*Biological Forum – An International Journal* **7**(1): 1589-1598(2015)

**ISSN No. (Print): 0975-1130**
**ISSN No. (Online): 2249-3239**

# Evaluation of Genetic Diversity in Bread Wheat using Genotype by Trait Biplot under Different Environmental Conditions

***Ezatollah Farshadfar*, **, Laila Akbari* and Mehrnoosh Naseri*****

**Campus of Agriculture and Natural Resources,*
*Razi University, Kermanshah, IRAN*
***Department of Agronomy and Plant Breeding,*
*Kermanshah Branch, Islamic Azad University, Kermanshah, IRAN*

*(Corresponding author: Ezatollah Farshadfar)*
*(Received 29 March, 2015, Accepted 15 May, 2015)*
*(Published by Research Trend, Website: www.researchtrend.nete_farshadfar@yahoo.com)*

**ABSTRACT: In this study 19 landraces of bread wheat were tested in a randomized complete block design with three replications under two irrigated and rainfed conditions. The results of analysis of variance (ANOVA) showed significant differences for RWL, SPAD, SC, PI, and GY under both rainfed (GYS) and irrigated (GYP) conditions. Positive correlations among GYS, SC, Fv/Fm, PI, Chla, Chlb, Chlt, CAR, RWL and SPAD suggested that every one of these traits should be enough as a selection criterion in rainfed condition. Similarly, positive correlations among the traits GYP, RWL, SPAD, CAR, Chla was observed in irrigated condition. In contrast to rain-fed conditions, GYP vs. SC, Fv/Fm and PI were not correlated under irrigated condition. Based on GYS, genotype G11, followed by G13 and G8, performed well in rainfed condition, whereas genotype G9, followed by G2 and G13, performed well in irrigated condition.**

**Keywords:** Bread wheat, physiological traits, GT-biplot, rainfed and irrigated conditions.

## INTRODUCTION

Wheat is the most important cereal crop in Iran, with a total area of 6.5 million ha. Rainfed wheat covers two-thirds of the total wheat area in Iran, but accounts for about one-third of the total wheat production (ICARDA, 2004). Improving grain yield is the major objective of wheat improvement programs in the highland areas of western Iran where the livelihood of poor farmers depends on successful wheat production (Mohammadi and Haghparast, 2011). Terminal drought which occurs during post-anthesis significantly reduces wheat grain yield (Simane *et al.,* 1993). Due to decreasing rainfall and rising temperatures, the frequency of exposure to terminal drought is predicted to increase for dryland wheat growing regions (Saradadevi *et al.,* 2014).

A crucial aspect in all studies dedicated to drought tolerance is the assessment of the degree of drought tolerance of different genotypes. The relative yield performance of genotypes in drought stressed and favorable environments seems tobe a common starting point in the identification of desirable genotypes for unpredictable rain-fed conditions (Sio-Se Mardeh *et al.,* 2006; Clarke *et al.,* 1992). The ability of a cultivar to produce high and satisfactory yield over a wide range of stress and non stress environments is very important (Rashid *et al.,* 2003).Considering that yield is a polygenic trait, selection for yield under drought stress conditions is complicated by low heritability and larger interactions between genotype and environment (Golabadi *et al.,* 2005).In many studies the identification of tolerant and susceptible cultivars is based on few physiological measures related to drought response (Richards, 2006; Fischer *et al.,* 1998; Siddique *et al.,* 1990; Saradadevi *et al.,* 2014).

Attempts to measure the degree of tolerance with a single parameter have a limited value because of the multiplicity of the factors and their interactive contributing to drought tolerance under field conditions. In this situation, the genotype-by-trait (GT) biplot proposed by Yan and Rajcan (2002) is a statistical tool for evaluating cultivars based on multiple traits and for identifying those that are superior in desired traits and hence could be candidates for use as parents in a breeding program or could be directly released for commercial production (Mohammadi and Amri, 2011).

This study was conducted to (i) evaluate the physiological characteristics of landraces of bread wheat under two irrigated and rainfed conditions (ii) determine the interrelationships among physiological traits using GT biplot technique in order to find suitable traits that could be used to improve yield in two irrigated and rainfed conditions.

## MATERIALS AND METHODS

*A. Experimental Data*

19 landraces of bread wheat (*Triticum aestivum* L.) listed in Table 1 were tested in the study. They were assessed in a randomized complete block design with three replications under two irrigated and rainfed conditions during 2013-2014 growing season in the experimental field of the College of Agriculture, Razi University, Kermanshah, Iran (47° 20'N, 34° 20' E and 1351 m above sea level). Non-stressed plots were irrigated three times after anthesis, while stressed plots received no water. At harvest time, yield potential (GYP) and stress yield (GYS) were measured from 3 rows 1 m in length. The following physiological characteristics were measured under both rain-fed and irrigated conditions:

**Table 1: Code and name of genotypes.**

| Genotype | Code | Genotype | Code |
|---|---|---|---|
| WC – 5047 | G1 | WC – 47636 | G11 |
| WC – 4530 | G2 | WC – 4584 | G12 |
| WC - 4780 | G3 | WC – 46697 – 11 | G13 |
| WC – 4566 | G4 | WC – 4823 | G14 |
| WC – 47360 | G5 | Pishtaz | G15 |
| WC – 4640 | G6 | WC– 47341 | G16 |
| WC – 47456 | G7 | WC – 47619 | G17 |
| WC - 47628 | G8 | WC – 4931 | G18 |
| WC – 47367 | G9 | WC – 47381 | G19 |
| WC – 47399 | G10 | - | - |

**Relative water loss (RWL).** Five youngest fully expanded leaves were sampled for each of three replications at anthesis stage. The leaf samples were weighted (Fw), wilted for4 hour at 35°C, reweighed (Ww), and transferred to the oven for 24 h at 72°C to obtain dry weight (Dw). The RWL was calculated using the formula suggested by Gavuzzi *et al.* (1997):

$$RWL\ (\%) = [(Fw - Ww)/(Fw - Dw)] \times 100$$

**Excised leaf water retention (ELWR).** Excised leaf water retention was determined according to Farshadfar and Sutka (2002), where the youngest leaves before anthesis stage were collected and weighed (Fw), left for 4 h, then wilted at 20°C and reweighed (Ww). ELWR was calculated using the following formula:

$$ELWR\ (\%) = [1 - ((Fw - Ww)/Fw)] \times 100$$

**Relative water content (RWC).** Relative water content was determined according to Siddique *et al.* (2000), where fresh leaves were taken from each genotype and each replication after anthesis stage and weighted immediately to record fresh weight (Fw). Then they were placed in distilled water for 4 h and weighted again to record turgid weight (Tw), and subjected to oven drying at 70°C for 24 h to record dry weight (Dw). The RWC was calculated using the following equation:

$$RWC = [(Fw - Dw)/(Tw - Dw)] \times 100$$

**Chl a, Chl b and carotenoid.** Weigh the plant sample about 0.25g; dry the sample with liquid nitrogen and grind it into powder with pestle and mortar; grind and extract total pigments with 5 ml of 80% acetone; centrifuge the crude extract at 1,500g for 5 min; keep the supernatant and discard the pellet; measure the absorbance at 663.3, 646.6 and 440.5 nm, which are the major absorption peaks of chlorophyll a and b and carotenoid, respectively; calculate the content of chlorophyll a and b and carotenoid using the equations of Porra *et al.* (1989) and Holm (1954), respectively. Calculate the pigment contents on the basis of g Chl/g fresh weight.

Chl a = 12.25 A663.3 - 2.55 A646.6

Chl b = 20.31 A646.6 - 4.91 A663.6

Chlt = 17.76 A646.6 + 7.34 A663.6

CAR = 4.69 A440.5- 0.267 Chlt

**Relative chlorophyll content (SPAD).** The chlorophyll content in the flag leaf also was determined using a chlorophyll meter (SPAD, 502, Minolta, Japan).

Three flag leaves of each genotype grown in both rainfed and irrigated conditions were measured after anthesis stage.

**Gas exchange parameters.** Stomatal conductance (SC, mmol $H_2O\ m^{-2}\ s^{-1}$) and photosynthesis intensity (PI, µmol $CO_2\ m^{-2}\ s^{-1}$) were measured using an infra-red gas analyzer system (IRGA, CIRAS-2 PPSystem) equipped with the universal photosynthesis chamber [PLC(U)].

**Fluorescence parameter.** Chlorophyll fluorescence (Fv/Fm) was measured using a MINI-PAM instrument. The photochemistry efficiency of PS II was determinate based on Fv/Fm value (the ratio of variable to the maximal fluorescence of dark-adapted leaves).

*B. Statistical Analyses*

The data recorded for each trait were subjected to a analysis of variance (ANOVA) and genotypic mean values were compared for each trait using the Duncan's multiple range test. The GT biplot method was employed to display the genotype-by-trait two-way data in a biplot for each environment (Yan and Rajcan, 2002). All biplots presented in this study were generated using the GGEbiplot software (Yan, 2001).

## RESULTS AND DISCUSSION

The results of analysis of variance (ANOVA) showed significant differences for the traits RWL, SPAD, SC, PI and GY under both rainfed and irrigated conditions (Table 2).

**Table 2: Analysis of variance for the studied physiological traits.**

| Source | df | RWC | | ELWR | | RWL | | Chla | | Chlt | | CAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated |
| | | 0.034** | 0.004 | 0.008 | 0.027** | 0.050* | 0.146* | 1.23 | 11.45 | 1.66 | 16.86 | 0.122 | 1.41 |
| Replication | 2 | 0.011 | 0.004 | 0.003 | 0.005* | 0.030** | 0.082** | 13.65 | 5.08 | 24.20 | 10.72 | 0.874 | 0.72 |
| Genotype | 18 | 0.006 | 0.002 | 0.003 | 0.002 | 0.010 | 0.030 | 11.42 | 15.64 | 19.31 | 29.39 | 0.654 | 1.13 |
| Error | 36 | 11.19 | 5.34 | 9.44 | 10.03 | 27.08 | 26.65 | 18.97 | 21.35 | 19.63 | 23.22 | 17.54 | 22.81 |
| CV (%) | | SPAD | | SC | | Fv/Fm | | PI | | GY | | | |
| | | 204.48* | 1.21 | 6.60 | 49.64 | 0.008 | 0.001 | 1.248 | 1.499 | 4100.84* | 21117.68 | | |
| Replication | 2 | 220.78** | 21.39** | 35.86** | 823.58** | 0.006 | 0.007** | 5.44** | 26.07** | 39684.34** | 131200.37** | | |
| Genotype | 18 | 44.62 | 7.86 | 8.20 | 159.65 | 0.005 | 0.001 | 1.42 | 1.25 | 810.32 | 11480.65 | | |
| Error | 36 | 16.10 | 5.70 | 18.16 | 23.34 | 9.65 | 3.20 | 23.25 | 12.70 | 18.50 | 23.16 | | |
| CV (%) | | | | | | | | | | | | | |

*:Significant at 1% probability level; **: Significant at 5% probability levelA. GT biplot analysis

The results of ANOVA also showed significant differences for the traits Fv/Fm and ELWR in the irrigated condition. Table 3 contains a comparison of means for tested genotypes on the basis of each studied trait under both rainfed and irrigated conditions. No genotype was the best for all traits (Table 3); so genotypes should be characterized by their every trait profiles. Based on GYS, genotype G11, followed by G13 and G8, performed well in rainfed condition, whereas G1 and G16 showed low yield performance. The results exhibited that the highest amount of RWL was attributed to genotypes G1 and G12. The highest SPAD belonged to genotypes G12 and G10. The highest SC belonged to genotypes G2 and G16. Genotypes G11, G12 and G10 had the highest values for PI. Based on GYP, genotype G9, followed by G2 and G13, performed well in irrigated condition, whereas G5 and G1 showed low yield performance. The results also exhibited that the highest amount of RWL was attributed to genotypes G12 and G3. The highest SPAD belonged to genotypes G11, G10 and G12. The highest SC was attributed to genotypes G13 and G7. Genotypes G7, G10 and G1 had the highest values for PI. Comparison of means also showed that genotypes G14 and G7 revealed the highest Fv/Fm, and genotypes G18, G1 and G10 had the highest ELWR in the irrigated conditions.

**Table 3: Comparing genotypes in two rain-fed and irrigated conditions for physiological traits.**

| Genotype | RWC (%) | | ELWR (%) | | RWL (%) | | Chla | | Chlb | | Chlt | | CAR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated |
| G1 | 0.698 | 0.838 | 0.547 | 0.517 | 0.553 | 0.549 | 15.60 | 16.92 | 3.83 | 3.95 | 19.43 | 20.87 | 4.24 | 4.23 |
| G2 | 0.704 | 0.879 | 0.542 | 0.411 | 0.527 | 0.648 | 17.17 | 20.15 | 4.31 | 5.23 | 21.48 | 25.38 | 4.68 | 5.00 |
| G3 | 0.754 | 0.834 | 0.538 | 0.398 | 0.377 | 1.004 | 21.18 | 20.35 | 5.52 | 6.91 | 26.70 | 27.60 | 5.32 | 5.28 |
| G4 | 0.781 | 0.868 | 0.543 | 0.461 | 0.450 | 0.804 | 17.47 | 18.89 | 4.11 | 4.79 | 21.58 | 23.68 | 4.68 | 5.18 |
| G5 | 0.686 | 0.865 | 0.640 | 0.502 | 0.354 | 0.474 | 17.10 | 19.27 | 4.50 | 4.93 | 21.60 | 24.19 | 4.69 | 4.39 |
| G6 | 0.857 | 0.829 | 0.575 | 0.446 | 0.332 | 0.628 | 18.96 | 19.17 | 4.75 | 4.83 | 23.71 | 24.00 | 5.12 | 4.79 |
| G7 | 0.828 | 0.831 | 0.610 | 0.476 | 0.317 | 0.665 | 17.67 | 16.64 | 4.60 | 4.32 | 22.27 | 20.96 | 4.74 | 4.47 |
| G8 | 0.699 | 0.883 | 0.598 | 0.452 | 0.263 | 0.791 | 16.29 | 18.21 | 4.06 | 4.67 | 20.35 | 22.87 | 3.70 | 4.94 |
| G9 | 0.666 | 0.887 | 0.563 | 0.457 | 0.322 | 0.691 | 21.85 | 19.79 | 6.62 | 5.24 | 28.47 | 25.03 | 5.78 | 4.91 |
| G10 | 0.771 | 0.873 | 0.607 | 0.512 | 0.424 | 0.510 | 18.82 | 20.20 | 4.93 | 5.17 | 23.75 | 25.38 | 4.74 | 5.33 |
| G11 | 0.742 | 0.917 | 0.545 | 0.447 | 0.422 | 0.645 | 17.33 | 19.68 | 4.45 | 4.86 | 21.77 | 24.54 | 4.45 | 5.11 |
| G12 | 0.682 | 0.856 | 0.538 | 0.417 | 0.527 | 1.010 | 20.84 | 17.45 | 5.25 | 4.89 | 26.09 | 22.34 | 5.15 | 3.81 |
| G13 | 0.635 | 0.866 | 0.557 | 0.456 | 0.441 | 0.700 | 19.87 | 16.86 | 4.97 | 4.12 | 24.84 | 20.97 | 4.92 | 4.35 |
| G14 | 0.666 | 0.884 | 0.645 | 0.490 | 0.286 | 0.617 | 17.53 | 18.82 | 4.67 | 4.42 | 22.20 | 23.24 | 4.32 | 5.23 |
| G15 | 0.716 | 0.778 | 0.544 | 0.472 | 0.350 | 0.623 | 17.76 | 18.86 | 4.51 | 4.94 | 22.27 | 23.81 | 4.81 | 4.70 |
| G16 | 0.730 | 0.881 | 0.590 | 0.492 | 0.316 | 0.486 | 12.70 | 18.30 | 3.01 | 4.92 | 15.71 | 23.22 | 3.55 | 3.79 |
| G17 | 0.629 | 0.782 | 0.593 | 0.442 | 0.179 | 0.398 | 17.15 | 18.60 | 4.27 | 4.78 | 21.42 | 23.38 | 4.45 | 4.56 |
| G18 | 0.721 | 0.827 | 0.580 | 0.549 | 0.429 | 0.498 | 16.90 | 17.84 | 4.44 | 4.66 | 21.33 | 22.50 | 4.22 | 4.16 |
| G19 | 0.704 | 0.853 | 0.591 | 0.420 | 0.273 | 0.545 | 16.23 | 15.93 | 4.11 | 3.84 | 20.34 | 19.77 | 4.08 | 4.13 |
| Mean | 0.719 | 0.854 | 0.576 | 0.464 | 0.376 | 0.647 | 17.81 | 18.52 | 4.57 | 4.81 | 22.39 | 23.35 | 4.61 | 4.65 |
| LSD | 0.128 | 0.074 | 0.091 | 0.074 | 0.166 | 0.287 | 5.60 | 6.55 | 1.73 | 1.59 | 7.28 | 8.98 | 1.34 | 1.75 |

**Table 3: Continued…..**

| Genotype | SPAD | | SC | | Fv/Fm | | PI | | GY (gr/m$^2$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated | Rainfed | Irrigated |
| G1 | 22.30 | 45.87 | 11.93 | 46.63 | 0.7033 | 0.7800 | 4.55 | 11.87 | 22.67 | 81.33 |
| G2 | 47.43 | 49.53 | 26.00 | 64.70 | 0.7333 | 0.6800 | 6.27 | 6.48 | 265.33 | 692.67 |
| G3 | 48.57 | 50.43 | 13.83 | 36.67 | 0.6867 | 0.6733 | 4.45 | 3.89 | 100.67 | 488.67 |
| G4 | 47.40 | 50.33 | 13.60 | 29.90 | 0.7033 | 0.7533 | 4.42 | 7.52 | 213.33 | 620.67 |
| G5 | 38.97 | 47.53 | 11.30 | 31.40 | 0.7167 | 0.7367 | 5.64 | 7.01 | 38.67 | 78.67 |
| G6 | 47.90 | 48.27 | 13.73 | 45.83 | 0.6967 | 0.7633 | 5.28 | 10.44 | 78.67 | 434.00 |
| G7 | 46.97 | 48.73 | 15.40 | 77.50 | 0.6567 | 0.8100 | 5.02 | 14.41 | 77.33 | 501.33 |
| G8 | 42.97 | 50.93 | 12.87 | 70.23 | 0.6700 | 0.7567 | 2.02 | 10.86 | 290.00 | 604.67 |
| G9 | 40.97 | 47.10 | 17.63 | 40.43 | 0.7200 | 0.7200 | 5.58 | 5.85 | 119.33 | 720.00 |
| G10 | 50.87 | 53.30 | 15.27 | 61.90 | 0.7067 | 0.7800 | 6.28 | 12.32 | 130.00 | 634.00 |
| G11 | 47.17 | 54.77 | 15.53 | 69.93 | 0.7267 | 0.7533 | 7.53 | 7.01 | 455.33 | 596.00 |
| G12 | 52.83 | 53.10 | 17.63 | 47.43 | 0.7233 | 0.7367 | 6.79 | 9.15 | 186.67 | 610.00 |
| G13 | 41.47 | 50.97 | 15.27 | 79.80 | 0.7267 | 0.6233 | 4.92 | 5.33 | 346.67 | 651.33 |
| G14 | 28.83 | 45.33 | 18.17 | 58.83 | 0.7100 | 0.8167 | 4.84 | 11.62 | 132.67 | 428.67 |
| G15 | 35.03 | 48.60 | 16.57 | 30.83 | 0.7133 | 0.7367 | 6.12 | 10.04 | 136.00 | 153.33 |
| G16 | 24.50 | 45.17 | 19.80 | 42.23 | 0.7133 | 0.7367 | 4.66 | 6.85 | 23.33 | 116.00 |
| G17 | 44.67 | 48.50 | 16.60 | 52.30 | 0.6767 | 0.7100 | 5.96 | 4.97 | 106.00 | 398.67 |
| G18 | 39.37 | 48.63 | 11.13 | 68.90 | 0.5367 | 0.7367 | 2.32 | 9.62 | 68.00 | 494.67 |
| G19 | 40.00 | 47.07 | 17.30 | 73.13 | 0.7133 | 0.7833 | 4.80 | 11.81 | 133.33 | 485.33 |
| Mean | 41.48 | 49.17 | 15.77 | 54.14 | 0.696 | 0.7414 | 5.13 | 8.79 | 153.89 | 462.63 |
| LSD | 11.06 | 4.64 | 4.74 | 20.92 | 0.1171 | 0.0524 | 1.98 | 1.85 | 47.14 | 177.4 |

The GT biplot for each of the two environments explained 79.3 and 79.7% of the total variation of the standardized data. Therefore, according to these results, it can bea fundamental patterns among the traits which were captured by the GT biplots.Figure1represents polygon view of a GT biplot generated from data on 13 physiologic traits of 19 genotypes in each of the two environments. Under rain-fed conditions, corner or vertex genotypes, which are the most responsive ones, were G6, G9, G13, G17 and G16 (Fig. 1A).

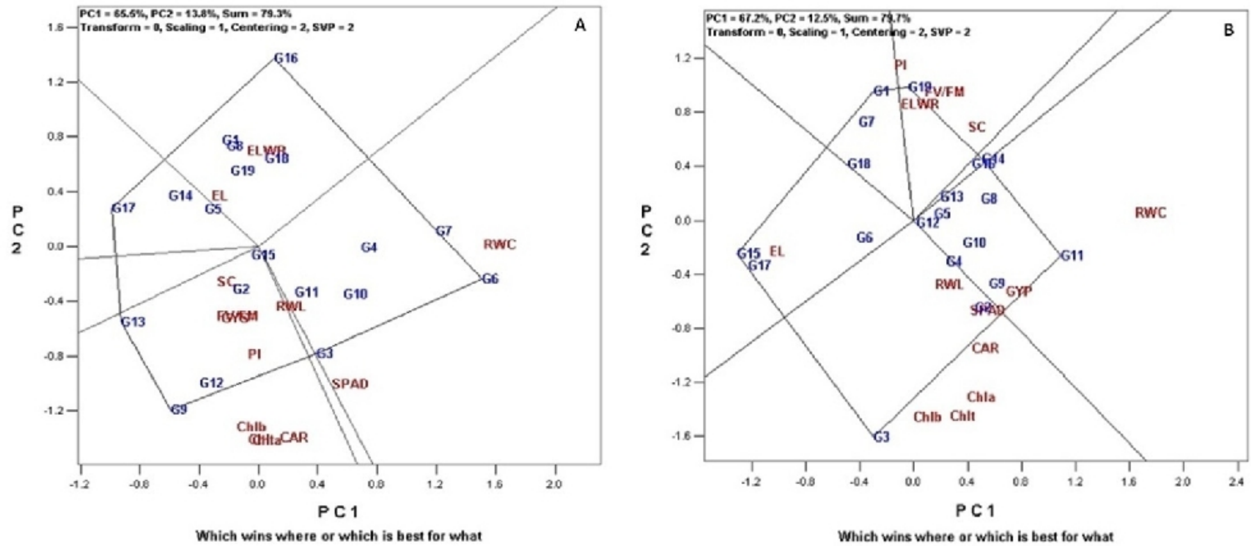


**Fig. 1.** Genotype by trait (GT) biplot of bread wheat genotypes physiological traits under rain-fed (A) and irrigated (B) conditions.

By connecting the markers of these corner genotypes, a polygon is formed. By drawing perpendicular lines to each side of the polygon passing through the origin, the traits are divided among several sectors, each with a different corner genotype. Only three of the four sectors contained traits, and these were identified as the three trait groups. The traits RWL, Chla, Chlb, Chlt, CAR, SC, Fv/Fm, PI and GYs made the first group, with genotype G9 being the winner. The trait ELWR was the second group, with genotype G16 being the winner. The third group consisted of the traits RWC and SPAD, where G6 is best genotype. Similarly, Fig. 1B represents the polygon view of GT biplot for the trial conducted under irrigated condition. The genotypes G11, G3, G15, G1 and G19 were more responsive. The first group contains the traits RWL, SPAD, Chla, Chlb, Chlt, and CAR with winner genotype G3; the second group consists of RWC and GYP with genotype G11 as the winner; The third group included ELWR, SC, Fv/Fm, and PI, where G19 is best genotype; the last group included the trait EL with genotype G5 as the winner. A correlation coefficient between any two traits can be approximated by the cosine of the angle between their vectors (Yan and Kang, 2003). In the GT biplot, vectors are drawn from the biplot origin to the markers of the traits to facilitate visualization of the relationships among the traits.

This biplot can be visualized from two perspectives. First, it shows the associations among the traits across the 19 genotypes. Second, it represents the trait profiles of the genotypes, particularly those that are placed farther away from the biplot origin (Yan and Fregeau-Reid, 2008). The most prominent associations among the traits under rain-fed conditions (Fig. 2A) were: (i) Moderate to high positive correlations among grain yield (GYS), SC, Fv/Fm, PI, Chla, Chlb, Chlt, CAR, RWL and SPAD, as indicated by the acute angles between their vectors. Significant relationship between SPAD reading (relative chlorophyll content) and grain yield was reported at the heading stage (Bavec and Bavec, 2001) and in the middle of the grain-filling period (Jiang *et al.*, 2004) in winter wheat.(ii) A near-zero correlation observed between RWC and ELWR, and RWC vs. Chla, Chlb, Chlt, CAR, and PI as indicated by the near-perpendicular vectors. (iii) Strong negative associations existed between RWC and SC, RWC and CAR, as indicated by the large obtuse angles between their vectors. The vector of trait ELWR made nearly a 180 degree angle with that of Chla, Chlb, Chlt, CAR and PI, indicating that it was opposite in genotype ranking. Stomatal regulation in wheat in response to water deficit is reported to be closely related to increased leaf ABA concentration following a reduction in leaf water potential (Henson *et al.*, 1989).

*C. Relationships among traits under irrigated condition*

Relationships among traits under irrigated conditions (Fig. 2B) were not similar to those under rain-fed conditions (Fig. 2A), which suggested that there was differential response of genotypes to the two growing conditions. Positive correlations observed among traits grain yield (GYP), SPAD, RWL, CAR, Chla , and Chlt, between GYP and RWC, and also among traits PI, ELWR , Fv/Fm and SC (Fig. 2B).

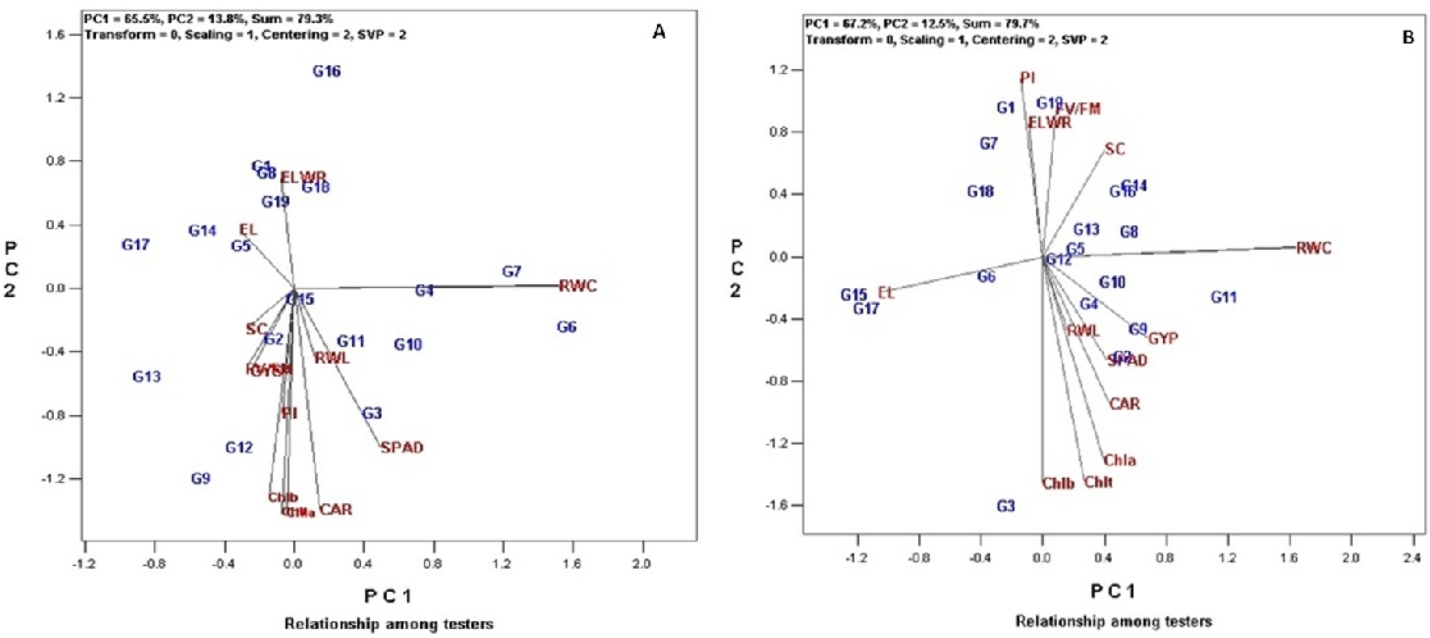


**Fig. 2.** GT-biplot showing relationship among physiological traits under rain-fed (A) and irrigated (B) conditions.

In contrast to rain-fed conditions, GYPvs. SC, Fv/Fm and PI were not correlated under irrigated condition. In accordance with rain-fed conditions, RWC vs. ELWR, PI, and Chlbwere not correlated under irrigated condition as indicated by the right angle between their vectors. The vectors of traits PI, ELWR, and Fv/Fm made nearly a 180 degree angle with that of Chlb and Chlt, indicating they were opposite in genotype ranking.

Application of GT biplot to this investigation on wheat genotypes shows visual interrelationships among the physiological traits, which provides more information in comparison to Pearson's correlation coefficients (Table 4) that only describe the relationships between two traits.

*D. Trait profiles of two genotypes on the GT biplot*

Trait profiles of two genotypes can be easily compared on the GT biplot. To compare two genotypes, here genotypes G11 (the highest yielding genotype) and G1 (the lowest yielding genotype) under rain-fed conditions (Fig. 3A), first connect their markers with a straight line; then draw a perpendicular line that passes through the biplot origin. This perpendicular divides traits into two groups; each of these two genotypes had larger values for a number of the traits. For instance, G11 had higher values than the G1 for RWL, Fv/Fm, SC, PI and was intermediate for SPAD; in contrast, G1, had higher values than the G11 for ELWR. Similarly, Fig. 3B represents GT biplot that compares the two contrasting yield performance genotypes (G1, the highest yielding genotype vs. G9, the lowest yielding genotype) under irrigated conditions.

**Table 4: Pearson's correlation coefficients between physiological traits under rain-fed and irrigated conditions.**

| **Rainfed** | RWC | ELWR | RWL | Chla | Chlb | Chlt | CAR | SPAD | SC | Fv/Fm | PI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ELWR | -0.05 | | | | | | | | | | |
| RWL | 0.08 | -0.59** | | | | | | | | | |
| Chla | -0.03 | -0.31 | 0.16 | | | | | | | | |
| Chlb | -0.10 | -0.17 | 0.05 | 0.95** | | | | | | | |
| Chlt | -0.05 | -0.28 | 0.13 | 0.99** | 0.97** | | | | | | |
| CAR | 0.10 | -0.36 | 0.22 | 0.92** | 0.89** | 0.92** | | | | | |
| SPAD | 0.32 | -0.24 | 0.10 | 0.60** | 0.46* | 0.57* | 0.51* | | | | |
| SC | -0.20 | -0.16 | 0.05 | -0.05 | -0.02 | -0.04 | 0.03 | 0.04 | | | |
| Fv/Fm | -0.17 | -0.17 | 0.13 | 0.14 | 0.10 | 0.13 | 0.24 | -0.00 | 0.47* | | |
| PI | -0.03 | -0.22 | 0.20 | 0.28 | 0.25 | 0.27 | 0.44 | 0.29 | 0.44 | 0.66** | |
| EL | -0.20 | -0.07 | -0.05 | -0.10 | -0.11 | -0.10 | -0.09 | -0.32 | -0.35 | -0.12 | -0.22 |
| GYS | -0.17 | -0.36 | 0.21 | 0.19 | 0.09 | 0.16 | 0.02 | 0.41 | 0.21 | 0.30 | 0.24 |
| **Irrigated** | | | | | | | | | | | |
| ELWR | -0.04 | | | | | | | | | | |
| RWL | 0.17 | -0.59** | | | | | | | | | |
| Chla | 0.22 | -0.13 | 0.09 | | | | | | | | |
| Chlb | -0.01 | -0.36 | 0.45 | 0.78** | | | | | | | |
| Chlt | 0.14 | -0.23 | 0.24 | 0.97** | 0.91** | | | | | | |
| CAR | 0.23 | -0.18 | 0.20 | 0.72** | 0.46* | 0.66** | | | | | |
| SPAD | 0.23 | -0.31 | 0.45 | 0.26 | 0.27 | 0.27 | 0.32 | | | | |
| SC | 0.24 | 0.001 | -0.13 | -0.43 | -0.46* | -0.47* | -0.07 | 0.26 | | | |
| Fv/Fm | 0.06 | 0.39 | -0.24 | -0.22 | 0.40 | -0.30 | 0.04 | -0.23 | 0.06 | | |
| PI | -0.08 | 0.40 | -0.17 | -0.45 | -0.55* | -0.51* | -0.09 | -0.13 | 0.33 | 0.83** | |
| GYP | 0.40 | -0.43 | 0.46* | 0.17 | 0.15 | 0.17 | 0.42 | 0.59** | 0.47* | -0.22 | -0.12 |

*:Significant at 1% probability level; **: Significant at 5% probability level

For instance, G9 had higher values than the G1 for SPAD, RWL and CAR; in contrast, G1, had higher values than the G9 for PI, Fv/Fm and ELWR. In contrast to rain-fed conditions, G1, the lowest yielding genotype under both rainfed and irrigated conditions, had high values for two traits Fv/Fm and PI. An important advantage of the GT biplot is that it can be used to identify redundant traits to reduce cost in measuring traits in field experiments without sacrificing precision. Therefore, positive correlations among grain yield (GYS), SC, Fv/Fm, PI, Chla, Chlb, Chlt, CAR, RWL and SPAD suggest that one (i.e., Fv/Fm and SC) of these traits should suffice as a selection criterion.

Similarly, positive correlations among traits grain yield (GYP), SPAD, RWL, CAR, Chla suggest that one (i.e., SPAD) of these traits should suffice as a selection criterion. The correlations among PI, ELWR, Fv/Fm and SC also suggest that one of these three traits (i.e., Fv/Fm) can be used as a selection criterion.

Similar reports demonstrated that the GT biplots were an excellent tool for visualizing genotype-by-trait data and revealing the interrelationships among traits (Yan & Kang 2003; Peterson *et al.*, 2005; Egesi *et al.*, 2007; Fernandez-Aparicio *et al.*, 2009; Mohammadi and Amri, 2011).

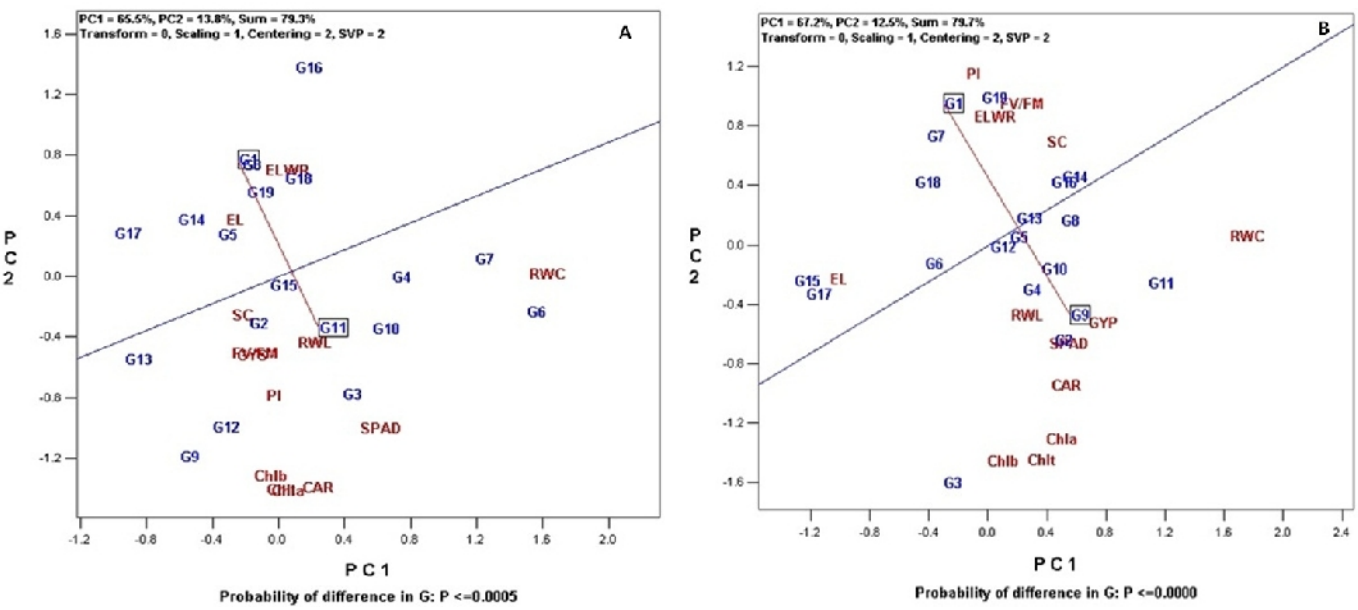


**Fig. 3.** The GT biplot that compares contrasting yield performance of two genotypes based on physiological traits under rain-fed (A) and irrigated (B) conditions.

## REFERENCES


Bavec, F., Bavec, M. (2001). Chlorophyll meter readings of winter wheat cultivars and grain yield prediction. *Communication in Soil Science and Plant Analysis*, **32**: 2709-2719.

Clarke, J.M., De Pauw, R.M., Townley-Smith, T.M. (1992). Evaluation of methods for quantification of drought tolerance in wheat. *Crop Science*, **32**: 728-732.

Egesi, C.N., Ilona, P., Ogbe, F.O., Akoroda, M., Dixon, A. (2007). Genetic variation and genotype × environment interaction for yield and other agronomic traits in Cassava in Nigeria. *Agronomy Journal*, **99**: 1137-1142.

Farshadfar, E., Sutka, J. (2002). Multivariate analysis of drought tolerance in wheat substitution lines. *Cereal Research Communication*, **31**: 33-39.

Fernandez-Aparicio, M., Flores, F., Rubiales, D. (2009). Field response of *Lathyrus cicera* germplasm to crenate broomrape (*Orobanche crenata*). *Field Crops Research*,**113**: 321-327.

Fischer, R.A., Rees, D., Sayre, K.D., Lu, Z.M., Condon, A.G., Larque Saavedra, A. (1998). Wheat yield progress associated with higher stomatal conductance and photosynthetic rate and cooler canopies. Crop Science, 38: 1467-1475.

Gavuzzi, P., Rizza, F., Palumbo, M., Campanile, R.G., Ricciardi, G.L., Borghi, B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science*, **77**: 52-531.

Golabadi, M., Arzani, A., Maibody, S.M.M. (2005). Evaluation of variation among durum wheat F3 families for grain yield and its components under normal and water stress field conditions. *Czech Journal of Genetic and Plant Breeding*, **41**: 263-267.

Henson, I. E., Jensen, C.R., Turner, N.C.(1989). Leaf gas exchange and water relations of lupins and wheat. III. Abscisic acid and drought-induced stomatal closure. Fun Plant Biology, **16**: 429-442.

Holms, G. (1954). Chlorophyll mutations in barley. *Acta Agriculture Scandinavia*, **4**: 457-461.

ICARDA. (2004). Taking research to farmers, fields in Iran. Caravan, Issue No. 20/21.

Jiang, D., Dai, T., Jing, G., Cao, W., Zhou, G., Zhao, H., Fan, X. (2004). Effects of long term fertilization on leaf photosynthetic characteristics and grain yield in winter wheat. *Photosynthesis,* **42**: 439-446.

Mohahmmadi, R., Haghparast, R. (2011). Evaluation of promising rainfed wheat breeding lines on farmers, fields in the west of Iran. *International Journal of Plant Breeding,* **5**(1): 30-36.

Mohammadi, R., Amri, A. (2011). Graphic analysis of trait relations and genotype evaluation in durum wheat. *Journal of Crop Improvement,* **25**: 680-696.

Peterson, D.M., Wesenberg, D.M., Burrup, D.E., Erickson, C.A. (2005). Relationships among agronomic traits and grain composition in oat genotypes grown in different environments. *Crop Science,* **45**: 1249-1255.

Porra, R.J., Thomson, W.A., Kriedemann, P.E. (1989). Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. *Biochimicaet Biophysica Acta*, **975**: 384-394.

Rashid, A., Saleem, Q., Nazir, A., Kazim, H.S. (2003). Yield potential and stability of nine wheat varieties under water stress conditions. *International Journal of Agricultural Biology,* **5**: 7-9.

Richards, R.A. (2006). Physiological traits used in the breeding of new cultivars for water-scarce environments. *Agricultural Water Management,* **80**: 197-211.

Saradadevi, R., Bramley, H., Siddique, K.H.M., Edwards, E., Palta, J.A. (2014). Reprint of "Contrasting stomatal regulation and leaf ABA concentrations in wheat genotypes when split root systems were exposed to terminal drought". *Field Crops Research,* **165**: 5-14.

Siddique, A., Hamid, A., Islam, M S. (2000). Drought Stress Effects on Water Relations of Wheat. *Botanical Bulletin- Academia Sinica Taipei*, **41**: 35-39.

Siddique, K.H.M., Tennant, D., Perry, M.W., Belford, R.K. (1990). Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean type environment. *Australian Journal of Agricultural Research,* **41**: 431-447.

Simane, B., Struik, P. C., Nachit, M.M., Peacock, J. M. (1993). Ontogenetic analysis of yield components and yield stability of durum wheat in water-limited environments. *Euphytica*, **71**: 211-219.

Sio-Se Mardeh, A., Ahmadi, A., Poustini, K.,Mohammadi, V. (2006). Evaluation of drought resistance indices under various environmental conditions. *Field Crops Research,* **98**: 222-229.

Yan, W. (2001). GGE biplot: A Windows application for graphical analysis of multi-environment trial data and other types of two-way data. *Agronomy Journal,* **93**:111-118.

Yan, W., Fregeau-Reid, J. (2008). Breeding line selection based on multiple traits. *Crop Science*, **48**: 417-423.

Yan, W., Kang, M. S. (2003). GGE Biplot Analysis: A graphical tool for breeders, geneticists, and agronomists. Boca Raton, FL: CRC Press.

Yan, W., Rajcan, I.R. (2002). Biplot analysis of test sites and trait relations of soybean in Ontario. *Canadian Journal of Plant Science,* **42**: 11-20.