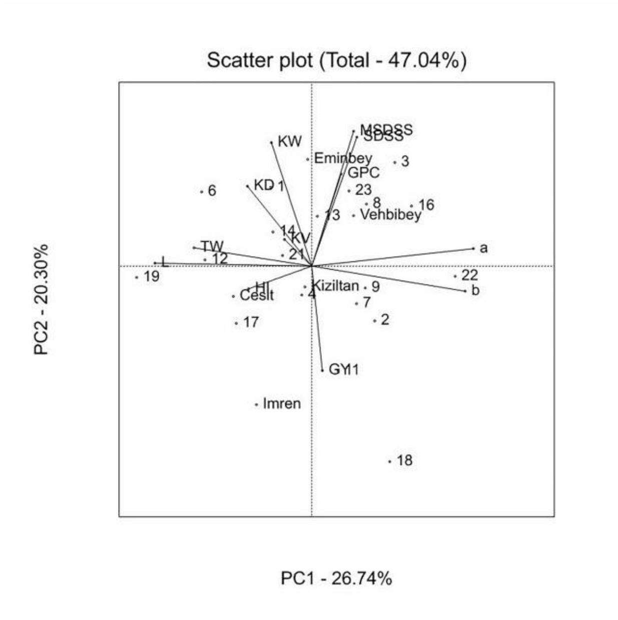

Figure 2. Biplot analysis for genotypes and traits

Traits: GY: Grain yield, TW: Test weight, KW: Kernel weight, HI: Hardness index, KD: Kernel diameter, KV: Kernel vitreousness, *L*: colour *L* value, *a*: colour *a* value, *b*: colour *b* value, GPC: Grain protein content, SDSS: SDS sedimentation value, MSDSS: Modified SDS sedimentation value.

The numbers are belonging to the lines.

The biplot analysis is used to assess the relation between traits and to compare the genotypes for multiple traits, thus identifying the lines with desired traits. Principal component 1 and principal component 2 (PC1 and PC2) explained 47.04% (PC1, 26.74% and PC2, 20.30%) of the variability among the genotypes and the traits (Figure 2). Vectors of the traits that display narrow angles on a biplot graph are positively correlated whereas ones that are straight or with obtuse angles are negatively correlated, and those with vertical angles present no correlation. The distance among the genotypes is evaluated with aspects of resemblance (YAN and HOLLAND, 2010). Regarding the traits, there was a strong relation between colour *a* and *b* values. Grain protein content, SDSS, and MSDSS were grouped together and significant relationships were observed among them. The traits KW, KD, TW, and colour *L* value were located at the top left of the chart, indicating strong positive relation among these parameters (Figure 2). These results indicate that it is difficult to achieve higher GY, grain protein content, and gluten quality in a single genotype according to the biplot analysis performed in the present study. KAYA and AKCURA (2014), also showed a negative correlation between the GY and GPC.

Regarding the genotypes, genotype 22 was located close to colour *a* and *b* values. The genotypes 3, 8, 16, 23 and cultivars Vehbibey and Eminbey were located around GPC, SDSS, and MSDSS traits. Genotypes 1 and 6 were close to KD, genotypes 13, 14, and 21 were close to KV, genotype 12 was close to TW, genotype 19 was close to colour *L* value, genotype 17 and cultivar Cesit were close to HI, while the remaining genotypes were close to GY in the biplot graph (Figure 2), which confirms the data presented in Table 3.

Colour and SDS are the most important quality parameters in durum wheat breeding programmes. Genotype selections are generally made on the basis of these two parameters, which shows high heritability in early generations (LONGIN *et al.,* 2013). When GY and these two quality traits were evaluated together in the biplot graph, the genotypes 2, 3, 7, 8, 9, 11, 16, 22, and 23 were located around SDSS, colour *b* value, and GY suggesting that these genotypes had similar and desired reactions for both quality analyses and GY in these environments. KAYA and AKCURA (2014) noted that the genotypes which were grouped in the biplot displayed similar performances for a number of quality parameters.

CONCLUSIONS

Outcomes of the current study revealed that there were wide variations among genotypes and environments for GY and all grain quality parameters. The traits HI, KV, colour *L* and *b* values, GPC, SDSS, and MSDSS showed wider variation across genotypes compared to across environments. The variability among these genotypes provides an opportunity for selection to wheat breeders to develop new and superior cultivars with good quality traits. Significant relationships were determined among traits according to both biplot and correlation analyses. Besides, according to biplot analysis nine genotypes showed desired responses for SDSS, colour *b* value, and GY in all environments. It might be beneficial to evaluate the genotypes for one more year to obtain more precise results.

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KARAKTERISTIKE PRINOSA I KVALITETA GENOTIPOVA DURUM PŠENICE U SUŠNIM USLOVIMA U REGIONU CENTRALNE ANATOLIJE

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Izvod

Studija je imala za cilj da ispita mogućnost integrisane procene genotipova durum pšenice u multi-ekološkim ispitivanjima kvaliteta i prinosa zrna. Analizirani su najvažniji selekcioni parametri za kvalitet zrna durum pšenice: masa zrna, prečnik zrna, indeks tvrdoće, staklastost zrna, *L*, *a*, *b* vrednosti, sadržaj proteina u zrnu, SDS sedimentacija i modifikovana SDS sedimentacija. Uočena je velika varijacija za sve karakteristike kvaliteta kao i za prinos zrna. Varijacije u težini i prinosu zrna u različitim sredinama bile su značajno veće od onih utvrđenih među sortama, dok su varijacije u indeksu tvrdoće, staklastosti zrna, vrednostima boje *L* i *b*, sadržaju proteina u zrnu, sedimentaciji SDS i modifikovanoj sedimentaciji SDS među sortama bile značajno veće nego one koje su utvrđene između sredina. Varijacije u težini zrna, prečniku zrna i vrednosti boje *a* bile su slične za sorte i okruženje. Vrednosti heritabilnosti ispitivanih osobina kretale su se od 0,28 za prinos zrna do 0,99 za SDS test sedimentacije. Uočene su značajne veze među osobinama prema biplot i korelacionoj analizi. Lokacija İkizce, gde je dobijen najveći prosečan prinos zrna i najmanja varijacija (347 kg/da, 299-412 kg/da, respektivno), može se smatrati najpogodnijom lokacijom za proizvodnju pšenice. Devet od dvadeset četiri ocenjena genotipa pokazalo je dobre vrednosti za SDS sedimentaciju, vrednost boje *b* i prinos zrna i mogu se smatrati linijama koje najviše obećavaju za selekciju.

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