

## The relationships of some traits in Turkish winter bread wheat landraces

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**Abstract:** In this study, 42 bread wheat pure lines obtained from 340 landraces, collected from 35 provinces of 7 regions in Turkey, and 7 modern bread wheat cultivars were evaluated under rainfed conditions in Konya, in 2005-2006 and 2006-2007 growing seasons. Experiments were conducted in a  $7 \times 7$  lattice design in 3 replicates. Both genotype-traits (GT) biplot analysis and path analysis were used to investigate the relationships between grain yield and 12 traits. Applying both types of analyses to the multiple traits data revealed that GT biplot graphically displayed the interrelationships among traits (breeding objectives), identified traits that are positively or negatively associated, and facilitated visual comparison trait profiles (strength and weakness) of genotypes, which is important for parent as well as variety selection. Vast variations existed in traits (number of grains  $m^{-2}$ , harvest index, number of spikes  $m^{-2}$ , number of grains spike $^{-1}$ , and weight of grains spike $^{-1}$  and biological yield) and grain yield. It was found that either pure lines or cultivars with the highest grain yield had the highest biological yield, number of grain  $m^{-2}$ , and harvest index. The results showed that pure lines combined with favorable traits G43 (Kars-TR15796-7), G33 (Kars-TR15796-4), G20 (Kütahya-TR55167-3), and G11 (Kütahya-TR55212-4) can be evaluated in multi-environment trials for a candidate winter bread wheat registration trial. Some pure lines that had high quality traits G26 (Samsun-TR37926-3), G45 (Erzurum-TR32881-6) and G49 (Erzurum-TR32668-1) might be good parents for enhancing quality in bread wheat. In conclusion, for the short-term improvement of Turkish bread wheat landraces may be possible through an indirect selection of the number of grain  $m^{-2}$  and biological yield, or direct selection for grain yield per se. In the long-run, crossing programs between indigenous and introduced exotic germplasm may be necessary for high industrial quality characters of bread wheat.

**Key words:** Biplot analysis, grain yield, multiple traits, path analysis, Turkey, winter bread wheat landraces

### Türkiye kışlık yerel ekmeklik buğdaylarında bazı karakterler arasındaki ilişkiler

**Özet:** Türkiye'nin 7 bölgesine ait 35 ilden toplanan 340 adet yerel ekmeklik buğday çeşidinden seçilen 42 saf hat, 7 modern ekmeklik buğday çeşidi ile birlikte Konya doğal koşullarında 2005-2006 ve 2006-2007 yetiştirme sezonlarında değerlendirilmiştir. Denemeler 3 tekerrürlü  $7 \times 7$  latis deneme desenine göre kurulmuştur. Tane verimi ile 12 karakter arasındaki ilişkiyi incelemek amacıyla elde edilen verilere genotip-karakter (GK)-biplot analizi ve path analizi

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uygulanmıştır. İncelenen karakterlerle oluşturulan GK biplot grafiği, karakterler arası ilişkileri göstermiş (ıslah amaçları bakımından), pozitif veya negatif ilişkili karakterleri belirlemiş, hat ve ebeveyn seleksiyonu için oldukça önemli olan genotiplerin (saf hat - çeşit) karakter profilini (güçlü-zayıf) görsel olarak değerlendirmeyi sağlamıştır. İncelenen karakterlerden, metrekarede tane sayısı, biyolojik verim, hasat indeksi, metrekarede başak sayısı, başakta tane sayısı ve başakta tane ağırlığında geniş varyasyonlar tespit edilmiştir. En yüksek tane verimine sahip olan saf hat veya çeşitlerin aynı zamanda en yüksek metrekarede tane sayısı, hasat indeksi ve biyolojik verim değerlerine de sahip oldukları belirlenmiştir. Tane verimi ile birlikte birkaç karakter bakımından iyi olan, G43 (Kars-TR15796-7), G33 (Kars-TR15796-4), G20 (Kütahya-TR55167-3) ve G11 (Kütahya-TR55212-4) yerel buğday saf hatları çeşit adayları olarak ekmeçlik buğday bölge verim denemelerine alınabilir. Yüksek kalite değerlerine sahip olan G26 (Samsun-TR37926-3), G45 (Erzurum-TR32881-6) ve G49 (Erzurum-TR32668-1) saf hatlar ise, kalite ıslahında ebeveyn olarak kullanılabilir. Araştırma sonuçlarına göre, Türkiye kışlık yerel ekmeçlik buğdayları kısa dönemde metrekaredeki tane sayısı ve biyolojik verim üzerinden yapılacak dolaylı ya da tane verimine göre yapılacak doğrudan seleksiyonla, uzun dönemde ise yüksek endüstriyel kalite karakterleri için yabancı genetik materyalle melezleme programlarına alınarak geliştirilebilir.

**Anahtar sözcükler:** Biplot analizi, tane verimi, çok karakter, path analizi, Türkiye, kışlık yerel ekmeçlik buğday çeşitleri

## Introduction

Bread (*Triticum aestivum* L.) and durum wheat (*T. turgidum* L. subsp. *durum* Desf.) have been cultivated in Turkey since ancient times where it was the center of origin (Gökgöl 1939; Vavilov 1950) and site of genetic diversity (Harlan 1971). A landrace is defined as a mixture of genotypes that evolved, largely by natural selection, under the environmental conditions in which they were grown Harlan (1971). Landraces of wheat generally are resistant to biotic and abiotic stresses, and are grown under low-input, sustainable farming conditions, where they produce a reasonable yield.

For future breeding and selection, it is important to ascertain the variation available for grain yield, quality traits, and yield components in wheat landraces of Turkey (Karagöz and Zencirci 2005). Akçura (2006) reported considerable differences in lots of traits, such as number of fertile tiller per plant, number of grains per spike, grain yield of the plant, glume color, and SDS sedimentations among wheat landraces of Turkey. He also found significant differences in some traits such as grain yield, semolina color, and 1000 kernel weight among durum wheat landraces from the central Anatolian region of Turkey (Akçura 2009). Bilgin et al. (2009) described variation in grain yield, 1000 kernel weight, and vitreousness among landraces of durum wheat landraces, and cultivars from Turkey. Zencirci (2008) found Turkish

durum wheat landraces revealed larger variations for some traits, such as flag leaf length and width, angle, flag leaf sheath length, number of fertile spikes, spike length and width, yield per plant, percent of vitreous kernel, pearling index, percent protein in grain, and 1000 kernel weight. Also, Akçura and Topal (2008) concluded that it may be possible to improve Turkish wheat landraces by indirect selection for an increased in the number of grains spike<sup>-1</sup>, and the weight of grain spike<sup>-1</sup>, or direct selection for grain yield per se.

Usually, a large number of genotypes are tested at a number of sites over years, and multiple traits recorded, and it is often difficult to determine the pattern of genotypic performance across environments. Numerous methods have been used in the search for an understanding of the causes of interactions, although strategies may differ in overall appropriateness, different methods usually lead to the same or similar conclusions for a given dataset (Flores et al. 1998). Recently, the GGE biplot methodology was developed originally for analyzing multi-environment trial data (Yan and Kang 2003). However, it can also be equally used for all types of 2-way data that assume an entry × tester structure (Yan 2001). The genotypes can be generalized as entries, and the multiple traits as testers (Rubio et al. 2004). The term GE interaction commonly refers to yield variation that cannot be explained by the genotype main effect (G), or the environment main effect (E). In addition, for genotype evaluation both

G and GE must be considered simultaneously, and a similar GGE biplot can also be used to genotype evaluation across environments. Yan and Rajcan (2002) used a GT biplot, which is an application of the GGE biplot technique to study the GT data. A GT biplot is an effective tool for exploring multi-trait data. It graphically displays the genotype by trait table, and allows the visualization of the associations among traits across the genotypes and of the trait profile of the genotypes (Yan and Kang 2003).

In the present study, a set of different pure lines selected from bread wheat landraces from 7 regions of Turkey were used to describe genotype evaluation on the basis of multiple traits using the path coefficient analysis (Li 1955), and the GT biplot technique (Yan et al. 2000) in order to: 1) reveal the interrelationship among bread wheat grain yield and 12 traits, 2) compare genotypes on the basis of multiple traits, 3) recommend possible selection strategies, 4) breed improved landraces and/or modern cultivars for rainfed areas of the central Anatolian region of Turkey.

## Materials and methods

Bread wheat landraces, 340, were used as primary material collected between 1964 and 1991 by the Turkish National GenBank's personnel from 7 regions (35 provinces) of Turkey. In 2002, at least 340 landraces were sown in Konya rainfed conditions to select single plants for head rows. In 2003, 1800 single plants were sown in Konya to select pure lines with respect to grain yield, length of the spike (LS), number of spikelets spike<sup>-1</sup> (NSS), weight of grains spike<sup>-1</sup> (WGS), number of grain spike<sup>-1</sup> (NGS), plant height (PH), 1000 kernel weight (TKW), protein content (PC), mini-SDS sedimentation (SDS), and yellow rust tolerance. In 2004, 266 pure lines were selected and 14 cultivars were evaluated with augmented design, and 42 pure lines were selected.

These 42 pure lines, and 7 modern bread wheat cultivars (Karahan-99, Gerek-79, Kırac-66, Bezostaja-1, Bayraktar-98, Altay-2000, and Dağdaş-94), were used in the study. Local names, origin of selected pure lines, history of selection, and standard cultivars are given in Table 1. A 7 × 7 lattice design with 3 replicates was laid out. The seeds were

planted using an experimental drill in 1.2 m × 7 m plots, consisting of 6 rows with 20 cm row space. The seeding rates were 550 seeds m<sup>-2</sup> for rainfed conditions. The plots were fertilized with 27 kg N ha<sup>-1</sup>, and 69 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> at planting, and 40 kg N ha<sup>-1</sup> in spring at the stem elongation. The 1.2 m × 5 m sized-plots were harvested by a combined harvester.

The experiments were performed in a clay loam soil with a pH of 7.7 under rainfed conditions in the 2005-2006, and 2006-2007 growing seasons in Konya. The climate in Konya is semi-arid with cold winters, rainy springs, and hot and dry summers (Figure 1). Since both the prevailing northerly wind and the common southerly wind are dry, the Konya Basin usually has a relative humidity below 50% (DMI 2007).

The grain yield (GY) was determined and expressed as ton per hectare (t ha<sup>-1</sup>). Different traits, other than grain yield, were considered, such as biological yield (BY), harvest index (HI), number of spikes m<sup>-2</sup> (NS), number of grains m<sup>-2</sup> (NG), length of spike (LS), number of spikelets spike<sup>-1</sup> (NSS), weight of grains spike<sup>-1</sup> (WGS), number of grains spike<sup>-1</sup> (NGS), plant height (PH), 1000 kernel weight (TKW), protein content (PC), and mini-SDS sedimentation (SDS).

PH, LS, WGS, NGS, and NSS were determined on the basis of 10 randomly chosen plants per plot, excluding the border plants (Dokuyucu et al. 2002). At the ripening, before grain harvest, plants within 1 m length in the central row of each plot were sampled to measure BY, NG, NS, and HI. BY was recorded in t ha<sup>-1</sup>, and HI was determined from the ratio of grain yield to biological yield. TKW was calculated as the mean weight of 4 sets of 100 kernels. PC was determined using the near infrared reflectance (NIR) method (Williams et al. 1982). The mini-SDS sedimentation was performed according to Pena et al. (1990).

Variance analyses were run on data obtained from 42 pure lines and 7 standard cultivars. In pooled analysis experiments, years were random, while genotypes were fixed. A linear correlation analyses was applied pairwise to all the parameters studied; yield and yield components (BY, NS, NG, NGS, WGS, HI) were also subject to path coefficient analysis (Li 1955) across the growing seasons.

Table 1. Details of landraces pure lines from landraces and cultivars\*.

GN	Local Name	Altitude (m)	P-NGB-NSP	GN	Local Name	Pr-N.G.B.-NSP	Altitude (m)
2	İtalyan buğdayı	1150	Kütahya-TR 55127-6	33	Tir buğdayı	Kars-TR 15796-4	1960
3	Germil buğdayı	1100	Yozgat-TR 35147-2	34	Zerun	Sivas-TR 46891-5	1300
4	Eski buğday	700	Adıyaman-TR 50465-2	35	Kızılca	Edirne-TR 33264-5	50
5	Zerun	1300	Sivas-TR 46890-1	36	Kirik	Erzurum-TR 32640-5	1650
6	Kırmızı buğday	1600	Gümüşhane-TR 44487-4	37	Zerun	Sivas-TR 53292-1	1420
7	Tir buğdayı	1870	Van-TR 32232-6	39	Kirik	Erzurum-TR 32798-6	1940
8	Çam buğdayı	380	Tokat-TR 54989-4	40	Sert başak	Adıyaman-TR 49018-3	620
9	Kobak Buğdayı	1000	Kütahya -TR 55146-6	41	Polatlı yazlığı	K.Maraş-TR 32009-5	1250
10	Kirik	1660	Erzurum-TR 15848-2	42	Ak buğday	Kars-TR 49108-6	1190
11	Akçalıbasan	1080	Kütahya -TR 55212-4	43	Tir buğdayı	Kars-TR 15796-7	1960
12	Buğday	1720	Hakkari -TR 46846-2	44	Elbistan yazlığı	K.Maraş-M-391-5	1000
13	Kılçıksız beyaz	1570	Konya-TR 63316-3	45	Ak buğday	Erzurum-TR 32881-6	1475
15	Zerun	1590	Sivas-TR 53312-5	46	Delihüseyin	Kütahya-TR 55166-4	1080
16	Beyaz Buğday	1350	Sivas-TR 53359-4	47	Kirik	Erzurum-TR 32628-2	1700
17	Zerun	1640	Sivas-TR 53313-2	49	Kirik	Erzurum-TR 32668-1	1950
18	Buğday	1720	Hakkari - TR 46846-3	<b>Modern Bread Wheat Cultivars</b>			
20	Akçalıbasan	1080	Kütahya-TR 55167-3	1	Karahan-99		
21	Çam Buğdayı	380	Tokat-TR 54988-7	14	Gerek-79		
22	Ak buğday	1090	Kayseri-TR 32034-3	19	Kıraç-66		
23	Kirik	1650	Erzurum-TR 45369- 5	24	Bezostaja-1		
25	Kırmızı buğday	1600	Erzurum-TR 45350-1	38	Altay-2000		
26	Yerli Deli Buğday	730	Samsun-TR 37926-3	29	Bayraktar-98		
27	Tir buğdayı	1300	Kars-TR 48020-6	48	Dağdaş-94		
28	Ak başak	1600	Erzurum-TR 45351-4				
30	Ak buğday	1190	Kars-TR 49108-2				
31	Kırmızı Buğday	530	Gümüşhane-TR 32111-4				
32	Zerun	1640	Sivas-TR 53313-4				

\*GN: Genotype No, P: Province, NGB: Registration Number of GenBank, NSP: Number of Selected plant

The GT biplot method (Yan and Rajcan 2002) was employed to display the genotype by trait 2-way data in a ballot. It is based on the following formula:

$$\frac{T_{ij} - \beta_j}{S_j} = \sum_{n=1}^2 \lambda_n \xi_{in} \eta_{jn} + \epsilon_{ij} \quad \text{Eq[1]}$$

$$\epsilon_{ij} = \sum_{n=1}^2 \xi_{in}^* \eta_{jn}^* + \epsilon_{ij}$$

where  $T_{ij}$  is the average value of genotype i for trait j.  $\beta_j$  is the average value of all genotypes in trait j,  $S_j$  is the standard deviation of trait j among the genotype averages,  $\lambda_n$  is the singular value for

principal component  $PC_n$ ,  $\xi_{in}$  and  $\eta_{jn}$  are scores for genotype i and trait j on  $PC_n$ , respectively, and  $\epsilon_{ij}$  is the residual associated with genotype i in trait j. To achieve symmetric scaling between the genotype scores and the trait scores, the singular value  $\lambda_n$  has to be absorbed by the singular vector for genotypes  $\xi_{in}$  and that for traits  $\eta_{jn}$ . That is,  $\xi_{in}^* = \lambda_n^{0.5} \xi_{in}$  and  $\eta_{jn}^* = \lambda_n^{0.5} \eta_{jn}$ . Only PC1 and PC2 are retained in the model, because such a model tends to be best for extracting patterns and rejecting noise from the data. The GT biplot is generated by plotting  $\xi_{i1}^*$  and  $\xi_{i2}^*$  against  $\eta_{j1}^*$  and  $\eta_{j2}^*$ , respectively, so that each genotype or trait is

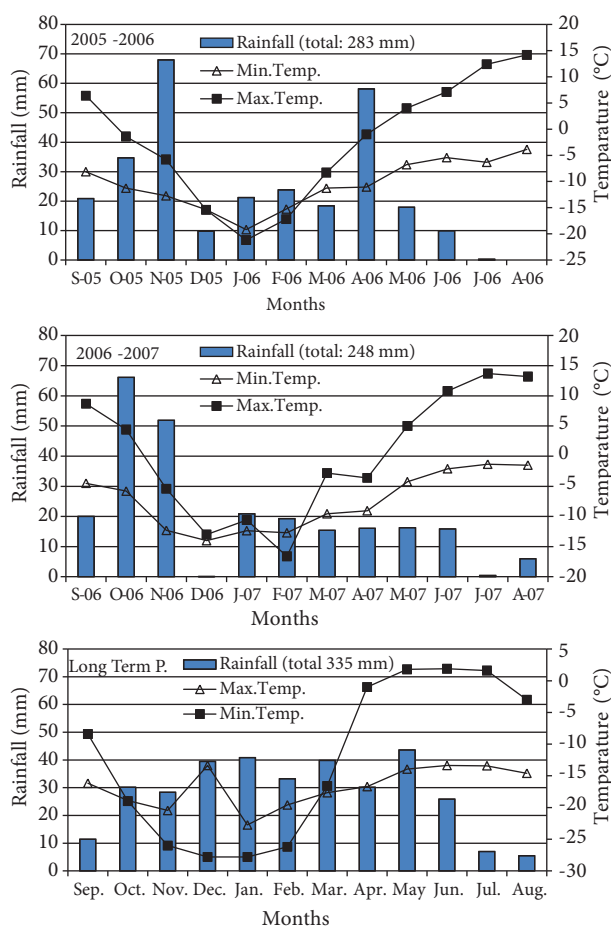


Figure 1. Rainfall, and minimum and maximum temperatures recorded during growing seasons and long term growing seasons.

represented by a marker in the biplot (Rubio et al 2004). In the GT biplot, a vector is drawn from the biplot origin to each marker of the traits to facilitate visualization of the relationships between and among the traits. Data were analyzed using SAS, version 9.0 (SAS Institute 1999).

## Results

There were significant ( $P \leq 0.01$ , and  $P \leq 0.05$ ) differences over growing seasons for all characters, except BY (Table 2). In terms of the general mean of the genotypes group, the pure line values for NS, PH, TKW, SDS, and PC were higher than the mean of modern bread wheat cultivars. In the other examined traits, the mean of the modern bread wheat cultivars was higher than the mean of the pure lines (Table 2).

The GT biplot of mean performance of bread wheat genotypes, based on Eq. [1], explained 50% of the total variation of the standardized data (Figure 2). This relatively low percentage variation reflects the complexity of the relationships among the measured characters (Yan and Rajcan 2002). According to Kroonenberg (1995) the fundamental patterns among the traits should be captured by the biplots. In the GT biplot, a vector is drawn from the biplot origin to each marker of the traits to facilitate visualization of the relationships between and among the traits. Provided that the biplot explained a sufficient amount of the total variation, the correlation coefficient between any 2 traits is approximated by the cosine of the angle between their vectors (Yan and Rajcan 2002).

The largest variation explained by the biplot came from GY, NG, NS, HI, WGS, NGS, and PC as indicated by the relative length of their vectors. It is the interrelationship among these traits that is most relevant to improving the bread wheat program. The most prominent relations revealed by this biplot are: 1) a strong negative association between GY, PC, and SDS, and between NS, NSS, and LS as indicated by the large obtuse angles between their vectors; 2) a near zero correlation between GY and PH, and between NS and BY as indicated by the near perpendicular vectors; and 3) a positive association between NG, HI, and BY indicated by being closely correlated to GY as indicated by the acute angles. Other relations revealed from the GT biplot include positive associations between NS and TKW, between PC and SDS, and between NGS and WGS (Table 3, Figure 2).

The correlations were analyzed further by the path coefficient technique, which involves partitioning the correlation coefficients into direct and indirect effects via alternative characters or pathways. GY was performed by the complex outcome of different characters considered to be the resultant variable, and BY, NS, NG, NGS, WGS, and HI were causal variables. The direct and indirect effects of the 6 grain yield related characters are shown in Table 4. Over the growing seasons NG, BY, WGS, HI showed positive direct effects on grain yield. The lowest direct effect belonged to NS (-0.02), and NGS (-0.10). NG had the highest direct effect (0.55) followed by BY (0.18) and WGS (0.11).

Table 2. Mean performance of genotypes across growing seasons.

GN	GY	BY	HI	NG	NS	LS	NSS	WGS	NGS	PH	TKW	SDS	PC
Pure Lines													
G2 <sup>s</sup>	1.39	6.32	26.6	5480.8	212.0	7.4	15.7	0.83	25.8	80.0	35.7	5.63	15.79
G3	1.53	5.99	19.4	5365.0	273.2	7.2	13.6	0.41	20.2	60.0	26.6	11.71	15.74
G4	1.76	5.74	26.1	5006.7	359.7	6.2	10.9	0.47	14.0	61.7	41.2	8.83	13.78
G5	1.74	6.86	22.5	5402.5	298.3	6.4	13.7	0.52	17.9	75.0	33.3	11.58	16.70
G6	1.30	5.47	20.1	5374.2	395.8	5.3	10.9	0.41	13.3	58.3	25.4	10.79	15.99
G7	1.62	6.66	21.6	6117.5	240.2	4.8	14.8	0.60	27.2	68.3	31.1	14.96	15.75
G8	1.66	5.41	17.5	3244.2	212.0	7.1	12.5	0.37	14.3	58.3	42.5	12.46	15.13
G9	1.70	6.70	22.6	5602.5	300.2	4.7	14.1	0.55	19.0	56.7	33.3	9.33	14.87
G10	1.59	7.07	20.1	5194.2	282.0	6.3	13.8	0.46	18.7	68.3	30.2	12.71	15.69
G11	1.94	6.99	20.8	4535.8	257.7	8.3	14.6	0.75	18.0	76.7	40.3	9.58	14.45
G12	1.75	6.87	25.7	5711.7	399.2	7.1	11.8	0.53	15.1	66.7	38.7	10.67	14.31
G13	1.64	7.30	21.6	5965.8	295.3	4.8	13.8	0.58	18.9	78.3	34.1	11.79	14.34
G15	1.33	6.33	18.3	4051.7	251.2	7.1	13.4	0.52	16.0	73.3	32.4	14.04	16.11
G16	1.47	6.76	20.0	5310.8	248.8	5.2	13.9	0.57	21.3	65.0	29.8	10.04	15.08
G17	1.35	5.87	19.8	3536.7	267.2	6.8	13.1	0.41	13.3	70.0	34.7	12.92	16.19
G18	1.89	8.06	29.3	6709.2	504.0	7.1	11.2	0.51	12.6	71.7	40.0	12.08	14.49
G20	2.00	6.81	31.8	7416.7	273.8	8.1	14.8	0.77	26.8	65.0	31.9	14.88	15.04
G21	1.51	6.32	22.5	4424.2	268.7	7.0	11.9	0.62	16.1	73.3	37.7	12.88	15.70
G22	1.27	5.73	19.7	4283.3	241.8	7.6	13.8	1.07	17.8	68.3	33.8	14.54	16.02
G23	1.71	6.79	21.6	4920.0	232.5	7.5	14.6	0.60	21.0	65.0	32.2	12.67	15.19
G25	1.80	7.35	21.0	5874.2	308.0	4.7	13.2	0.64	18.5	71.7	33.3	12.38	15.56
G26	1.84	5.86	26.4	7261.7	394.7	7.5	13.2	0.62	18.5	70.0	36.3	15.33	14.60
G27	1.56	6.51	24.1	5792.5	268.2	5.3	14.2	0.65	22.1	61.7	27.9	12.54	15.38
G28	1.66	6.83	30.8	7064.2	378.2	7.7	20.7	0.56	18.6	68.3	34.0	13.08	14.94
G30	1.34	6.57	23.2	4375.0	261.2	7.3	13.0	0.54	16.5	70.0	34.3	11.92	16.34
G31	1.47	5.82	21.9	4878.3	325.8	6.8	10.8	0.44	15.3	55.0	32.3	10.08	14.80
G32	1.32	6.25	21.4	4167.5	214.0	8.1	13.6	0.63	19.7	73.3	34.5	15.08	16.61
G33	2.07	6.81	22.3	7743.3	329.0	6.4	11.8	0.85	22.3	80.0	35.0	10.02	14.46
G34	1.49	7.18	21.9	4778.3	293.0	7.7	13.4	0.55	17.8	71.7	35.8	15.00	16.27
G35	1.64	6.59	26.6	6641.7	284.8	7.4	13.2	0.78	23.8	76.7	30.1	13.88	15.79

Table 2. (Continued).

GN	GY	BY	HI	NG	NS	LS	NSS	WGS	NGS	PH	TKW	SDS	PC
Pure Lines													
G36	1.32	6.45	22.5	4318.3	280.0	7.6	12.3	0.50	15.1	73.3	33.4	13.83	16.17
G37	1.24	5.70	16.6	2813.3	181.3	7.8	13.9	0.46	16.1	66.7	35.4	14.83	15.98
G39	1.42	6.35	26.7	5676.7	341.2	7.5	13.5	0.50	16.9	66.7	35.5	14.33	16.12
G40	1.61	7.02	20.0	5727.5	291.2	4.6	13.4	0.58	19.1	71.7	34.1	13.25	15.64
G41	1.34	5.64	21.4	3489.2	214.5	7.1	14.1	0.52	16.5	66.7	33.3	13.75	16.49
G42	1.73	7.31	25.2	8290.7	423.0	4.1	13.1	0.67	20.8	63.3	31.4	13.13	15.71
G43	2.31	7.24	32.2	7560.8	269.5	7.2	12.9	0.85	27.8	73.3	34.5	10.25	14.33
G44	1.61	6.38	27.7	5325.8	389.5	7.0	11.1	0.48	13.6	63.3	40.7	12.92	15.72
G45	1.51	5.52	25.7	6023.3	408.7	6.8	10.2	0.44	14.9	60.0	31.8	15.67	14.91
G46	1.86	6.59	24.8	5202.5	286.0	8.1	13.5	0.78	18.3	75.0	40.8	9.00	14.95
G47	1.50	5.26	21.2	4601.7	259.5	7.5	13.8	0.47	17.3	75.0	34.4	15.17	16.17
G49	1.51	6.09	22.9	4742.5	268.0	7.5	13.1	0.57	17.0	80.0	34.4	15.67	16.46
Means (Pure Lines)	1.60	6.46	23.2	5381.0	297.2	6.8	13.3	0.59	18.4	68.9	34.2	12.50	15.47
Modern Bread Wheat Cultivars													
G1(Karahan-99)	1.89	7.05	27.7	7465.8	295.5	7.7	14.1	0.73	24.4	70.0	32.7	14.83	14.96
G14 (Gerek-79)	1.67	6.95	25.7	7834.2	329.8	6.6	13.9	0.65	23.6	63.3	29.0	12.42	14.80
G19 (Kıraç-66)	1.52	6.62	17.1	4014.2	203.5	7.8	14.9	0.56	19.5	61.7	30.8	11.58	15.17
G24 (Bezostaja-1)	1.65	8.22	27.0	8231.0	276.2	7.3	15.2	0.84	29.4	71.7	33.6	12.75	14.12
G29 (Bayraktar-98)	1.81	6.47	24.8	6920.0	353.5	6.6	13.6	0.59	19.4	60.0	31.5	11.33	13.89
G38 (Altay-2000)	1.69	6.13	22.0	5951.7	219.2	7.2	15.3	0.72	28.2	61.7	35.8	12.33	13.87
G48 (Dağdaş-94)	1.59	7.25	21.6	5356.7	189.2	7.3	14.7	0.73	26.1	85.0	36.2	10.50	15.01
Means (Cultivars)	1.61	6.58	23.6	5645.8	295.4	6.9	13.5	0.62	19.4	69.3	34.1	12.90	15.33
Mean of Genotypes	1.61	6.52	23.4	5513.4	296.3	6.8	13.4	0.60	18.9	69.1	34.1	12.70	15.40
Genotypes	**	ns	*	**	**	**	**	**	**	**	**	**	**

ns: not significant, \*  $P \leq 0.05$ , \*\*  $P \leq 0.01$ , <sup>s</sup>: Pure lines, GY: grain yield ( $t\ ha^{-1}$ ), HI: harvest index (%), BY: biological yield ( $t\ ha^{-1}$ ), NS: number of spikes  $m^{-2}$  (no), NG: number of grains  $m^{-2}$  (no), LS: length of spike (cm), NSS: number of spikelets spike<sup>-1</sup> (no), WGS: weight of grains spike<sup>-1</sup> (g), NGS: number of grains spike<sup>-1</sup> (no), PH: plant height (cm), TKW: 1000 kernel weight (g), SDS: mini-SDS sedimentation (mL), PC: protein content (%)

## Discussion

### Trait relationships

The GT biplot (Figure 2) revealed that the largest variation explained by biplot came from NS, WGS, NGS, PC, BY, HI, NG, and NSS as indicated by the relative length of their vectors. It is the interrelationships among these traits that are most relevant to bread wheat breeding programs. The most prominent relations revealed by the GT biplot were a positive association among GY, HI, BY, NG, NGS, WGS, and NS as indicated by the acute angles. The trait associations shown in Figure 2 are consistent with the actual correlation coefficients (Table 3). The correlation coefficients for the traits of the GT biplot correctly displayed relationships among the traits that had relatively large loadings on either PC1 or PC2. An exact match is not to be expected, however, because the biplot describes the interrelationships among all traits on the basis of overall pattern of the data, whereas correlation coefficients only describe the relationships between 2 traits (Yan and Reid 2008).

The path coefficient study revealed that NG had high positive direct and indirect effects on GY, and BY had the second highest direct effect on GY. It was suggested from this analysis for grain yield improvement that selection can be based on high NG and BY. This is consistent with the results of the GT biplot analyses, although this alternative method is more interpretable and more GT informative. The main advantage of the biplot is its graphical presentation of the data, which greatly enhances the ability to understand the patterns among the traits (Yan and Kang 2003).

From Figure 2, the bread wheat genotypes with the highest GY were the highest BY, NG, and HI. Thus, the GT biplot graphically displayed the trait relations in bread wheat landraces that are documented elsewhere (Akçura and Topal 2008). They stated that the characteristics of plant height, grain weight spike<sup>-1</sup>, and number of grains spike<sup>-1</sup> could be used as selection criteria to increase grain yield in bread wheat landraces in the central Anatolian

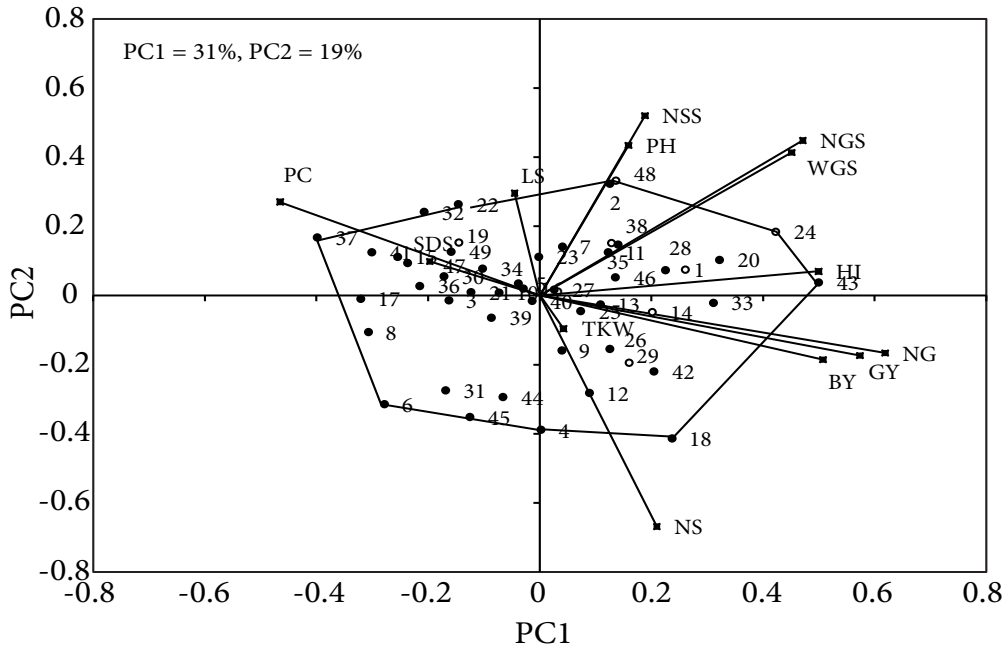


Figure 2. The genotype by trait (GT) biplot of 49 genotypes (42 pure lines, 7 modern cultivars) for 13 traits.

[●: pure lines from landraces (see Table 1 for details), ○: modern bread wheat cultivars (1: Karahan-99, 14: Gerek-79, 19: Kıraç-66, 24: Bezostaja-1, 29: Bayraktar-98, 38: Altay-2000, 48: Dağdaş-94), ■: traits; GY: grain yield, HI: harvest index, BY: biological yield, NS: number of spikes m<sup>-2</sup>, NG: number of grains m<sup>-2</sup>, LS: length of spike, NSS: number of spikelets spike<sup>-1</sup>, WGS: weight of grains spike<sup>-1</sup>, NGS: number of grains spike<sup>-1</sup>, PH: plant height, TKW: 1000 kernel weight, SDS: mini-SDS sedimentation, PC: protein content]



Table 3. Coefficients of correlation among traits across growing seasons (n = 49).

Traits	GY	HI	BY	NS	NG	LS	NSS	WGS	NGS	PH	TKW	SDS
HI	0.49**											
BY	0.49**	0.33*										
NS	0.31*	0.54**	0.27									
NG	0.66**	0.72**	0.56**	0.46**								
LS	-0.04	0.12	-0.18	-0.19	-0.24							
NSS	0.01	0.06	0.25	-0.381**	0.14	0.16						
WGS	0.37**	0.32*	0.38**	-0.20	0.44**	0.17	0.31*					
NGS	0.38**	0.23	0.43**	-0.37**	0.57**	-0.01	0.51**	0.67**				
PH	0.11	0.13	0.35*	-0.17	0.03	0.23	0.18	0.44**	0.22			
TKW	0.25	0.16	0.02	0.14	-0.22	0.34*	-0.16	0.04	-0.29*	0.27		
SDS	-0.26	-0.05	-0.17	-0.01	-0.05	0.17	0.02	-0.15	-0.09	-0.01	-0.18	
PC	-0.66**	-0.36**	-0.31*	-0.293*	-0.52**	0.06	0.00	-0.24	-0.29*	0.20	-0.24	0.42**

\*:  $P \leq 0.05$ , \*\*:  $P \leq 0.01$ , GY: grain yield, HI: harvest index, BY: biological yield, NS: number of spikes  $m^{-2}$ , NG: number of grains  $m^{-2}$ , LS: length of spike, NSS: number of spikelets spike $^{-1}$ , WGS: weight of grains spike $^{-1}$ , NGS: number of grains spike $^{-1}$ , PH: plant height, TKW: 1000 kernel weight, SDS: mini-SDS sedimentation, PC: protein content

Table 4. The direct, indirect effects and contribution of 6 traits to grain yield in bread wheat genotypes.

Traits	Indirect Effect							Corr
	Direct Effect	HI	BY	NS	NG	NGS	WGS	
HI	0.04 (7.61%)		0.06 (10.19%)	-0.01 (2.30%)	0.39 (69.60%)	-0.02 (3.92%)	0.04 (6.37%)	0.49**
BY	0.18 (29.91%)	0.01 (2.37%)		-0.01 (1.09%)	0.31 (52.34%)	-0.04 (7.14%)	0.04 (7.16%)	0.49**
NS	-0.02 (5.93%)	0.02 (5.71%)	0.05 (11.60%)		0.25 (62.18%)	0.04 (9.01%)	-0.02 (5.57%)	0.31*
NG	0.55 (68.92%)	0.03 (3.89%)	0.10 (12.58%)	-0.01 (1.40%)		-0.06 (7.00%)	0.05 (6.21%)	0.66**
NGS	-0.10 (16.94%)	0.01 (1.68%)	0.08 (13.17%)	0.01 (1.55%)	0.31 (53.67%)		0.08 (12.99%)	0.38**
WGS	0.11 (22.40%)	0.01 (2.73%)	0.07 (13.21%)	0.00 (0.96%)	0.24 (47.70%)	-0.07 (13.00%)		0.37**

\*:  $P \leq 0.05$ , \*\*:  $P \leq 0.01$ , HI: harvest index, BY: biological yield, NS: number of spikes  $m^{-2}$ , NG: number of grains  $m^{-2}$ , NGS: number of grains spike $^{-1}$ , WGS: weight of grains spike $^{-1}$ .

region. This is typical of wheat landraces that excel in their capacity to support kernel growth by large stem reserve mobilization under arid and semiarid Mediterranean environments (Jaradat 1991).

### Genotype comparisons

The GT biplot have been used to compare genotypes on the basis of multiple traits and to identify genotypes or groups of genotypes that are particularly good in certain aspects, and therefore can be candidates for both variety and parent selection in bread wheat breeding programs. On a GT biplot, the vector length of a genotype, which is the distance between the genotype and the biplot origin, is a measure of the genotype's peculiarity (i.e. how it differs from an "average" genotype), which is a hypothetical genotype that has an average level for all traits and is represented by the biplot origin. Therefore, genotypes with long vectors are those that have extreme levels for one or more traits. Such genotypes may or may not be a superior variety, but they may be useful as parents (Yan and Rajcan 2002).

Specifically, a comparison between G43 (Kars-TR15796-4) and G48 (Dağdaş-94) indicated that G43 (Kars-TR15796-4) was better in GY, HI, GN, and BY, whereas G48 (Dağdaş-94) was better in PH and NSS. Similarly, G43 (Kars-TR15796-4) had a greater value than G18 (Hakkari-TR46846-3) in all grain yield traits except NS. G22 (Kayseri-TR32034-3) was slightly better than G37 (Sivas-TR53292-1) in SDS and PC, but had a lower value than G43 (Kars-TR15796-4) on all other traits; G24 (Bezostaja-1) had a higher BY, but lower values on all other yield traits than G43 (Kars-TR15796-7). Also, analogous to the interpretation of the GT biplot indicates that genotype G43 was the highest in GY and HI, G24 (Bezostaja-1) was the highest in BY, and G48 (Dağdaş-94) was the tallest. In addition, G32 (Sivas-TR53313-4) was the highest in PC, and G4 (Adıyaman-TR50465-2) was the highest in TKW (Figure 2).

In addition, the GT biplot had shown the trait profiles of the genotypes, particularly, those that were placed farther away from the biplot origin (Figure 2). For example, it had shown that genotypes G20 (Kütahya-TR55167-3) and G33 (Kars-TR15796-7)

had high GY and BY, but low PC and SDS; G42 (Kars-TR49108-6) and G45 (Erzurum-TR32881-6) had high NS but the other traits lower; and G38 (Altay-2000) and G2 (Kütahya-TR55127-6) had high NGS, but near or below average levels for other traits. The measured trait values of genotypes are presented in Table 2 to validate the statements on the basis of the GT biplot. A GT biplot may not accurately reflect the means as it did not explain all variations of the data; however, it displays the most important patterns of the data.

Mean comparison between the lines and modern cultivars revealed that the former group had higher values for NG, HI, and GY than the latter group. Some pure lines from landraces also showed some degree of plant lodging. However, the grain yield of some pure lines from landrace G43 (Kars-TR15796-4), G33 (Kars-TR15796-7), G20 (Kütahya-TR55167-3) G11 (Kütahya-TR55212-4) were higher than 7 modern cultivars. In addition, 5 pure lines belonging to landraces G43 (Kars-TR15796-4), G20 (Kütahya-TR55167-3), G28 (Erzurum-TR 45351-4), G18 (Hakkari-TR46846-3), G44 (K.Maraş-M391-5) had higher harvest index values than 7 standard cultivars. Similarly, Belay et al. (1993) found several durum landrace wheat genotypes from Ethiopia that had values for the number of grains per spike, grain yield, and harvest index that were greater than those of commercial durum wheat cultivar developed from CIMMYT germplasm.

From my observations, it appears possible to improve Turkish bread wheat landraces by selecting for genotypes with higher number of grains per m<sup>2</sup>, higher biological yield, and higher harvest index. Also, the advanced lines produced by intercrossing the pure landrace lines could be further crossed with exotic germplasm to broaden the genetic basis of high quality industrial potential wheat breeding programs in the central Anatolian plateau of Turkey. In addition, this study demonstrated that the GT biplot is an excellent tool for visualizing genotype by trait data. First, it effectively reveals the interrelationships among the bread wheat traits. Second, it provides a tool for visual comparison among genotypes on the basis of multiple traits (Yan and Reid 2008). Third, it can be used in independent culling based on multiple traits and in comparing selection strategies. Based on

the trait relationships, selection for grain yield alone is not only the simplest, but also the most effective

strategy in the early stages of Turkish bread wheat landraces breeding.

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