RELATIONSHIPS BETWEEN GRAIN YIELD AND PHYSIOLOGICAL TRAITS OF DURUM WHEAT VARIETIES UNDER DROUGHT AND HIGH TEMPERATURE STRESS IN MEDITERRANEAN ENVIRONMENTS

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ABSTRACT

Drought and associated high temperatures are the major environmental stresses limiting wheat productivity in Mediterranean region. To evaluate the physiological and yield responses of durum wheat varieties under high temperature and drought stress in Mediterranean region, 15 durum wheat cultivars were grown in two consecutive years (2007-08 and 2008-09). The varieties were grown under two temperature regimes viz. normal temperature (normal sowing time) and high temperature (late sowing time), and/with two water regimes viz. rain-fed (RF) and supplement irrigation (SI) conditions. Our results indicated that at rain-fed environment (water stress) caused a significant reduction in physiological parameters and grain yield. Water stress reduced 30.0 and 13.8% grain yield in 2007-08 and 2008-09, respectively. Warm environment (heat stress) caused significant reductions in physiological parameters and grain yield of 54 and 32% in 2007-08 and 2008-09, respectively. Hence, delayed sowing associated with high temperature resulted in an overall decrease in grain yield. Significant differences in grain yield was found among the varieties. Based on the growth traits and economic-yield, the cool irrigated environment is most suitable followed by the environment in cool rain-fed. However, the variety Balcalı-2000 and Fuatbey-2000 achieved the highest yield under cool well-watered conditions and hence best for grown under well-watered cropping systems. Grain yield was strongly correlated with SPAD value in cool environment (RF) while, negative correlation in warm conditions (RF). On the other hand, grain yield was strongly correlated with specific leaf weight (SLW) value in cool environment (RF). A negative correlation between grain yield and flag leaf nitrogen content (FLNC) was observed under warm conditions (RF). A positive and significant correlation between SLW and FLNC was recorded under warm conditions (RF). The ash content (AC) has a positive correlation with FM in cool environment (SI). A positive and significant correlation between FLNC and SPAD under cool (SI) and warm (Rf) conditions. The chlorophyll fluorescence contributes significantly to yield stability under stressed environments. Positive correlations of chlorophyll with grain yield make it possible to evaluate genotypes with high yield stability and consequently, can be used as a selection criterion to identify the environment stress tolerance of wheat genotypes. Balcalı-2000 and Sölen-2002 cultivars are potentially good candidates for producing good yield in the hot and dry climates in Mediterranean conditions.

KEYWORDS:
Chlorophyll fluorescence, grain yield, flag leaf area, SPAD, durum wheat

INTRODUCTION

Wheat represents about 30% of the world's cereal area, with over 220 million ha cultivated worldwide under abiotic stress conditions [1]. Wheat as a strategic crop has a vital role on the national economy of the third world countries and known as a main food crop in abiotic stress prone areas where productivity is very low [2]. To support climate-related decisions such as which varieties to plant and when, how much water is needed for irrigation; monthly, seasonal and decadal climate predictions in case of drought, are needed [3]. The global demand for wheat by the year 2020 is forecasted around 950 million tonnes to meet food requirements imposed by population growth. This target will be achieved only, if global wheat production is increased by 2.5% per annum. This must he achieved under reduced water availability, a scenario of global warming, and evolving pathogen and pest infestations [4].

The greater adaptation of bread wheat relative to other cultivated species has made it one of the most important global food crops cultivated across different environments [5]. In the process of screening wheat genotypes for breeding, grain yield is considered the most important parameter [6]. Drought and high temperature (heat) stress are considered to be the two major environmental factors limiting crop growth and yield [7].

These two stress factors induce many biochemical and physiological changes that influence various cellular and metabolic processes that affect crop yield and quality.

Heat stress, a major abiotic stress induces complex morpho-physiological changes in plants and reduces productivity [8, 9]. In addition, heat stress can reduce carbohydrate production and translocation, as well as increase carbohydrate starvation throughout the periods of high respiration, especially during high night temperature [10]. Carmo-silva *et al.* [11] revealed that stomatal closure during high temperature and limited water availability resulted in increased leaf temperature, especially when ambient temperature increased. This increases in leaf temperature resulted in a heat stress effect on the photosynthetic apparatus. Terminal heat stress is a major abiotic stress influencing yield in wheat [12].

The stay-green trait has been suggested as a beneficial trait to determine heat stress tolerance [12]. Stay-green plants have been used successfully to select for yield and yield stability and revealed as a promising selection criterion in wheat [13]. Different physiological traits such as chlorophyll content; the normalized difference vegetation index have also been associated with stress tolerance [14]. The visual observation of stay-green trait has been associated with maintenance of leaf chlorophyll and photosynthetic capacity [15]. The studies on stay-green trait of wheat genotypes are largely elusive [16], and are yet to be evaluated for their association with stress tolerance in the winter wheat [17]. It was reported that leaf area decreased noticeably with increasing water stress could be attributed to decline in the cell enlargement and more leaf senescence in the plant under water stress [18]. Drought led to substantial impairment of growth related traits of plant in terms of leaf area, shoot fresh and dry weight. Kamara *et al.* [19] revealed that water deficit imposed at various developmental stages of maize reduced total biomass accumulation. Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate. The decrease in chlorophyll content under drought stress has been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation. Photosynthetic pigments are important to plants mainly for harvesting light and production of reducing powers [20].

Understanding the physiological basis of water stress tolerance in plants is important to select and breed plants for improving crop water stress tolerance [21]. The research on physiological changes that occur during leaf senescence due to drought stress focused on loss of photosynthetic pigments, degradation of protein, and re-absorption of mineral nutrients [22]. Further, understanding the influence of heat stress will be critical in evaluating the effect of climate change on crop production. Heat stress affect physiological, growth, development, yield, and quality of crops. Short- and long-term stresses can significantly affects growth and yield, particularly when stresses occur at sensitive stages [7]. However, given the limited knowledge of how the yield and physiological traits respond to water and heat stress, this correlative analysis has not been used as a selection criterion for durum breeding. Therefore, the study was undertaken to determine the effect of heat and water stress on some physiological traits of durum wheat at different growth stages and provide valuable information that can be used for the genetic basis of improvement of wheat to enhance yield under stress conditions.

MATERIALS AND METHODS

Plant material and growing conditions. The field trials were conducted in Cukurova University research area of Turkey (36º59′ N and 35º18′ E, 20 m above the sea level) during the 2007-08 and 2008-09 growing seasons. Commercially cultivated sixteen spring durum wheat genotypes were used as plant materials (Table 1). The seeds of each genotype was sown at standard seed rate (450 seeds m^{-2}) in 8.4 m^2 plots. Recommended fertilizer rates were applied before sowing (triple super phosphate (60 kg P_2O_5 ha^{-1}, ammonium nitrate in three split doses (40+80+40 kg N ha^{-1}) at Zadok's growth stages (ZGS) 00, 20 and 30, respectively).

Treatments and field design. Experiments were established as an optimum sowing time (3 December, 2007) and late sowing time (6 March, 2008) in the first year and optimum sowing time (21 October, 2008) and late sowing time (13 March, 2009) in the second year. While the first sowing time represented the conventional sowing date, the second sowing time with growing period was rather drought and high temperature than the previous sowing time. Daily mean temperature and amount of water in the soil during the growing periods were given in Fig. 1 and Fig. 2, respectively. The experiment was set up as a split-split plot design. Sowing times were allocated in main plots, optimum sowing (cool environment) and late sowing (hot environment) and sub plots were irrigation conditions (rain-fed and irrigation) finally sub-sub plot put as a genotypes.

Measurement and calculation of traits. Flag leaf chlorophyll photochemical properties, Fo, the initial (the signal emitted when the PSII reaction centers are open) and Fm, maximum fluorescence were measured.

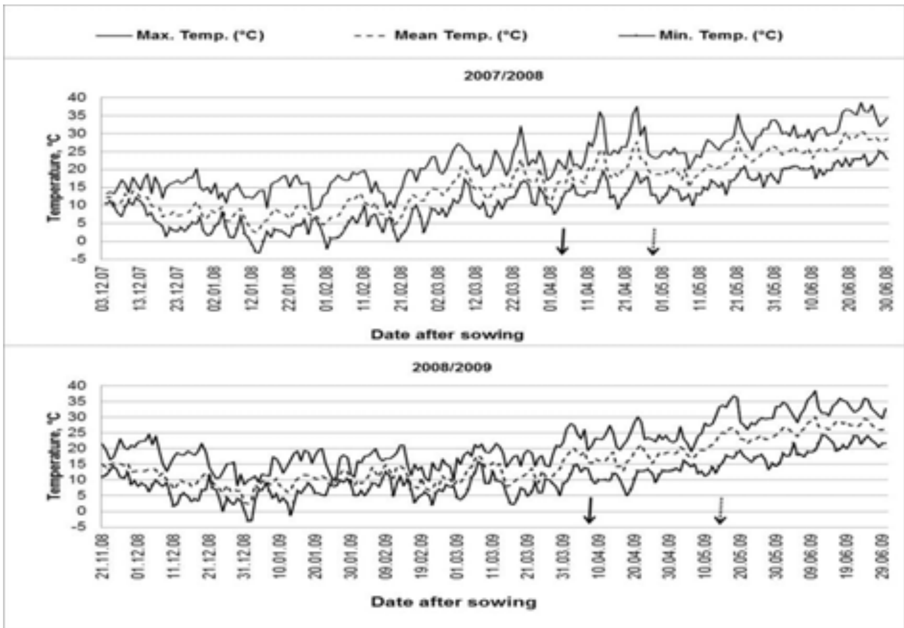

FIGURE 1
Daily temperature during 2007-08 and 2008-09 growing seasons. Solit and dashed arrows indicate anthesis in cool and warm environments.

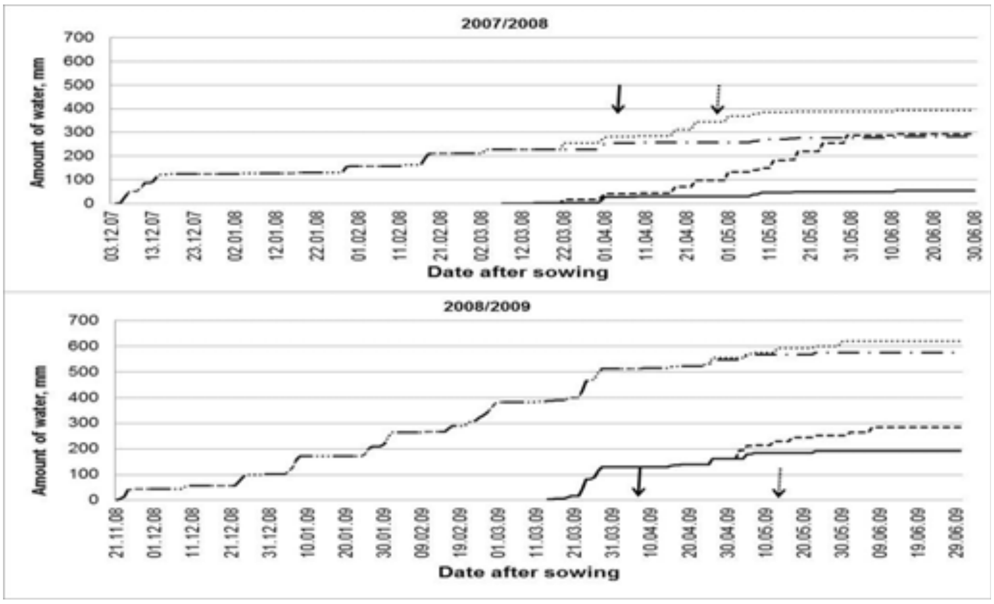

FIGURE 2
Daily precipitation (mm) and irrigation during 2007-08 and 2008-09 growing seasons. Solit and dashed arrows indicate anthesis in cool and hot environments.

The signal emitted when all the PSII reaction centers are closed, and photochemical efficiency expressed as the ratio of variable to maximum chlorophyll fluorescence. Fv/Fm ratio was determined on five individual leaves in each plot with a fluorescence induction monitor (Fim 1500; ADC Bioscientific, Hoddeston, UK) after dark adaptation for 30 min.

Flag leaf total chlorophyll was measured by the SPAD meter (SPAD 502; Minolta Camera Co., Osaka, Japan).

Specific leaf weight was measured base on randomly selected ten plants from each plot, their flag leaves were separated and their area was calculated with a leaf area meter (model Li-Cor 3100). The leaves were oven dried at 60°C to constant weight and the specific leaf weight (SLW) was expressed as leaf weight per unit of leaf area. Flag leaf nitrogen and ash conten were analyzed according to the approved method of the American Association of Cereal Chemists, Method 46-11.02 and Method 08-01.01, respectively [23]. At harvest, grain yield ha^{-1} was estimated from square meter from the inner rows per each plot.

TABLE 1
Genotype name and source of seeds of durum wheat used in the study

Cultivars	Seed source (in Turkey)
Akcakale-2000	GAP International Agricultural Research and Training Center, Diyarbakır
Altıntoprak-98	GAP International Agricultural Research and Training Center, Diyarbakır
Amanos-97	Eastern Mediterranean Agricultural Research Institute, Adana, Turkey
Aydın-93	Gap Agricultural Research Institute, Diyarbakır
Balcalı-2000	Cukurova University, Adana
Diyarbakır-81	GAP International Agricultural Research and Training Center, Diyarbakır
Ege-88	Aegean Agricultural Research Institute, Izmir
Fırat-93	GAP International Agricultural Research and Training Center, Diyarbakır
Fuatbey-2000	Eastern Mediterranean Agricultural Research Institute, Adana, Turkey
Gediz-75	Aegean Agricultural Research Institute, Izmir
Harran-95	GAP International Agricultural Research and Training Center, Diyarbakır
Salihli-92	Aegean Agricultural Research Institute, Izmir
Sarıcanak-98	GAP International Agricultural Research and Training Center, Diyarbakır
Sölen-2002	Aegean Agricultural Research Institute, Izmir
Tüten-2002	Aegean Agricultural Research Institute, Izmir

Statistical analysis. Data were analyzed by using ‘analysis of variance’ with the help of computer package MSTAT-C and the mean differences among the treatments were adjusted with Least Significant Test (LSD, $P\leq0.05$) [24].

RESULTS AND DISCUSSION

Significant differences were observed for all measured traits. Genotypes and environment contributed for the variation of yield (Table 2). The genotype × stress interactions showed significant differences among wheat genotypes to various environmental conditions. Our results indicated that at rain-fed environment (water stress) and warm environment (heat stress) caused a significant reduction in grain yield for all genotypes. Hence, delayed sowing associated with high temperature resulted in an overall decrease in grain yield. Drought stress reduced grain yield up to 30.0 and 13.8% at the first and the second year, respectively. High temperature stress also declined 54 and 32% grain yield at the growing season of 2007-08 and 2008-09, respectively.

With cool rain-fed environment cultivar Fuatbey-2000 showed the heighest yield while with cool irrigated environment Tüten-2002 and Sarıcanak-98 showed the best yield. On the other hand, under warm rain-fed environment Balcalı-2000 and Sölen-2002 showed the heighest yield while under warm irrigated environment Akcakale-2000 and Balcalı-2000 produced the maximum yield. Based on the growth tratits and yield, the cool irrigated environment is the most suitable environment followed by the cool rain-fed environment. It is also observed that the variety Balcalı-2000 and Sölen-2002 performed the best over other tested varieties in respect to important traits under stress environment (water stress and heat stress) in both years. Balcalı-2000 and Fuatbey-2000 genotypes achieved the highest yield under well-watered in both environment conditions.

The differences for showing of plant traits among wheat genotypes under various environmental conditions could be due to the delay of the time of sowing. Their variation could be attributed to grain filling process that is harmfully affected by high temperatures and shortened grains filling periods [25]. Drought stress along with high temperature occur most frequently after heading, during the grain filling period, which remarkably influence the yield of the wheat [26]. Under heat stress, the reduction of wheat yield could be caused by accelerating phase’s development, accelerated senescence, increased respiration, reduced photosynthesis and inhibition of starch synthesis in developing kernels [27]. The water deficit stress affects physiological processes in plants [28]. Saleh [29] found that crop productivity decreased under drought stress conditions. Facing plants to drought stress during the grain filling period is known to induce grain abortion and to reduce grain filling capacity, i.e. sink strength adjusts to reduce source capacity [30]. The delay of sowing date may encounter the critical growth impairment with high temperature. At grain filling, grain number was reduced under high temperature conditions [31]. Genetic variability exists among winter wheat genotypes in response to sowing dates and late-season drought stress, and thus, the choice of sowing date and cultivars are important as a management strategy to optimise grain yields in such semi-arid regions [32]. Water stress reduces plant growth and development, leading to hampered flower production and grain filling and thus smaller and fewer grains [33]. A reduction in grain filling occurs due to a reduction in the assimilate partitioning and activities of sucrose and starch synthesis enzymes [20].

Maintenance of the appropriate plant water status during water-deficit and heat stress is essential for wheat growth and yield. The adaptive physiological traits contribute greatly for yield performance under environment stress conditions. The correlations reported among physiological traits and yield made it possible to identify adapted genotypes under stress conditions and to develop and release of genotypes with good agronomic adaptation to stress conditions Chlorophyll content can determine the photosynthetic rate and reflect photosynthetic potential and primary yield of crops [20].

It was observed that grain yield and flag leaf total chlorophyll content (SPAD) value positively and significantly correlated when plants grown under cool rainfed environment (CRf).

TABLE 2
Durum wheat grain yield (g m^{-2}) under different temperature and irrigation regimes in 2007-08 and 2008-09 growing seasons.

	2007 / 2008				2008 / 2009			
	Cool environment		Hot environment		Cool environment		Hot environment	
Genotypes	Rainfed	Supplement irrigation	Rainfed	Supplement irrigation	Rainfed	Supplement irrigation	Rainfed	Supplement irrigation
Akcakale-2000	600	806	310	443	464	493	343	371
Altıntoprak-98	567	776	329	382	512	638	327	403
Amanos-97	619	784	263	376	479	543	305	375
Aydın-93	619	725	274	396	476	529	263	372
Balcalı-2000	590	835	243	322	534	566	353	478
Diyarbakır-81	480	700	202	326	460	526	272	333
Ege-88	551	828	307	340	518	540	298	406
Fırat-93	565	905	295	398	483	543	329	394
Fuatbey-2000	548	959	245	309	508	658	272	444
Gediz-75	533	847	299	417	519	597	285	338
Harran-95	594	872	306	405	482	630	297	427
Salihli-92	593	822	305	421	366	543	324	392
Sarıcanak-98	681	841	287	374	542	616	262	374
Sölen-2002	609	876	355	427	491	573	292	344
Tüten-2002	584	908	276	365	552	566	275	384
Mean	582	832	286	380	492	571	300	389
$LSD_{0.05}$								
Temperature (T)	34.9				88.4			
Irrigation (I)	31.0				9.5			
TxI	43.9				ns			
Genotype (G)	36.1				26.9			
TxG	51.0				38.0			
IxG	51.0				38.0			
TxIxG	2.9				53.8			

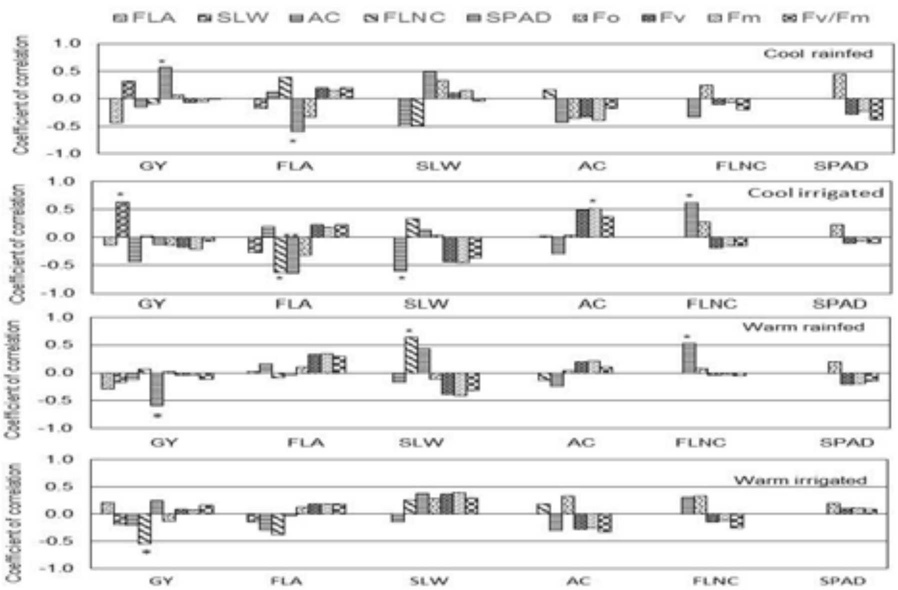

FIGURE 3
Coefficient of correlation between grain yield (GY) and flag leaf traits
***, **, significant P<0.05and *P*<0.01 probability respectively.**
FLA (flag leaf area); SLW (specific leaf weight); AC (ash content); FLNC (flag leaf nirogen content); SPAD (flaf leaf total chlorophyll); Fo (minimal fluorescence); Fv (fluorescence); Fm (maximal fluorescence); Fv/Fm (maximum potential quantum yield of PSII).

Our results indicated that yield was positively correlated with SLW, when plants grown at cool irrigated environment (CIr) (Fig. 3). Flag leaf area (FLA), was negatively correlated with (SPAD) and flag leaf nitrogen content (FLNC) values while specific leaf weight (SLW) was negatively correlated with ash content (AC). Further, strong positive correlations were observed between AC and Fm, as well as FLNC with the SPAD value (Fig. 3). Concerning warm rain-fed environment (WRf), the yield was negatively correlated with the SPAD value (Fig. 3).

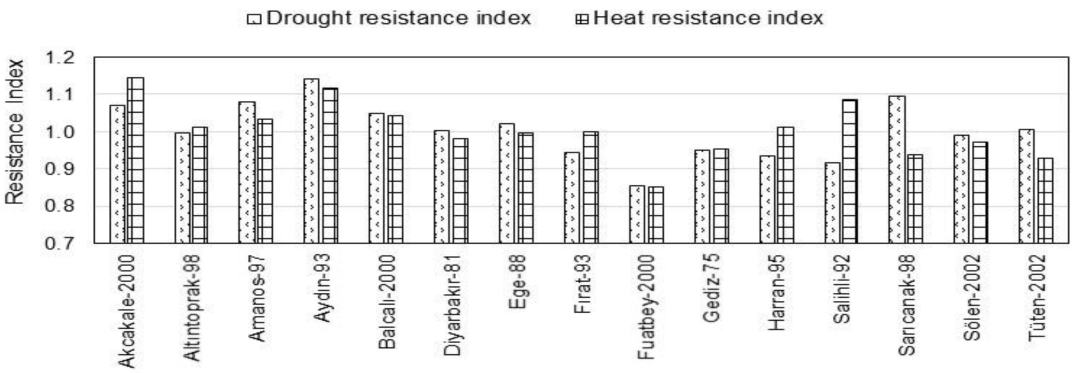

FIGURE 4
Drought and heat resistance induces for grain yield of durum wheats (Over two years mean).

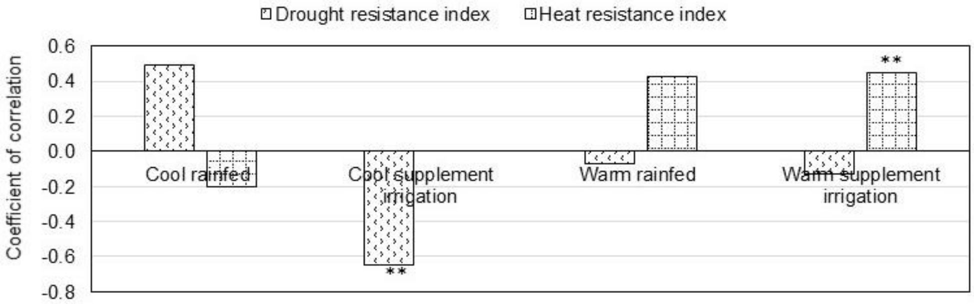

FIGURE 5
Correlation between grain yield and drought and heat resistance indices (Over two years mean).
****, significant P<0.01 probability level.**

The SLW was also observed positive correlation with SPAD value but Warm-Rf, GY negatively correlated with SPAD, indicating leaves have to be light green color for more grain yield. The data showed that yield was negatively correlated with the FLNC under warm irrigated environment (WIr) condition (Fig. 3). The FLNC had dropped drastically under Warm-Ir, while having negative association with grain yield (r =- 0.539**).Warm-Ir and GY negatively correlated with the FLNC, indicating more nitrogen requirement of the crop than recommended doses.

The reduction in leaf area under drought stress conditions could be considered as an avoidance mechanism which minimizes water losses [34] to avoid the excessive transpiration with low stomatal density [35]. Smaller leaves under drought stress, decrease light absorption capacity and photosynthesis rate, and eventually leading to reduce plant growth and yield [36]. It is noted that the chlorophyll reduction is identified as a drought response mechanism to minimize light absorption by chloroplasts [37]. The sensitivity of chlorophyll pigment with increasing environmental stresses was previously reported [38]. Hozayn *et al.*[39] reported that the highest values of certain vegetative traits and grain yields when wheat was planted earlier in the growing season. They also reported that the decrease in growth and yield attributed traits might be due to water stress during grain filling stage and decreased wheat yield might be due to the inhibition of photosynthetic efficiency under water deficit conditions [40]. The decrease of grain yield of wheat by delaying sowing date as a result of exposure plants to high temperature, reduces grain filling periods [41]. The optimum sowing of wheat favored vigorous growth plant growth and stored metabolites in heat prone areas [27, 39]. Under optimum irrigation, no significant correlation was observed between grain yield and other morphological characters but, there was a strong positive correlation between grain yield and other morphological characters under drought stress conditions [42]. Grain yield positively correlated with green leaf area at maturity stage and negatively correlated with the rate of leaf senescence under drought stress conditions [43]. However, Ismail et al. [44] could not find any correlation between heat tolerance and seed weight. Jiang et al. [45] found that a negative correlation between stay-green and yield traits. Leaf chlorophyll content or stay-green was correlated with the efficiency of transpiration, which affects to the enhancement of WUE under drought stress condition [46]. Grain yield had a significant positive relation with leaf area and chlorophyll content and, the correlation between leaf area and chlorophyll content was also positive. Furthermore, the chlorophyll content can simultaneously enhance grain yield, and plants with large leaves and grate chlorophyll content can also produce higher grain yield [33].

The mean values of drought resistance index and heat resistance index (stress tolerance index-

STI) for characterizing drought and heat stress tolerance and adaptation of genotypes to stress conditions are presented in Fig. 4. The genotype Aydın-93 showed the highest resistance indexes (drought resistance index and heat resistance index) followed by Akcakale-2000 and Amanos-97 and considered to be most tolerant genotypes. Drought stresss index (DSI) was negatively and significantly correlated with grain yield under cool supplement irrigation (Fig. 5). Moreover, heat stress index (HSI) was also positively and significantly correlated with grain yield under warm supplement irrigation (Fig. 5). This means, heat stress was more effective to grain yield than drought stress under the warm environment. The higher drought stress index (DRI) indicated that more tolerance wheat genotypes under stress environments and might be used as stress tolerant index (STI) in wheat breeding program. The STI is the significant trait to identify the stress-tolerant for high yielding genotypes [47, 48]. These findings are in full compliance with those of [49 - 62].

CONCLUSION

Wheat plants appeared to suffer yield losses due to deficiency of water and late sowing. Water and heat stress reduced grain yield by inducing negative physiological traits. Further, the cool irrigated environment is most suitable for wheat growth, followed by the environment in cool rain-fed. Balcalı-2000 and Sölen-2002 performed better under water stress and heat stress. Grain yield was strongly correlated with SPAD value in cool environment while, negatively correlated with warm conditions. On the other hand, grain yield was strongly correlated with SLW value in cool environment. Based on the results, chlorophyll fluorescence contribute significantly to yield stability under environments stress. The positive correlations of chlorophyll with grain yield make it possible to evaluate genotypes with high yield stability using these physiological attributes in various environmental conditions. Therefore, the mentioned traits can be used as a selection criterion to identify the environment stress tolerance of wheat genotypes. Finally, our results clearly inferred the fitness of Balcalı-2000 and Sölen-2002 cultivars as potential candidates for producing good yield in the hot and dry climates in Mediterranean conditions.

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