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Full Length Research Paper

Screening cotton varieties (*Gossypium hirsutum* L.) for heat tolerance under field conditions

Emine KARADEMIR[1]*, Cetin KARADEMIR[1], Remzi EKINCI[1], Sema BASBAG[2] and Hüseyin BASAL[3]

[1]Republic of Food, Agricultural and Livestock Ministry, General Directorate of Agricultural Research and Policy, GAP, International Agricultural Research and Training Center P. O. Box: 72, 21110, Diyarbakir, Turkey.
[2]Department of Field Crops, Faculty of Agriculture, University of Dicle, Diyarbakır, Turkey.
[3]Department of Field Crops, Faculty of Agriculture, University of Adnan Menderes, Aydın, Turkey.

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Fifteen upland cotton *Gossypium hirsutum* L., were evaluated for heat tolerance based on agronomical and physiological characteristics under field conditions where temperature exceeded 40°C in July and August. Genotypes showed statistically significant differences for stomatal conductance, photosynthetic yield, fluorescence, photosynthetically active radiation (PAR), seed cotton yield, plant height, boll weight, seed cotton weight, number of seeds per boll and 100 seed weight. In the study, relative cell injury level (RCIL), ranged from 54.56 to 79.44% and stomatal conductance ranged from 264.86 to 570.50 mol $m^{-2}s^{-1}$. Associations between investigated traits indicated that there were some positive correlations. These data indicated that photosynthetic yield, fluorescence, chlorophyll content (SPAD value), cell membrane thermostability (CMT), plant height and number of bolls per plant can be used for improving seed cotton yield. However, among these measurements CMT, SPAD value and fluorescence were more practical in large breeding trials. The results showed that AGC 375 and AGC 208 cotton varieties had lower relative cell injury level (higher cell membrane thermostability) and higher seed cotton yield and photosynthetic yield than other investigated varieties.

Key words: Cotton, heat tolerance, physiological traits, cell membrane thermostability (CMT).

INTRODUCTION

High temperature stress is one of the most important abiotic stress influencing productivity of cotton. Therefore, identification of cotton cultivars with high- temperature tolerance would be beneficial in both current and future climates (Kakani et al., 2005). The temperature increase is expected to continue 1.5 to 5.9°C within the next century because of global warming (Hodges and McKinion, 1996). Thus, if global warming occurs as projected, cotton production in the future will be reduced, and breeding heat tolerant cotton cultivars will be necessary. Cultural practices, such as earlier planting, may be used to avoid the flowering of cotton in the high temperatures that occur during mid to late summer (Reddy et al., 2002).

During the growing stage, cotton is sensitive to high temperature stress, especially flowering and boll-formation period. Early studies revealed that maximum number of bolls and squares retain occur at 30/22°C day/night temperatures (Reddy et al., 1992a). Mean maximum temperatures in the range of 27 to 32°C are more desirable during the period of boll development and

*Corresponding author. E-mail: emine_karademir@hotmail.com.

Abbreviations: PAR, Photosynthetically active radiation; **CMT,** cell membrane thermostability; **LEL,** leaf electrolyte leakage; **CTD,** canopy temperature depression, **VPD,** leaf air vapor pressure deficit; **RCIL,** relative cell injury level; **QTLs,** quantitative trait loci.

maturation (Gipson and Joham, 1968; Mauney, 1974; Freeland et al., 2006). Plants gained more total biomass and partitioned more of it to bolls and squares at 30/20°C day/night temperatures than any other temperature regimes examined (Reddy et al., 1991).

Bibi et al. (2008) reported that the optimum temperature for photosynthetic carbon fixation of cotton was approximately 33°C and that photosynthesis in cotton decreased significantly at temperatures of 36°C and above. High temperature environments of 35 to 40°C are frequently associated with cotton sterility and boll retention problems (Reddy et al., 1992b). Number of bolls produced, bolls retained, and percent retention were progressively reduced as time per day at 40°C was increased.

The physiological processes affecting the overall performance of cotton and their associations with high temperature stress are reported by some researchers. According to these researchers, there were strong negative association between photosynthesis and high temperature (Schrader et al., 2004; Bibi et al., 2004a, b), photosynthetically active radiation (PAR) and maximum temperature (Bhardwaj and Sing, 1991). On the other hand, some researchers indicated that there were positive association between photorespiration and high temperature (Krieg, 1986), stomatal conductance and transpiration (Kolb and Robberecht, 1996).

Cell membrane thermostability (CMT) has been proposed by Sullivan (1972), as a means for measuring the amount of electrolyte leakage from leaf disks bathed in deionized water after exposure to heat treatment and this method has been used as a measure of heat tolerance in several crops, including rice, soybean, potato, tomato and cotton (Sing et al., 2007; URL 1). CMT has been used in cotton as an appropriate screening and selection criterion for heat tolerance owing to its ability to discriminate among heat sensitive and heat tolerant genotypes within the species (Malik et al., 1999; Ashraf et al., 1994, Rahman et al., 2004, Azhar et al., 2009).

The use of relatively new physiological techniques such as CMT, leaf electrolyte leakage (LEL), carbon isotope discrimination; ecophysiologically based remote sensing/ infrared techniques such as canopy temperature depression (CTD), leaf air vapor pressure deficit (VPD), chlorophyll fluorescence; and biochemical parameters such as chlorophyll a and b contents and a:b ratio are gaining popularity to screen efficiently and quickly with reliability (Singh et al., 2007).

Breeding programs with most agricultural crops have successfully increased yields by empirical selection for higher yields, without any explicit selection for yield-related physiological traits (Lu et al., 1998). Selection for higher yields in Pima cotton and bread wheat appear to have generated selection pressures for higher stomatal conductances that are independent of operating pressures for higher photosynthetic rates. Stomatal conductance could be a valuable selection criterion for higher yields in irrigated crops grown at supra-optimal temperatures (Lu et al., 1998; Ulloa et al., 2000; Rahman, 2005). Chlorophyll fluorescence and membrane leakage were the most sensitive and practical techniques for quantifying tolerance to high temperatures in both controlled and field conditions (Oosterhuis et al., 2009). Photosynthesis was also sensitive but was not practical for screening large numbers of genotypes for temperature tolerance (Bibi et al., 2008).

Singh et al. (2007) indicated that better understanding of the possible impact of high temperature stress on physiological, morphological, and yield processes would not only help in mitigating the adverse effects of high temperature stress, but also in developing reliable field screening tools, however screening tools used for stress tolerance are difficult to operate and time consuming. One of the most important and economic way to overcome negative effect of heat stress is to identify and/or develop heat tolerant cultivars. Current commercial cotton cultivars do not appear to have much tolerance to high temperatures (Brown and Oosterhuis, 2005). In recent years, some cotton varieties were developed and registered for superior lint yield, fiber length, and competitive fiber strength under heat stress environments (Ulloa et al., 2006).

Most cotton heat tolerance studies have been conducted in the greenhouse and growth chambers. The objective of this study was to determine the effect of high temperature stress on some agronomical and physiological parameters of cotton under field studies and to use efficiently the most appropriate screening tools and physiological traits associated with cotton yield.

MATERIALS AND METHODS

Field experiment was carried out at the GAP International Agricultural Research and Training Center's experimental area during 2010 cotton growing season in Diyarbakır/Turkey. The experimental field is located (37°55'36" N, 40°13'49" E) at 670 m above sea level. Generally, this region is characterized by a semi-arid continental climate with very hot and dry summers and cold, rainy or snowy winters. The long-term (62 years) average annual temperature is 15.8°C, total rainfall is 491 mm and the average relative humidity is about 29.9%.

The meteorological data of the experimental site during the study period have been presented in Figures 1 and 2. Both maximum and mean temperatures during the experiment were higher than that of long term periods, and precipitation were inadequate during sowing time of experiments when compared with long term precipitation at the sowing time (Figure 1). On the contrary, long term precipitations were higher than that of the experiment at harvest time (Figure 2).

The soil is low in organic matter and phosphorus. It has adequate potassium, calcium, and high clay content (49 to 67%) in the 0 to 150 cm profile.

The experiment was laid out as randomized complete block design with four replications. In this study 15 cotton varieties were used as plant material. Seeds of these cotton varieties were planted with a combine cotton drilling machine on 17th May, before sowing total herbicide (200 ml da^{-1} doses) were applied for weed control and once herbicides at the doses 60 ml/da was applied after emergence for *Sorghum halepense.*

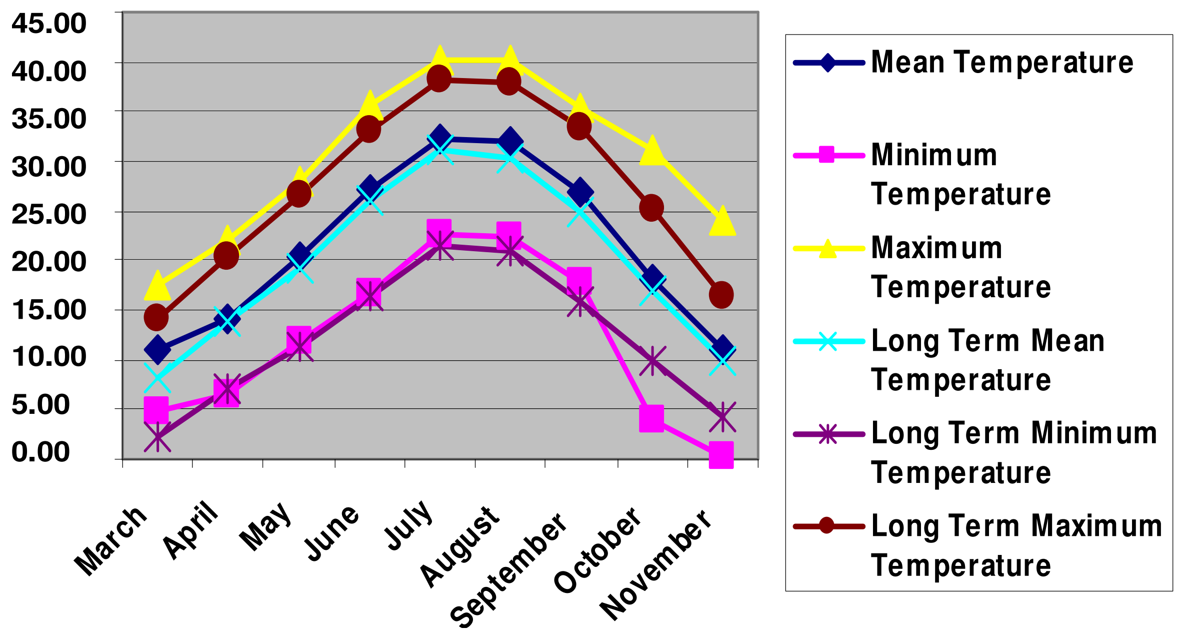

Figure 1. Monthly average and maximum temperature (°C) during experiment and long term period.

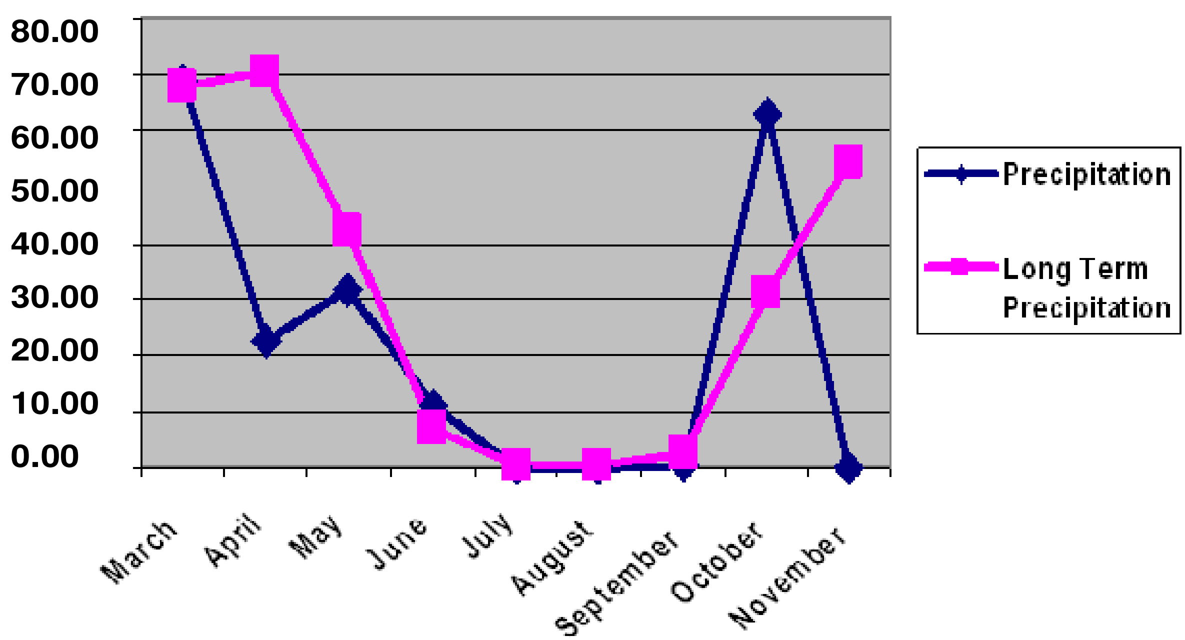

Figure 2. Average monthly precipitation levels (mm) and long term values.

Each plot consisted of four rows of 12 m. The between and within the row spacing was 0.70 and 0.20 m, respectively. All plots were treated with 20-20-0 composite fertilizer to provide 70 kg N ha^{-1} and 70 kg P_2O_5 ha^{-1}. Just before flowering, 70 kg N ha^{-1} were applied as ammonium nitrate as an additional N dose. Insects were monitored throughout the experiment and no insect control was necessary during these growing seasons. Plants were grown under recommended cultural practices for commercial production; the experiment was thinned and hoed three times by hand and two times with a machine. Experimental plots were irrigated by drip irrigation method. Adequate irrigation was provided for minimizing effect of drought stress during cotton growing stage, especially in the reproductive stage. In the study, five plants were selected randomly for observations in each plot. All physiological traits were measured 80 days after planting, the time of peak flowering and fruiting.After all bolls had opened, a 50-boll sample was collected from each plot by hand-harvesting for boll weight, seed cotton weight per boll and number of seeds per boll. Plots were harvested twice by hand and yield of four rows of plot were weighed and calculated for seed cotton yield. First harvest was done on 22

Table 1. Average values of the investigated agronomical, morphological and physiological traits of different 15 cotton varieties.

Cultivar	PH	BN	BW	SCW	NSB	100 SW	CC	LT	SC	RCIL	PAR	FL	PY	SCY
1. DP 396	88.73^{b-e}	18.06	6.57^{cd}	5.12^{cd}	33.22^{c-g}	8.50^{i}	46.96	29.36	541.85^{ab}	54.73	718.30^{a}	3870.33^{f-h}	47.00^{d-f}	3474.52^{a-c}
2. DP 90	90.06^{b-e}	16.73	6.72^{a-d}	5.23^{a-d}	32.55^{d-g}	9.31^{e-g}	44.93	28.73	570.50^{a}	60.16	435.80^{e}	5038.70^{b}	44.93^{ef}	2997.6 5^{cd}
3. DP 499	94.80^{a-d}	14.53	6.78^{a-c}	5.32^{a-d}	34.44^{a-f}	9.17^{f-h}	45.06	29.36	469.61^{a-c}	60.71	336.90^{f}	4867.20^{bc}	51.66^{cd}	3123.41^{a-d}
4. STV 453	89.60^{b-e}	16.26	6.71^{a-d}	5.24^{a-d}	36.00^{a-c}	10.31^{a-c}	46.70	26.66	291.23^{de}	65.82	458.46^{de}	4005.60^{e-g}	47.20^{c-f}	3225.91^{a-d}
5. STV 468	86.33^{c-e}	15.66	5.60^{f}	4.34^{e}	30.00^{g}	8.62^{hi}	45.76	28.20	382.75^{b-e}	67.93	767.40^{a}	6780.40^{a}	42.20^{f}	3079.08^{cd}
6. STV 474	88.13^{b-e}	15.46	6.60^{b-d}	5.16^{b-d}	32.77^{c-g}	9.58^{d-f}	46.93	28.10	496.60^{a-c}	63.92	279.63^{fg}	4092.20^{ef}	50.80^{c-e}	3477.77^{a-c}
7. SJ-U 86	95.33^{a-c}	15.46	6.83^{a-c}	5.36^{a-c}	34.66^{a-e}	9.45^{ef}	45.03	26.36	461.45^{a-c}	70.71	476.80^{de}	3695.50^{gh}	52.93^{b-d}	2572.81^{de}
8. AGC 85	86.13^{de}	13.60	6.44^{c-e}	5.17^{b-d}	36.66^{ab}	8.50^{i}	44.06	27.73	264.86^{e}	55.13	288.90^{fg}	3549.40^{hi}	51.53^{cd}	3783.96^{a}
9. AGC 208	85.06^{e}	15.53	6.02^{d-f}	4.76^{de}	31.11^{fg}	9.43^{e-g}	46.96	26.83	403.85^{b-e}	64.72	297.76^{fg}	3693.13^{gh}	58.73^{ab}	2750.55^{d}
10. AGC 375	95.66^{ab}	19.86	6.50^{cd}	5.11^{cd}	35.33^{a-d}	8.85^{g-i}	49.80	26.93	341.25^{c-e}	54.56	242.30^{g}	3767.33^{f-h}	60.50^{a}	3771.19^{ab}
11. Fiber Max 819	96.73^{ab}	16.46	5.75^{ef}	4.41^{e}	30.33^{g}	9.15^{f-h}	47.23	26.96	458.85^{a-c}	61.15	444.33^{de}	4516.60^{cd}	50.76^{c-e}	3151.54^{a-d}
12. Fiber Max 832	92.66^{b-e}	16.00	7.30^{ab}	5.78^{a}	37.44^{a}	9.83^{c-e}	47.13	27.40	510.23^{ab}	66.42	636.73^{b}	4251.20^{de}	53.50^{bc}	1955.07^{ef}
13. Fiber Max 958	92.46^{b-e}	16.30	7.36^{a}	5.74^{ab}	33.77^{b-f}	10.12^{b-d}	48.63	26.93	436.25^{a-d}	60.16	321.66^{f}	2942.50^{j}	48.86^{c-e}	1794.00^{f}
14. Acala 1517-95	97.26^{ab}	16.46	6.85^{a-c}	5.34^{a-d}	34.44^{a-f}	10.45^{ab}	42.73	25.26	471.55^{a-c}	63.18	536.46^{c}	3322.60^{i}	50.70^{c-e}	3094.84^{b-d}
15. Acala 1517-99	103.46^{a}	15.06	6.93^{a-c}	5.34^{a-d}	31.88^{e-g}	10.78^{a}	44.63	25.26	400.00^{b-e}	79.44	501.33^{cd}	4001.20^{e-g}	49.20^{c-e}	3144.04^{a-d}
Mean	92.16	16.10	6.60	5.16	33.64	9.47	46.17	27.34	433.39	63.25	449.52	4159.59	50.70	3026.42
CV (%)	5.93	15.83	6.51	6.78	6.09	3.69	5.47	10.53	22.73	21.67	7.84	5.04	7.49	13.41
LSD (0.05)	9.11*	ns	0.72**	0.58**	3.42**	0.57**	ns	ns	164.09*	ns	58.75**	349.28**	6.32**	67.64**

* and **, Significant at 0.05 and 0.01 level of probability, respectively; PH, plant height; BN, boll number (per/plant); BW, boll weight (g); SCW, seed cotton weight per boll (g); NSB, number of seeds per boll; 100 SW, 100 seed weight (g); CC, chlorophyll content (SPAD value); LT, leaf temperature; SC, stomatal conductance (mol $m^{-2}s^{-1}$); RCIL, relative cell injury level (%); PAR, photosynthetically active radiation, FL, fluorescence, PY, photosynthetic yield, SCY, seed cotton yield (kg ha^{-1}).

October, 2010; second harvest was done on 10 November, 2010. The samples were ginned on a laboratory roller gin, and seed samples of 100 seeds were taken from each of the replicates of field plots for 100 seed weight. Statistical analyses were performed using JMP 5.0.1 statistical software (http://www.jmp.com) and the means were grouped with LSD $_{(0.05)}$ test.

Measurement of physiological traits

All physiological traits were measured at the first week of August, approximately 80 days after planting, the time of peak flowering and fruiting. Measurements were taken during mid-day on the fifth fully expanded leaf below the terminal with one reading per leaf of the plant according to Johnson and Saunders (2003). Photosynthesis was measured using the EARS-PPM Plant Photosynthesis System. Photosynthetic yield (µmol CO_2 $m^{-2}s^{-1}$), photosynthetic ally active radiation (PAR) and fluorescence were measured by this tool. Stomatal conductance (mol $m^{-2}s^{-1}$) was measured by a leaf porometer (Model SC-1), leaf temperature was measured by an infrared thermometer (DT-8811H) and leaf chlorophyll contents were measured by a Minolta SPAD-502 chlorophyll meter. Relative cell injury level (RCIL), a measurement for cell membrane thermostability (CMT) under high temperature stress, was determined according to Sullivan (1972).

RESULTS AND DISCUSSION

The analysis of variance of the investigated traits indicated that significant differences among the varieties were obtained for plant height, boll weight, seed cotton weight per boll, number of seeds per boll, 100 seed weight, stomatal conductance, PAR, fluorescence, photosynthetic yield and seed cotton yield. Non-significant differences were observed for boll number per plant, chlorophyll content (SPAD value), leaf temperature and RCIL as seen in Table 1.

The analysis of variance indicated that there were significant differences ($P \leq 0.05$) among the varieties for stomatal conductance. Among the genotypes screened, DP 90, DP 396, Fiber Max 832, Stoneville 474, DP 499, Acala 1517-95 and

SJ-U 86 had the highest stomatal conductance value. Comparisons of stomatal responses in cultivars with contrasting agronomic characteristics have been reported by Roark and Quisenberry (1977), but no conclusive evidence has emerged on defined relations between stomatal conductance and yield. Recent studies have used such an approach to investigate the relationship between stomatal conductance and yield and revealed that low yielding lines showed a lower stomatal conductance than high yielding advanced lines (Lu et al., 1998).

Lu et al. (1997) observed that an upland cotton cultivar DP 90 showed 25 to 35% higher stomatal conductance, 35 to 50% higher photosynthetic rate, and 45% smaller leaf area than Pima S-6. Furthermore, the higher photosynthetic rate and stomatal conductance of DP 90 leaves were partly related to their sun-tracking ability.

RCIL ranged from 54.56 to 79.44%. Among the cotton cultivars AGC 375, DP 396 and AGC 85 had the lowest relative injury level (higher cell membrane thermostability), while Acala 1517-99, SJ-U 86, Stoneville 468, Fiber Max 832 and Stoneville 453 had the highest. However, cultivar differences were not significant statistically (Table 1). Azhar et al. (2009) used relative cell injury percentage to measure heat tolerance in cotton, and reported that heat tolerant accessions had more stable yield and yielded more seed cotton with better quality fiber than the heat-intolerant accessions across four environments.

Wang (1988), indicated that when plants are under high-temperature stress, the structure of membrane is altered, permeability increases, electrolyte leakage increases, and eventually the cell dies. Rahman et al. (2004) indicated that exposure to high temperature prior to the CMT test produced better distinction between heat-tolerant and heat-susceptible cultivars; however, they cautioned regarding its indirect selection on the basis of seed cotton yield under non-heat stressed environments.

The cultivar effect on photosynthetic yield, fluorescence and PAR are shown in Table 1. There were significant differences between cultivars for fluorescence, photosynthetic yield and PAR at ($P \leq 0.01$) probability level.

The data revealed that the Stoneville 468, DP 90 and DP 499 cotton cultivars showed statistically higher fluorescence value when compared to all the other cultivars. Stoneville 468, DP 396 and Fiber Max 832 showed numerically higher PAR compared to all the other cultivars. AGC 375 and AGC 208 had the highest value for photosynthetic yield.

The cultivars used in the experiment AGC 85, AGC 208, AGC 375 and SJ-U 86 were registered as modern cultivars for heat tolerance and better fiber quality (Ulloa et al., 2006). The other used standard cultivars (Stoneville and DP cultivars) commonly have been planting in this region. The results of this study showed that photosynthesis could be used as indicator of heat tolerance, but these results were inconsistent with Bibi et al. (2008), who reported that photosynthesis sensitivity was not practical for screening large numbers of genotypes for temperature tolerance. This inconsistency may be stem from differences of the used photosynthesis measurement devises.

Among the varieties, Acala 1517-99 was taller than the other cotton genotypes. The highest boll number were obtained from AGC 375 (19.86 per/plant) and DP 396 (18.06 per/plant) cotton genotypes, but differences between genotypes was non-significant for boll number per plant. Fiber Max 958 and Fiber Max 832 genotypes had the highest value for boll weight and seed cotton weight per boll and Fiber Max 832 also had the highest value for number of seed per bolls.

Comparing the response to high temperature of all the cultivars used in this study revealed that cultivar variation existed for seed cotton yield at ($p \leq 0.01$) probability level, rangeing from 1794.00 to 3783.96 kg ha^{-1}. Among the cotton cultivars AGC 85, AGC 375, Stoneville 474, DP 396, Stoneville 453, Fiber Max 819, Acala 1517-99 and DP 499 had the highest seed cotton yield (Table 1). The lowest seed cotton yields were obtained from Fiber Max 958 and Fiber Max 832, respectively. Oosterhuis et al. (2009) screened 134 entries from the Arkansas Variety tests to heat tolerance; only PHY370WR and DP515BGRR exhibited both tolerance to elevated temperatures as well as an ability to recover from the high temperature without any subsequent detrimental effect. In general, the majority of the 134 lines tested to date did not show any appreciable tolerance to high temperatures. They reported that the tolerant lines selected from the study (PHY370WR and DP515BGRR) will be compared with the yields in field tests that experienced heat stress.

Correlation coefficient between seed cotton yield, yield components and some morphological and physiological traits are presented in Table 2. Seed cotton yield positively correlated with chlorophyll content, fluorescence, photosynthetic yield, plant height and boll number. Seed cotton yield negatively correlated with leaf temperature, stomatal conductance, RCIL, PAR, boll weight, seed cotton weight, number of seeds per boll and 100 seed weight. The results of this study indicated that photosynthesis yield, fluorescence, chlorophyll content, cell membrane thermo stability, plant height and the number of bolls per plant can be used as selection criterion for seed cotton yield. Similar results were also reported by Malik et al. (1999), Rahman, (2005), Cottee et al. (2007), Bibi et al. (2008), Khan et al. (2008), Azhar et al. (2009) and Oosterhuis et al. (2009). Consistent with previous research, cultivar differences in yield were correlated with fruit retention that affected boll number, which reflected that high temperature stress during flowering induced fruit abscission that limited yield (Cottee et al., 2010). In that study, which was carried out under tents and ambient field conditions, stomatal conductance was not found to be correlated with seed cotton yield, however a strong positive correlation was

Table 2. Correlation coefficients between seed cotton yield, yield components and physiological traits.

Parameter	LT	SC	RCIL	PAR	FL	PY	PH	BN	BW	SCW	NSB	100 SW	SCY
CC	-0.1518	-0.0308	0.1506	-0.1801	-0.0645	0.2248	-0.1751	0.0818	-0.0173	-0.0270	0.0212	-0.1152	0.0241
LT	-	0.2182	-0.3833**	0.0705	0.1816	-0.2546	-0.1920	-0.1220	-0.1700	-0.1502	-0.0586	-0.2625	-0.0733
SC	-	-	0.1235	0.2051	0.0280	-0.1220	-0.1225	-0.1181	0.1427	0.0964	-0.0672	-0.0011	-0.3106*
RCIL	-	-	-	0.0818	0.0672	0.1812	-0.0342	-0.1082	0.0772	0.0409	-0.0207	0.1847	-0.0816
PAR	-	-	-	-	0.4626**	-0.5200**	0.0261	0.0384	-0.0973	-0.1265	-0.1600	-0.0338	-0.1477
FL	-	-	-	-	-	-0.4164**	-0.1195	-0.0085	-0.4134**	-0.4375**	-0.3739*	-0.3103*	0.1546
PY	-	-	-	-	-	-	0.0740	0.1724	0.0706	0.1010	0.3338*	-0.0992	0.0212
PH	-	-	-	-	-	-	-	0.3476*	0.4478**	0.4103**	0.0488	0.4956**	0.0011
BN	-	-	-	-	-	-	-	-	0.1843	0.1820	0.0429	-0.0133	0.1461
BW	-	-	-	-	-	-	-	-	-	0.9903**	0.5451**	0.4888**	-0.3024*
SCW	-	-	-	-	-	-	-	-	-	-	0.5927**	0.4427**	-0.2830
NSB	-	-	-	-	-	-	-	-	-	-	-	0.0394	-0.0076
100 SW	-	-	-	-	-	-	-	-	-	-	-	-	-0.3278*

*Correlation that is significant between measurements for $p < 0.05$; ** Correlation that is significant between measurements for $p<0.01$; PH, plant height; BN, boll number (per/plant); BW, boll weight (g); SCW, seed cotton weight per boll (g); NSB, number of seeds per boll; 100 SW, 100 seed weight (g); CC, chlorophyll content (SPAD value); LT, leaf temperature; SC, stomatal conductance (mol $m^{-2}s^{-1}$); RCIL, relative cell injury level (%); PAR, photosynthetically active radiation, FL, fluorescence, PY, photosynthetic yield, SCY, seed cotton yield (kg ha^{-1})

reported between stomatal conductance and transpiration rate. Previous studies showed that showed that stomatal conductance can be used as selection criterion for seed cotton yield, however, in this study such a correlation was not obtained. The reason for these differences can be related with measuring time and the quantity of observations. Some literatures have confirmed these results.

According to Radin et al. (1994), the physiological benefits of very high stomatal conductance are unexplained. Ulloa et al. (2000) reported that the strong enviro-nmental dependence of stomatal conductance and the large number of required measurements may limit the breeder's use of stomatal conductance as a selection criterion. Therefore, they suggested that quantitative trait loci (QTLs) and molecular markers provide breeders alternatives for selection.

Stomatal conductance at high temperature is positively correlated with stomatal sensitivity to temperature, and independent from photosynthesis (Lu and Zeiger, 1994).

In addition, the differences in stomatal conductance between the low- and high-yielding pima lines is under genetic control (Percy et al., 1996; Ulloa et al., 2000). Rahman (2005) revealed that the selection efficiency of stomatal conductance in segregating populations was likely to be affected by the complexity of its inheritance, environmental dependency, and presence of substantial non-allelic and genotype × tempe-rature regime interactions. Radin et al. (1994) determined that yield was more closely related to conductance in the afternoon than to that determined in the morning.

The stomatal component of heat resistance is apparently dependent on evapo-rative cooling.

The result of this study provided evidence that there are cultivar differences with respect to stomatal conductance, photosynthetic yield and seed cotton yield.

Therefore, this information is important in the development of adaptation studies, particularly concerning heat stress. Further confirmation of this approach is needed, that is, correlation between seed cotton yield and stomatal conductance of genotypes under field and controlled conditions.

There are many mechanisms by which plants are able to tolerate higher temperatures. Pollen germination, pollen tube growth and boll retention have been proposed as tools to identity cultivars tolerant to high temperature tolerance (Kakani et al., 2005; Liu et al., 2006). It is estimated that these methods are more sensitive therefore studies are needed for the current and future climates.

Conclusion

In the cotton growing areas of Turkey, especially Southeastern Anatolia Region, several episodes of temperatures higher than35°C usually occur in mid-July to mid-August. It is known that optimum temperature of cotton during growth and boll formation period is between 27 and 32°C. If global warming occurs as projected, cotton production in the future will be reduced and most of cottonproduction in semi-arid regions probably will be more affected. Therefore, this study represents an initial field investigation into the impact of heat stress on cotton yields in this region. The results of this study indicated that photosynthetic yield, fluorescence, chlorophyll content (SPAD value), CMT, plant height and the number of bolls per plant can be used as selection criterion for seed cotton yield in breeding studies for heat tolerance.

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