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Relationship between Chlorophyll and other Features in Durum Wheat (*Triticum turgidum* L. var. *durum*) Using SPAD and Biplot Analyses

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ABSTRACT

The aim of this study was to evaluate Genotype×Environment Interaction (GEI) of chlorophyll meter readings (SPAD) of ten durum wheat cultivars, using data obtained from multi-environment trials during two years, at eight locations. Stability and genotypic superiority for SPAD reading was identified using ANOVA and GGE biplot analysis. Furthermore, the interrelationships among SPAD reading and other yield components and cultivars-by-traits, environment-by-traits, and cultivars-by-environment were studied using scatter, ranking, and comparison of biplot techniques. Substantial variations were found among SPAD reading, yield components, and quality criteria as related to each other, environment, and cultivars. There were positive correlations among SPAD reading with GY, some quality criteria [Protein Content (PC); Wet Gluten (WG), Vitreous Kernels (VIT)], and yield components [stalks m-^{2} (SS); ear m-^{2} (ES); Plant Height (PH), Length of Spike (LS)], while Maturation Time (MT) had negative correlation with SPAD. Also, there was relationship among SPAD and SC (Semolina Color) and SDS (Mini Sedimentation) with obtuse angles (< 90^0), but the correlation was not significant. The GGE biplot indicated that Kızıltepe environment (E6) and Eyyubi cultivar (G3) were the best in terms of SPAD reading. The GGE biplot provided useful information for experimentation of SPAD readings of cultivars when grown under multi-environment. Moreover, SPAD should be considered as the preferred tool, when the breeder is looking for the best and useful tool to determine flag leaf chlorophyll content.

Keywords: Chlorophyll, Cultivar-environment interaction, GGE biplot, Wheat.

INTRODUCTION

Durum wheat (*Triticum durum Desf.)* is produced in some special agro-ecological zones of Turkey. Generally, it has been well adapted to Aegean, Mediterranean, and southeastern Anatolian regions and some part of central Anatolia (Feldman, 2001). Southeastern Anatolian region is particularly known as gene center of durum wheat, due to Karacadağ basin (Ozkan *et al.,* 2011). Durum wheat has been cultivated with high yield and best quality in southeastern Anatolian region. But, based on meteorological data, the conditions are changing from part to part of this region, with different soil type and altitude. Although a lot of study has been made in this region on yield, yield components, and quality criteria, there are no adequate studies examining the physiological properties (Ozlem, 2014).

Durum wheat is adapted to regions having dry climate, with difference in day and night temperature throughout the growing period, characteristic of Mediterranean climates where drought is the main abiotic stress limiting crop production (Bozzini, 1988). Also, it is widely grown under rain-fed environment, where dryness and heat stress ordinarily occurs and effect the grain formation period (Simane *et al.,* 1993). The

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effects of dryness stress on the yield and other traits of durum wheat at different growth phases have been the topic of many studies (Javed *et al.,* 2011). However, there are few studies on the relations between chlorophyll and yield components of wheat cultivars, especially in those dry environments, under irrigation conditions. High chlorophyll content is a desirable characteristic because it shows a low degree of photo inhibition of the photosynthetic process in the Mediterranean, thus, decreasing carbohydrates losses affecting cereal development (Farquhar *et al.,* 1998).

Spectral reflectance has also been improved to forecast the concentration of different leaf pigments such as chlorophyll and carotenoid. Changes in photosynthesis more nearly parallels change in chlorophyll content; all changes happen throughout the grain filling stage which affects the grain weight (Guendouza and Maamarı, 2012). A portable field chlorophyll meter (SPAD) has been broadly used in the last years, practically to control the relationship between chlorophyll content with yield components (Peltonen *et al.,* 1995). Moreover, SPAD values correlated with diverse photosynthetic parameters, such as foliar structure (Araus *et al.,* 1997). These simple devices can be used in practical breeding programs at early generations when a large number of genotypes must be screened (Schuhwerk, 2011).

A positive relation between SPAD reading and grain protein content has been found in durum wheat under rainfed conditions (Rharrabti *et al.,* 2001). Bavec and Bavec (2001) reported that the relationships between SPAD reading and grain yield at the heading stage were significant, and Jiang *et al.* (2004) found similar results for the middle of the grain filling period in winter wheat. One of the necessary conditions for breeding of cultivars with high chlorophyll content is the presence of genetic diversity for that trait. Genetic variability for chlorophyll content exists in winter wheat (Le Bail *et al.,* 2005), wheat landrace (Hede *et al.,* 1999), hexaploid and octaploid wheat amphipods (Yan and Rajcanw, 2002), and durum wheat (Giunta *et al.,* 2002; Yildirim *et al.,* 2010), as measured by chlorophyll meter readings (SPAD).

Plant breeders have been attempting to develop genotypes with superior grain yield, quality, and other desirable characteristics over a wide range of different environmental conditions. Genotype by Environment interaction (G×E) makes it difficult to select the best performing and the most stable genotypes. G×E refers to the differential ranking of genotypes among locations or years. It is an important consideration in plant breeding programs because it impedes progress of selection in any given environment (Yau, 1995). Furthermore, identification of the genotypes with the highest chlorophyll content across a number of environments would be useful to breeders and producers (Ilker *et al.,* 2011). The aim of this study was to determine chlorophyll content of durum wheat cultivars by SPAD readings, and investigate the relationship among chlorophyll content, grain yield, yield components, and quality criteria in three sub-regions of southeastern Anatolia region, using the GGE-biplot methodology.

MATERIALS AND METHODS

Plant Material and Experimental Design

Ten durum wheat cultivars (Table 1) were evaluated in two rain-fed (Diyarbakir, Hani), one irrigated (Diyarbakir) and one supplementary irrigated (Kızıltepe) location in 2010-2011, and two rainfed (Diyarbakir, Hazro), one irrigated (Diyarbakir), and one supplementary irrigated (Kızıltepe) location in 2011-2012 growing season (Table 2). The experiment was conducted in a randomized block design with four replications. The seeding rate was 450 seeds m^{-2}. Plot size was 7.2 m^{-2} (1.2×6 m) consisting of 6 rows spaced 20 cm apart. Sowing was done by Wintersteiger drill. The fertilization rates used for all plots were 60 kg N ha^{-1} and 60 kg P ha^{-1} with sowing time and 60 kg N ha^{-1} was applied to plots at the early stem elongation. Irrigation was done after pollination on time (Zadox 7) in 2011-2012 season. But, due to excessive rainfall in April, it was done in the period of slight yellowing of the plant (Zadox 8) in 2010-2011 season at Diyarbakir irrigated location. Supplemental irrigation was done two times: for germination after sowing time, and prior to heading time at Kızıltepe supplementary irrigated location in 2010-2011 and 2011-2012 seasons. Harvest was done using Hege 140 harvester in 6 m^2. Also, soil analysis results related to the studied locations are shown in Table 3 and sum of precipitation, air humidity, and temperatures in each study year and long term averages are presented in Table 4.

Table 1. The code name, origin, and time of registration of wheat cultivars used in the experiment.[a]

Code name cultivar[a]	Name of cultivar	Origin	Time of registration
G1	Artuklu	GAPIARTC[b]	2008
G2	Aydın 93	GAPIARTC	1993
G3	Eyyubi	GAPIARTC	2008
G4	Guneyyıldızı	GAPIARTC	2010
G5	Harran 95	GAPIARTC	1995
G6	Sarıçanak 98	GAPIARTC	1998
G7	Svevo	TASAKOALC[c]	2001
G8	Sahinbey	GAPIARTC	2008
G9	Zenit	TASAKOALC	2001
G10	Zuhre	GAPIARTC	2010

[a] Cultivar; [b] GAP International Agricultural Research and Training Center, [c] TASAKO Agricultural Liability Company.

Table 2. Years of the study, names of the sites, abbreviations, codes, and coordinates of the studied environments.

Years	Sites	Abbreviation	Code name	Status	Altitude (m)	Latitude	Longitude
2010-2011	Diyarbakir	Dyb1	E1	Rain-fed	611	37° 55' N	40°14' E
	Diyarbakir	Dyb2	E2	Irrigated	611	37° 55' N	40°14' E
	Kızıltepe	Kztp1	E3	Support irrigated	484	37° 19' N	40^0 58' E
	Hani	Hani	E4	Rain-fed	995	38° 24' N	40° 24' E
2011-2012	Diyarbakir	Dyb3	E5	Rain-fed	611	37° 55' N	40°14' E
	Diyarbakir	Dyb 4	E6	Irrigated	611	37° 55' N	40°14' E
	Kızıltepe	Kztp2	E7	Support irrigated	484	37° 19' N	40^0 58' E
	Hazro	Hazro	E8	Rain-fed	700	38°25' N	40^0 78' E

Table 3. Soil analysis results related to locations.[a]

Locations	depth (cm)	(%) Saturation with water	(%) Total salt	(%) Organic matter	(%) Lime CaCo3	Phosphor P$_2$O$_5$ (kg ha^{-1})	pH
Diyarbakir	0-30	64	0.060	1.330	16.6	0.272	7.86
Kızıltepe	0-30	54	0.044	1.937	18.5	1.464	7.95
Hani	0-30	62	0.235	1.220	18.3	0.563	7.91
Hazro	0-30	63	0.060	1.640	18.6	0.400	7.64

[a] Samples were analyzed at GAP International Agricultural Research and Training Center lab.

Table 4. Sum of precipitation, humidity and temperatures in each year and long term average.[a]

Locations	Meteorological data	Season	Months										Total /Average
			September	October	November	December	January	February	March	April	May	Jun	
Diyarbakir	Temperature (°C)	2010-11	27.0	18.1	11.1	6.5	3.5	4.7	9.0	13.0	17.7	25.5	13.6
		2011-12	25.0	16.4	6.4	2.3	2.4	1.9	5.1	15.2	19.6	27.7	12.2
		Long T.	24.7	17.1	9.0	3.7	1.6	3.6	8.6	13.8	19.2	26.3	12.7
	(%) Humidity	2010-11	27.4	56.0	41.1	68.9	73.4	69.5	56.4	75.7	67.6	38.0	57.4
		2011-12	30.2	41.6	58.8	73.9	84.4	68.2	59.2	58.5	58.0	27.8	56.0
		Long T.	31.0	48.0	68.0	77.0	77.0	73.0	66.0	63.0	56.0	36.0	59.5
	Precipitation (mm)	2010-11	0.4	63.0	0.0	48.0	40.0	49.9	46.6	209.0	80.1	13.6	550.6
		2011-12	9.2	11.8	73.0	40.2	78.3	74.4	44.0	26.2	41.0	7.0	405.1
		Long T.	4.3	32.1	51.1	67.4	62.8	67.8	67.3	67.7	39.6	9.0	469.1
Hani	Temper. (°C)	Long T.	24.4	17.4	9.2	4.0	2.3	2.8	7.0	13.6	17.6	23.7	12.2
	(%) Humidity	Long T.	27.2	38.5	53.3	59.9	62.3	63.3	56.8	54.3	46.4	33.7	49.8
	Precipit. (mm)	Long T.	1.9	44.9	119.2	150.5	127.3	141.4	120.2	112.4	60.3	13.8	891.9
Hazro	Temper. (°C)	Long T.	24.4	17.4	9.2	4.0	2.3	2.8	7.0	13.6	17.6	23.7	12.2
	(%) Humidity	Long T	34.0	50.0	63.0	68.0	64.0	61.0	54.0	51.0	48.0	34.0	52.7
	Precipit. (mm)	Long T.	1.7	63.2	156.0	153.9	141.4	179.9	109.8	88.8	72.4	10.8	977.9
Kızıltepe	Temperature (°C)	2010-11	27.0	21.0	13.0	8.7	5.9	7.3	11.2	15.5	21.2	29.1	16.0
		2011-12	26.5	18.2	21.4	5.7	5.1	6.1	9.1	18.6	22.7	30.6	18.8
		Long T.	25.0	18.7	12.8	6.0	5.6	6.5	13.6	16.1	23.6	28.1	15.6
	(%) Humidity	2010-11	37.0	46.0	37.0	67.6	79.2	72.8	56.2	69.8	50.1	31.5	57.4
		2011-12	36.7	49.3	61.7	70.7	82.8	66.7	56.6	50.9	49.2	25.8	55.0
		Long T.	34.0	43.2	64.4	74.1	76.8	69.2	52.1	44.7	43.7	28.6	48.8
	Precipitation (mm)	2010-11	0	3.4	0	31.9	31.3	19.6	10.0	67.8	9.2	1.8	175.0
		2011-12	4.2	15.2	38.2	19.7	66.0	26.8	16.4	7.4	5.2	0	217.0
		Long T.	2.7	23.3	30.2	40.7	40.9	44.4	25.5	35.9	10.8	0.9	231.3

[a] Reference: www.tuik.gov.tr.

Chlorophyll Meter Measurements

Chlorophyll content at heading stage, on the midpoint of flag leaf of ten plants taken at random in each plot, were recorded by a portable chlorophyll meter (Minolta SPAD-502, Osaka, Japan), hereafter referred to as SPAD reading (Yildirim *et al*., 2010). SPAD measurements, which are a measure of relative greenness, range from 0 to 100 SPAD values and are proportional to leaf chlorophyll content. The Growth Stages (GS) of winter wheat are defined by a decimal code developed by Zadox *et al.* (1974).

Statistical Analysis (GGE)

The data were analyzed separately for each location, and then combined and analyzed across locations for SPAD reading, grain yield, yield component, and quality criteria with JMP Statistical Discovery Software from SAS to determine if G×E interaction effects were significant. In the joint analysis of variance, genotypes were considered as fixed effects, while environments, replications, GEI and all other sources of variation were considered as random effects. Means were separated using the LSD at *P*< 0.05 (Tables 5 and 6). Large utility to breeders would contain the improved chlorophyll content of choosing in different locations and to terminate the use of poor location Separator capability applies to a locations' capability to maximize the variance among cultivars in a research (Blanche and Myers 2006).

GGE biplot analyses were carried out using GGE biplot software to determine predominant SPAD reading in all environments (Yan, 2001; Yan and Kang, 2003). The GGE biplot model, decomposes G plus GE effects though the Singular Value Decomposition (SVD) into two or more principal components, thereby it removes the noise caused by the Environment main effects (E) and divide into the two components; Genotype effect (G) and Genotype×Environment (GE), which have great importance to breeders and agronomists (Yan, 2001; Yan and Rajcanw, 2002).The GGE biplot was used to: (1) evaluate the distance of environments and genotypes to an ideal; (2) calculate genotypic stability; (3) estimate phenotypic correlations among SPAD reading (chlorophyll) grain yield and other parameters, and (4) evaluate the distance of environments and parameters, as well as cultivars in terms of SPAD reading(chlorophyll).

Table 5. Combined analysis of variance of SPAD reading data of 10 durum wheat cultivars tested across 8 environments.

Source of variation	*df*	Sum of squares	Mean squares	(%) G×E explained
Treatments	79	5859	74.17**	
Genotypes (G)	9	639	71.05**	9.76
Environments (E)	7	4515	645.07**	88.69
Block	24	308	12.82**	
Interactions (GEI)	63	704	11.18**	1.53
IPCA	15	380	25.33**	
IPCA	13	160	12.32**	
Residuals	35	164	4.69**	
Error	216	723	3.35**	
Total	319	6890	21.60**	

CV (%): 3.85%, ** Value significant for 0.01 probability level.

Table 6. Combined analyses of variance of SPAD reading belonging to genotype data at eight environments.

Genotipe	E1	E2	E3	E4	E5	E6	E7	E8	Mean values
G1	42.5 bc	45.7 bd	50.2 a	42.4 ac	53.9 b	53.5 b	52.7 b	45.4 de	48.3 B
G2	45.5 a	46.2 ad	44.3 cd	44.1 a	50.5 cd	50.0 c	52.8 b	48.1 b	47.7 BD
G3	45.8 a	48.3 a	48.1 ab	40.4 cd	58.7 a	60.1 a	56.0 a	51.1 a	51.1 A
G4	40.6 c	42.6 e	44.5 cd	43.3 ab	49.1 d	49.1 c	48.2 d	44.8 e	45.3 F
G5	42.8 bc	43.9 de	46.6 bc	42.3 ac	51.8 bd	51.8 bc	52.1 b	47.4 bd	47.3 CE
G6	44.6 ab	44.8 ce	48.5 ab	41.3 bc	52.4 bc	53.6 b	51.3 bc	45.9 ce	47.8 BC
G7	44.5 ab	44.3 ce	46.8 bc	38.8 d	51.5 bd	51.7 bc	50.7 bc	46.5 be	46.8 DE
G8	43.9 ab	45.6 bd	45.6 bd	40.3 cd	52.3 bd	51.3 bc	48.9 cd	47.7 bc	46.9 CE
G9	43.8 ab	46.4 ec	43.3 d	41.3 bc	51.9 bd	50.1 c	50.7 bd	45.3 de	46.6 E
G10	45.0 ab	47.3 ab	46.3 bd	42.0 ac	50.8 bd	50.3 c	50.4 bd	46.3 be	47.3 CE
Average	43.9 E	45.5 D	46.4 C	41.6 F	52.3 A	52.2 AB	51.4 B	46.8 C	

RESULTS AND DISCUSSION

The combined ANOVA showed that at $P< 0.01$, all factors had significant effect on ten durum cultivars tested in eight environments and total sum of squares explained 86.69% for environmental effects, only 9.67% for genotypic effects, and 1.53% for GEI effects (Table 5). The results of Biplot analysis showed similar results of Ilker *et al*. (2011). Moreover, Bantayehu (2013) reported, respectively, 75.24, 9.32 and 15.44%, Rezene (2014) reported 89.6, 1.8, and 8.6%., *Brar et al.* (2010) and Mohammadi *et al.* (2013) reported more than 78% estimates for environment and years. Naroui Rad *et al.* (2013) found that the yield performance of wheat was highly influenced by GE interaction effects; the magnitude of the environment effect was about two times that of genotype effect.

Some researchers reported heritability of environment estimates between 40.5 to 84.8% for grain yield (Singh *et al.*, 2009).The results of environment, genotype and G×E effects obtained in this study illustrated similar results of the studies described above and the effect of Environment> G×E> Genotype.

Interrelationship among Cultivars and Environments

The biplot for SPAD reading explained 75.00% (58.18 and 16.82% by protein contents PC1 and PC2, respectively) of the total variation (Figures 1 and 2). In GGE-biplot, the correlation coefficient between any two or more environments is approximated by the cosine of the angle between their vectors. Acute angles ($+90^0$) indicates a positive correlation, obtuse angles (-90^0) a negative correlation, and right angles ($= 90^0$) indicate no correlation (Yan, 2001). A short vector may indicate that the test environment is not related to other environments. The long and short angle of vectors showed two groups or mega- environment (Figures 1 and 2).

The first group occurred among E1, E2, E8, E7, and E5, E6, and E3 environments with high correlation. The second group occured E4 environment. There was negative correlation between the first and second group environments depend on with wide angles ($> 90^0$). The conditions have main effect on groups which consist of two groups. The second group (E4) was affected by cold on high altitude (995 m), while the first group had similar condition with high yielding durum wheat. A comparison has

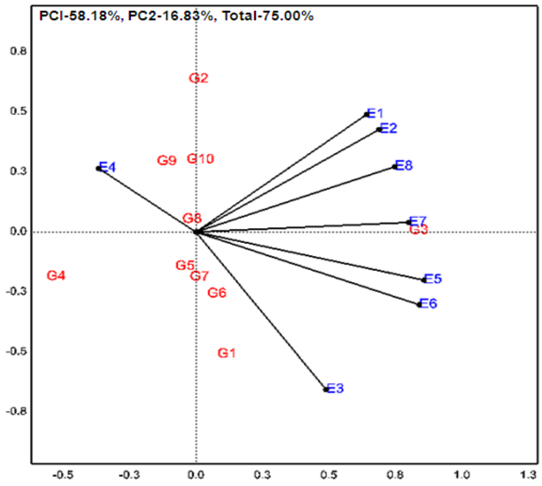

Figure 1. GGE biplot model showing SPAD reading of cultivars based on environment.

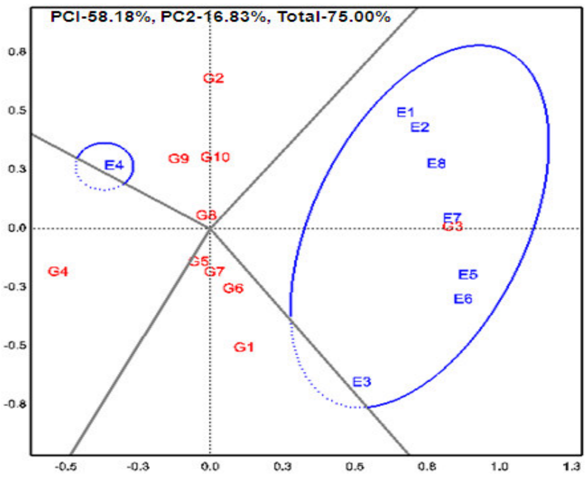

Figure2. GGE biplot model showing mega-environments of SPAD reading.

been made between varieties and relationship with environments in terms of SPAD reading. The cultivars closer with environments on the biplot, indicate that they discriminate similarly and show that it may be possible to reduce the number of cultivars testing environments and thereby economize on the conduct of GGE (Yuksel and Akcura, 2012). As mentioned above, the biplot showed that G3 was ideal and stable for 7 environments, unlike E4. It can be said that G2, G10, and G9 are available for E4, E1, E2 and E8, while G1, G5, G6, and G7 are favorable for E3, E5, E6, and G8 is centered for all environments in terms of SPAD reading. The biplot showed that G3 had the best performance among the genotypes and was stable for 7 environment, while G9 only for E4 (Figures 1 and 2). The research has made by some researchers showed that each cultivar was comfortable for different test environments (Mortavazian *et al*. 2010).

Stability of Cultivars through the Environments

Figures 3 and 4 show the "Average Environment Coordination" (AEC) of the GGE biplot for 12 cultivar evaluations regarding the mean vs. stability. This AEC is based on genotype-focused Singular Value Partitioning (SVP) (Yan and Kang, 2003). Because of the inner-product property of the biplot, the projections of the cultivar markers on the “average environment axis” are proportional to the rank-two approximation of the cultivar means representing the main effects of the cultivar (Mortazavian *et al.,* 2014). An ideal environment or genotype should have the representativeness and discrimination ability (Malla *et al.,* 2010; Yan, 2001). Thus, using the ideal genotype or environment as the center, concentric circles were drawn to help visualize the distance between each genotype or environment and the more stable genotype or environment (Figures 3 and 4).

An ideal genotype, which is located at the center of the concentric circles in Figure 4, is the one that has both high mean SPAD reading value and high stability. Therefore, G3 can be regarded as an ideal cultivar for seven environments, excluding E4. On the other hand, G4 is unstable for all test environments except E4. Comparison of other genotypes and environments are not stable, because they are far away from the ideal genotype and environment (Figure 4). Letta *et al.* (2008) tested genotypes in different environment and the results showed that some genotypes were desirable

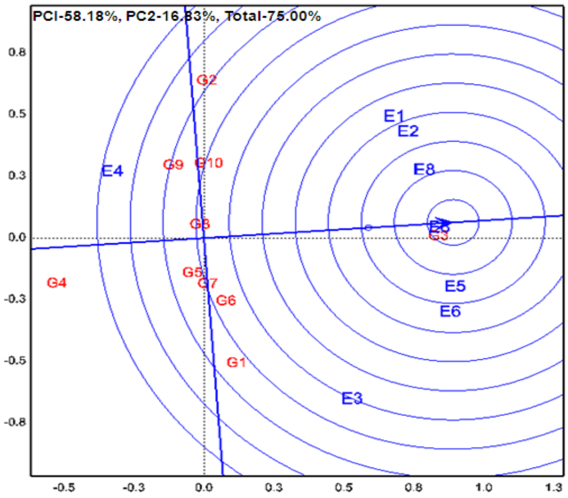

Figure 3. Comparison of SPAD of the syudied cultivars with the ideal environment.

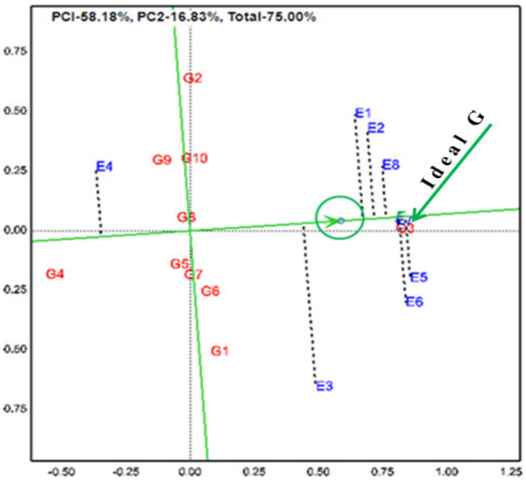

Figure 4. Ranking SPAD of the cultivars with the ideal environments.

in terms of some traits and stability.

Interrelationship among Traits and Cultivars

The biplot occurred in four sectors and explained 61.50% (44.33 and 17.11% by PC1 and PC2, respectively) of the relation among traits-by-cultivars (Figures 5 and 6). Further, PCI and PC2 scores, either negative or positive, are indication of the relationship among traits and show special adaptation of genotypes to character which is put on the biplot (Figure 5).

In the biplot, a vector is drawn from the biplot center to each marker of the traits to facilitate visualization of the relationships between traits and cultivars. The biplot showed that there is correlation between SPAD reading and quality criteria (Table 7). There was positive correlation between SPAD (chlorophyll content) and chemical quality criteria [PC; Wet Gluten (WG); SC, SDS], VIT and some yield components [stalks m^{-2} (SS), ear m-^{2} (ES)] and because the acute of angle is <90, negative correlation between SPAD and some technological quality criteria, grain yield/ and some yield component (HW; YS; TGW; NGS; NSS; MT; LS, PH), because the acute of angle is >90^{0} in Figure 5.

The study indicated that biplot analysis is a good method to evaluate cultivars-by-traits, and it showed that high values of SPAD related with quality criteria low values of SPAD related with grain yield. The length of the trait vector is a good marker to show the ability of traits in discriminating cultivar; the traits with longer vectors will have more success in discriminating cultivars (Yan, 2001). On the other hand, GGE biplot analysis showing sectors s of traits based on genotypes (Figure 6). The biplot showed that G4, G7, and G1 were representative ability on SPAD, WG, SDS, PC, SC SS, ES, in Sector 1, and G1, G2, G3 and G6 on PY, GY, VIT, HW, NGS and YS in Sector 2, G8 on TGW, HD, NSS MT in Sector 3, G5 and G9 on LY in Sector 4. The results of the relation among traits with genotypes by ranking biplot model demonstrated that the relationship among SPAD and WG, SDS, PC, SC SS, ES, was positive and represented by two genotypes (G4, G10), while the relationship among SPAD and other traits were negative (Figure 6). According to biplot analysis based on the rank correlation, the breeder can define more factors on the same figure and make selection with real foresight. Moreover, Gauch and Zobel (1997), demonstrated that

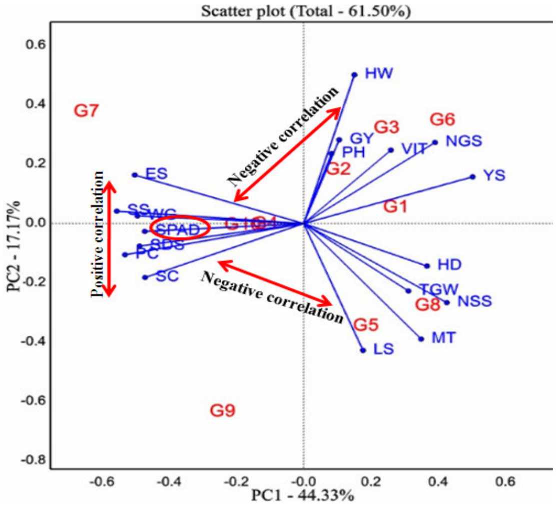

Figure 5. Scatter plot showing relationship among SPAD and other traits by genotypes.

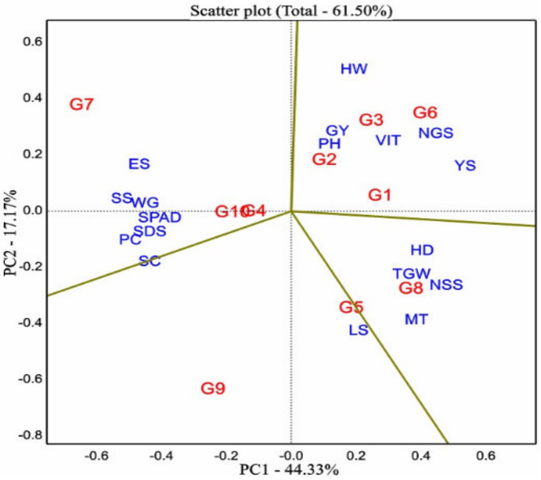

Figure 6. GGE biplot analysis showing sectors of traits based on genotypes.

Table 7. Correlation analysis of SPAD reading, yield component and quality criteria data.

	GY[a]	HD[b]	SS[c]	ES[d]	MT[e]	PH[f]	LS[g]	NSS[h]	NGS[i]
HD	-0.44**	1.00							
SS	0.78**	0.02	1.00						
ES	0.76**	0.01	0.93**	1.00					
MT	0.04	0.40***	0.19**	0.08	1.00				
PH	0.73**	-0.33**	0.59**	0.53**	0.12*	1.00			
LS	0.11	-0.11	0.07	0.15*	-0.17*	-0.05	1.00		
NSS	0.02	0.07	-0.08	-0.07	0.20*	-0.01	0.41**	1.00	
NGS	0.13*	-0.09	-0.06	-0.09	0.07	0.30**	-0.08	0.12*	1.00
YS	0.37**	-0.43**	0.03	0.04	-0.16*	0.38**	0.20*	0.11*	0.65**
VIT	0.03	0.33**	0.29**	0.35**	-0.21*	-0.10	0.23**	-0.11*	-0.37**
SPAD	0.39**	0.06	0.51**	0.64**	-0.32**	0.20*	0.26**	-0.09	-0.10
TGW	0.21**	-0.48**	-0.12*	-0.09	-0.03	0.18*	0.25**	0.18*	0.19*
HW	0.21*	-0.16*	0.09	0.14*	0.11	0.12*	0.02	0.19*	0.05
PC	0.08	0.28**	0.40**	0.45**	-0.21*	0.01	0.17*	-0.27**	-0.33**
SC	-0.03	0.05	0.15*	0.13*	-0.12*	-0.10	0.10*	-0.15**	-0.25**
SDS	-0.29**	0.26**	-0.09	-0.12*	-0.09	-0.22**	0.05	-0.24**	-0.25**
WG	0.10	0.30**	0.38**	0.38**	0.07	0.07	0.07	-0.24**	-0.28**

	YS[j]	VIT[k]	SPAD[l]	TGW[m]	HW[n]	PC[o]	SC	SDS
YS	1.00							
VIT	-0.24**	1.00						
SPAD	0.10	0.45**	1.00					
TGW	0.57**	-0.34**	-0.11	1.00				
HW	0.11*	0.00	0.09	0.12*	1.00			
PC	-0.28**	0.56**	0.59**	-0.35	-0.28**	1.00**		
SC	-0.29**	0.29**	-0.03	-0.29	-0.29**	0.37**	1.00	
SDS	-0.35**	0.38**	-0.01	-0.31	-0.34**	0.41**	0.53**	1.00
WG	-0.29**	0.45**	0.44**	-0.37	-0.22**	0.87**	0.27**	0.38**

[a] Grain Yield; [b] Heading Date; [c] Stalks per Square meter; [d] Ear per Square meter; [e] Maturation Time; [f] Plant Height; [g] Length of Spike; [h] Number of Spikelet Spike; [i] Number of Grains Spike; [j] Yield of Spike; [k] Vitreous Kernels; [l] Leaf Chlorophyll Meter; [m] Thousand Grain Weight; [n] Hectoliter Weight; [o] Protein Content; [p] Semolina Color; [q] Mini Sedimentation, WG: Wet Gluten. ** Value significant for 0.01 probability level, * Value significant at 0.05 probability level.

the outcome of this model is widely suitable for recommendation purposes.

Interrelationship among Traits and Environments

The environments-by-traits fell into five sectors and explained 61.56% (34.9 and 26.5% by PC1 and PC2, respectively) of the relation among environment-by-traits (Figures 7 and 8). In the biplot, a vector is drawn from the center to each marker of the traits to facilitate visualization of the relationships between traits and environment. The biplot showed that there is correlation between SPAD reading, yield component, and environment (Table 7). The study indicated that biplot analysis is a good method to evaluate features and environments, and it showed that the studies showed a significant association between quality criteria and grain yield by SPAD. A high and positive correlation occurred between SPAD reading and grain yield. The biplot also showed that optimum condition have high SPAD values, while extreme conditions have low values. The length of the trait vector is a good marker to show the ability of traits in discriminating

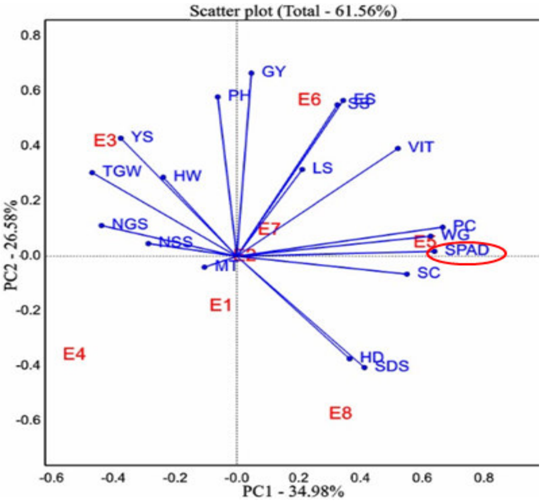

Figure 7. GGE biplot showing relationship among SPAD and other traits based on environment.

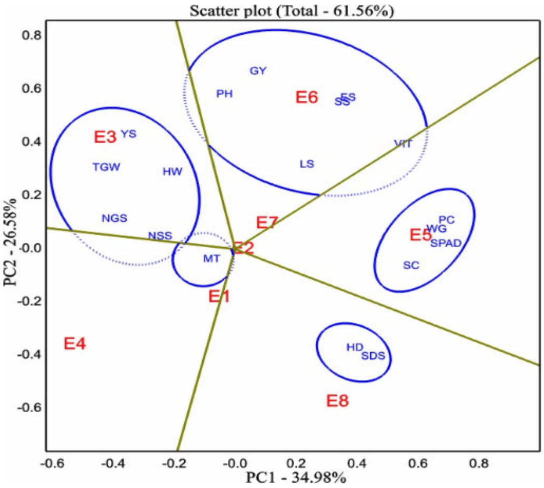

Figure 8. GGE biplot showing sectors and group of traits based on environments.

environment; the traits with longer vectors will have more success in discriminating environments (Yan, 2001).

GGE biplot analysis showing sectors and group of traits based on environments is presented in Figure 8. The biplot showed that E6 was representative ability on GY, PH, SS, ES, LS and VIT in Sector 1, and E5 on SPAD, WG, PC and SC in Sector 2, E3 on TGW, YS, HW, NGS and NSS in Sector 3, while MT, HD and SDS were not related with any special environments. On the other hand, some traits were related to specific environments and each other in the same sector, unlike, E1, E2, E4, E7 and E8 environment which stayed out of all groups and were not associated with any trait (Figures 7 and 8). The results of the relation among traits with environments showed that the relation among SPAD and PC, WG, and SC were positive and represented on E5. The results of this study have been supported by Kiliç *et al.* (2010), who demonstrated that stability methods could be classified into groups based on biplot analyses.

Ranking of Traits through Cultivars and Environments

The ranking of traits-by-cultivars explained 61.50% (44.33 and 17.11% by PC1 and PC2, respectively) and explained traits-by-environments 61.56% (34.98 and 26.58% by PC1 and PC2, respectively) in Figures 9 and 10. An ideal and stable trait should be on the stability axis and it has to high average as well as having representativeness and discrimination ability between each cultivar and environments. (Malla *et al.,* 2010; Yan, 2001).

The results indicated that the SPAD reading has high stability in ranking methods based on both cultivar and environments. The biplot showed that G4 and G10 were located at the center of the stability axis and near in SPAD in Figure 9. Also, E5 located at the side of SPAD in ranking methods based on environments. An ideal environment is that located at the center of the stability axis in Figures 9 and 10. Therefore, E6 has high stability and available environment. Also, E5 was related with SPAD with low stability and high ability, while E1, E4 and E8 were not related with SPAD. Therefore, they can be regarded as ideal cultivars and environment in terms of SPAD. These results indicate that breeders have the choice to select both the best cultivar and environment which is a suitable aspect of SPAD (chlorophyll content), Also, the breeders can see relationships between SPAD, yield component, and quality criteria. A study conducted in similar environments supported that Diyarbakir irrigation condition provided the best environment in terms of SPAD chlorophyll, also, there was high correlation between grain yield and SPAD values (Yildirim *et al.,* 2010).

CONCLUSIONS

Results of the study indicated that biplot analysis clearly discriminated between cultivars with wide adaptation and those showing a specific adaptation in wide environment or specific environment. The relationship between SPAD readings, quality criteria, grain yield, and some yield component were positive. The coefficients between SPAD reading, TGW, HW and some other yield component were negative. The GGE biplot indicated that E6 (Diyarbakir irrigation) was ideal environment in terms of SPAD reading. G3 (Eyyubi) was the best cultivar in terms of SPAD reading. The statistical model GGE biplot provides useful information for experimentation of SPAD readings of cultivar when grown under multi-environment. It identifies clearly the ideal and representative environment for experimentation and underlines the effect of specific traits for each cultivar on SPAD reading performance and stability across environments. If the strategy of a breeding program is to develop flag leaf chlorophyll content in specific or wide environments, it can be possible to concentrate on local adaptation to upgrade SPAD readings for environment. However, the choosing of SPAD should be based on the available device, when the breeder is looking for the best and useful device.

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رابطه بین کلروفیل و دیگر ویژگی های گندم دوروم (***Triticum turgidum* L. var. *durum***) با استفاده از اعداد SPAD و تجزیه بای پلات

ا. کندال

چکیده

پژوهش حاضر با هدف ارزیابی برهمکنش ژنوتیپ و محیط در مورد اعداد قرائت شده از دستگاه کلروفیل سنج (SPAD) برای ۱۰ کالتیوار گندم دورم با استفاده از آزمون های چند-محیطی در طی دوسال در هشت منطقه مختلف اجرا شد. پایداری و برتری ژنتیکی در مورد SPADبا استفاده از تجزیه واریانس و تجزیه بای پلات GGEشناسایی شد. افزون بر این، رابطه های بین اعداد SPAD و دیگر اجزای عملکرد و صفات کالتیوارها (cultivars-by-traits) و صفات آنها در محیط های مختلف(environment-by-traits) ، و عملکرد کالتیوارها در محیط های مختلف (cultivars-by-environment) با استفاده از نمودار پراکنش، درجه بندی، و مقایسه در روش بای پلات مطالعه شد. نتایج حاکی از تغییرات چشمگیر در مورد ارتباط اعداد SPAD، اجزای عملکرد، و ضوابط کیفیتی با یکدیگر و محیط های مختلف و کالتیوارهای مطالعه شده بود. همچنین، همبستگی مثبتی بین اعداد SPADبا وزن دانه و برخی ضوابط کیفیتی (محتوای پروتئین، گلوتن تر، دانه شیشه ای

vitreous kernels) و اجزای عملکرد (ساقه در متر مربع، خوشه در متر مربع، بلندی گیاه، طول خوشه) وجود داشت در حالی که زمان رسیدن محصول با SPADرابطه منفی داشت. نیز، بین SPADو رنگ سمولینا SC(رنگ آرد) و آزمون ته نشینی (SDS) رابطه ای با زاویه منفرجه (کمتر از ۹۰ درجه) وجود داشت ولی این رابطه معنی دار نبود. تجزیه داده ها با بای پلات GGE نشان داد که شرایط محیط منطقه قزل تپه (Kızıltepe) که با نماد E6 مشخص شده و کولتیوار ایوبی (Eyyubi) با نماد(G3) از نظر اعداد SPADبهترین بودند. تجزیه داده ها با بای پلات GGE اطلاعات مفیدی برای بررسی اعداد SPADدر کولتیوارهای کشت شده در آزمون های چند-محیطی فراهم کرد. به این قرار، می توان گفت که برای بهنژاد گرانی که مقدار کلروفیل برگ پرچم را تعیین میکنند، SPAD ابزار بهتر و مفیدی است.