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Physiological characterization of Turkish bread wheat genotypes for resistance to late drought stress

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Abstract: A number of physiological traits have been proposed as selection criteria for late drought resistance and grain yield improvement in wheat. To characterize them in terms of late drought resistance, 64 bread wheat genotypes were evaluated for canopy temperature difference (CTD), leaf senescence rate (LSR), SPAD chlorophyll value, initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), maximum quantum efficiency of PSII (Fv/Fm), leaf ash content, and grain ash content in two field experiments conducted in irrigated and late drought conditions during the 2011–12 and 2012–13 seasons in Erzurum, Turkey. The experiments were conducted in an 8 × 8 lattice design with two replicates. Significant variation was observed among the genotypes for all the traits. Late drought decreased the grain yield, CTD, SPAD, Fm, Fv, Fv/Fm, and leaf ash content but increased LSR and grain ash content. The drought sensitivity of the genotypes was determined by a ranking method based on 25 traits measured in the late drought conditions. According to the rank-sum (RS) values of the genotypes, four genotypes were defined as resistant, 15 genotypes as medium resistant, 34 genotypes as medium sensitive, and 11 genotypes as sensitive. Resistant genotypes Müfitbey and Dağdaş 94 produced the highest grain yields in late drought conditions and appeared to be promising parents for the breeding of resistant cultivars. RS was negatively correlated with CTD, SPAD, Fm, Fv, and Fv/Fm, while it was positively correlated with LSR. For screening late drought-resistant genotypes, 15 days post anthesis (15DPA) is the optimum time for Fv, CTD, and SPAD measurements. The stepwise multiple linear regression analysis indicated that the Fv_{15DPA}, Fv_{25DPA}, CTD_{15DPA}, and $SPAD_{15DPA}$ could explain 75.2% of the total variation in RS. Therefore, the Fv_{15DPA}, Fv_{25DPA}, CTD_{15DPA}, and $SPAD_{15DPA}$ traits can be used as selection criteria as a combination for the classifying of wheat genotypes in terms of late drought resistance.

Key words: Ash content, canopy temperature, chlorophyll, chlorophyll fluorescence, leaf senescence, ranking method

1. Introduction

Drought is the most important limiting factor for wheat yields and it is becoming an increasingly severe problem in many regions of the world. In Turkey, wheat is commonly grown in semiarid regions as a rainfed crop, and it is frequently exposed to mild to severe drought stress during grain filling. Development of genetically drought-resistant cultivars is considered as the most promising strategy for high and stable yields under rainfed conditions. Selection for grain yield under rainfed conditions is difficult due to its low heritability results from variations in the intensity of the stress throughout the field (Ludlow and Muchow, 1990). A number of physiological traits have been proposed as indirect selection criteria for genetic improvement of drought resistance in breeding programs (Merah et al., 2001; Sayar et al., 2008; Feng et al., 2009; Kumar et al., 2012). However, drought sensitivity is not a simple phenomenon; it is a result of the cumulative action of various physiological processes (Chandrasekar et al., 2000; Gupta et al., 2001). Therefore, the breeding for drought resistance requires a combination of measurements of physiological traits associated with yield response in controlled environments (Li et al., 2012).

Canopy temperature reflects the interactions among plants, soil, and atmosphere and it is an indirect measure of transpiration at the whole crop level. Higher transpiration means colder leaves, higher stomatal conductance, and a relatively lower canopy temperature in drought-stressed plants, which indicates relatively greater capacity for taking up soil moisture or for maintaining a better plant water status (Monneveux et al., 2012). Therefore, canopy temperature difference during grain filling stage among wheat genotypes has been used as a selection criterion for predicting high yield in rainfed environments (Araus et al., 2002; Balota et al., 2007) and evaluation of tolerance to drought stress (Feng et al., 2009; Pierre et al., 2010). The timing and rate of leaf senescence are important determinants of grain yield under drought stress and

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genetic variations for these traits have been reported in wheat (Hafsi et al., 2007; Lopes and Reynolds, 2012). Delayed senescence in wheat has increased grain yield under water-stressed conditions (Verma et al., 2004). A low rate of leaf senescence has also been associated with yield increases in wheat (Hafsi et al., 2007; Lopes and Reynolds, 2012). Therefore, delayed senescence or low senescence rate has been proposed as a secondary selection criterion under drought conditions by several authors (Lopes and Reynolds, 2012). Photosynthesis is sensitive to drought stress and it is one of the main metabolic processes determining grain yield (Araus et al., 2002). Chlorophyll content and chlorophyll fluorescence are linked strongly to photosynthesis, and these parameters have been used to identify drought tolerant genotypes in wheat (Sayed, 2003; Kumar et al., 2012). Chlorophyll content has a positive relationship with photosynthesis rate (Gutierrez-Rodriguez et al., 2004) and maintaining higher chlorophyll content for a longer period of time is one of the strategies for increasing grain yield under drought conditions (Guo et al., 2008). According to Farquhar et al. (1989), high chlorophyll content indicates a low photoinhibition of the photosynthetic apparatus, therefore reducing carbohydrate losses in grain growth. Balota et al. (2007) and Kumar et al. (2012) identified the drought tolerant cultivars in regard to more leaf chlorophyll retention under stress conditions. Chlorophyll fluorescence parameters, such as initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and maximum quantum efficiency of PSII (Fv/Fm), have been used to detect the genotypic differences in response to drought stress in wheat (Araus et al., 1998; Sayar et al., 2008). Fo and Fm measured during the grain filling period of wheat under drought stress showed high genetic correlation with grain yield (Araus et al., 1998). Fm, Fv, and Fv/Fm parameters in dark-adapted flag leaves decreased during severe drought stress and these parameters were positively correlated with grain yield in wheat (Paknejad et al., 2007). The Fv/Fm ratio has been shown to be the most reliable indicator in classification of wheat genotypes according to drought tolerance (Sayar et al., 2008). Leaf ash content provides information on photosynthetic and transpirative gas exchange while grain ash content represents an integrated performance measurement of photosynthesis and translocation processes (Araus et al., 2001). A decrease in soil water content after anthesis led to a decrease of leaf ash content (Araus et al., 2001; Zhu et al., 2008) and an increase of grain ash content (Misra et al., 2006; Zhu et al., 2008). Grain yield was positively correlated with leaf ash content (Monneveux et al., 2005; Tsialtas et al., 2005) and negatively correlated with grain ash content (Merah et al., 2001; Tsialtas et al., 2005) under late drought conditions. Therefore, these traits have been proposed as promising selection criteria for the improvements of drought resistance in wheat (Merah et al., 2001; Monneveux et al., 2005). The objectives of the current research were to identify drought-resistant wheat genotypes under late drought stress, determine the efficiency of selection criteria to classify genotypes for resistance to late drought, and investigate relationships among the selection criteria and grain yield.

2. Materials and methods

2.1. Plant material, experimental conditions, and crop management

Sixty-four bread wheat genotypes (*Triticum aestivum* L.), including 11 landraces and 53 cultivars, were used in this study. According to the ranking by Öztürk (1999), two drought sensitive cultivars (Bezostaja 1, Karasu 90) were chosen as the control. The other 62 genotypes are adapted for rainfed conditions of Turkey (Table 1). The genotypes were grown in two separate experiments under irrigated and late drought conditions at the Experimental Farm of Atatürk University, Faculty of Agriculture, Erzurum, Turkey (29°55′N, 41°16′E; altitude of 1850 m a.s.l.) during the 2011–12 and 2012–13 crop seasons. The climate is semiarid with an average annual precipitation of 398.8 mm and an average annual air temperature of 5.0 °C. Growing conditions and agronomic details of the experiments are summarized in Table 2.

The experimental design for all the trials was an 8 × 8 lattice design with two replicates per genotype. The experiments were performed in a field that had lain fallow during the previous year. In the irrigated experiments, plots were sown by a planter. The plots consisted of six rows spaced 20 cm apart, with row length of 6.0 m. For the late drought experiments, sowing was done by hand in plots with two rows of 1.5 m in length and 20 cm apart. The seed rate was adjusted for a density of 475 viable seeds m^{-2} according to the standard practices for all trials. In each experiment, 60 kg N ha^{-1} as ammonium sulfate and 50 kg P ha^{-1} as triple superphosphate were applied to the soil. Half of N and all P were applied at sowing; the second half of N was applied at the beginning of stem elongation (Feekes 6.00; Harrel et al., 1993). Water was applied by flood irrigation. Irrigation was done after sowing in all the experiments to ensure proper seed germination. Volumetric soil water content was determined by a soil moisture meter (GMS, Watermark Soil Moisture Sensor Model 200SS, Irrometer Co. Inc., Riverside, CA, USA) by weekly measurements from the beginning of stem elongation to maturity (Feekes 11.4). For measuring water content, two probes per experiment were inserted into a 60-cm plastic pipe, buried vertically in the field, and readings were recorded at intervals of 20 cm. In the irrigated experiment, plots were watered three

Table 1. Bread wheat genotypes used in the study.

No.	Genotype	Origin / Institute	Growth habit
Listed in 2011 national cultivar list			
1	Aksel 2000	Central Research Institute of Field Crops, Ankara	Facultative
2	Aldane	Trakya Agricultural Research Institute, Edirne	Facultative
3	Alparslan	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
4	Altay 2000	Anatolia Agricultural Research Institute, Eskişehir	Winter
5	Atlı 2002	Central Research Institute of Field Crops, Ankara	Facultative
6	Aytın 98	Anatolia Agricultural Research Institute, Eskişehir	Winter
7	Bağcı 2002	Bahri Dağdaş International Agricultural Research Institute, Konya	Facultative
8	Bayraktar 2000	Central Research Institute of Field Crops, Ankara	Facultative
9	Bolal 2973	Anatolia Agricultural Research Institute, Eskişehir	Facultative
10	Bereket	Trakya Agricultural Research Institute, Edirne	Winter
11	Çetinel 2000	Anatolia Agricultural Research Institute, Eskişehir	Winter
12	Dağdaş 94	Bahri Dağdaş International Agricultural Research Institute, Konya	Facultative
13	Demir 2000	Central Research Institute of Field Crops, Ankara	Facultative
14	Doğu 88	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
15	ES 26	Anatolian Agricultural Research Institute, Eskişehir	Winter
16	Gerek 79	Anatolia Agricultural Research Institute, Eskişehir	Winter
17	Gün 91	Central Research Institute of Field Crops, Ankara	Winter
18	Harmankaya 99	Anatolian Agricultural Research Institute, Eskişehir	Winter
19	İkizce 96	Central Research Institute of Field Crops, Ankara	Facultative
20	İzgi 2001	Anatolia Agricultural Research Institute, Eskişehir	Winter
21	Karahan 99	Bahri Dağdaş International Agricultural Research Institute, Konya	Winter
22	Kate A-1	Trakya Agricultural Research Institute, Edirne	Winter
23	Kıraç 66	Anatolia Agricultural Research Institute, Eskişehir	Winter
24	Kırgız 95	Anatolia Agricultural Research Institute, Eskişehir	Winter
25	Kırik	Eastern Anatolia Agricultural Research Institute, Erzurum	Facultative
26	Kutluk 94	Anatolia Agricultural Research Institute, Eskişehir..	Winter
27	Lancer	Eastern Anatolia Agricultural Research Institute, Erzurum (introduction, USA)	Winter
28	Mızrak	Central Research Institute of Field Crops, Ankara	Facultative
29	Müfitbey	Anatolia Agricultural Research Institute, Eskişehir	Winter
30	Nacibey	Anatolia Agricultural Research Institute, Eskişehir	Winter
31	Nenehatun	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
32	Palandöken 97	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
33	Pehlivan	Trakya Agricultural Research Institute, Edirne	Winter
34	Prostor	Trakya Agricultural Research Institute, Edirne	Winter
35	Soyer02	Anatolia Agricultural Research Institute, Eskişehir	Winter
36	Sönmez 2001	Anatolia Agricultural Research Institute, Eskişehir	Winter
37	Sultan 95	Anatolia Agricultural Research Institute, Eskişehir	Winter
38	Süzen 97	Anatolia Agricultural Research Institute, Eskişehir	Winter
39	Tosunbey	Central Research Institute of Field Crops, Ankara	Winter
40	Türkmen	Central Research Institute of Field Crops, Ankara	Facultative

Table 1. (Continued).

41	Uzunyayla	Central Research Institute of Field Crops, Ankara	Facultative
42	Yakar 99	Central Research Institute of Field Crops, Ankara	Facultative
43	Zencirci 2002	Central Research Institute of Field Crops, Ankara	Facultative
Local and old genotypes not listed in 2011 national cultivar list			
44	Ak-702	Anatolia Agricultural Research Institute, Eskişehir	Winter
45	Ak Buğday	Local genotype (Central Anatolia Region)	Winter
46	Ankara 093/44	Central Research Institute of Field Crops, Ankara	Winter
47	Conkesme	Local genotype (Eastern Anatolia Region)	Facultative
48	Haymana 79	Central Research Institute of Field Crops, Ankara	Winter
49	Hawk (Şahin)	Eastern Anatolia Agricultural Research Institute, Erzurum (introduction, USA)	Winter
50	Kılçıksız Buğday	Local genotype (Central Anatolia Region)	Winter
51	Kırkpınar 79	Trakya Agricultural Research Institute, Edirne	Facultative
52	Kırmızı Kılçık	Local genotype (Eastern Anatolia Region)	Facultative
53	Kırmızı Yerli	Local genotype (Eastern Anatolia Region)	Facultative
54	Koca Buğday	Local genotype (Central Anatolia Region)	Winter
55	Köse 220/39	Central Research Institute of Field Crops, Ankara	Facultative
56	Özlü Buğday	Local genotype (Central Anatolia Region)	Winter
57	Polatlı Kösesi	Local genotype (Central Anatolia Region)	Facultative
58	Sert Buğday	Local genotype (Central Anatolia Region)	Winter
59	Sürak 1593/51	Central Research Institute of Field Crops, Ankara	Winter
60	Tir	Local genotype (Eastern Anatolia Region)	Winter
61	Yayla 305	Anatolia Agricultural Research Institute, Eskişehir	Winter
62	Zerin	Local genotype (Central Anatolia Region)	Facultative
Control genotypes			
63	Bezostaja 1	Anatolia Agricultural Research Institute, Eskişehir (Introduction, Russia)	Winter
64	Karasu 90	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter

times so that the average water content in the top 60 cm of soil was not less than 50% of field capacity (Figure 1). In the late drought experiment, plots were covered by fixed rain shelter (polyethylene, 0.25 mm thickness, 95% permeability photosynthetic light) starting from the 50% booting stage (Feekes 10.0) to maturity. The shelter was constructed 1.5 m above the soil surface and extended 2.0 m beyond the plots' sides to protect the soil from rain. Weeds were eliminated manually when required. Fungicide was applied at the 50% booting stage and 7 days after anthesis to prevent foliar fungal diseases.

2.2. Agronomical and physiological measurements

In all the plots, spikes per m^2 were determined from a 1-m row sample. Ten spikes were randomly harvested from within plots for kernels per spike determination. At maturity, the plots were trimmed to 5.0 m, and the four inner rows were harvested by a plot combine in irrigated experiments. In late drought experiments, the plots were trimmed to 1.0 m and the two rows were harvested by hand, and the weight of cleaned grain from each plot was recorded. Kernel weight was determined from 4 × 100 kernel samples. Date of anthesis (Feekes 10.51) was recorded as the date when 50% of spikes showed anthers. Canopy temperatures were measured at the canopy surface of each plot with an infrared thermometer (Model AG-42, Telatemp Corp., Fullerton, CA, USA) between 1300 and 1500 hours on fine windless and cloudless days. Three measurements per plot were taken at 1.0 m from the edge of the plot and approximately 50 cm above the canopy with an angle of 30° from the horizontal. Air temperatures were simultaneously measured using a digital thermometer (temperature-humidity, TFA Dostmann, Wertheim, Germany). Canopy temperature difference was calculated as CTD = $T_a - T_c$, where T_a and T_c are the mean values of air temperature readings and canopy temperatures, respectively (Xiao et al., 2012). Ten flag leaves per plot

Table 2. Growing conditions and agronomic details in the field experiments under irrigated and late drought conditions during 2011–12 and 2012–13 crop seasons in Erzurum, Turkey.

	2011–12		2012–13	
	Irrigated	Late drought	Irrigated	Late drought
Soil characteristics				
Texture	Clay-loam	Clay-loam	Clay-loam	Clay-loam
pH	7.6	7.8	7.5	7.8
Organic matter (%)	1.86	1.66	1.69	1.71
Total N (g kg^{-1})	0.85	0.73	0.82	0.93
Available P (mg kg^{-1})	11.89	11.83	14.09	11.47
Available K (mg kg^{-1})	791.8	754.7	679.3	703.9
Volumetric soil water content (%)				
Field capacity	47.2		45.4	
50% field capacity	33.2		31.7	
Permanent wilting capacity	19.2		18.0	
Precipitation (mm)				
Total (1 September–31 August)	250.5		311.1	
1 September–30 November	44.2		86.9	
1 December–30 April	83.7		153.8	
1 May–31 August	122.6		70.4	
Previous crop season (fallow)	513.3		250.5	
Mean air temperature (°C)				
Annual	3.9		6.4	
1 September–30 November	5.0		9.4	
1 December–30 April	–8.2		–3.3	
May	11.4		11.6	
June	15.7		15.0	
July	19.0		19.4	
August	20.0		19.5	
Maximum temperature	32.7		31.7	
Minimum temperature	–35.0		–31.5	
Sowing date	21 September 2011		24 September 2012	
Anthesis date (the earliest–latest genotype)	14–23 June 2012	14–22 June 2012	10–17 June 2013	10–16 June 2013
Date of when 50% of the genotypes showed anthers	18 June 2012		14 June 2013	
Physiological maturity date	24 July–7 Aug 2012	18–26 July 2012	13–21 July 2013	4–13 July 2013
Rain-out sheet covering date	-	29 May 2012	-	24 May 2013
Prevented rainfall in covered plots (mm)	-	49.6	-	42.1
Amount and timing of irrigation				
Sowing (mm)	30	30	30	30
Anthesis + grain filling 1 + 2 (mm)	50+50+50	-	50+50+50	-
Range of plant height (cm)	63.3–116.0	69.8–117.6	58.0–112.7	56.3–112.6
Average of plant height (cm)	98.2	94.7	97.0	89.8
Range of spikes per m^2	408.3–1213.5	477.5–950.0	442.0–1176.2	335.0–810.0
Average of spikes per m^2	781.4	695.4	755.7	531.7
Range of kernel per spike	21.4–46.1	21.0–42.8	16.9–45.9	16.3–40.5
Average of kernel per spike	33.1	30.9	28.0	24.2
Range of thousand kernel weight (g)	38.0–53.6	29.6–47.0	27.9–44.3	24.4–38.7
Average of thousand kernel weight (g)	44.7	38.4	37.7	31.5

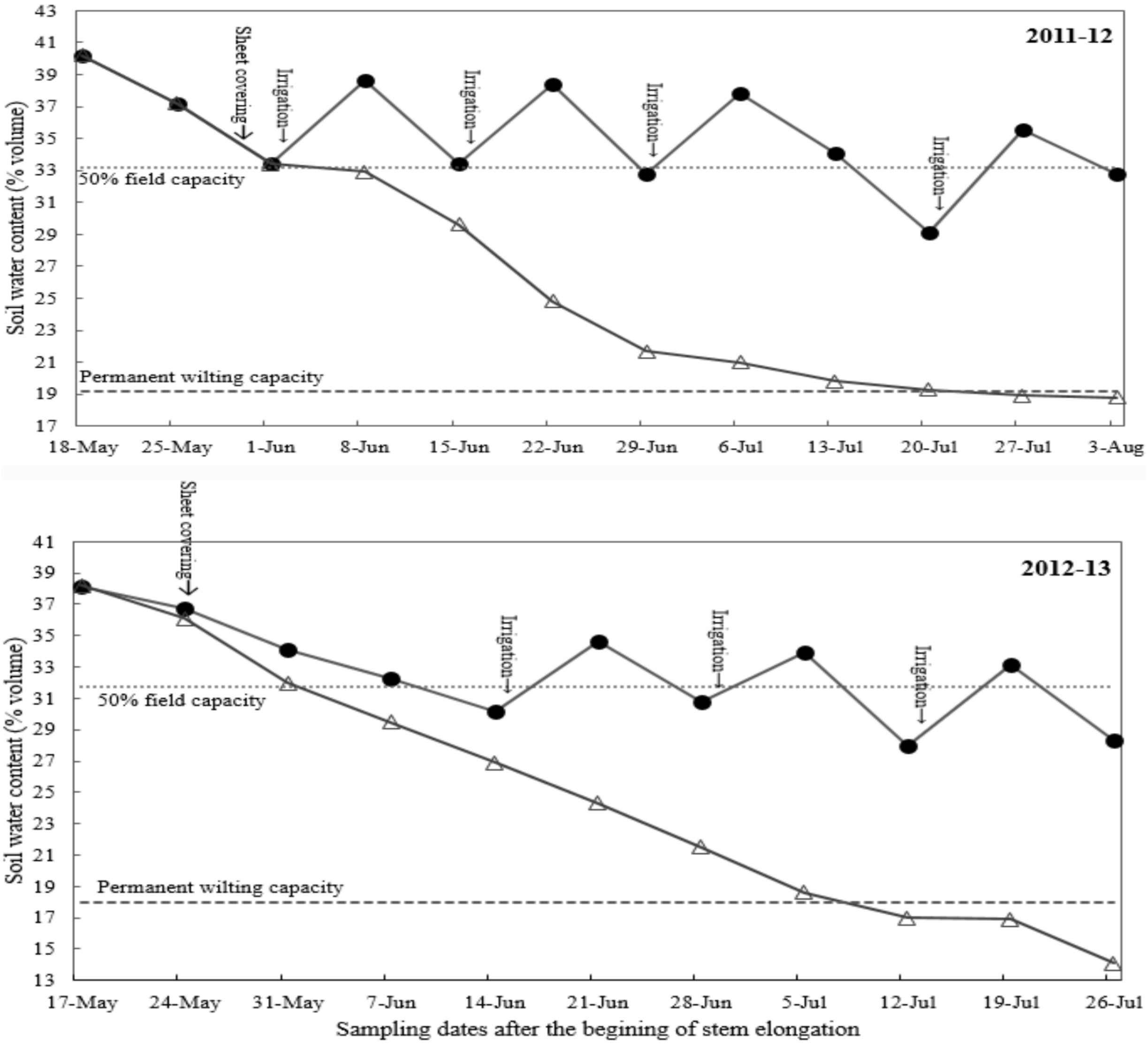

Figure 1. Weekly soil water content in irrigated (=) and late drought (Δ) treatments from the beginning of stem elongation to maturity of the wheat genotypes in 2011–12 and 2012–13 crop seasons.

were randomly sampled and leaf area was measured by an area meter (LI-3000C model, LI-COR, Lincoln, NE, USA), and green leaf area was measured with a green area meter (model CI-202, CID Inc., Camas, WA, USA). The leaf senescence rate (%) was calculated as LSR = 100 – [(GLA/LA) × 100], where GLA and LA are the total green area and total area of the 10 flag leaf laminae samples, respectively (Verma et al., 2004). Mean chlorophyll of 10 flag leaves (laminae) was determined in situ for each plot by a chlorophyll meter (model SPAD 502, Minolta, Tokyo, Japan) between 0900 and 1100 hours. Three readings were taken along the middle section of the leaf, the mean was used for analysis, and values were expressed as SPAD units (Guo et al., 2008). Chlorophyll fluorescence parameters, including initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and maximum quantum efficiency of PSII (Fv/Fm), were measured with a portable chlorophyll fluorescence system (Handy Pea, Hansatech Instruments, King's Lynn, UK) between 1100 and 1300 hours. The dark adaptation period for all the measurements was 25–30 min, the 10 flag leaves (laminae) for each plot were randomly selected, three measurements were made along the leaf, and the mean was used for analysis (Guo et al., 2008). Physiological parameters were measured on the same day in irrigated and late drought conditions at anthesis (A) (when 50% of the genotypes showed anthers in irrigated and late drought conditions), on 15 days post anthesis (15DPA), and on 25DPA. Ash content was determined at maturity in flag leaf laminae and grain. A set of 20 leaves were randomly sampled and 10 g of grain sample was collected from each plot. All the samples were oven-dried at 80 °C for 48 h and ground. Approximately 1.5 g of dry mass was incinerated at 575 °C for 16 h (until light gray ash was obtained). Ash content (%) was expressed on a dry mass basis (AACC, 1995).

2.3. Statistical analysis

Analyses of variance (ANOVA) were carried out separately for irrigated and late drought experiments using the mixed model procedure. After confirming homogeneity of variances (Levene's test; $P > 0.05$), a combined analysis of variance across years was conducted to test the significances of genotypes and genotype × year interactions. Replications, blocks within replications, and years were regarded as random effects, while genotypes were regarded as fixed effect, and adjusted means were calculated. Differences among the means of genotypes were compared by the least significant differences (LSD) test at the 0.01 probability level. Pearson correlation coefficients were calculated on the 2-year means ($n = 64$) to determine the relationships among the traits. The ranking method (Kang, 1988) was used to determine the drought sensitivity of the genotypes according to a total of 25 traits [24 traits measured in late drought conditions in Table 3 and grain yield reduction percentage (GYRP) compared with irrigated conditions]. The genotype with the highest grain yield, CTD, SPAD, Fo Fm, Fv, Fv/Fm, and leaf ash and the lowest LSR, grain ash, and GYRP was given a rank of 1 and that with the lowest grain yield, CTD, SPAD, Fo, Fm, Fv, Fv/Fm, and leaf ash and the highest LSR, grain ash, and GYRP was assigned a rank of 64. All the genotypes were ranked in this manner and the mean rank (R) of the 25 traits and standard deviation of ranks (SDR) were determined. Rank-sum values were calculated as $RS = R + SDR$ for each genotype. The genotypes were finally ranked based on RS values, such that those with the lowest and highest RS values were ranked respectively as the most and least resistant genotypes. Stepwise regression analysis was carried out to determine the most important selection criteria measured in the late drought conditions that significantly contributed to RS (drought sensitivity) variability. Principle component analysis (PCA) was used to study the interrelationship among the traits measured in late drought conditions. All statistical analysis was carried out using the IBM SPSS Statistics 20.0 (IBM Corporation, Armonk, NY, USA).

3. Results

3.1. Effects of growing conditions on grain yield and physiological traits

The crop seasons were characterized by low total rainfall. The experimental area received more rainfall during the fallow year and soil water content was higher in the 2011–12 than in the 2012–13 crop season. Strong terminal drought stress occurred during the grain filling stage in the late drought conditions and soil water content decreased gradually from 40.2% to 18.9% in 2011–12 and 38.2% to 14.1% in 2012–13 as drought stress increased (Figure 1).

The analysis of variance showed that most of the traits were significantly influenced by year (except $SPAD_A$ in the irrigated experiment and Fo_{15DPA} in late drought) (Table 3). In 2011–12, high soil water content increased spike number per m^2, kernel number per spike, kernel weight (data not shown), grain yield, SPAD, Fm, Fv, Fv/Fm, and leaf ash content, but decreased CTD, LSR, and grain ash content (Tables 4–10). Genotype × year interaction effects were significant for all studied traits. The late drought treatment decreased grain yield by 36.2%; CTD_A, CTD_{15DPA}, and CTD_{25DPA} values by 23.3%, 36.9%, and 30.9%; $SPAD_A$, $SPAD_{15DPA}$, and $SPAD_{25DPA}$ values by 9.4%, 15.8%, and 59.9%; Fm_A, Fm_{15DPA}, and Fm_{25DPA} values by 3.7%, 6.0%, and 40.2%; Fv_A, Fv_{15DPA}, and Fv_{25DPA} values by 5.5%, 8.9%, and 48.7%; Fv/Fm_A, Fv/Fm_{15DPA}, and Fv/Fm_{25DPA} values by 2.0%, 3.3%, and 29.9%; and leaf ash content by 20.2%, respectively, compared with irrigated conditions. When compared with the irrigated experiment, the late drought increased LSR_A, LSR_{15DPA}, and LSR_{25DPA} by 99.2%, 78.5%, and 115.0% and grain ash content by 13.4%, respectively.

3.2. Genotype effect on grain yield and physiological traits

The differences among the bread wheat genotypes were highly significant for all the studied traits under irrigated and late drought conditions (Table 3). Grain yield for 64 wheat genotypes ranged from 4763 to 9360 kg ha^{-1} in the irrigated experiment and from 2161 to 5282 kg ha^{-1} in late drought. Under irrigated conditions, the maximum grain yield was obtained from Kate A-1, followed by Palandöken 97, while the minimum was in Prostor. In the late drought experiment, genotypes Dağdaş 94 and Müfitbey had the highest grain yield, while Kırmızı Yerli had the lowest (Table 4). Grain yield decreased under late drought conditions in all the genotypes. The percentage reduction in grain yield under late drought stress was highest in Kate A-1 (68.5%), followed by Palandöken 97 (56.2%), and lowest was in Hawk (6.4%), followed by Dağdaş 94 (12.9%). Under late drought conditions, CTD varied from 7.28 (Yakar 99) to 10.75 °C (Demir 2000) at anthesis, from 4.08 (Prostor) to 7.63 °C (Ankara 093/44) at 15DPA, and from 1.86 (Prostor) to 6.11 °C (Kıraç 66) at 25DPA (Table 4). As the average of genotypes, CTD was higher at the anthesis stage than at 15DPA and 25DPA under irrigated and late drought conditions. In the late drought experiment LSR ranged from 0.89% (Kıraç 66) to 9.84% (Alparslan) at the anthesis stage, from 15.87% (ES 26) to

Table 3. Combined analysis of variance for grain yield and physiological traits of 64 bread wheat genotypes grown under irrigated and late drought conditions in 2011–12 and 2012–13 crop seasons.

Traits[1]	Irrigated conditions				Late drought conditions			
	Genotype effect (P)	Year effect (P)	Genotype × year effect (P)	CV (%)	Genotype effect (P)	Year effect (P)	Genotype × year effect (P)	CV (%)
Grain yield	0.000	0.002	0.000	11.70	0.000	0.000	0.001	14.44
CTD$_{A}$	0.000	0.000	0.000	4.75	0.000	0.000	0.000	6.45
CTD$_{15DPA}$	0.000	0.000	0.000	5.55	0.000	0.000	0.000	6.51
CTD$_{25DPA}$	0.000	0.000	0.000	9.77	0.000	0.000	0.000	11.35
LSR$_{A}$	0.000	0.000	0.000	22.86	0.000	0.000	0.000	20.33
LSR$_{15DPA}$	0.000	0.000	0.000	16.99	0.000	0.000	0.000	14.77
LSR$_{25DPA}$	0.000	0.000	0.000	6.74	0.000	0.000	0.000	3.80
SPAD$_{A}$	0.000	0.230	0.000	3.94	0.000	0.000	0.000	4.99
SPAD$_{15DPA}$	0.000	0.000	0.000	4.40	0.000	0.000	0.000	8.38
SPAD$_{25DPA}$	0.000	0.000	0.000	10.37	0.000	0.000	0.000	26.85
Fo$_{A}$	0.000	0.000	0.000	2.35	0.000	0.000	0.000	2.88
Fo$_{15DPA}$	0.000	0.000	0.000	2.58	0.000	0.362	0.000	3.80
Fo$_{25DPA}$	0.002	0.000	0.000	5.02	0.000	0.000	0.000	5.67
Fm$_{A}$	0.002	0.000	0.015	6.67	0.001	0.000	0.000	5.89
Fm$_{15DPA}$	0.029	0.000	0.018	10.13	0.002	0.000	0.000	9.20
Fm$_{25DPA}$	0.000	0.000	0.000	8.79	0.000	0.000	0.000	7.97
Fv$_{A}$	0.002	0.000	0.013	8.06	0.001	0.000	0.000	7.11
Fv$_{15DPA}$	0.024	0.000	0.021	13.00	0.001	0.000	0.000	11.74
Fv$_{25DPA}$	0.000	0.000	0.000	12.21	0.000	0.000	0.000	10.97
Fv/Fm$_{A}$	0.000	0.000	0.000	0.97	0.000	0.000	0.000	1.22
Fv/Fm$_{15DPA}$	0.001	0.000	0.003	2.11	0.000	0.000	0.000	1.98
Fv/Fm$_{25DPA}$	0.000	0.000	0.000	1.91	0.000	0.000	0.000	6.43
Leaf ash	0.000	0.000	0.000	5.09	0.000	0.000	0.000	5.65
Grain ash	0.000	0.000	0.000	5.11	0.000	0.000	0.000	4.11

[1] CTD$_{A}$, CTD$_{15DPA}$, and CTD$_{25DPA}$, canopy temperature difference at anthesis and 15 and 25 days post anthesis; SPAD$_{A}$, SPAD$_{15DPA}$, and SPAD$_{25DPA}$, SPAD chlorophyll value at anthesis and 15 and 25 days post anthesis; LSR$_{A}$, LSR$_{15DPA}$, and LSR$_{25DPA}$, leaf senescence rate at anthesis and 15 and 25 days post anthesis; Fo$_{A}$, Fo$_{15DPA}$, and Fo$_{25DPA}$, initial fluorescence at anthesis and 15 and 25 days post anthesis; Fm$_{A}$, Fm$_{15DPA}$, and Fm$_{25DPA}$, maximum fluorescence at anthesis and 15 and 25 days post anthesis; Fv$_{A}$, Fv$_{15DPA}$, and Fv$_{25DPA}$, variable fluorescence at anthesis and 15 and 25 days post anthesis; Fv/Fm$_{A}$, Fv/Fm$_{15DPA}$, and Fv/Fm$_{25DPA}$, maximum quantum efficiency of PSII at anthesis and 15 and 25 days post anthesis.

42.46% (Hawk) at 15DPA, and from 76.40% (Kırgız 95) to 97.96% (Aldane) at 25DPA (Table 5).

The maximum SPAD value at anthesis, 15DPA, and 25DPA was 55.7 (Harmankaya 99), 52.8 (Nacibey), and 27.4 (Kırgız 95) in late drought (Table 6). There was marked decrease in chlorophyll content at 25DPA in each experiment. Under late drought conditions, the percentage decrease in SPAD value was the lowest in Kırik (27.4%) and highest in Özlü Buğday (90.5%) at 25DPA as compared to the irrigated conditions. Fo values of genotypes at anthesis, 15DPA, and 25DPA changed between 260.3 and 308.1, 291.2 and 327.6, and 307.3 and 368.3 in the irrigated experiment and between 286.0 and 320.2, 302.5 and 349.2, and 163.5 and 423.7 in the late drought experiment, respectively (data not shown). In both experiments, Fm, Fv, and Fv/Fm values gradually decreased at the grain filling stage, especially at 25DPA under late drought conditions (Tables 7–9). Under late drought conditions, the highest Fm and Fv values were obtained from İkizce, Kate A-1, and Uzunyayla at anthesis, 15DPA, and 25DPA,

Table 4. Grain yield and canopy temperature difference (CTD) at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions

No.	Genotype	Grain yield (kg ha^{-1})		CTD$_A$ (°C)		CTD$_{15DPA}$ (°C)		CTD$_{25DPA}$ (°C)	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	6497	4335	10.23	8.14	8.26	5.79	3.86	3.13
2	Aldane	4863	3509	11.09	7.91	8.02	6.77	4.45	3.39
3	Alparslan	6664	4765	11.95	8.71	8.61	6.05	5.66	4.20
4	Altay 2000	5966	4692	11.86	9.32	8.68	6.49	5.42	2.80
5	Atlı 2002	5837	4750	12.06	9.72	9.76	6.37	6.23	3.44
6	Aytın 98	5940	3917	11.34	8.86	9.15	7.10	5.64	4.11
7	Bağcı 2002	5998	4138	11.61	7.61	9.04	5.41	6.45	4.56
8	Bayraktar 2000	6579	4320	11.81	7.96	9.14	6.80	6.06	5.23
9	Bolal 2973	6616	4619	9.67	7.30	7.92	5.24	3.94	3.45
10	Bereket	6793	4758	12.16	8.94	8.98	6.85	6.28	4.09
11	Çetinel 2000	7291	4202	11.64	8.96	9.23	5.76	5.73	3.16
12	Dağdaş 94	6066	5282	11.92	10.22	9.27	6.44	6.50	4.50
13	Demir 2000	7107	4351	12.25	10.75	10.25	6.19	6.94	4.14
14	Doğu 88	6585	4078	12.03	9.64	8.32	5.05	5.72	3.06
15	ES 26	5769	4435	11.30	8.89	9.15	5.24	6.16	5.77
16	Gerek 79	6594	4521	12.00	9.36	9.54	6.26	6.27	4.94
17	Gün 91	7225	4220	10.81	9.07	9.44	7.16	5.38	4.55
18	Harmankaya 99	7578	3806	11.92	8.33	8.47	6.40	5.59	3.81
19	İkizce 96	7330	3787	11.78	9.25	9.69	6.18	6.30	4.88
20	İzgi 2001	6368	3288	12.56	9.99	9.70	6.49	6.44	5.34
21	Karahan 99	6989	3672	12.27	10.02	10.37	6.87	7.13	4.36
22	Kate A-1	9360	2952	11.80	9.03	10.12	5.98	6.03	4.53
23	Kıraç 66	5494	3817	11.44	8.53	9.07	5.91	6.72	6.11
24	Kırgız 95	7746	4411	12.14	9.00	9.86	6.80	6.45	5.53
25	Kırik	5951	3098	10.03	8.99	8.71	5.24	3.19	3.08
26	Kutluk 94	7316	3966	11.52	9.38	9.72	6.73	7.16	4.84
27	Lancer	6243	3918	11.75	10.18	8.81	5.51	5.73	2.78
28	Mızrak	5756	3745	10.66	9.66	8.52	5.82	6.25	3.88
29	Müfitbey	6043	4863	12.36	9.82	10.70	6.32	7.19	4.39
30	Nacibey	6316	3079	11.77	9.21	9.41	5.55	6.22	3.81
31	Nenehatun	5816	3664	11.28	9.08	9.24	5.12	6.53	4.77
32	Palandöken 97	7950	3482	11.11	8.93	9.52	6.01	6.52	6.06
33	Pehlivan	5655	4604	10.44	8.78	8.61	5.35	3.55	3.72
34	Prostor	4763	3798	10.80	8.66	9.34	4.08	5.52	1.86
35	Soyer02	6398	3248	11.66	9.60	10.39	5.87	6.34	3.80
36	Sönmez 2001	5594	3873	11.56	9.96	9.49	5.80	5.86	4.77
37	Sultan 95	5337	3451	11.27	9.61	10.34	6.43	6.67	4.16
38	Süzen 97	5603	4155	12.17	9.12	10.77	6.54	6.70	4.33
39	Tosunbey	5695	4509	11.56	9.00	9.17	5.23	6.27	4.78
40	Türkmen	5685	4594	11.77	9.22	10.09	6.99	6.13	5.70

Table 4. (Continued).

41	Uzunyayla	6245	4186	10.78	8.64	8.85	6.69	5.05	4.77
42	Yakar 99	6697	3724	10.39	7.28	10.13	5.30	5.64	3.78
43	Zencirci 2002	6389	4101	11.00	8.83	10.24	6.58	6.47	5.22
44	Ak-702	5467	2922	11.16	9.81	9.98	5.15	6.86	3.81
45	Ak Buğday	5474	3529	11.86	8.97	9.28	6.15	6.55	3.70
46	Ankara 093/44	5763	2569	11.14	7.86	10.5	7.63	6.70	5.50
47	Conkesme	5016	3551	11.91	7.49	7.43	4.44	4.89	3.83
48	Haymana 79	7285	4026	11.23	8.08	10.19	6.58	7.13	5.25
49	Hawk (Şahin)	5128	4801	11.14	8.94	9.06	5.88	6.36	4.95
50	Kılçıksız Buğday	6573	3721	12.63	8.83	10.07	5.74	6.08	4.09
51	Kırkpınar 79	6049	3781	11.73	8.75	10.81	5.65	7.16	4.03
52	Kırmızı Kılçık	5235	4541	11.52	9.86	9.57	7.08	6.80	4.63
53	Kırmızı Yerli	4939	2161	12.59	9.77	10.16	4.96	6.61	3.27
54	Koca Buğday	5358	4294	12.13	8.41	11.12	6.44	6.27	4.81
55	Köse 220/39	5646	4361	12.39	8.16	9.48	5.03	5.45	3.14
56	Özlü Buğday	6487	4469	11.84	8.50	10.21	6.65	5.56	4.69
57	Polatlı Kösesi	5243	3807	12.42	8.21	8.28	5.71	4.91	2.50
58	Sert Buğday	7120	4028	12.53	7.97	9.14	5.19	5.50	2.27
59	Sürak 1593/51	5992	3603	12.02	9.14	9.78	5.23	5.08	3.33
60	Tir	5687	3355	11.80	10.00	9.19	4.79	4.59	3.17
61	Yayla 305	5395	4417	12.88	8.66	10.04	6.29	5.41	3.44
62	Zerin	5885	3519	12.66	8.18	9.54	5.77	6.19	4.48
63	Bezostaja 1	6394	3697	11.80	8.30	9.33	5.58	6.00	2.94
64	Karasu 90	6494	3794	12.38	8.52	10.81	5.98	6.86	1.98
Mean		6209	3963	11.64	8.93	9.47	5.98	5.96	4.12
LSD$_{0.01}$		1350	1063	1.03	1.05	0.98	0.72	1.08	0.87
2011–12		6352	4112	9.96	6.98	6.14	3.91	4.89	3.33
2012–13		6065	3814	13.32	10.89	12.80	8.05	7.02	4.90

while the highest Fv/Fm values were recorded for Dağdaş 94, Doğu 88, and Uzunyayla, respectively. Leaf ash content ranged from 14.60% (Lancer) to 22.47% (Gün 91) in the irrigated experiment and from 11.70% (Lancer) to 20.00% (Pehlivan) in late drought. In the irrigated and late drought experiments, grain ash content changed between 1.231%–1.812% and 1.440%–2.034%, respectively (Table 10). Under late drought, the lowest grain ash content was obtained from Dağdaş 94, followed by Türkmen, while it was the highest in Kate A-1.

3.3. Relationships between physiological traits, grain yield, and drought sensitivity

In both experiments, CTD$_A$ was positively correlated with 1000-kernel weight (Table 11). Under late drought conditions, LSR$_A$ was negatively associated with 1000-kernel weight and positively associated with grain yield. CTD and LSR values at 15DPA and 25DPA did not correlate with grain yield. Spike number per m^2 was negatively correlated with both SPAD$_A$ and SPAD$_{15DPA}$, while kernel number per spike was positively correlated. Fo values were not associated with grain yield and yield components under late drought conditions. Grain yield was significantly and positively associated with Fm$_{15DPA}$, Fv$_{15DPA}$, Fv$_{25DPA}$, and Fv/Fm$_{15DPA}$ in the late drought experiment. A negative correlation was found between grain ash content and grain yield in both experiments. Under late drought stress, the RS value was significantly and negatively associated with CTD, SPAD, Fm, Fv, Fv/Fm, and grain yield ($r = -0.378^{**}$) and positively correlated with LSR, but RS showed insignificant correlations with leaf ash and grain ash (Table 11).

In both experiments, days to anthesis was positively associated with plant height, SPAD$_{25DPA}$, Fm$_{25DPA}$, Fv$_{25DPA}$, and Fv/Fm$_{25DPA}$ and negatively correlated with kernels per

Table 5. Leaf senescence rate (LSR) at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions.

No.	Genotype	LSR_A		LSR_{15DPA}		LSR_{25DPA}	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	5.02	6.07	11.91	29.93	57.24	92.26
2	Aldane	2.98	3.73	15.09	29.64	50.48	97.96
3	Alparslan	2.36	9.84	12.39	23.19	33.97	83.11
4	Altay 2000	3.61	3.71	9.85	16.71	40.86	82.64
5	Atlı 2002	4.07	5.03	15.91	28.02	32.01	80.10
6	Aytın 98	1.52	3.17	17.54	30.04	44.81	81.71
7	Bağcı 2002	2.12	3.67	16.32	25.43	41.09	83.56
8	Bayraktar 2000	0.94	6.46	11.54	17.41	42.43	91.10
9	Bolal 2973	0.96	2.14	11.08	23.43	40.06	92.09
10	Bereket	2.19	7.45	16.70	24.28	43.08	87.91
11	Çetinel 2000	2.08	4.29	14.01	19.32	39.96	83.84
12	Dağdaş 94	2.95	4.97	15.39	25.77	41.04	88.25
13	Demir 2000	0.61	6.70	9.35	19.17	36.91	86.97
14	Doğu 88	1.14	4.20	14.94	20.17	36.84	82.95
15	ES 26	1.09	4.57	11.11	15.87	40.20	85.00
16	Gerek 79	1.55	2.58	12.66	19.47	40.36	78.65
17	Gün 91	0.93	1.60	11.55	18.85	39.34	88.67
18	Harmankaya 99	0.69	1.97	17.02	26.72	40.77	90.44
19	İkizce 96	1.02	1.01	14.87	23.08	41.26	91.11
20	İzgi 2001	0.92	0.91	14.48	19.31	39.75	86.55
21	Karahan 99	1.68	2.40	13.35	21.50	34.97	82.65
22	Kate A-1	1.22	1.90	12.44	18.99	34.54	78.14
23	Kıraç 66	0.31	0.89	12.01	21.49	37.75	79.58
24	Kırgız 95	1.46	2.84	12.77	22.10	38.34	76.40
25	Kırik	0.48	0.89	11.47	18.76	36.56	83.41
26	Kutluk 94	1.10	1.23	12.98	22.84	38.25	87.99
27	Lancer	1.04	1.71	12.48	20.01	38.86	86.32
28	Mızrak	1.05	1.95	14.62	23.24	36.64	82.65
29	Müfitbey	1.10	1.08	9.47	19.81	35.89	78.04
30	Nacibey	0.65	1.31	11.69	20.32	38.84	85.76
31	Nenehatun	1.00	1.54	13.23	21.35	40.22	86.53
32	Palandöken 97	0.53	1.09	14.12	20.71	40.51	87.12
33	Pehlivan	0.89	1.45	15.67	24.78	45.58	92.79
34	Prostor	1.87	2.91	20.65	40.75	56.91	94.52
35	Soyer02	0.91	2.32	18.07	31.16	42.91	88.27
36	Sönmez 2001	0.94	1.24	14.82	27.02	46.25	86.30
37	Sultan 95	1.18	1.84	12.75	23.55	35.71	85.28
38	Süzen 97	0.87	1.19	17.74	23.78	42.19	88.84
39	Tosunbey	0.82	2.62	17.31	37.16	47.48	87.64

Table 5. (Continued).

40	Türkmen	1.04	3.59	18.37	33.96	43.90	88.00
41	Uzunyayla	0.73	1.33	17.98	28.07	37.52	81.98
42	Yakar 99	1.03	1.35	10.45	29.82	38.27	92.56
43	Zencirci 2002	0.87	1.52	14.96	31.41	43.63	88.55
44	Ak-702	1.28	1.62	10.99	27.89	41.07	84.35
45	Ak Buğday	1.05	1.61	18.89	27.44	39.81	87.78
46	Ankara 093/44	0.80	1.27	15.92	22.27	39.54	86.40
47	Conkesme	0.73	1.17	18.61	28.77	38.69	83.05
48	Haymana 79	0.93	2.58	12.63	23.47	36.01	86.10
49	Hawk (Şahin)	1.12	3.56	14.93	42.46	38.93	84.07
50	Kılçıksız Buğday	0.93	1.40	14.00	35.05	45.67	95.77
51	Kırkpınar 79	1.36	1.78	17.40	26.72	43.91	88.73
52	Kırmızı Kılçık	1.15	1.60	13.43	27.38	35.11	85.16
53	Kırmızı Yerli	1.24	1.83	12.18	24.19	36.01	85.39
54	Koca Buğday	0.72	1.92	14.61	23.97	37.42	86.79
55	Köse 220/39	0.82	2.43	13.84	32.05	37.30	85.69
56	Özlü Buğday	1.16	1.47	15.59	29.70	45.60	88.60
57	Polatlı Kösesi	1.73	3.05	14.40	31.72	43.25	81.37
58	Sert Buğday	0.92	2.14	13.82	28.58	38.05	86.83
59	Sürak 1593/51	0.88	2.17	16.36	26.22	38.45	89.96
60	Tir	1.26	2.67	15.01	21.45	34.40	80.94
61	Yayla 305	0.69	2.30	18.07	24.10	37.69	90.37
62	Zerin	0.82	1.35	16.19	22.82	38.64	84.53
63	Bezostaja 1	0.78	1.04	15.69	35.65	39.41	87.45
64	Karasu 90	0.85	1.50	11.99	37.95	32.69	94.56
Mean		1.29	2.57	14.34	25.60	40.18	86.38
$LSD_{0.01}$		0.548	0.971	4.527	6.88	5.04	6.10
2011–12		0.53	0.79	10.18	19.13	34.48	80.47
2012–13		2.00	4.35	18.50	32.05	45.89	92.28

spike, LSR_{25DPA}, and leaf ash content (tables not given). Plant height was negatively correlated with kernels per spike, LSR_{25DPA}, and leaf ash content and positively correlated with $SPAD_{25DPA}$. Days to anthesis and plant height did not correlate with grain yield and GYRP. CTD_{15DPA} was positively correlated with Fm_{15DPA} (r = 0.293*) and Fv_{15DPA} (r = 0.288*) under late drought conditions and negatively correlated with grain ash content in irrigated (r = –0.257) and late drought (r = –0.313*) conditions. LSR_{25DPA} showed negative correlation with $SPAD_{25DPA}$, Fm_{25DPA}, Fv_{25DPA}, and Fv/Fm_{25DPA} traits, with coefficients of r = –0.437***, –0.550***, –0.536 and –0.522*** for irrigated and –0.659***, –0.436***, –0.494***, and –0.439*** for late drought conditions, respectively. $SPAD_{25DPA}$ was significantly associated with Fm_{25DPA}, Fv_{25DPA}, and Fv/Fm_{25DPA} traits (r = 0.550***, 0.536***, 0.522*** in irrigated and 0.553***, 0.588***, 0.522*** in late drought conditions, respectively). Highly significant and positive correlations between Fm, Fv, and Fv/Fm were found in each experiment. Fv/Fm_{15DPA} was significantly and negatively correlated with grain ash content (r = –0.345**) in the late drought experiment, but not in the irrigated (r = –0.096). For better understanding of the relationships among the traits measured in late drought conditions, PCA was performed based on the rank correlation matrix (tables not given; Figure 2). PCA revealed that the first eight components with eigenvalues greater than 1 accounted for 81.00% of the total variation. The first component (PC1), explaining 17.27% of the total variation, was positively associated with Fm_{25DPA}, Fv_{25DPA}, Fv/Fm_{25DPA}, Fo_{25DPA}, and $SPAD_{25DPA}$ and negatively

Table 6. SPAD chlorophyll value at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions.

No.	Genotype	SPAD$_{A}$		SPAD$_{15DPA}$		SPAD$_{25DPA}$	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	46.1	45.8	45.4	45.8	25.7	12.6
2	Aldane	49.0	50.0	49.3	46.1	29.5	4.1
3	Alparslan	49.4	42.4	44.5	43.2	20.5	11.1
4	Altay 2000	54.1	49.1	51.4	47.7	34.1	18.2
5	Atlı 2002	48.9	42.0	47.9	40.8	37.1	19.1
6	Aytın 98	48.5	42.3	47.1	37.0	26.7	18.7
7	Bağcı 2002	44.9	42.4	45.2	39.3	32.0	15.0
8	Bayraktar 2000	47.2	41.0	43.2	37.6	33.2	13.4
9	Bolal 2973	56.0	49.7	54.1	45.5	28.8	7.1
10	Bereket	44.5	42.7	47.3	36.6	32.9	7.4
11	Çetinel 2000	48.3	50.2	50.8	47.7	43.7	14.5
12	Dağdaş 94	50.8	49.1	52.4	43.2	46.4	16.6
13	Demir 2000	52.3	48.1	51.4	40.9	44.7	13.9
14	Doğu 88	43.8	42.6	43.6	40.2	33.3	17.7
15	ES 26	45.1	41.6	44.3	37.3	33.0	12.4
16	Gerek 79	48.3	38.8	47.8	36.7	37.7	14.0
17	Gün 91	48.3	43.2	52.8	44.4	49.1	20.5
18	Harmankaya 99	57.6	55.7	51.9	50.4	39.1	9.7
19	İkizce 96	45.8	47.0	52.1	42.5	40.8	12.5
20	İzgi 2001	47.9	43.9	49.6	41.1	40.4	14.9
21	Karahan 99	55.0	45.8	56.4	43.3	47.1	13.0
22	Kate A-1	54.0	47.8	51.0	45.1	29.9	15.9
23	Kıraç 66	48.6	45.3	48.9	37.8	39.8	15.3
24	Kırgız 95	50.2	45.1	50.7	44.8	40.6	27.4
25	Kırik	49.2	45.7	50.2	40.1	32.5	23.6
26	Kutluk 94	49.8	42.5	47.3	37.6	48.7	15.3
27	Lancer	44.2	39.6	45.9	40.4	34.5	17.5
28	Mızrak	47.6	42.5	45.9	37.5	34.7	21.6
29	Müfitbey	49.4	48.1	55.1	48.5	45.5	22.2
30	Nacibey	53.9	52.2	56.4	52.8	38.7	18.6
31	Nenehatun	46.4	46.1	44.2	46.5	38.1	13.5
32	Palandöken 97	48.5	41.5	47.8	43.6	39.0	13.9
33	Pehlivan	48.0	45.9	51.3	46.0	26.8	15.3
34	Prostor	52.6	48.8	51.3	41.9	24.5	4.3
35	Soyer02	47.1	45.2	48.0	34.2	33.7	17.7
36	Sönmez 2001	53.3	45.5	50.5	41.4	37.9	20.8
37	Sultan 95	49.9	41.1	51.1	37.2	44.8	14.3
38	Süzen 97	53.1	45.7	56.7	40.9	39.4	12.5
39	Tosunbey	44.2	43.5	41.9	37.3	24.3	9.2l

Table 6. (Continued).

40	Türkmen	47.8	40.1	48.8	40.8	28.7	12.6
41	Uzunyayla	47.9	45.7	50.9	44.7	46.7	24.8
42	Yakar 99	50.0	50.2	53.1	44.3	38.2	8.4
43	Zencirci 2002	45.0	40.8	46.5	40.4	39.6	6.7
44	Ak-702	46.5	42.2	49.0	38.0	40.6	12.5
45	Ak Buğday	48.4	46.4	48.9	40.6	33.9	17.7
46	Ankara 093/44	46.1	40.3	45.0	41.7	29.0	17.4
47	Conkesme	42.6	43.2	43.6	39.7	33.0	20.1
48	Haymana 79	46.7	39.9	46.8	38.4	37.6	10.1
49	Hawk (Şahin)	47.1	38.0	42.2	35.2	36.7	23.3
50	Kılçıksız Buğday	49.9	46.9	50.5	39.8	34.0	4.8
51	Kırkpınar 79	49.4	46.7	47.4	43.8	39.9	17.1
52	Kırmızı Kılçık	47.4	39.6	45.6	36.6	39.7	17.8
53	Kırmızı Yerli	49.0	42.6	51.1	36.1	44.4	14.6
54	Koca Buğday	48.0	47.5	47.0	46.1	35.9	16.4
55	Köse 220/39	45.7	42.4	48.4	37.0	36.1	17.9
56	Özlü Buğday	49.2	40.9	48.7	35.9	31.7	3.0
57	Polatlı Kösesi	49.0	37.1	47.4	37.5	34.6	21.5
58	Sert Buğday	52.2	42.5	51.6	40.1	44.7	15.7
59	Sürak 1593/51	49.9	46.9	49.4	42.5	35.1	10.6
60	Tir	46.2	40.2	46.9	41.4	38.6	20.3
61	Yayla 305	47.6	43.1	48.6	39.4	36.4	11.8
62	Zerin	49.2	41.4	47.3	40.3	36.4	10.7
63	Bezostaja 1	49.9	42.4	50.7	37.2	34.4	3.7
64	Karasu 90	49.7	36.9	46.8	35.3	34.2	9.0
Mean		48.8	44.2	48.8	41.1	36.4	14.6
$LSD_{0.01}$		3.6	4.1	10.0	6.4	6.9	7.8
2011–12		48.9	48.6	49.5	49.9	45.6	23.3
2012–13		48.6	39.8	48.2	32.4	27.2	5.9

associated with $LSR_{25DPA.}$ The second component (PC2), accounting for 12.00% of the total variation, was positively associated with Fv_{15DPA}, Fm_{15DPA}, Fv/Fm_{15DPA}, and CTD_A. The third component (PC3) explained 11.21% of the total variation and was positively correlated with Fv_A, Fm_A, and Fv/Fm_A. The first three components explained 40.47% of the total trait variation and were positively and strongly associated with chlorophyll fluorescence parameters such as Fv, Fm, and Fv/Fm.

3.4. Identification of drought sensitivity of genotypes and efficiency of selection criteria

The identification of drought-resistant genotypes based on a single selection criterion or a few criteria is not a realistic approach. For example, according to measurements made at 15DPA in late drought conditions, the best drought-resistant genotype based on CTD was Ankara 093/44, on LSR was ES 26, on SPAD value was Nacibey, on Fm was Kate A-1, and on Fv/Fm was Doğu 88. The drought sensitivity was identified based on RS values of the genotypes and the genotype with the lowest RS was the most resistant to late drought (Table 10). Variation in RS values among genotypes ranged from 26.7 to 66.3 and genotypes were classified into four groups. Four genotypes (Müfitbey, Uzunyayla, Gün 91, and Dağdaş 94) had the lowest RS values (RS < 36.5), and hence they were identified as drought-resistant; 15 genotypes (Altay 2000, Kate A-1, Kırgız 95, Pehlivan, Kıraç 66, Mızrak, Sultan 95, Bolal 2973, Sönmez 2001, Doğu 88, Süzen 97, Aytın 98, Zerin, Yayla 305, Gerek 79) had low RS values (in the range of 36.6 < RS < 46.5) and they were classified as

Table 7. Maximum fluorescence (Fm) at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions.

No.	Genotype	Fm_{A}		$\mathrm{Fm}_{\mathrm{15DPA}}$		$\mathrm{Fm}_{\mathrm{25DPA}}$	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	1596.2	1512.6	1512.7	1244.4	933.5	547.9
2	Aldane	1430.1	1489.3	1293.0	1208.0	975.1	507.0
3	Alparslan	1621.4	1569.3	1468.1	1306.5	1144.3	660.1
4	Altay 2000	1595.1	1625.8	1405.1	1317.6	1200.8	1049.2
5	Atlı 2002	1694.5	1526.3	1548.3	1393.1	1390.8	730.0
6	Aytın 98	1659.8	1588.4	1474.5	1339.1	1102.9	804.7
7	Bağcı 2002	1714.2	1596.1	1516.3	1325.0	1146.1	598.9
8	Bayraktar 2000	1650.5	1433.8	1442.9	1288.0	1118.2	613.6
9	Bolal 2973	1705.0	1581.0	1647.8	1407.5	1201.2	1003.6
10	Bereket	1647.9	1447.3	1297.1	1321.0	1195.5	857.5
11	Çetinel 2000	1660.8	1499.5	1544.7	1322.3	1249.8	751.8
12	Dağdaş 94	1756.1	1695.0	1620.7	1501.4	1329.2	1071.3
13	Demir 2000	1706.0	1541.1	1492.9	1405.7	1365.0	593.9
14	Doğu 88	1659.9	1566.5	1501.5	1483.0	1142.7	1083.1
15	ES 26	1591.5	1408.8	1409.1	1343.3	1190.8	889.9
16	Gerek 79	1681.1	1543.5	1524.1	1459.3	1411.8	521.4
17	Gün 91	1724.2	1595.8	1626.6	1514.9	1375.4	1052.3
18	Harmankaya 99	1656.1	1707.9	1403.5	1458.9	1293.7	545.6
19	İkizce 96	1572.2	1770.8	1553.8	1399.2	1267.1	464.5
20	İzgi 2001	1513.6	1521.6	1310.2	1301.3	1216.4	752.0
21	Karahan 99	1559.3	1538.9	1361.1	1265.6	1261.5	846.5
22	Kate A-1	1598.3	1680.5	1410.6	1549.7	997.9	847.7
23	Kıraç 66	1725.2	1531.8	1296.4	1275.4	1198.6	940.4
24	Kırgız 95	1739.2	1475.2	1308.3	1404.6	1330.6	996.7
25	Kırik	1584.9	1434.0	1426.5	1272.5	1212.8	990.4
26	Kutluk 94	1640.4	1486.6	1281.4	1265.8	1123.5	819.8
27	Lancer	1617.4	1605.4	1296.3	1324.1	1103.7	955.4
28	Mızrak	1516.5	1513.0	1274.4	1420.8	1213.5	1086.8
29	Müfitbey	1701.3	1543.5	1383.4	1431.5	1384.0	937.4
30	Nacibey	1628.5	1517.3	1399.1	1254.7	1143.9	716.4
31	Nenehatun	1505.2	1450.5	1399.5	1127.5	1278.8	868.3
32	Palandöken 97	1539.4	1472.9	1267.5	1137.3	1080.4	457.7
33	Pehlivan	1643.7	1524.2	1421.4	1372.8	1222.9	833.5
34	Prostor	1693.9	1497.7	1426.2	1374.4	976.5	453.3
35	Soyer02	1641.0	1626.4	1566.2	1416.6	1299.8	703.3
36	Sönmez 2001	1529.6	1498.7	1485.2	1358.2	1201.6	541.5
37	Sultan 95	1566.3	1623.6	1371.2	1450.7	1248.1	596.1
38	Süzen 97	1482.2	1611.2	1372.5	1234.5	1169.2	609.5
39	Tosunbey	1508.7	1500.7	1240.5	1333.2	1243.0	474.8

Table 7. (Continued).

40	Türkmen	1501.8	1539.4	1355.2	1417.9	1141.4	573.6
41	Uzunyayla	1724.1	1690.9	1422.1	1418.7	1306.3	1175.9
42	Yakar 99	1714.9	1562.3	1438.3	1385.2	1216.6	477.7
43	Zencirci 2002	1551.9	1606.8	1367.7	1244.0	1165.6	693.7
44	Ak-702	1505.5	1562.5	1335.1	1199.9	1183.6	500.5
45	Ak Buğday	1597.7	1561.6	1406.2	1321.9	1024.6	808.2
46	Ankara 093/44	1528.9	1597.9	1409.6	1334.1	978.7	575.9
47	Conkesme	1645.5	1535.8	1474.3	1198.7	1106.6	540.9
48	Haymana 79	1590.3	1436.6	1220.1	1338.0	1104.0	494.0
49	Hawk (Şahin)	1532.8	1571.7	1552.8	1358.6	1179.9	888.3
50	Kılçıksız Buğday	1687.6	1554.6	1493.3	1375.5	1263.6	505.5
51	Kırkpınar 79	1605.6	1539.2	1460.5	1286.0	1214.0	451.1
52	Kırmızı Kılçık	1367.7	1454.1	1367.9	1465.7	1241.9	581.0
53	Kırmızı Yerli	1498.0	1533.1	1494.1	1239.1	1224.0	529.2
54	Koca Buğday	1557.8	1541.0	1417.1	1308.6	1155.4	594.6
55	Köse 220/39	1501.9	1452.8	1271.0	1222.2	1215.3	701.1
56	Özlü Buğday	1592.8	1495.6	1485.7	1370.2	1175.9	478.6
57	Polatlı Kösesi	1640.2	1514.3	1375.8	1256.5	1130.9	988.6
58	Sert Buğday	1562.5	1523.0	1304.8	1293.2	1281.0	603.6
59	Sürak 1593/51	1552.0	1575.9	1327.2	1137.3	1235.5	975.5
60	Tir	1472.0	1487.9	1256.1	1248.8	1220.9	794.1
61	Yayla 305	1625.0	1584.4	1496.5	1305.1	1326.8	587.1
62	Zerin	1550.1	1517.4	1307.8	1317.3	1047.2	606.9
63	Bezostaja 1	1594.8	1544.3	1359.1	1185.1	1265.4	477.2
64	Karasu 90	1533.0	1407.3	1433.1	1133.8	1231.8	453.5
Mean		1601.4	1542.9	1412.7	1327.7	1196.5	716.1
$LSD_{0.01}$		198.5	168.7	265.8	226.8	195.3	104.8
2011–12		1819.1	1761.1	1526.9	1470.2	1393.0	1046.2
2012–13		1383.7	1324.7	1298.5	1185.2	1000.1	386.0

moderately resistant; 34 genotypes had high RS values (in the range of $46.6 < RS < 56.5$) and they were characterized as moderately sensitive; and 11 genotypes (Karasu 90, Palandöken 97, Prostor, Aldane, Bezostaja 1, Kırmızı Yerli, Köse 220/39, Ak-702, Conkesme, Aksel 2000, and Kırik) had the highest RS values ($RS > 56.6$) and were classified as drought-sensitive. On the other hand, the local genotypes Zerin and Sert Buğday with the lowest standard deviations were the most stable in terms of the selection criteria.

The partial and cumulative R^2 as well as the probability for the accepted 10 limiting selection criteria in RS (drought sensitivity) prediction were determined and are shown in Table 12. The stepwise multiple linear regression analysis of RS (dependent) and 25 selection criteria (independent) indicated that Fv_{15DPA}, Fv_{25DPA}, CTD_{15DPA}, and $SPAD_{15DPA}$ explained 45.0%, 21.5%, 4.7%, and 4.0% of RS variation, respectively. According to the results, 85.7% of the total variation in RS was attributed to 10 criteria. The other 15 criteria were not included in the analysis due to their low relative contributions. A combination of grain ash content and Fv_{25DPA} explained up to 34.1% of the variance in grain yield under the late drought conditions (tables not given).

4. Discussion

4.1. Effects of growing conditions on grain yield and physiological traits

Grain yield and yield components were significantly higher in the 2011–12 season than in 2012–13 because of higher rainfall during the fallow year. The present results underline the potential value of the rainfall quantity stored

Table 8. Variable fluorescence (Fv) at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions.

No.	Genotype	Fv_{A}		Fv_{15DPA}		Fv_{25DPA}	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	1312.7	1226.5	1210.7	940.0	605.1	350.5
2	Aldane	1160.2	1189.9	996.4	878.1	659.3	271.0
3	Alparslan	1334.8	1275.1	1171.9	1004.0	827.6	446.8
4	Altay 2000	1315.5	1335.2	1101.8	1007.5	876.7	682.9
5	Atlı 2002	1404.6	1232.2	1241.4	1085.1	1066.9	493.4
6	Aytın 98	1360.1	1291.9	1167.6	1033.8	755.9	558.0
7	Bağcı 2002	1426.8	1302.2	1205.1	1007.7	798.0	409.8
8	Bayraktar 2000	1354.0	1135.8	1133.8	962.0	762.3	406.0
9	Bolal 2973	1418.4	1283.5	1343.8	1089.8	854.4	603.1
10	Bereket	1363.3	1141.8	986.1	994.0	874.0	450.2
11	Çetinel 2000	1371.9	1207.8	1243.0	1010.2	912.2	468.0
12	Dağdaş 94	1465.4	1396.7	1317.0	1174.6	989.5	719.9
13	Demir 2000	1418.7	1245.3	1187.6	1095.8	1033.3	393.4
14	Doğu 88	1371.5	1272.5	1196.4	1174.4	820.8	667.0
15	ES 26	1297.0	1115.6	1111.1	1031.6	883.5	533.1
16	Gerek 79	1420.8	1244.3	1213.4	1125.2	1080.0	327.4
17	Gün 91	1430.6	1293.6	1311.6	1169.5	1016.1	679.2
18	Harmankaya 99	1368.2	1397.6	1085.8	1126.3	969.5	315.6
19	İkizce 96	1293.2	1457.6	1244.4	1082.8	929.6	276.8
20	İzgi 2001	1235.4	1219.7	997.8	979.2	890.5	384.2
21	Karahan 99	1258.2	1222.0	1051.8	953.4	931.3	502.0
22	Kate A-1	1307.1	1364.8	1103.9	1207.0	665.0	491.6
23	Kıraç 66	1426.0	1227.0	992.1	958.0	884.0	594.2
24	Kırgız 95	1454.0	1177.3	999.5	1086.4	1011.1	640.6
25	Kırik	1299.1	1135.6	1114.5	943.9	853.5	631.3
26	Kutluk 94	1341.7	1170.8	953.8	942.4	795.8	477.8
27	Lancer	1326.6	1298.6	978.1	1003.5	777.2	570.3
28	Mızrak	1225.8	1212.8	958.2	1104.1	885.3	736.7
29	Müfitbey	1420.6	1234.8	1073.6	1110.0	1045.6	558.5
30	Nacibey	1341.4	1216.5	1092.3	950.8	800.3	336.1
31	Nenehatun	1207.4	1145.6	1086.6	815.5	951.9	526.0
32	Palandöken 97	1252.8	1177.2	964.1	806.9	752.9	273.8
33	Pehlivan	1361.3	1223.9	1119.8	1052.2	902.1	409.9
34	Prostor	1397.4	1183.6	1119.4	1051.2	648.2	258.3
35	Soyer02	1355.5	1319.9	1266.4	1085.6	955.0	343.7
36	Sönmez 2001	1250.5	1197.0	1192.0	1052.7	879.4	348.7
37	Sultan 95	1281.7	1318.9	1065.2	1116.2	921.0	408.7
38	Süzen 97	1188.9	1296.9	1059.3	910.9	836.9	428.0
39	Tosunbey	1217.8	1203.1	934.7	1006.4	914.9	311.3

Table 8. (Continued).

40	Türkmen	1214.5	1228.2	1044.8	1092.1	816.7	386.1
41	Uzunyayla	1424.1	1386.0	1109.7	1088.3	979.2	847.1
42	Yakar 99	1409.5	1250.6	1126.8	1058.4	883.3	290.3
43	Zencirci 2002	1269.0	1291.1	1047.0	922.9	824.6	337.8
44	Ak-702	1224.4	1266.7	1022.8	877.3	839.7	325.5
45	Ak Buğday	1304.0	1241.4	1083.5	985.8	656.3	423.7
46	Ankara 093/44	1236.2	1291.8	1099.1	1015.7	653.8	376.2
47	Conkesme	1350.1	1238.8	1167.2	849.4	743.7	348.5
48	Haymana 79	1307.1	1133.6	914.8	1010.8	782.9	300.5
49	Hawk (Şahin)	1250.1	1267.8	1243.8	1012.5	822.3	529.3
50	Kılçıksız Buğday	1379.6	1241.5	1174.1	1048.1	921.2	313.7
51	Kırkpınar 79	1318.1	1227.9	1150.9	957.3	874.2	252.6
52	Kırmızı Kılçık	1077.7	1143.7	1058.0	1138.1	901.9	383.3
53	Kırmızı Yerli	1200.4	1230.3	1181.3	919.7	893.6	353.1
54	Koca Buğday	1263.0	1226.2	1112.0	990.6	832.4	425.9
55	Köse 220/39	1210.1	1154.7	958.1	906.2	880.3	504.9
56	Özlü Buğday	1306.1	1193.7	1183.7	1040.3	839.7	308.9
57	Polatlı Kösesi	1349.3	1204.6	1060.9	927.3	789.3	632.7
58	Sert Buğday	1274.0	1212.9	994.2	970.2	940.3	343.9
59	Sürak 1593/51	1265.2	1274.3	1016.3	827.5	895.5	588.7
60	Tir	1191.7	1195.0	965.0	937.9	894.2	452.0
61	Yayla 305	1331.4	1285.3	1189.3	982.0	990.6	348.5
62	Zerin	1252.8	1214.6	984.0	997.1	713.6	399.4
63	Bezostaja 1	1310.5	1245.1	1057.4	873.4	935.3	305.5
64	Karasu 90	1257.1	1117.5	1133.6	820.5	909.1	265.2
Mean		1312.7	1239.9	1104.2	1005.9	863.0	442.6
$LSD_{0.01}$		196.5	163.6	266.7	219.3	195.6	90.2
2011–12		1515.3	1448.8	1213.3	1149.1	1064.9	697.3
2012–13		1110.0	1031.0	995.1	862.7	661.1	187.9

in the soil at sowing time on grain yield. High soil water contents during the 2011–12 season led to an increase of SPAD, Fm, Fv, Fv/Fm, and leaf ash content, but it decreased CTD, LSR, and grain ash content, as the average of genotypes.

Late drought causes reductions in yield components and grain yield of wheat. The late drought decreased spikes per m^2, kernels per spike, kernel weight, and grain yield by 12.8%, 18.4%, 16.8%, and 36.2% compared with irrigated conditions, respectively. Similar results were also reported by Monneveux et al. (2005) and Balota et al. (2008). In irrigated plants, the CTD, SPAD, Fm, Fv, Fv/Fm, and leaf ash content values were higher than in late drought, but LSR and grain ash content were low. At both anthesis and grain filling, the highest CTD values were measured in the irrigated experiment, suggesting that transpiration rates were much higher in these plants (Gupta et al., 2001; Li et al., 2012). Late drought increased the LSR at all the evaluated stages and the differences tended to be greater at advanced stages. LSR in wheat is sensitive to water stress and it can be influenced by stomal closure, internal levels of hormones, reduction in water content, decrease in nutrient supply, remobilization of nutrients to younger parts of plant, and destruction of chlorophyll (Hafsi et al., 2000; Shah and Paulsen, 2003; Verma et al., 2004). Late drought caused a decline in SPAD values at all the measurements dates, as has been observed in other studies (Paknejad et al., 2007; Guo et al., 2008), and chlorophyll losses were increased by advancing stress. Chloroplasts need nitrogen to accumulate chlorophyll through proteins

Table 9. Maximum quantum efficiency of PSII (Fv/Fm) at anthesis and 15 days and 25 days post anthesis of 64 bread wheat genotypes grown under irrigated and late drought conditions.

No.	Genotype	Fv/Fm_{A}		Fv/Fm_{15DPA}		Fv/Fm_{25DPA}	
		Irrigated	Late drought	Irrigated	Late drought	Irrigated	Late drought
1	Aksel 2000	0.822	0.811	0.799	0.750	0.595	0.430
2	Aldane	0.811	0.799	0.773	0.724	0.639	0.371
3	Alparslan	0.820	0.807	0.793	0.765	0.700	0.392
4	Altay 2000	0.825	0.819	0.782	0.766	0.725	0.605
5	Atlı 2002	0.825	0.807	0.799	0.779	0.766	0.438
6	Aytın 98	0.815	0.811	0.788	0.772	0.671	0.691
7	Bağcı 2002	0.829	0.812	0.790	0.758	0.681	0.390
8	Bayraktar 2000	0.816	0.792	0.785	0.740	0.643	0.390
9	Bolal 2973	0.832	0.812	0.816	0.771	0.703	0.599
10	Bereket	0.826	0.789	0.762	0.744	0.730	0.524
11	Çetinel 2000	0.825	0.804	0.805	0.760	0.728	0.596
12	Dağdaş 94	0.833	0.822	0.812	0.777	0.742	0.671
13	Demir 2000	0.831	0.805	0.796	0.776	0.755	0.358
14	Doğu 88	0.825	0.811	0.796	0.790	0.715	0.605
15	ES 26	0.810	0.789	0.787	0.764	0.733	0.561
16	Gerek 79	0.846	0.805	0.792	0.765	0.761	0.371
17	Gün 91	0.828	0.809	0.805	0.764	0.733	0.647
18	Harmankaya 99	0.825	0.817	0.774	0.770	0.749	0.342
19	İkizce 96	0.823	0.813	0.802	0.771	0.733	0.323
20	İzgi 2001	0.812	0.790	0.749	0.736	0.711	0.485
21	Karahan 99	0.799	0.785	0.768	0.748	0.729	0.550
22	Kate A-1	0.815	0.804	0.778	0.766	0.644	0.529
23	Kıraç 66	0.825	0.796	0.763	0.745	0.729	0.631
24	Kırgız 95	0.836	0.796	0.764	0.770	0.759	0.622
25	Kırik	0.812	0.788	0.777	0.735	0.691	0.625
26	Kutluk 94	0.812	0.784	0.747	0.741	0.708	0.574
27	Lancer	0.820	0.805	0.752	0.745	0.702	0.580
28	Mızrak	0.806	0.796	0.750	0.767	0.721	0.666
29	Müfitbey	0.832	0.798	0.774	0.774	0.751	0.581
30	Nacibey	0.821	0.797	0.780	0.759	0.676	0.453
31	Nenehatun	0.797	0.785	0.768	0.728	0.732	0.592
32	Palandöken 97	0.810	0.797	0.752	0.706	0.692	0.412
33	Pehlivan	0.825	0.803	0.786	0.763	0.706	0.461
34	Prostor	0.820	0.786	0.780	0.762	0.548	0.338
35	Soyer02	0.823	0.805	0.804	0.755	0.727	0.467
36	Sönmez 2001	0.811	0.796	0.800	0.775	0.719	0.537
37	Sultan 95	0.815	0.806	0.772	0.757	0.726	0.643
38	Süzen 97	0.800	0.797	0.765	0.737	0.712	0.493
39	Tosunbey	0.801	0.793	0.748	0.743	0.707	0.378

Table 9. (Continued).

40	Türkmen	0.805	0.794	0.768	0.764	0.696	0.427
41	Uzunyayla	0.825	0.817	0.781	0.766	0.745	0.715
42	Yakar 99	0.819	0.795	0.778	0.761	0.719	0.344
43	Zencirci 2002	0.815	0.796	0.765	0.744	0.703	0.448
44	Ak-702	0.811	0.805	0.759	0.713	0.682	0.355
45	Ak Buğday	0.813	0.791	0.768	0.744	0.558	0.430
46	Ankara 093/44	0.806	0.804	0.778	0.760	0.664	0.452
47	Conkesme	0.819	0.804	0.786	0.710	0.624	0.532
48	Haymana 79	0.817	0.786	0.751	0.745	0.711	0.586
49	Hawk (Şahin)	0.814	0.803	0.799	0.740	0.688	0.582
50	Kılçıksız Buğday	0.809	0.794	0.780	0.755	0.714	0.350
51	Kırkpınar 79	0.819	0.795	0.784	0.743	0.721	0.330
52	Kırmızı Kılçık	0.787	0.783	0.770	0.773	0.725	0.381
53	Kırmızı Yerli	0.798	0.797	0.785	0.737	0.716	0.371
54	Koca Buğday	0.807	0.793	0.781	0.757	0.712	0.461
55	Köse 220/39	0.803	0.793	0.745	0.735	0.698	0.486
56	Özlü Buğday	0.819	0.797	0.789	0.745	0.698	0.431
57	Polatlı Kösesi	0.822	0.795	0.771	0.737	0.687	0.639
58	Sert Buğday	0.811	0.792	0.761	0.747	0.718	0.497
59	Sürak 1593/51	0.811	0.802	0.764	0.728	0.721	0.606
60	Tir	0.806	0.797	0.767	0.748	0.728	0.474
61	Yayla 305	0.816	0.807	0.790	0.752	0.742	0.437
62	Zerin	0.806	0.797	0.750	0.757	0.665	0.501
63	Bezostaja 1	0.82 b	0.803	0.774	0.731	0.730	0.369
64	Karasu 90	0.818	0.790	0.787	0.716	0.731	0.510
Mean		0.816	0.800	0.778	0.752	0.705	0.494
$LSD_{0.01}$		0.019	0.018	0.019	0.019	0.019	0.098
2011–12		0.832	0.822	0.791	0.779	0.762	0.762
2012–13		0.801	0.777	0.764	0.725	0.647	0.647

(Paknejad et al., 2007), and decrease of SPAD values in stress conditions may be related to a reduction of nitrogen uptake. Photosystem II (PSII) is one of the main components in photosynthesis, and PSII reaction centers and its biochemical processes are sensitive to drought stress (Guo et al., 2008). The decreases of Fm and Fv under late drought conditions may be associated with an increase of the nonphotochemical quenching process, which may result from photoinhibition (Araus et al., 1988; Guo et al., 2008), while a decline in Fv/Fm may represent either photoprotective downregulation or an inactivation of PSII (Paknejad et al., 2007; Guo et al., 2008). The differences in leaf and grain ash content between the irrigated and late drought conditions were related to the soil moisture content. Previous studies have reported a decrease in leaf ash content (Misra et al., 2006; Zhu et al., 2008) and an increase in grain ash content (Zhu et al., 2008; Bogale and Tesfaye, 2011) with a decrease of soil water. However, Monneveux et al. (2005) and Misra et al. (2010) determined the highest grain ash content in irrigated conditions. Higher transpiration increases the amount of passively transported minerals in the vegetative organs (Masle et al., 1992). The highest leaf ash contents were noted in irrigated conditions, suggesting that transpiration rates were much higher in this experiment. Under late drought, photosynthesis is more affected than translocation (Loss and Siddique, 1994) and the translocation of minerals from the leaves is higher than in irrigated conditions, which led to a decline of leaf ash content and an increase in grain ash content (Misra et al., 2006; Zhu et al., 2008).

Table 10. Leaf ash content and grain ash content of 64 bread wheat genotypes grown under irrigated and late drought conditions and ranks mean, standard deviation of ranks, and rank-sum of the 25 traits investigated by genotype.

No.	Genotype	Leaf ash content (%)		Grain ash content (%)		Ranks mean	Standard deviation	Rank sum
		Irrigated	Late drought	Irrigated	Late drought			
1	Aksel 2000	18.99	15.94	1.467	1.524	39.0	18.3	57.3
2	Aldane	20.92	16.15	1.671	1.819	41.9	20.0	61.9
3	Alparslan	18.81	17.24	1.582	1.600	30.5	16.8	47.4
4	Altay 2000	18.77	14.59	1.409	1.629	20.2	18.7	38.9
5	Atlı 2002	17.53	13.08	1.371	1.687	29.4	18.3	47.7
6	Aytın 98	18.50	15.36	1.469	1.780	28.1	17.8	45.9
7	Bağcı 2002	17.83	14.34	1.438	1.637	33.8	14.8	48.6
8	Bayraktar 2000	19.68	15.64	1.325	1.627	38.0	17.9	55.9
9	Bolal 2973	21.28	18.58	1.446	1.715	25.0	19.7	44.7
10	Bereket	16.85	14.33	1.363	1.644	34.0	17.7	51.7
11	Çetinel 2000	20.20	14.40	1.535	1.715	31.8	15.5	47.3
12	Dağdaş 94	16.11	13.22	1.386	1.440	16.4	18.4	34.7
13	Demir 2000	17.48	12.75	1.435	1.555	29.9	18.4	48.3
14	Doğu 88	15.32	13.88	1.480	1.562	24.7	20.6	45.4
15	ES 26	18.87	14.94	1.473	1.575	32.6	20.3	52.9
16	Gerek 79	18.55	13.98	1.513	1.598	28.4	18.0	46.4
17	Gün 91	22.47	16.05	1.466	1.735	16.9	13.5	30.4
18	Harmankaya 99	21.04	14.15	1.447	1.725	28.7	21.0	49.7
19	İkizce 96	16.30	12.32	1.561	1.821	31.0	21.9	53.0
20	İzgi 2001	21.40	16.11	1.426	1.935	31.6	17.2	48.8
21	Karahan 99	18.93	12.06	1.493	1.764	32.0	17.4	49.5
22	Kate A-1	21.19	16.16	1.574	2.034	20.5	18.7	39.2
23	Kıraç 66	17.58	14.31	1.484	1.627	27.3	14.6	41.9
24	Kırgız 95	18.47	14.73	1.479	1.668	23.5	16.8	40.2
25	Kırik	16.69	13.31	1.715	1.871	35.0	21.8	56.8
26	Kutluk 94	17.76	14.31	1.574	1.734	33.0	16.1	49.2
27	Lancer	14.60	11.70	1.812	1.952	29.6	18.2	47.8
28	Mızrak	18.99	13.31	1.584	1.721	27.4	16.2	43.5
29	Müfitbey	18.41	13.87	1.406	1.581	15.2	11.4	26.7
30	Nacibey	20.23	16.42	1.429	1.946	33.2	19.4	52.6
31	Nenehatun	16.78	14.28	1.475	1.788	36.7	18.3	55.1
32	Palandöken 97	20.04	12.78	1.399	1.520	41.4	20.9	62.3
33	Pehlivan	22.01	20.00	1.487	1.647	26.9	14.9	41.8
34	Prostor	21.78	19.34	1.513	1.749	41.0	20.8	61.9
35	Soyer02	20.19	14.31	1.489	1.641	30.5	17.2	47.8
36	Sönmez 2001	20.23	15.52	1.452	1.569	29.2	15.6	44.8
37	Sultan 95	18.71	14.82	1.488	1.797	27.7	16.1	43.8
38	Süzen 97	16.41	13.99	1.391	1.593	30.0	15.7	45.7
39	Tosunbey	20.91	16.15	1.617	1.707	39.9	16.4	56.3

Table 10. (Continued).

40	Türkmen	19.51	14.55	1.427	1.516	29.5	18.1	47.6
41	Uzunyayla	19.71	16.39	1.639	1.695	15.6	12.8	28.4
42	Yakar 99	20.48	15.35	1.512	1.743	37.0	18.9	55.9
43	Zencirci 2002	17.56	13.94	1.535	1.585	33.7	16.6	50.3
44	Ak-702	17.95	15.24	1.597	1.773	42.6	16.1	58.7
45	Ak Buğday	16.57	12.15	1.722	1.837	32.6	15.5	48.2
46	Ankara 093/44	17.79	13.97	1.477	1.682	31.4	17.0	48.3
47	Conkesme	16.22	13.25	1.805	1.994	39.6	18.9	58.5
48	Haymana 79	17.83	14.71	1.231	1.587	38.3	17.0	55.3
49	Hawk (Şahin)	18.45	15.31	1.772	1.939	27.4	19.8	47.3
50	Kılçıksız Buğday	15.94	14.89	1.524	1.668	37.3	16.0	53.3
51	Kırkpınar 79	20.43	15.14	1.502	1.669	37.2	14.7	51.8
52	Kırmızı Kılçık	17.82	14.07	1.511	1.623	29.1	20.8	49.9
53	Kırmızı Yerli	15.94	12.31	1.750	1.938	44.8	14.4	59.2
54	Koca Buğday	15.22	13.23	1.651	1.829	32.2	14.9	47.1
55	Köse 220/39	16.62	13.13	1.617	1.907	43.9	15.1	59.0
56	Özlü Buğday	15.67	13.40	1.479	1.748	39.6	16.4	56.0
57	Polatlı Kösesi	16.19	14.91	1.531	1.813	35.0	19.4	54.4
58	Sert Buğday	15.85	13.23	1.610	1.839	41.2	11.0	52.2
59	Sürak 1593/51	16.32	13.66	1.534	1.900	36.6	18.3	54.9
60	Tir	18.38	15.29	1.648	1.812	37.6	17.4	55.0
61	Yayla 305	16.57	14.29	1.459	1.684	33.7	12.4	46.1
62	Zerin	15.79	13.73	1.423	1.662	36.0	10.0	46.0
63	Bezostaja 1	20.16	16.41	1.486	1.671	44.8	16.6	61.5
64	Karasu 90	17.40	15.29	1.460	1.665	51.2	15.1	66.3
Mean		18.33	14.63	1.516	1.719			
$LSD_{0.01}$		1.734	1.534	0.144	0.131			
2011–12		18.913	14.942	1.440	1.615			
2012–13		17.749	14.316	1.592	1.823			

4.2. Genotypic variations in the physiological traits and their relationship with grain yield and drought sensitivity

Broad genotypic variations were found among the tested wheat genotypes for the grain yield, CTD (Balota et al., 2008; Li et al., 2012), LSR (Li et al., 2012; Lopes and Reynolds, 2012), SPAD (Lopes and Reynolds, 2012; Xiao et al., 2012), Fm and Fv (Araus et al., 1998; Bogale et al., 2011), Fv/Fm (Sayar et al., 2008; Kumar et al., 2012), and leaf and grain ash content (Merah et al., 2001; Zhu et al., 2009) in both experiments, as has been reported by other authors. Grain yield is very sensitive to drought stress and it remarkably decreased under the late drought conditions. The highest yielding cultivars in the irrigated conditions, Kate A-1 and Palandöken 97, showed the most GYRP under late drought. GYRP was positively correlated with grain yield (r = 0.601***) in the irrigated conditions and negatively correlated with grain yield (r = –0.763***) in late drought and RS (r = –0.378**). Similarly, Foulkes et al. (2007) noted that higher yield potential is associated with higher yield loss in drought conditions. The extent of late drought effects on the physiological traits was different among the wheat genotypes. Under late drought stress, the highest CTD values at anthesis, 15DPA, and 25DPA were recorded for Demir 2000, Ankara 093/44, and Kıraç 66, respectively. Higher CTD values in wheat might result from higher proportions of roots in deeper and moister soil (Lopes and Reynolds, 2010) and higher stomal conductance and transpiration (Monneveux et al., 2012). However, the genotypes with high or low CTD did not show continuously high or low CTD at all measured

Table 11. Correlation coefficients of selection criteria with grain yield, yield components, and rank sum values of the 64 bread wheat genotypes.

Criterion[1]	Irrigated conditions				Late drought conditions				
	Spikes per m^2	Kernels per spike	1000 kernel weight	Grain yield	Spikes per m^2	Kernels per spike	1000-Kernel weight	Grain yield	Rank-sum (drought sensitivity)
$\mathrm{CTD}_{\mathrm{A}}$	0.184	−0.267*	0.304*	0.030	−0.064	−0.025	0.311*	0.004	−0.291*
$\mathrm{CTD}_{\mathrm{15DPA}}$	0.038	0.110	0.138	0.124	0.197	0.057	0.099	0.232	−0.411**
$\mathrm{CTD}_{\mathrm{25DPA}}$	0.036	0.157	−0.043	0.129	0.036	0.063	0.077	0.114	−0.291*
$\mathrm{LSR}_{\mathrm{A}}$	−0.059	0.127	−0.093	−0.053	0.200	0.136	−0.315*	0.483***	0.002
$\mathrm{LSR}_{\mathrm{15DPA}}$	0.053	−0.092	0.144	−0.306*	0.128	−0.065	0.004	0.077	0.384**
$\mathrm{LSR}_{\mathrm{25DPA}}$	−0.170	0.080	0.015	−0.207	−0.112	0.095	0.046	−0.020	0.439***
$\mathrm{SPAD}_{\mathrm{A}}$	−0.343**	0.418***	0.184	0.278*	−0.434***	0.555***	0.051	−0.022	−0.180
$\mathrm{SPAD}_{\mathrm{15DPA}}$	−0.401**	0.360**	0.295*	0.222	−0.357**	0.498***	0.082	0.040	−0.306*
$\mathrm{SPAD}_{\mathrm{25DPA}}$	−0.207	0.100	0.176	0.200	0.030	−0.052	0.120	−0.002	−0.505***
Fo_{A}	0.316*	−0.093	0.032	−0.039	−0.164	−0.082	0.189	−0.183	−0.132
$\mathrm{Fo}_{\mathrm{15DPA}}$	0.224	−0.194	0.212	0.063	−0.146	−0.130	0.073	−0.064	−0.101
$\mathrm{Fo}_{\mathrm{25DPA}}$	0.116	−0.216	0.287*	−0.072	−0.154	0.033	0.163	0.102	−0.464***
Fm_{A}	−0.098	0.234	−0.025	0.322**	−0.142	0.280*	0.044	−0.028	−0.489***
$\mathrm{Fm}_{\mathrm{15DPA}}$	−0.090	0.060	0.017	0.028	−0.070	0.289*	0.077	0.328**	−0.665***
$\mathrm{Fm}_{\mathrm{25DPA}}$	−0.290*	0.047	0.125	0.118	0.001	0.009	0.108	0.226	−0.624***
Fv_{A}	−0.131	0.247*	−0.029	0.331**	−0.128	0.296*	0.024	−0.008	−0.487***
$\mathrm{Fv}_{\mathrm{15DPA}}$	−0.104	0.072	0.003	0.024	−0.055	0.311*	0.070	0.344**	−0.671***
$\mathrm{Fv}_{\mathrm{25DPA}}$	−0.302*	0.072	0.091	0.126	0.098	−0.007	0.059	0.273*	−0.640***
$\mathrm{Fv/Fm}_{\mathrm{A}}$	−0.244	0.278*	−0.063	0.326**	−0.036	0.312*	−0.089	0.189	−0.434***
$\mathrm{Fv/Fm}_{\mathrm{15DPA}}$	−0.160	0.117	−0.046	0.022	−0.036	0.347**	0.070	0.401**	−0.650***
$\mathrm{Fv/Fm}_{\mathrm{25DPA}}$	−0.225	0.123	−0.087	0.232	0.114	−0.122	0.097	0.148	−0.522***
Leaf ash	−0.548***	0.671***	−0.163	0.206	−0.216	0.446***	0.045	0.121	−0.034
Grain ash	0.126	−0.431***	0.084	−0.306*	0.019	−0.122	−0.050	−0.513***	0.215
GYRP	−0.166	0.126	−0.038	0.601***	−0.036	0.117	−0.120	−0.763***	0.203

*, **, and *** = significant at 0.05, 0.01, and 0.001 probability level, respectively.

[1] $\mathrm{CTD}_{\mathrm{A}}$, $\mathrm{CTD}_{\mathrm{15DPA}}$, and $\mathrm{CTD}_{\mathrm{25DPA}}$, canopy temperature difference at anthesis and 15 and 25 days post anthesis; $\mathrm{SPAD}_{\mathrm{A}}$, $\mathrm{SPAD}_{\mathrm{15DPA}}$, and $\mathrm{SPAD}_{\mathrm{25DPA}}$, SPAD value at anthesis and 15 and 25 days post anthesis; $\mathrm{LSR}_{\mathrm{A}}$, $\mathrm{LSR}_{\mathrm{15DPA}}$, and $\mathrm{LSR}_{\mathrm{25DPA}}$, leaf senescence rate at anthesis and 15 and 25 days post anthesis; Fo_{A}, $\mathrm{Fo}_{\mathrm{15DPA}}$, and $\mathrm{Fo}_{\mathrm{25DPA}}$, initial fluorescence at anthesis and 15 and 25 days post anthesis; Fm_{A}, $\mathrm{Fm}_{\mathrm{15DPA}}$, and $\mathrm{Fm}_{\mathrm{25DPA}}$, maximum fluorescence at anthesis and 15 and 25 days post anthesis; Fv_{A}, $\mathrm{Fv}_{\mathrm{15DPA}}$, and $\mathrm{Fv}_{\mathrm{25DPA}}$, variable fluorescence at anthesis and 15 and 25 days post anthesis; $\mathrm{Fv/Fm}_{\mathrm{A}}$, $\mathrm{Fv/Fm}_{\mathrm{15DPA}}$, and $\mathrm{Fv/Fm}_{\mathrm{25DPA}}$, maximum quantum efficiency of PSII at anthesis and 15 and 25 days post anthesis; GYRP, grain yield reduction percentage compared with irrigated conditions.

stages. Similar variations in canopy temperature were also observed in wheat by Fang et al. (2012), who reported that a cooler canopy was associated with higher activities of antioxidant enzymes and higher cytokinin levels in the flag leaf. Although a positive correlation between CTD and grain yield was found previously (Li et al., 2012; Lopes and Reynolds, 2012), in the present study, no significant correlations of CTD and grain yield at any of the three stages were found in either experiment (Xiao et al., 2012). On the other hand, correlation analysis showed that the CTD was significantly and negatively correlated with RS, and $\mathrm{CTD}_{\mathrm{15DPA}}$ could explain 4.7% of the total variation in

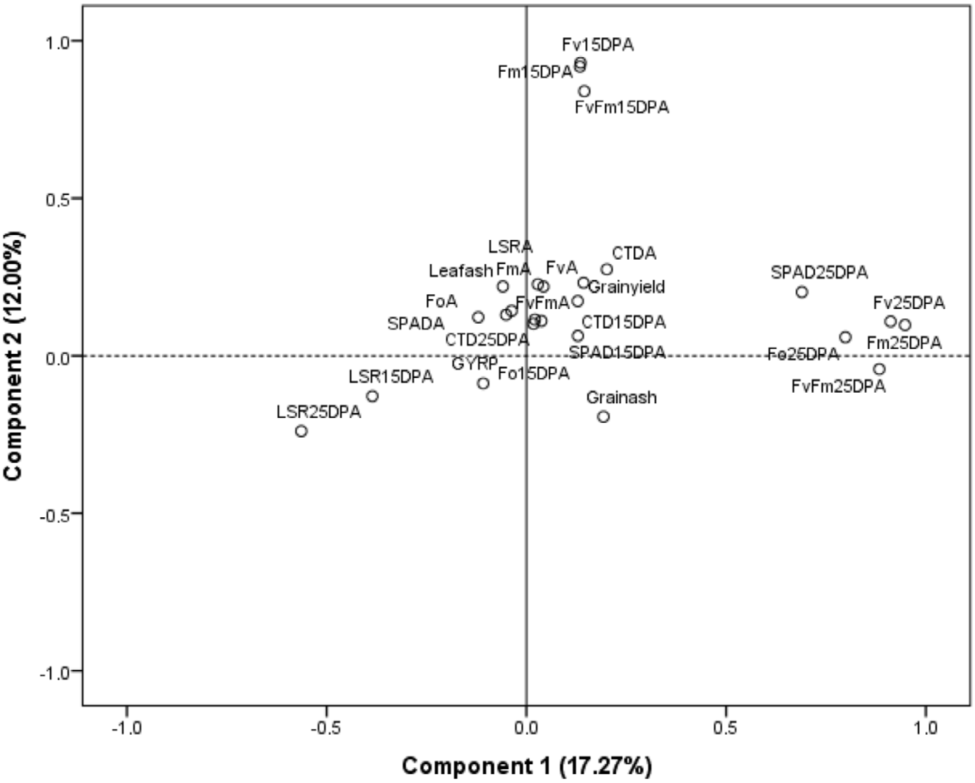

Figure 2. Biplot analysis of selection criteria measured in late drought conditions based on the first principal component (17.27%) and second principal component (12.00%) for 64 bread wheat genotypes.

Table 12. Stepwise regression analysis considering RS (drought sensitivity) as dependent variable and the 25 selection criteria as independent variables in 64 wheat genotypes grown in late drought conditions.

Step	Independent variables[1]	Constant	Standard error	t-value	Partial R^2	Model R^2	P-value model
1	Fv_{15DPA}	106.2	7.98	13.30	0.450	0.450	0.000
2	Fv_{25DPA}	106.5	6.28	16.97	0.215	0.665	0.000
3	CTD_{15DPA}	115.8	6.59	17.58	0.047	0.712	0.000
4	$SPAD_{15DPA}$	130.5	7.78	16.78	0.040	0.752	0.000
5	Fm_{A}	149.1	11.05	13.49	0.021	0.773	0.000
6	LSR_{25DPA}	123.0	15.20	8.09	0.021	0.794	0.000
7	GYRP	117.7	14.82	7.95	0.018	0.812	0.000
8	LSR_{A}	114.2	14.22	8.03	0.019	0.831	0.000
9	LSR_{15DPA}	111.0	13.88	8.00	0.013	0.844	0.000
10	Leaf ash	114.4	13.50	8.48	0.013	0.857	0.000

[1] Fv_{15DPA} and Fv_{25DPA}, variable fluorescence at 15 and 25 days post anthesis; CTD_{15DPA}, canopy temperature difference at 15 days post anthesis; $SPAD_{15DPA}$, SPAD chlorophyll value at 15 days post anthesis; Fm_{A}, maximum fluorescence at anthesis; GYRP, grain yield reduction percentage compared with irrigated conditions; LSR_{A}, LSR_{15DPA} and LSR_{25DPA}, leaf senescence rate at anthesis and 15 and 25 days post anthesis.

RS. The ranking of genotypes varied at all the measurement dates according to the LSR, suggesting that measurement only on one date is not sufficient for determining genotypic variations for senescence (Hafsi et al., 2013). For example, cultivars Alparslan, Bereket, Demir 2000, and Bayraktar 2000 had the highest LSR values at anthesis but relatively low LSR at 15DPA and 25DPA under late drought. In the late drought experiment, grain yield was positively correlated with LSR_A ($r = 0.431^{***}$) and biomass ($r = 0.872^{***}$). A significant positive correlation was found between LSR_A and biomass ($r = 0.431^{***}$), suggesting that the onset of senescence could have been affected by decrease of soil water availability under the late drought conditions. RS was positively correlated with LSR_{15DPA} and LSR_{25DPA} under late drought, in agreement with Feng et al. (2009), Li et al. (2012), and Lopes and Reynolds (2012).

The SPAD value (leaf chlorophyll content) is a measure of photosynthetic potential. The SPAD values of the genotypes showed significant differences and decreased under late drought; however, the SPAD for different genotypes decreased differently (Chandrasekar et al., 2000). In the genotypes Kırik and Aytın 98, $SPAD_{25DPA}$ declined by 27.4% and 30.0%, while in genotypes Bezostaja 1 and Özlü Buğday it decreased by 89.2% and 90.5%, respectively. Genotypic differences in SPAD values could result from differences in leaf and cell morphology (Munns et al., 2010), leaf N statuses (Paknejad et al., 2007), chlorophyllase enzyme activation (Nikolaeva et al., 2010), nitrogen demand of spikes and limitation of water supply (Ommen et al., 1999), and sensitivity to late drought (Chandrasekar et al., 2000; Kumar et al., 2012). There was a significant correlation between SPAD and grain yield at anthesis only in the irrigated experiment, while RS significantly correlated with $SPAD_{15DPA}$ and $SPAD_{25DPA}$ under late drought. Chlorophyll fluorescence parameters (Fm, Fv, Fv/Fm) are related to the activity of the photosynthetic apparatus (Guo et al., 2008), and there were significant differences among genotypes in respect to these parameters at all the measured stages under irrigated and late drought conditions. Differences among the genotypes in fluorescence parameters could be due to differences in chlorophyll content (Paknejad et al., 2007; Kumar et al., 2012), plant height, and leaf characteristics (Slapakauskas and Ruzgas, 2005). The higher Fm, Fv, and Fv/Fm values were associated with higher SPAD values, especially at 25DPA in both experiments. These parameters were positively correlated with grain yield at all the stages but correlations were significant at anthesis only in the irrigated experiment (Araus et al., 1998). In the late drought conditions, significant relationships between grain yield and Fm_{15DPA}, Fv_{15DPA}, Fv_{25DPA}, and Fv/Fm_{15DPA} are in agreement with the results of Araus et al. (1998), Paknejad et al. (2007), and Kumar et al. (2012). Significant correlations were found between fluorescence parameters (Fm, Fv, and Fv/Fm) and RS under late drought, and Fv_{15DPA} and Fv_{25DPA} could explain 66.5% of the total variation in RS. These results are in agreement with the results of Araus et al. (1988) and Guo et al. (2008) that chlorophyll fluorescence parameters could be efficient selection criteria for grain yield under drought conditions.

Genotypic variations in leaf ash content may result from differences in either transpiration rate or translocation efficiency of carbon products from the vegetative parts to the growing grain (Monneveux et al., 2005). Merah et al. (2001) reported higher leaf ash contents in improved cultivars compared to landraces. When compared with the irrigated experiment, leaf ash content decreased from 6.6% (Kılçıksız Buğday) to 36.3% (Karahan 99) under late drought and leaf ash content was not correlated with grain yield and RS, similarly to Zhu et al. (2009) and Misra et al. (2010). Under late drought conditions, cultivar Nacibey had the highest grain ash content (36.2%), while Alparslan had the lowest (1.2%). Significant differences among the bread wheat genotypes observed in grain ash content could depend on the retranslocation of minerals from vegetative plant parts and photosynthesis processes during grain filling (Merah et al., 2001; Zhu et al., 2008), and higher grain ash contents suggest a higher retranslocation and lower photosynthesis rates. The negative association between grain ash content and grain yield observed in both experiments supports the results of Merah et al. (2001) and Zhu et al. (2008). The association of grain ash content with the grain yield suggests that, under late drought conditions, high grain yield is the result of the higher contribution of photosynthetic assimilates in grain filling (Merah et al., 2001). Grain ash content has been proposed as an alternative criterion for evaluating drought tolerance in wheat (Merah et al., 2001). The positive, nonsignificant correlation between grain ash content and RS agrees with Bogale and Tesfaye (2011). Those authors reported that the grain ash content positively correlated with drought susceptibility index and increased in those genotypes susceptible to drought stress.

The results from the field study show that there were significant differences among the wheat genotypes for all the traits. Late drought stress decreased grain yield, CTD, SPAD, Fm, Fv, Fv/Fm, and leaf ash content values but increased LSR and grain ash content in the genotypes. The ranking method was used as a comprehensive characterization method for evaluation of late drought resistance. Four genotypes with drought resistance, 15 genotypes with moderate resistance, 34 genotypes with moderate sensitivity, and 11 genotypes with sensitivity were screened according to their RS values. Drought-resistant genotypes Müfitbey and Dağdaş 94 produced the highest grain yields in the late drought conditions and intermediate grain yields in the irrigated, and they appeared to be promising parents for the breeding of late drought-resistant cultivars. Correlation analysis showed that the RS value negatively correlated with CTD, SPAD, Fm, Fv, and Fv/Fm, while it positively correlated with LSR. Responses of wheat genotypes to late drought are complex and one particular physiological trait cannot make a plant resistant to late drought. The stepwise multiple linear regression analysis indicated that the Fv_{15DPA}, Fv_{25DPA}, CTD_{15DPA}, and $SPAD_{15DPA}$ could explain 75.2% of the total variation in RS. Therefore, these four criteria can be used in combination to screen bread wheat genotypes for late drought resistance. For screening of the late drought-resistant genotypes, 15DPA is the optimum time for Fv, CTD, and SPAD measurements. Development of a new technique that allows the simultaneous measurement of Fv, CTD, and SPAD can be useful for more accurate identification of the sensitivity of genotypes to late drought stress.

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