Genotypic variation in response to heat stress in Upland cotton

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ABSTRACT

The effect of heat stress on cotton morphological characters, earliness, boll retention, yield and yield components and fiber traits was studied in thirty-six upland cotton genotypes. Field experiments were conducted in Alcalá del Rio (Seville) on a sandy loam soil. A heat-stress treatment was provided by using a plastic shelter while running side-by-side an unsheltered control. A split-plot design with three replications was used. The main factor was heat treatment and the genotypes sub treatment. Heat treatment had significant effects on traits plant height, boll number, boll retention, seed cotton yield, fiber percentage, seed index, and fiber properties (micronaire, length, resistance and elongation). The Analysis of Variance showed significant genotypic variation for all characters and significant genotype by treatment interaction for traits seed cotton yield, boll number, fiber percentage and micronaire. The biplot of seed cotton yield under heat stress and the control treatment showed a differential performance of the genotypes. Some genotypes had a high yield potential but low yield after heat treatment. The positive association among boll number, fiber percentage and micronaire with seed cotton yield considering both treatments (heat stress, no stress) indicates that this characters might be used for selection in a heat-stress tolerance program.

Introduction

Air temperature is a main factor controlling the growth rate and reproductive events of cotton plants. Simulation models used for predicting cotton yield sometimes are not accurate enough for cotton grown in Andalusia (Gutiérrez *et al.*, 2000). Cumulative heat units in Andalusia reach 1320 days-degree (180 days season growth from April to September) and higher yield should be expected in the absence of other limiting factors. A possible yield-limiting factor might be high summer temperatures, which have been negatively, associated to seed cotton yield and some fiber traits (length, uniformity) (López *et al.*, 2002).

Cotton is relatively heat tolerant in comparison with other C3 crops but high temperature may increase square and boll shedding and decrease yield (Guinn, 1998). Leaf temperatures higher than 28 ^{0}C might affect metabolic processes (Hatfield and Burke, 1991). A decrease in boll retention is observed when temperatures are above 29 ^{0}C (Phene *et al.*, 1978; Reddy *et al.*, 1992). Temperatures above 32 ^{0}C reduce gross photosynthesis (Perry and Krieg, 1981), boll size and fiber length (Stockton and Walhood, 1960) while increasing boll-fill period (Yfoulis and Fasoulas, 1978). Increase in leaf temperature by a decrease in transpiration has been related to reduction in yield in drought-stressed cotton (López *et al.*, 1995). Temperature might also modify fiber traits when affecting basic processes like photosynthesis (Bradow and Davidonis, 2000).

In spite of the negative effects of high temperatures on cotton yield, only limited research has been carried out for the identification of heat-tolerance related traits. Some traits have been associated to higher yield after breeding Pima cotton in areas commonly bearing high temperatures during the season (Lu *et al.*, 1994). However, to our knowledge, no specific breeding programs for heat resistance have been developed. Breeding programs are normally undertaken in favorable environments, because greater progress is considered easier to achieve by selecting under optimum conditions (Rosielle and Hamblin, 1981).

The growing season for the main cotton-producing area in Spain (Guadalquivir River Valley) is characterized by a long dry period with high temperatures. The cotton yield variation found from year to year in that area has been closely associated with temperatures during the growing season (López *et al.*, 2002). The objective of this study was to determine the effect of heat stress on seed cotton yield and fiber properties of genotypes in cultivation in the SW of Spain.

Experimental procedure

Thirty-six Upland cotton genotypes (Table 1) were planted in Alcalá del Río (Sevilla, Spain) on a sandy loam soil (typic xerofluvent) in plots of one row 10 m long spaced 0.95 m apart. Sowing date was May 28th 2001. A heat stress treatment during 21 days was provided at flowering and boll set (August 8th - September 7th) (Figure 1). The increase in air temperature was reached by using a plastic shelter of polyethylene film set up at 1.75 m height. Air temperatures were continuously recorded in and out the shelter by using temperature data loggers (HOBO, Onset Computer Co.). The shelter was removed during irrigation. An unsheltered field trial with the same genotypes and experimental design was run simultaneously as a control. The statistical design was a split plot with three replications and heat stress as primary factor and genotypes as secondary factor. At harvest, plant height, number of nodes, number of fruiting sites and bolls were recorded. The bolls and seed cotton were weighed and fiber properties were determined by HVI after ginning. Seed index was determined as the weight of 100 seeds. Earliness was calculated as the ratio between the final yield and yield recorded at first picking.

Results and Discussion

As it can be seen in Table 2, highly significant differences were observed in plant height, number of nodes, boll retention and earliness among the genotypes. Heat treatment only affected plant height and boll retention (Table 2).

Genotypic differences in yield and yield components were also recorded (Table 3), and the heat stress affected significantly yield, number of bolls, seed index and the percentage of fiber. A significant interaction genotype by treatment was observed for seed cotton yield, total of harvested bolls and fiber percentage (Table 3).

Fiber quality characters also varied among genotypes (Table 4), and heat stress had an effect on traits like fiber length, strength, micronaire and elongation. Significant interaction between genotypes and heat treatment was observed for micronaire (Table 4).

In Figure 2, the biplot between seed cotton production under shelter and the control (no stress) is shown. A significant positive relationship between yield under optimum conditions and under heat stress was observed ($r=0.586$, $P<0.001$, $n=36$). Genotypes 15, 16, 19, 21 and 28 were more affected by heat stress than the rest, although genotype 15 had the highest yield in both treatments. Meanwhile, genotypes 3, 6, 12, 23 and 36 showed similar yield under stress or without stress.

Under no stress conditions, yield was positively correlated with plant height ($r=0.411$, $P<0.01$, $n=36$) and the number of nodes ($r=0.517$, $P<0.001$, $n=36$), whereas under heat stress, only boll retention was associated with cotton yield ($r=0.488$, $P<0.01$, $n=36$). A positive correlation between seed cotton yield and the number of bolls or the percentage of fiber was observed for cotton genotypes grown under optimum conditions ($r=0.872$, $P<0.001$; $r=0.472$, $P<0.01$, respectively) or under heat stress ($r=0.893$, $P<0.001$; $r=0.437$, $P<0.01$, respectively).

Boll shedding was the main factor associated with yield reduction under heat stress in the conditions of our experiment, and this result is in agreement with previous reports showing a decrease of boll retention under high temperature (Reddy *et al.*, 1992; Guinn, 1998). The relationship between potential yield and yield under heat stress might suggest selection under no stress. However, the magnitude of the interaction genotype x treatment for yield and some yield components (number of bolls, fiber percentage) makes doubtful the progress of selection under no stress for the potential risk of selecting genotypes with low performance under heat stress.

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Table 1. List of cotton genotypes studied with reference to their origin.

Genotypes	Code	Origin	Genotypes	Code	Origin
Virgen de Gracia	1	Spain	Carmen	19	Australia
Sor Angela	2	id	Corona	20	USA
Marismas	3	id	Crema 111	21	id
Carlota	4	id	Anita	22	id
Conchita	5	id	Bravada	23	id
Max 9	6	USA	María del Mar	24	Spain
Celia	7	Australia	La Chata	25	id
Sonia	8	id	Avangard 264	26	Bulgaria
Delta Opalo	9	id	GC 510	27	USA
Atina	10	USA	Rosita	28	Spain
Tauro	11	id	Guadalquivir	29	id
Theka	12	Spain	Cristi	30	id
Coketa	13	id	Acala 1517/77/BR	31	USA
Tashkent 6	14	Russia	DP 90	32	id
Nata	15	USA	Precoce 1	33	Brazil
Flora	16	Australia	Acala Prema	34	USA
Montana	17	USA	CNPA 3H	35	Brazil
Fotini	18	Australia	Koralle	36	USA

Table 2. Means and results of ANOVA for morpho-physiological traits in thirty-six cotton geno types grown under different heat treatment. Means followed by the same letter are not significantly different (LSD test, P<0.05).

	PH	NN	FS	%R	Earliness
Control	99.75 b	18.46 a	21.81 a	39.93 a	70.22 a
Heat stress	104.33 a	18.99 a	24.27 a	24.79 b	43.59 a
ANOVA					
Treatment (T)	P<0.05	Ns	Ns	P<0.05	Ns
Genotypes (G)	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
G*T	Ns	Ns	Ns	Ns	Ns

PH = Plant height (cm)

NN = number of nodes

FS = number of fruiting sites

%R = percentage of boll retention

Ns = not significant

Table 3. *Means and results of ANOVA for yield and yield components in thirty-six cotton genotypes grown under different heat treatment. Means followed by the same letter are not significantly different (LSD test, P<0.05).*

	Yield (kg/ha)	NB	BW	F%	SI
Control	4171 a	877680 a	4.81 a	39.00 a	9.86 b
Heat stress	3274 b	614571 b	5.39 a	36.86 b	11.99 a
ANOVA					
Treatment (T)	P<0.05	P<0.05	ns	P<0.01	P<0.001
Genotypes (G)	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
G*T	P<0.001	P<0.01	Ns	P<0.01	Ns

NB = bolls per hectare

BW = boll weight (g $boll^{-1}$)

F% = fiber percentage

SI = seed index

Ns = not significant

Table 4. *Means and results of ANOVA of fiber properties in thirty-six cotton genotypes grown under different heat treatment. Means followed by the same letter are not significantly different (LSD test, P<0.05).*

	Micronaire	Length (mm)	Strength g $tex^{-1)}$	Uniformity (%)	Elongation (%)
Control	3.80 b	29.78 b	32.83 a	83.39 a	6.12 a
Heat stress	4.22 a	30.44 a	30.37 b	83.40 a	5.54 b
ANOVA					
Treatment (T)	P<0.01	P<0.05	P<0.05	ns	P<0.05
Genotypes (G)	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
G*T	P<0.01	Ns	Ns	Ns	Ns

Ns = not significant.

Figure 1. *Mean air temperatures recorded in plastic-sheltered and control plots during heat treatment.*

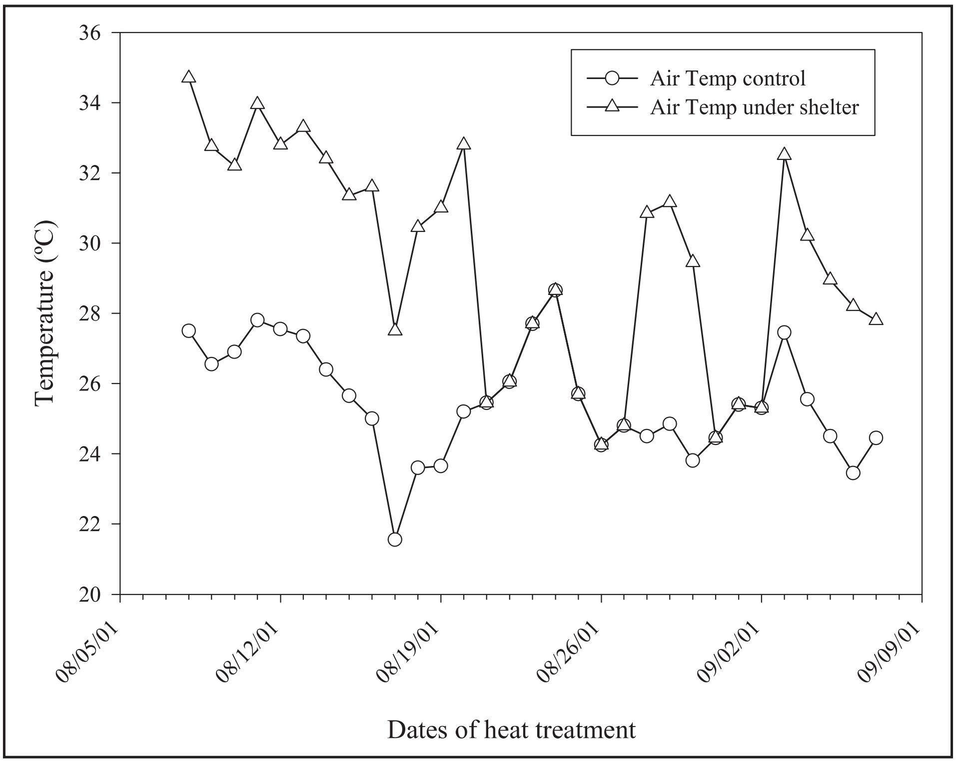

Figure 2. *Genotypic productivity of seed cotton under heat stress conditions versus productivity under favorable conditions.*