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EVALUATION OF FLAG LEAF PHYSIOLOGICAL TRAITS OF TRITICALE GENOTYPES UNDER EASTERN MEDITERRANEAN CONDITIONS

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ABSTRACT

The primary objective of the present study is to determine the variations for physiological traits of triticale genotypes. Experiments were carried out in randomized complete block design with 3 replications during the cropping years of 2011-2012 and 2012-2013. Totally 5 cultivars and 20 lines of triticale were used as the plant material of the experiments. The relationships of grain yield with net photosynthesis rate (Pn), stomatal conductance (gs), internal CO_2 concentration/ambient CO_2 ratio (Ci/Ca), mesophyll conductance (Mc), transpiration efficiency (TE), transpiration rate (Tr) and the leaf temperature (Tl) were assessed through correlation and biplot analyses. For all three growth stages (booting, anthesis, grain filling), significant positive correlations were observed between Tr and Tl; gs and Tr; gs and Pn; gs and Ci/Ca and Mc and Pn, and the greatest negative correlations were observed between TE and Tl. Current findings were not able indicate a single physiological trait has significant correlations with grain yield in all growth stages. However, significant negative correlations were observed between grain yield and Tl-Tr at booting and anthesis stages. It was concluded that low temperature, high net photosynthesis rate, high Ci/Ca and low transpiration rate might be used as reliable selection criteria in further triticale breeding programs.

Keywords: Correlation, flag leaf, gas exchange parameters, grain yield, triticale

INTRODUCTION

Triticale is a cross of wheat (*Triticum* spp.) and rye (*Secale* spp.). It is an important small grain crop. Triticale has higher tolerance to biotic and abiotic stresses than wheat and higher grain yield than rye (Tohver et al., 2005). Triticale can be grown in marginal lands and is especially tolerant to drought and harsh winter conditions successfully. It also has less nutrient requirement and higher disease tolerance than the other cereal crops such as wheat, barley, corn and rice. Moreover, its grain and straw yield especially under unfavorable soil and climate conditions are higher than grain and straw yield of wheat crop (Igne et al., 2007; Kaplan et al., 2015).

Triticale has been gaining an increasing significance especially because of its higher tolerance to biotic and abiotic stresses, higher straw and grain yield and multiple uses. Therefore, triticale grown area almost was doubled in Europe during the last decade (Faostat, 2010). Several studies have been carried out in many countries to develop superior triticale varieties. It was reported that there were spring and winter triticale genotypes for grain and biomass production (Santiveri and Romagosa, 2004; Kozak et al., 2007; Lekgari et al., 2008; Bilgili et al., 2009). On the other hand, Gowda et al. (2011) reported that most of current triticale cultivars with high grain yield tend to be poor for biomass yield, whereas the excellent forage cultivars tend to be poor for grain yield. They also indicated that based on the developed regression model, at least during earlier stages of selection, field testing could be carried out for grain yield and related traits to select potential genotypes with high biomass yield.

As mentioned above, triticale generally provides more grain and straw yields than wheat in both favorable and unfavorable growing conditions. The higher yield of triticale has been attributed to earlier stem elongation stage, longer spike formation period (Lopez-Castaneda and Richards, 1994; Giunta et al., 2001) and higher spike fertility (Giunta et al., 2001, 2003). It was also shown that triticale produced fewer tillers, had greater early vigour levels (Lopez-Castaneda and Richards, 1994; Giunta et al., 2003) and larger root system at early growth stages (Richards et al., 2007). Simulations performed by Bassu et al., (2011) showed that the highest levels in wheat could be achieved through increasing transpiration-water use efficiency. But they also suggested that early vigour, remobilization of stem carbohydrates to grains and early root growth also contributed positively to a yield increase in different growing environments.

Triticale can remobilize more assimilates, which have been accumulated prior to grain filling period, to grains (Lopez-Castaneda and Richards, 1994; Ruuska et al., 2006). The net photosynthetic rate differences of wheat cultivars at high temperatures have been found to be associated with lower leaf chlorophyll concentration and changes of chlorophyll a:b ratio caused by accelerated leaf senescence (Al-Khatib and Paulsen, 1984; Harding et al., 1990).

Measurement of whole canopy carbon exchange rate in a very short time is generally an expensive method and several internal and external factors can simultaneously affect photosynthetic rate throughout growing period of crop. Therefore, it is suggested that in order to relate accurately crop productivity to leaf photosynthesis, quantification of canopy photosynthesis is required (Reynolds et al., 2000). Scientists measured net photosynthesis rate, stomatal conductance, chlorophyll content and dark respiration rate of 16 wheat cultivars and indicated that differences in net photosynthesis rate throughout the crop cycle as well as variation in onset of senescence might be important variables affecting wheat yield potential in warm environments, and net photosynthetic rate during the grain filling period was also strongly associated with chlorophyll loss (Reynolds et al., 2000). Hura et al., (2009) aimed to determine the differences in the activity of the photosynthesis apparatus in 10 genotypes of winter triticale grown under optimal conditions and to determine whether or not such measurements could provide a correlation that explains the usefulness of photosynthetic parameters in the estimation of harvest and growth of plants. They found out that there were significant correlations between the yield and some parameters of chlorophyll fluorescence and indicated that leaf gas exchange and parameters of chlorophyll fluorescence were useful for estimation of the functional state of the photosynthetic apparatus and could be selection criteria in plant breeding.

The present research was conducted to evaluate the relationships between grain yield and flag leaf physiological traits (net photosynthesis rate, stomatal conductance, intercellular CO_2 concentration, ambient CO_2 concentration, transpiration rate, mesophyll conductance, transpiration efficiency and leaf temperature) of triticale genotypes grown under Eastern Mediterranean conditions.

MATERIALS AND METHODS

Experiments were carried out in the research fields of Eastern Mediterranean Transition Zone Agricultural Research Center during the growing seasons of 2011-12 and 2012 -13. The genotypes used as material in experiments are provided in Table 1.

Table 1. Triticale genotypes used in the experiments and their pedigrees

Genotypes	Pedigrees
Line 1	MİKHAM-2002 / 01-02 STBVD-21
Line 2	CIMMYT-3 / ANOAS_3/TATU_4//SUSI_2
Line 3	431_TU_1-11/3/DARGO/IBEX//CIVET#2/KARMA
Line 4	SAMUR SORTU / 01-02 STBVD-19
Cultivar 1	TATLICAK-97
Line 6	CIMMYT-3 / KARMA
Line 7	01-02 KTBVD-1/ KARMA
Line 8	23FAHAT5/POLLMER3CTSS/POLLMER_3/FOCA_2-1
Line 9	23FAHAT5/POLLMER3CTSS/POLLMER_3/FOCA_2-1
Cultivar 2	MELEZ-2001
Line 11	23FAHAT5/POLLMER3CTSS/POLLMER_3/FOCA_2-1
Line 12	BAGAL_3/FARAS_1/3/ARDI_1/TOPO1419//ERIZO_9/KARMA
Line 13	FAHAD_8-2*2//PTR/PND-T/3/ERIZO_11//YOGUI_3/ POLLMER_3/FOCA_2-1
Line 14	CT179.80/3/150.83//2*TESMO_1MUSX603/01-02KTVD-17
Cultivar 3	MİKHAM-2002
Line 16	CIMMYT-3 / ANOAS_3/TATU_4//SUSI_2
Line 17	CIMMYT-3 / KARMA
Line 18	23FAHAT5/POLLMER3CTSS/POLLMER_3/FOCA_2-1
Line 19	CHD1089/POLLMER_2.3.1/POLLMER_3/FOCA_2-1
Cultivar 4	ALPERBEY
Line 21	CT179.80/3/150.83//2*TESMO_1MUSX603/01-02KTVD-17
Line 22	PRESTO 6D(6A)//BULL_10/MANATI_1/01-02 KTVD-32
Line 23	BULL_10/MANATI_1//FARAS/CMH84.4414
Line 24	33--1/42—2
Cultivar 5	KARMA-2000

The research province, Kahramanmaras is located in Eastern-Mediterranean Region between 37º 38’ North latitudes and 36º 37’ East longitudes and has an altitude of 568 m. Mediterranean climate is dominant in the province and day-night temperature difference is low. The Mediterranean climate is typical of the region and some climatic data are given in Table 2. Some chemical and physical traits of two years experiment soil sampled from 0-30 cm topsoil are given in Table 3.

Table 2. Climate parameters for experimental years and long term averages

Months	Precipitation (mm)			Temperature (°C)			Relative Humidity (%)		
	2011-2012	2012-2013	Long Term (1975-2011)	2011-2012	2012-2013	Long Term	2011-2012	2012-2013	Long Term
November	93.2	36.4	90.9	8.7	13.4	11.5	60.6	70.6	64.7
December	85.2	67.6	124.4	6.3	7.7	6.6	64.7	76.4	71.3
January	325.0	111.0	125.4	6.9	6.2	4.9	79.9	72.3	70.0
February	199.1	131.9	112.3	4.1	8.6	6.3	61.9	74.0	66.0
March	0.0	77.5	94.8	8.6	11.3	10.6	51.8	52.1	60.5
April	0.0	65.9	76.1	17.7	17.1	15.4	49.3	52.5	58.4
May	41.3	76.5	39.3	19.9	22.4	20.4	55.8	53.4	54.7
June	13.0	16.3	5.9	27.9	25.4	25.2	33.4	43.9	50.7
Total	756.8	583.1	669.1						
Mean				12.5	14.0	12.6	57.2	61.9	62.0

Table 3. Physical and chemical characteristics of experimental soils

Years	Texture	pH	$CaCO_3$ (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Organic matter (%)
2011-12	Loamy	7.61	12.55	0.46	4.59	1.22
2012-13	Loamy	8.00	24.59	0.80	12.70	0.97

Experiments were carried out in randomized complete block design with 3 replicated. Seeding rate was 500 seeds m^{-2} and seeding was performed with a plot-drill over 6 x 1.5 m size plots. There were 6 rows in each plot with row spacing of 20 cm. Sowing dates were on 5 December 2011 and 3 January 2013; harvesting date were 20 June for each two years. In both years, 80 kg N and 80 kg P_2O_5 ha^{-1} were applied to soil during sowings and additional 100 kg ha^{-1} N was supplied during tillering period. Irrigation was not performed in both years and herbicide with active ingredient of Tribenuron-Methyl was used for broad-leaf weeds.

During the booting, anthesis and grain filling stages, clear sunny days were selected for gas-exchange measurements, namely: net photosynthesis rate (Pn), stomatal conductance (gs), intercellular CO_2 concentration (Ci), ambient CO_2 concentration (Ca), transpiration rate (Tr) and leaf temperature (Tl) using a portable photosynthesis system (LCpro+ Portable Gas Analyser). The measurements were conducted under sunlight between 9:00 and 12:00 and the leaves were maintained at right angles with respect to incident solar radiation. At least five different flag leaves were measured per genotype for each plot on a single day. Due to phonological differences among the cultivars, three approximate growth stages were designated as booting, anthesis and grain filling periods for measurements in all cultivars. The flag leaf transpiration efficiency (TE) was calculated as: TE = Pn/Tr. Internal CO_2 concentration/ambient CO_2 ratio (Ci/Ca) were estimated from gas exchange measurements using the equations developed by von Caemmerer and Farquhar (1981). The apparent leaf mesophyll conductance (Mc=Pn/Ci) was also calculated.

Correlations analyses were performed by using SAS (SAS Inst., 1999) statistical software. The GT biplot is generated by plotting standardized data of physiological traits in different stages of triticale respectively, so that each genotype or trait is represented by a marker in the biplot (Yan and Kang, 2003). 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 generated by Excel Macro (Lipkovich and Smith, 2002).

RESULTS AND DISCUSSIONS

Two years experimental results revealed significant differences in all traits except for gs, Ci/Ca and Tr of the years ($P < 0.01$), in TE of genotypes ($P < 0.01$) and in Tl, Tr, gs, Pn, Mc and TE of the growth stages (Table 4, 5 and 6).

The differences in grain yields of genotypes were found to be significant ($P \leq 0.01$). Grain yield values under rain-fed conditions varied between 4258-6519 kg/ha with the greatest yield in Line 19 genotype and the lowest yield in Line 9 genotype (Table 7). The differences in grain yields of the years were mainly resulted from differences in precipitations of the years. Lack of precipitations especially in March and April (with rapid developments in plants) of the first year and high precipitations of the second year ultimately affected the grain yields resulted in significant differences in grain yields of the years.

Table 4. Mean values for leaf temperature (Tl), stomatal conductance (gs), net photosynthesis rate (Pn), internal CO_2 concentration/ambient CO_2 ratio (Ci/Ca), mesophyll conductance (Mc), transpiration rate (Tr) and transpiration efficiency (TE) during booting stage

Genotypes	**Tl (^{0}C)**	**gs (mol·m^{-2} s^{-1})**	**Pn (µmol·m^{-2} s^{-1})**	**Ci/Ca**	**Mc**	**Tr (mmol m^{-2} s^{-1})**	**TE (mmol mol^{-1})**
Line 1	33.80	0.320	17.15	0.590	76.16	6.232	3.304
Line 2	32.65	0.320	18.84	0.580	82.38	5.793	3.945
Line 3	33.92	0.340	19.14	0.580	84.48	6.318	3.358
Line 4	34.23	0.310	18.76	0.560	85.56	6.257	3.287
Tatlıcak-97	34.15	0.380	20.38	0.570	91.35	6.837	3.439
Line 6	34.32	0.350	19.96	0.560	91.16	6.855	3.503
Line 7	34.15	0.362	19.80	0.567	89.34	6.665	3.458
Line 8	33.97	0.310	18.67	0.561	84.56	5.978	3.602
Line 9	34.37	0.343	19.41	0.558	88.18	6.410	3.564
Melez-2001	34.52	0.402	18.65	0.604	77.73	7.135	3.182
Line 11	35.52	0.345	18.84	0.584	82.25	7.317	3.018
Line 12	34.33	0.297	18.47	0.560	84.34	6.363	3.517
Line 13	34.40	0.402	21.71	0.578	94.52	7.632	3.663
Line 14	35.12	0.340	18.67	0.584	82.15	7.075	3.017
Mikham-2002	34.40	0.330	19.65	0.568	86.33	6.992	3.594
Line 16	35.25	0.295	17.84	0.580	77.25	6.843	2.945
Line 17	35.57	0.348	18.69	0.591	81.23	7.720	2.962
Line 18	36.05	0.318	19.76	0.545	91.92	7.548	3.041
Line 19	34.63	0.365	18.43	0.575	82.63	7.048	2.942
Alperbey	35.93	0.380	20.44	0.557	91.32	7.863	2.983
Line 21	34.60	0.330	19.99	0.557	91.27	7.087	3.463
Line 22	35.75	0.392	20.52	0.579	89.34	8.395	2.910
Line 23	34.83	0.320	19.13	0.573	83.49	6.952	3.216
Line 24	35.32	0.352	18.55	0.578	81.16	7.540	2.777
Karma-2000	35.88	0.350	19.45	0.574	86.39	7.827	2.954
Mean	34.71	0.344	19.24	0.573	85.46	6.987	3.149
Mean of 2012	38.74	0.344	17.60	0.579	78.28	9.012	2.056
Mean of 2013	30.67	0.344	20.87	0.566	91.84	4.963	4.476
LSD	2.32	0.11	2.94	0.06	17.4	1.74	0.98
CV	5.83	28.8	13.4	9.31	17.8	21.7	26.1
Year	**	ns	**	ns	**	**	**
Genotypes	ns	ns	ns	ns	ns	ns	ns
YearxGenotypes	ns	ns	ns	ns	ns	ns	ns

ns, non-significant and **, mean significant difference at 0.01.

Regarding the stage of development, most of the physiological traits were relatively stable between booting and anthesis. Tl, Ci/Ca and TE increased moderately between booting and anthesis. However, Tl, Tr, gs, Pn and Mc declined between anthesis and grain filling (Table 5 and 6). Although varied based on genotype, average 23% decrease was observed in Pn between booting and anthesis. A similar reduction in Pn at a later stage, between anthesis and grain filling was also observed as 6%. In previous studies, strong decreases were reported in Pn, gs ve Tr of wheat and barley genotypes with decreasing temperature and soil moisture (Allahverdiyev et al., 2015; Azhand et al., 2015).

Table 5. Mean values for leaf temperature (Tl), stomatal conductance (gs), net photosynthesis rate (Pn), internal CO_2 concentration/ambient CO_2 ratio (Ci/Ca), mesophyll conductance (Mc), transpiration rate (Tr) and transpiration efficiency (TE) during anthesis stage

Genotypes	Tl (^{0}C)	gs (mol·m^{-2} s^{-1})	Pn (µmol·m^{-2} s^{-1})	Ci/Ca	Mc (mmol m^{-2} s^{-1})	Tr (mmol m^{-2} s^{-1})	TE (mmol mol^{-1})
Line 1	36.25	0.190	13.99	0.535	68.63	5.243	2.767
Line 2	35.90	0.240	15.61	0.566	72.55	5.880	2.722
Line 3	36.20	0.262	16.25	0.566	77.20	6.185	2.635
Line 4	35.58	0.302	15.88	0.617	68.16	6.487	2.487
Tatlıcak-97	35.33	0.238	14.61	0.566	68.00	5.162	2.885
Line 6	35.63	0.267	16.60	0.559	78.78	5.797	2.872
Line 7	35.65	0.242	14.47	0.586	65.25	5.565	2.644
Line 8	35.72	0.227	13.99	0.561	67.32	5.275	2.777
Line 9	36.02	0.250	14.94	0.586	67.33	5.922	2.570
Melez-2001	36.05	0.233	14.48	0.582	65.13	5.795	2.598
Line 11	35.68	0.255	14.82	0.597	66.37	5.802	2.597
Line 12	35.73	0.257	14.48	0.608	62.28	5.878	2.525
Line 13	35.55	0.215	13.55	0.576	62.55	5.130	2.678
Line 14	35.87	0.238	15.13	0.569	55.37	5.655	2.764
Mikham-2002	35.63	0.242	14.24	0.601	62.27	5.595	2.615
Line 16	36.12	0.250	14.16	0.603	62.58	5.953	2.492
Line 17	36.00	0.198	15.82	0.487	85.26	5.147	3.234
Line 18	35.87	0.218	14.79	0.552	71.20	5.317	2.815
Line 19	36.28	0.252	15.39	0.568	71.64	6.025	2.588
Alperbey	35.85	0.250	14.26	0.604	62.55	5.857	2.488
Line 21	35.93	0.252	14.65	0.599	64.05	5.900	2.505
Line 22	36.13	0.218	14.57	0.535	74.13	5.387	2.837
Line 23	35.72	0.242	15.65	0.559	73.08	5.697	2.855
Line 24	36.37	0.215	13.60	0.586	61.73	5.627	2.441
Karma-2000	35.88	0.267	14.50	0.615	61.28	6.127	2.446
Mean	35.88	0.241	14.82	0.575	67.79	5.696	2.570
Mean of 2012	37.02	0.265	16.10	0.563	76.33	6.597	2.465
Mean of 2013	34.73	0.217	13.53	0.588	58.57	4.795	2.881
LSD	0.87	0.06	2.08	0.06	14.6	0.87	0.39
CV	2.11	22.7	12.3	9.84	18.8	13.4	12.6
Year	**	**	**	**	**	**	**
Genotypes	ns	ns	ns	ns	ns	ns	*
YearxGenotypes	ns	ns	ns	ns	ns	ns	ns

ns, non-significant; * and ** mean significant difference at 0.05 and 0.01, respectively.

Leaf temperature was measured as 34.7 ºC in booting stage, 35.9 ºC in anthesis and 30.9 ºC in grain filling stages. While low daily temperature in grain filling stage and during the period in which Tl measurements were made were similar to findings of Delgado et al., (1994) and such low temperatures resulted in low leaf temperatures in triticale genotypes. On the other hand, high temperature and relative humidity post-booting growth stage resulted in higher temperatures in Tl. Delgado et al. (1994) carried out a study on bread wheat for two years and reported average daily maximum temperatures of the first and the second year respectively as 32 and 36 ºC and resultant leaf temperatures respectively as 31.7 ºC 34.7 ºC.

As an average of genotypes, Tr decreased from booting to grain filling and observed as 6.585 mmol m^{-2} s^{-1} in the first year and 4.629 mmol m^{-2} s^{-1} in the second year. Higher precipitations were observed in May of the second year in which measurements were made than the first year. The 50 mm precipitation received on May 13 before the measurements resulted to have higher transpiration rates in the first year. Qui et al. (2008) indicated significant effects of irrigation intervals on transpiration rates and reported Tr as between 4.8-5.8 mmol m^{-2} s^{-1} in the first year and between 7.3-8.4 mmol H_2O m^{-2} s^{-1} in the second year. Dry soil conditions caused a reduction in transpiration rates. Different decrease trends were observed for Tr of triticale genotypes. Similar effects were also reported for flowering and legume formation of field bean (Hura et al., 2007).

Table 6. Mean values for leaf temperature (Tl), stomatal conductance (gs), net photosynthesis rate (Pn), internal CO_2 concentration/ambient CO_2 ratio (Ci/Ca), mesophyll conductance (Mc), transpiration rate (Tr) and transpiration efficiency (TE) during grain filling stage

Genotypes	Tl (^{0}C)	gs (mol·m^{-2} s^{-1})	Pn (µmol·m^{-2} s^{-1})	Ci/Ca	Mc	Tr (mmol m^{-2} s^{-1})	TE (mmol mol^{-1})
Line 1	30.62	0.205	14.50	0.585	60.57	4.172	3.933
Line 2	30.25	0.205	13.33	0.627	57.62	3.825	3.541
Line 3	29.57	0.237	13.79	0.607	58.32	3.802	3.984
Line 4	29.93	0.230	14.63	0.612	60.58	4.043	3.723
Tatlıcak-97	30.47	0.190	14.67	0.571	59.05	3.840	3.931
Line 6	30.95	0.183	13.13	0.588	53.68	3.867	3.502
Line 7	29.88	0.227	13.97	0.641	56.27	3.963	3.704
Line 8	30.32	0.215	13.67	0.644	54.57	4.048	3.468
Line 9	30.13	0.198	14.37	0.596	62.03	3.947	3.846
Melez-2001	31.47	0.165	13.63	0.569	59.58	3.987	3.501
Line 11	31.68	0.200	14.06	0.610	58.27	4.413	3.285
Line 12	30.78	0.188	13.76	0.608	59.13	3.905	3.537
Line 13	30.98	0.223	13.78	0.616	56.62	4.097	3.472
Line 14	30.58	0.203	14.52	0.609	63.47	4.072	3.728
Mikham-2002	31.05	0.180	14.22	0.581	62.29	3.960	3.662
Line 16	30.68	0.193	13.16	0.625	54.47	3.947	3.418
Line 17	31.98	0.218	14.88	0.608	60.45	4.757	3.226
Line 18	32.03	0.198	14.63	0.607	58.53	4.708	3.210
Line 19	31.27	0.213	13.64	0.625	52.45	4.353	3.222
Alperbey	31.82	0.185	12.92	0.591	55.05	4.180	3.200
Line 21	30.53	0.193	14.16	0.537	75.00	3.775	3.893
Line 22	31.87	0.210	13.84	0.641	57.68	4.910	2.926
Line 23	31.45	0.163	12.45	0.581	51.27	3.715	3.589
Line 24	31.05	0.202	14.30	0.620	61.54	4.352	3.426
Karma-2000	32.00	0.228	14.21	0.629	61.29	4.823	3.042
Mean	30.93	0.202	13.93	0.605	58.79	4.138	3.519
Mean of 2012	32.12	0.148	13.21	0.563	61.33	4.147	3.354
Mean of 2013	29.75	0.257	14.64	0.647	55.27	4.130	3.684
LSD	1.73	0.06	1.49	0.07	13.2	0.85	0.79
CV	4.87	27.4	9.31	9.44	19.7	17.91	19.8
Year	**	**	**	**	**	ns	**
Genotypes	ns	ns	ns	ns	ns	ns	ns
YearxGenotypes	ns	ns	ns	ns	ns	ns	ns

ns, non-significant and **, mean significant difference at 0.01.

Stomatal conductance was measured as 0.252 mol H_2O m^{-2} s^{-1} in the first year and 0.272 mol H_2O m^{-2} s^{-1} in the second year **(**data not shown**)**. Compared to the second year, gs values decreased in the first year because of insufficient precipitations in grain filling period. Therefore, under insufficient moisture conditions, stomatal closure to prevent water loss and consequent decreases in gs were reported (Cornic, 2000). Ethylene amount and ABA synthesis in plants are increasing under drought conditions. Thus, stomata are closing and senescence of leaves is accelerating. Therefore, stomatal conductance is decreasing. Also lower minimum temperatures of the first year at the time of measurements decreased gs values. It was reported that stomatal conductance was influenced by minimum temperatures and low night temperatures reduced gs and Ci values (Bunce, 1998). As the average of genotypes, gs values gradually decreased from booting to grain filling stage. Delgado et al. (1994) reported in wheat that gs value of booting, anthesis and grain filling stages respectively as 0.678, 0.586 and 0.317 mol H_2O m^{-2} s^{-1}; Reynolds et al. (2000) reported the values respectively as 0.680, 0.590 and 0.320 mol H_2O m^{-2} s^{-1} and indicated decreasing gs values with aging of the leaves. Boutraa et al. (2015) compared gs values under 20 ^{o}C and reported 28% decrease under moderate temperatures and 46% decrease under high temperatures. Additionally, compared species differed in gs, particularly in pre-anthesis period in which triticale showed a stomatal conductance markedly higher than durum wheat. The difference in stomatal conductance between two species persisted after anthesis, although only in the irrigated treatment. Under rainfed conditions, on the contrary, initially higher stomatal conductance of triticale decreased to values very similar to those of durum wheat (Motzo et al., 2013).

Table 7. The values of grain yield (kg/ha) of triticale genotypes

Genotypes	2011-12		2012-13	Mean	
Line 1	6016.3	abcd	6688.3	6352.3	ab
Line 2	5790.7	abcd	6790.0	6290.3	abc
Line 3	5126.7	bcdefg	6508.7	5817.7	abc
Line 4	5708.3	abcde	7141.0	6424.7	a
Tatlıcak-97	4115.0	fg	5176.7	4645.8	de
Line 6	5481.7	abcde	7460.7	6471.2	a
Line 7	5738.3	abcde	6517.7	6128.0	abc
Line 8	5884.3	abcd	6329.7	6107.0	abc
Line 9	3933.0	g	4582.3	4257.7	e
Melez-2001	4487.7	efg	6111.7	5299.7	cd
Line 11	5236.3	abc	6710.3	6473.3	a
Line 12	5797.0	abcd	7087.0	6442.0	a
Line 13	6126.3	abc	5769.0	5947.7	abc
Line 14	5076.7	cdefg	6109.3	5593.0	abcd
Mikham-2002	5694.7	abcde	6300.0	5997.3	abc
Line 16	4814.7	defg	6305.0	5559.8	abcd
Line 17	5226.0	bcdef	6015.0	5620.5	abcd
Line 18	5161.3	bcdefg	6761.0	5961.2	abc
Line 19	6583.7	a	6455.0	6519.3	a
Alperbey	5853.3	abcd	5970.3	5911.8	abc
Line 21	6360.7	ab	6388.3	6374.5	ab
Line 22	6551.0	a	6430.0	6490.5	a
Line 23	5874.7	abcd	5939.0	5906.8	abc
Line 24	6265.0	abc	6661.0	6463.0	a
Karma-2000	4513.3	efg	6345.0	5429.2	bcd
Mean	5537.0 b		6342.0 a	5918.4	
CV	13.96		14.95	14.56	
LSD	1269.1**		1556.4	991.3**	

** mean significant difference at 0.01.

Pn values of genotypes varied between 17.15-21.71 µmol CO_2 $m^{-2}s^{1}$ booting stage, between 13.55-16.60 µmol CO_2 $m^{-2}s^{1}$ in anthesis and between 12.45-14.88 µmol CO_2 $m^{-2}s^{1}$ grain filling periods. As the growth progresses, Pn values of genotypes decreased with leaf aging. Many researchers reported photosynthesis as one of the most sensitive processes that can be inhibited by high temperature (Boutraa et al., 2015). The primary effect of high temperature on wheat is to accelerate phenological development, which seems to be associated with premature leaf senescence (Midmore et al., 1982; Al-Khatib and Paulsen, 1984). It was reported in previous studies that photosynthesis rate in bread wheat decreased by 6.1% between pre and post-anthesis (Rees et al., 1993) and decreased by 48.4% between anthesis and late-dough stage (Jiang et al., 2000). It was also indicated that net photosynthesis rate was closely related to chlorophyll loss and besides leaf aging, variations in photosynthesis rates throughout growth stages had also significant impacts on yield potential of wheat (Reynolds et al., 2000). Decreasing leaf water content initially induces stomatal closure (Pasban Eslam, 2011), imposing a decrease in CO_2 supply to mesophyll cells and consequently, results in a decrease in leaf photosynthesis rates (Lawlor and Cornic, 2002). A genetic variation in this case was reported for triticale (Hura et al., 2007) and wheat (Loggini et al., 1999). Roohi et al., (2013) found that triticale had a lower reduction in photosynthetic traits under water deficit conditions than wheat and barley.

As the average of genotypes, Ci/Ca ratio was observed as 0.568 in the first year and 0.600 in the second year. Despite the higher precipitations throughout the growing season in the first year, insufficient precipitations in grain filling period (Table 2) exerted a stress on plants and consequently plants closed their stomatas to prevent water loss and ultimately leaf CO_2 diffusion was limited. Therefore, under insufficient moisture conditions, stomatal closure, decreased cell CO_2 concentrations and Ci/Ca ratios were reported by Cornic (2000). Low Ci/Ca ratios can be considered as a plant response to drought stress under dry conditions (Feng, 1998; Erbs et al., 2009).

The decrease in mesophyll conductance is mainly resulted from the decrease in Pn rather than Ci (Allahverdiyev et al., 2015). It was reported that mesophyll conductance was mostly influenced by light (Evans et al., 1994), leaf angle (Loreto et al., 1994; Scartazza et al., 1998), drought stress (Lauteri et al., 1997), salt stress (Delfine et al., 1998; 1999) and cultivar-specific characteristics (Koç et al., 2003). Mesophyll conductance of the present study was observed as 85.46 mmol m^{-2} s^{-1} in booting stage, 67.79 mmol m^{-2} s^{-1} in anthesis and 58.79 mmol m^{-2} s^{-1} grain filling stage.

Flag leaf TE values varied between 2.777-3.945 mmol mol^{-1} at booting stage, between 2.441-3.234 mmol mol^{-1} at anthesis stage and between 2.926-3.984 mmol mol^{-1} at grain filling stage. Motzo et al. (2013) indicated that before anthesis the average leaf TE was higher in irrigated treatment than in rainfed one, but differences disappeared after anthesis. Species were not different with regard to average of water treatments, although a higher leaf TE was observed in triticale compared to durum wheat in rainfed treatment after anthesis.

According to Kroonenberg (1995), the fundamental patterns among the traits should be captured by biplots. In 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 (Rubio et al., 2004; Akçura, 2011). Since the cosine of the angle between the vectors of any two traits approximates the correlation coefficient between them, this view of the biplot is best for visualizing the interrelationship among the traits (Yan and Kang, 2003). The GT biplot for each of three stages (booting, anthesis and grain filling stages) explained 76%, 69% to 63% of the total variation of the standardized data (Figures 1, 2 and 3).

For booting stage, the largest variation explained by biplot was for Pn and gs (Figure 1). While there were significant positive correlations between grain yield and Pn-Mc-TE; between Tl and Tr-Ci/Ca (P<0.01) in this stage, there were significant negative correlations between grain yield and Tl-Tr and between Tl and Pn-Mc-TE (Table 8; Figure 1). There were also significant positive correlations between Tr and gs-Ci/Ca and significant negative correlations were observed between Pn, Mc and TE (Figure 1). Tavakoli et al. (2011) reported a positive correlation between gs and transpiration rate. The correlation between photosynthesis and stomatal conductance showed that the stomatal limitation was more important than non-stomatal limitation. The decrease in transpiration rate per leaf area under stress was related to stomatal closure and such a closure decreased stomatal conductance (Abdoli and Saeidi, 2013). While there were significant positive correlations between stomatal conductance (gs) and Pn-Ci/Ca, between Pn and Mc-TE and between Mc and TE, significant negative correlations were observed between Ci/Ca ratio and Mc-TE (Figure 1). Throughout the vegetative and generative stages, a positive correlation was also reported between Pn and gs of triticale (Hura et al., 2007). Koç et al. (2003) and Del Pozo et al. (2005) also reported significant correlations between gs and Ci/Ca ratio.

Table 8. Correlation coefficients for physiological traits during booting, anthesis and grain filling stages

Stage	Traits	GY	Tl	Tr	gs	Pn	Ci/Ca	Mc
Booting	Tl	-0.33**						
	Tr	-0.18*	0.89**					
	gs	0.14	0.13	0.49**				
	Pn	0.30**	-0.54**	-0.23**	0.46**			
	Ci/Ca	0.03	0.32**	0.52**	0.69**	-0.15		
	Mc	0.22**	-0.55**	-0.42**	-0.02	0.82**	-0.66**	
	TE	0.33**	-0.92**	-0.81**	-0.12	0.66**	-0.45**	0.71**
Anthesis	Tl	-0.34**						
	Tr	-0.30**	0.71**					
	gs	-0.11	0.08	0.71**				
	Pn	-0.16*	0.25**	0.64**	0.65**			
	Ci/Ca	0.06	-0.25**	0.18*	0.52**	-0.25**		
	Mc	-0.15	0.37**	0.42**	0.22**	0.78**	-0.59**	
	TE	0.27**	-0.70**	-0.72**	-0.37*	0.03	-0.49**	0.13
Grain Filling	Tl	-0.14						
	Tr	0.08	0.69**					
	gs	0.31**	-0.40**	0.33**				
	Pn	0.12	-0.44**	0.03	0.60**			
	Ci/Ca	0.28**	-0.31**	0.29**	0.74**	0.03		
	Mc	-0.07	0.03	-0.11	-0.13	0.59**	-0.72**	
	TE	0.00	-0.81**	-0.78**	0.07	0.56**	-0.23**	0.43**

* and ** mean significant difference at 0.05 and 0.01, respectively.

For anthesis stage, the largest variation explained by biplot was for Ci/Ca, TE, Tr (Figure 2). While there were significant positive correlations between grain yield and TE in this stage, negative correlations were observed between grain yield and the other physiological traits (Table 8; Figure 2). While significant positive correlations were observed between Tl and Tr-Pn-Mc (P<0.01), there were significant negative correlations between Ci/Ca and TE (Figure 2). Significant positive correlations were also observed between Tr and gs-Pn-Ci/Ca-Mc, between gs and Pn-Ci/Ca-Mc, between Pn and Mc and between and significant negative correlations were observed between Tl and Ci/Ca-TE, between Tr and TE, between gs and TE, between Pn and Ci/Ca and finally between Ci/Ca and Mc- TE.

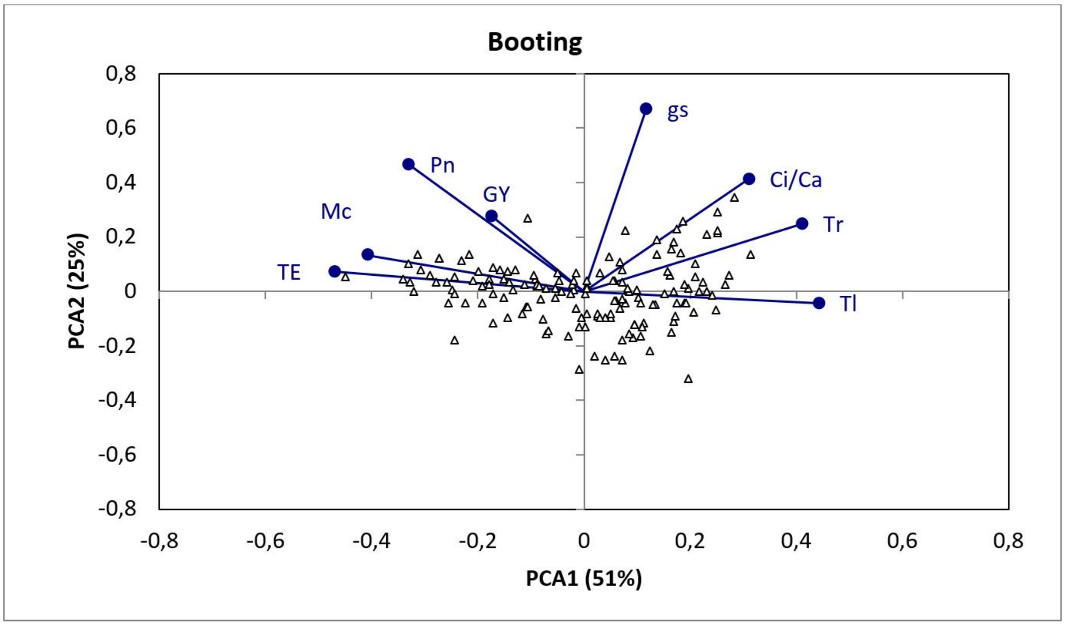

Figure 1. Relationships between physiological traits of triticale genotypes at booting stage (n=150)

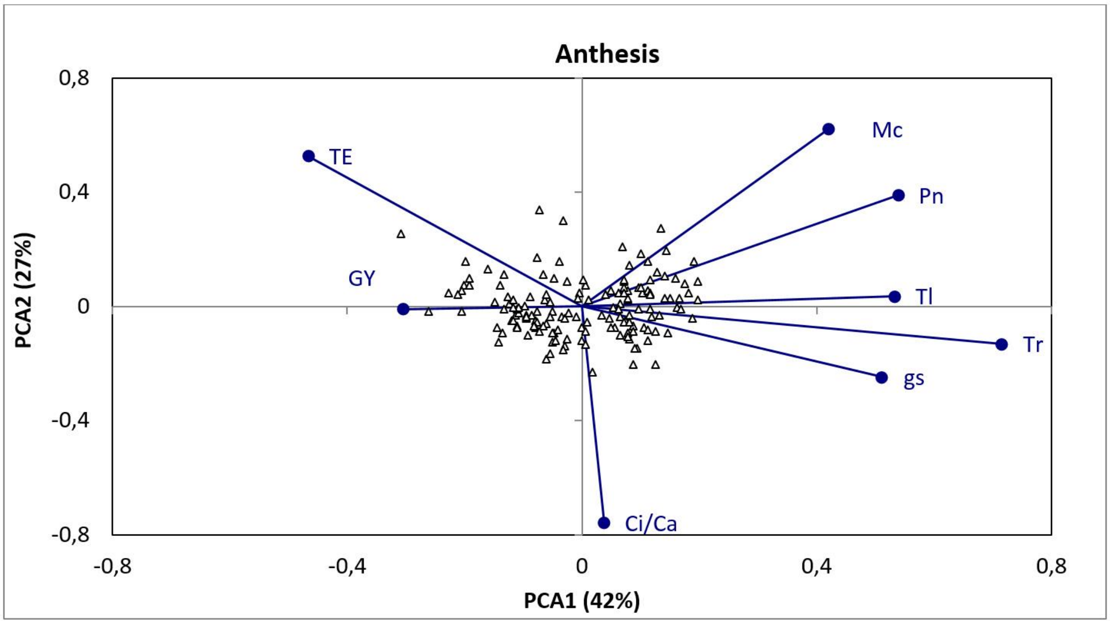

Figure 2. Relationships between physiological traits of triticale genotypes at anthesis stage (n=150)

For grain filling stage, the largest variation explained by biplot was for TI, Tr, and TE (Figure 3). While there were significant positive correlations between grain yield and gs-Ci/Ca (P<0.01) in this stage, the correlations between grain yield and the other physiological traits were not found to be significant (Table 8, Figure 3). Significant positive correlations were also observed between Tl and Tr, between Tr and gs-Ci/Ca, between gs and Pn-Ci/Ca, between Pn and Mc-TE and between Mc and TE and significant negative correlations were observed between Tl and gs-Pn-Ci/Ca-TE, between Tr and TE and finally between Ci/Ca and Mc-TE (Figure 3). Hui et al. (2008) reported significant positive correlations between Tr and Tl in late grain filling stage of wheat. Fischer et al. (1998) studied the yield of wheat associated with gs and Pn, and concluded that gs may be potential indirect selection criteria for yield.

Delgado et al. (1994) and Monneveux et al. (2006) indicated a significant correlation between grain yield and net photosynthesis rate in wheat and Fischer et al. (1981) indicated the same correlation as insignificant in wheat. Rees et al. (1993) reported positive correlations between grain yield and photosynthesis rate in pre and post anthesis stages and Reynolds et al. (2000) indicated significant correlations between net photosynthesis rate and grain yield at 3 growth stages (booting, anthesis and grain filling).

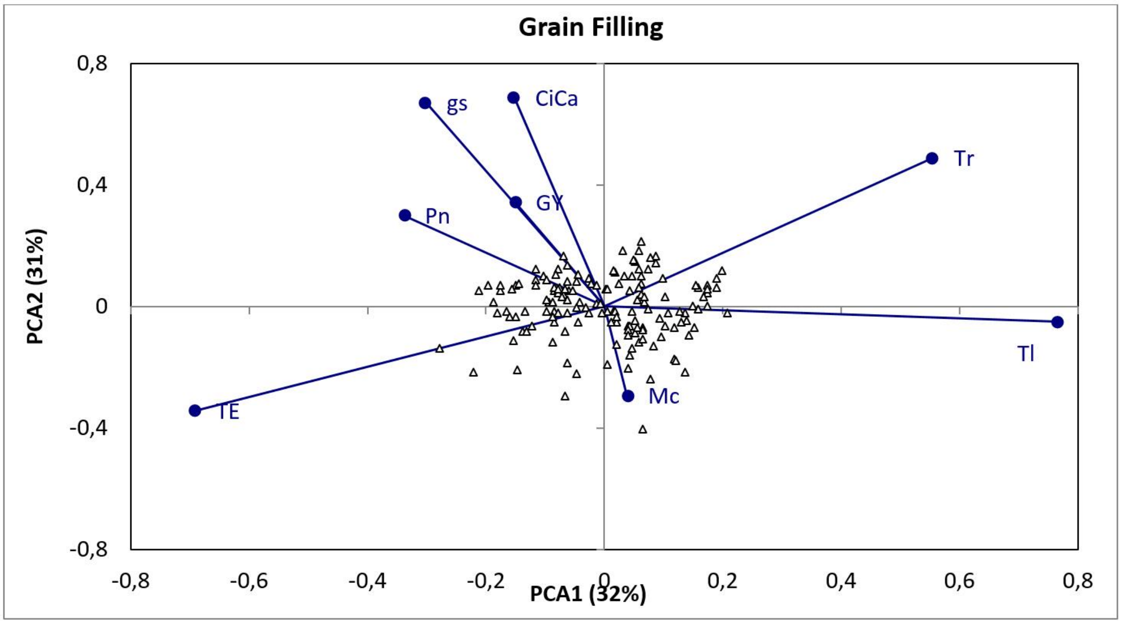

Figure 3. Relationships between physiological traits of triticale genotypes at grain filling stage (n=150).

There were highly positive correlations between stomatal conductance (gs) and Tr for all three stages (Table 8). The level of correlation between gs and TE decreased with increasing drought stress in grain filling period. Such a case then resulted in decreasing gs values through weakened flag leaf functions because of high leaf temperature (Shao et al. 2005; Tan et al., 2006).

The negative correlation between leaf temperature (TI) and TE was observed for all 3 stages. Feng et al. (2005) indicated that there was always a negative correlation between Tl and TE and such a correlation was stronger especially in late grain filling stage. Inefficient water use throughout late ripening stage because of increasing temperatures was indicated as a disadvantage for wheat (Shao et al. 2005).

A negative correlation was reported between net photosynthesis rate (Pn) and Ci/Ca ratio (Del Pozo et al., 2005) and significant positive correlations were reported between Mc and Pn (Fischer et al., 1998; Del Blanco et al., 2000). Correlation analyses revealed the dominant role of Mc in regulation of Pn. Such a finding is in agreement with the result of Siddique et al., (1999).

CONCLUSIONS

The relationships between grain yield and physiological parameters of triticale were investigated in this study. Physiological parameters positively correlated with grain yield varied for three growth stages. Therefore, results of each stage should be assessed separately. It is recommended for further triticale breeding studies that the genotypes with high Pn, TE and Mc values at booting stage, high TE values at anthesis stage and high gs and Ci/Ca values at grain filling stage should be investigated. On the other hand, the traits of Tl and Tr with significant stable negative correlations with grain yield could also be used for selections. The results of this research showed that the selection of triticale genetic materials with high-photosynthesis (Pn), high-tranpiration efficiency (TE) low-transpiration (Tr) and low- leaf temperature (Tl) during all stages. According to this results, Line 1, Line 2, Line 3, Line 5, Line 7, Line 13 and Line 22 genotypes can be investigated for physiological traits for further breeding.

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