Turk J Biol
31 (2007) 119-126

Modified Path to High Lint Yield in Upland Cotton (*Gossypium hirsutum* L.) under Two Temperature Regimes

Saeed RAUF[1,*], Tariq Manzoor KHAN[2], Abdul NAVEED[2], Hassan MUNIR[3]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad 38040 - PAKISTAN

[2]Directorate of Research, University of Agriculture, Faisalabad 38040 - PAKISTAN

[3]Department of Crop Physiology, University of Agriculture, Faisalabad 38040 - PAKISTAN

Received: 03.10.2006

Abstract: In this study 23 genotypes, including 8 cultivars and 15 advanced lines were consecutively grown under 2 temperature regimes in 2004 and 2005 at the Post Graduate Agriculture Research Station, University of Agriculture, Faisalabad, Pakistan. Lint yield and its component traits, i.e. lint weight per boll, lint weight per seed, fiber length, fibers per seed, fibers per unit surface area, lint weight per unit surface area, and fiber weight per unit surface area, were measured and analyzed for heritability, genetic advance, and correlations. Phenotypic correlations were also partitioned into path coefficients, keeping lint yield as the resultant variable and other components as causals.

The heat-stress regime showed higher estimates of broad sense heritability, genetic variability, and genetic advance for all basic lint yield traits, except for fiber weight per unit length. Similarly, response to the selection was high under the heat-stress regime. The basic lint yield component showed a stronger relationship to lint yield (R^2 = 0.77) under the heat-stress regime, indicating some value of these traits under heat stress. Both path analysis and multiple regressions revealed that fibers per seed had the greatest direct effect on the lint yield under both regimes.

Key Words: Gossypium hirsutum, basic lint yield traits, correlation, path analysis

Introduction

Developing crop cultivars with high lint yield is considered to be a principal aim of upland cotton breeding programs worldwide. Most breeding programs initiated for lint yield improvement usually aim at improving the lint yield through selection for high boll number, higher lint percentage, and smaller seed and boll size (1). Although it is recognized that lint yield has steadily increased through selection based on these traditional criteria, in recent years it became evident that further improvement in lint yield was very slow, highlighting the absence of the necessary variation in these traditional selection criteria. These criteria for the evolution of high yielding genotypes should therefore be combined with other yield components.

Within the boll, yield can be dissected further. Seed cotton comprises 2 primary components, the number of seeds per boll and number of fibers borne on these seeds. The amount of surface area on each seed, the number of fibers produced per seed, fibers per unit surface area, lint weight per seed, lint weight per unit surface area, and fiber weight per unit length all contribute to fiber production and, therefore, lint yield. Combining ability for within-boll yield components was evaluated by Coyle and Smith (2), indicating that genotypes with positive GCA effects for fiber quality had negative GCA effects for basic within-boll yield components, such as fibers per seed.

In addition to contributions to yield, primary lint yield components tend to be affected by environmental stressors (3). The relative sensitivity of these primary lint components to the environment, especially high temperature, should also affect their relative contribution to the resultant lint yield (4-6). Cotton fiber (lint) consists predominantly of carbohydrates. High, above average day temperatures result in reduced photosynthesis and production of carbohydrates, whereas hot night temperatures increase respiration and photorespiration, with an additional loss of carbohydrates. The overall result is the depletion of carbohydrates, creating a deficit in meeting the requirements to retain and mature fruit. The result is the shedding of flowers and immature bolls, and decreased boll weight and lint percentage of matured bolls. Decreased lint percentage and boll size is the consequence of a decrease in the number of fibers per seed due to reduced carbohydrates (7).

Although growth chambers provide control over environmental variation, they are not necessarily representative of performance under field conditions (8). For example, soil volume in containers is typically small, affecting nutrient- and moisture-holding capacity, as well as buffering of the root zone from fluctuations in air temperature. Light intensity and quality also can differ from natural sunlight. Therefore, appropriate phenotypic characterization of plant responses to heat stress is crucial to studies of heat tolerance. Field evaluation of cotton under high temperatures (35-47 °C), but with irrigation, is a practical approach to evaluate heat responses (9).

The present study, therefore, was initiated to understand the impact of high temperature on the relative genetic contribution of basic lint components towards ultimate lint yield during the boll maturation period. Information hence gathered will be useful in selecting for high lint yield through its components.

Materials

Experiments were carried out with 23 genotypes: 8 upland cotton (*Gossypium hirsutum* L.) cultivars and 15 advanced lines. The genotypes used in the present study represented a wide range of morphological and yield traits.

Methods

Experiments were carried out at the Post Graduate Research Station, University of Agriculture, Faisalabad, Pakistan (lat 31°26'N, long 73°-06'E, 184.5 m asl), in the center of a mixed cropping zone of Punjab Province. Plot size in all experiments was 450 × 75 cm. Experiments were laid out in a randomized complete block design with 3 replicates. Plants within rows were spaced 30 cm apart. Soil at the experimental site was loam texture with the following characteristics: EC: 0.41 dS m^{-1}; pH: 8.5; organic matter: 0.93%; saturation: 27%; available phosphorus: 28.8 ppm; available potassium: 142 ppm. Heat-stress and non-stress regimes were provided in the field by sowing the seeds at 2 intervals during the crop seasons: on April 7 and May 29, 2004, and on April 15 and June 4, 2005. Minimum and maximum prevalent temperatures during the phenological development of the plants in the 2 regimes differed substantially; temperatures for the early-sown experiments were higher than those for the later-sown ones. Provision of different temperature regimes in the field experiments through sowing dates is a valid technique and has been used in several crops, for example cotton (10,11).

Agronomic practices were similar to the recommendations for growing cotton in every regime, for both years of the study. Adequate irrigation was applied to eliminate confounding effects of drought on crop growth and fiber development. Irrigation intervals varied from 7 to 12 days depending upon the weather and crop requirements. Insect pests were managed before they crossed the economic threshold level.

Yield components measured

Seeds were delinted with concentrated sulfuric acid. Seed volume was determined by placing 100 delinted seeds collected from each plot into 20 ml of ethyl alcohol. Seed volume was converted to surface area per seed with Hodson's (12) estimation table.

Fiber quality parameters obtained from HVI testing included fiber length (FL) and micronaire.

The other traits computed were:

i. Lint yield per plant (LY/P) = Lint weight obtained from each plot after ginning with a single roller electric ginner/ number of plants per plot.

ii. Lint weight per boll (LW/B) = Lint weight per sample/number of bolls in the sample.

iii. Fibers per seed (F/S) = Lint weight per seed/fiber length in meters × (HVI micronaire × 39.37 × 10^{-6}).

iv. Fibers per unit surface area (F/USA) = Fibers per seed/surface area of seed.

v. Lint weight per seed (LW/S) = (Boll weight in grams/seeds per boll) × (lint percentage/100).

vi. Lint weight per unit surface area (LW/USA) = Fibers per unit surface area × fiber length in meters × (HVI micronaire × 39.37 × 10^{-6}).

vii. Fiber weight per unit length (FW/UL) = (Lint weight per unit surface area/fibers per surface area)/fiber length in meters.

Statistical and Biometric procedures

Heritability and Genetic Advance

Broad sense heritability (h^2) and genetic advance at 5% level of selection estimates were calculated using the formula of Falconer (13).

Correlations and Path Coefficients

The estimates of phenotypic correlation coefficients were worked out using the formulae suggested by Kwon and Torrie (14). Statistically, significance of phenotypic correlation coefficients was determined by t-test, as described by Steel and Torrie (15). Phenotypic correlations were partitioned into path coefficients using the technique outlined by Dewey and Lu (16). In all, 8 paths were run to determine the direct effects, keeping each trait in each path as resultant variables, while other were kept as causal variables for the construction of the path diagram in each regime. LY/P was not considered a causal variable in any of the paths. The effects were distributed according to their magnitude into different categories (Table 1). The values with negligible effects were not used in the construction of path diagrams.

Table 1. Categories of direct and indirect effects on the basis of their magnitude.

Value	Effect
0.00-0.09	Negligible
0.10-0.29	Weak
0.30-0.49	Moderate
0.50-0.79	Moderately strong
0.80-0.99	Strong
≥ 1.00	Very strong

Multiple Regression

Path analysis usually gives us the intensity of direct or indirect effect of a particular variable on other traits, but does not quantify the yield if selection is done on the basis of that trait. Therefore, LY/P was modeled using multiple regression with LW/B, LW/S, F/S, F/USA, FW/UL, and FL and LW/USA, under both heat-stress and non-stressful regimes.

$$y = \alpha + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7$$

where y is estimated lint yield, α is a constant, b_1 through b_7 are regression coefficients, x_1 is LW/B, x_2 is LW/S, x_3 is LW/USA, x_4 is F/S, x_5 is F/USA, x_6 is FW/UL, and x_7 is FL. Lint yield in response to the selection of particular traits was estimated by using the multiple regression equations obtained under each temperature regime.

The data were analyzed in a factorial arrangement. All effects were assumed fixed. The genotypes × years interaction was non-significant ($P > 0.05$), while genotypes × temperature regimes was highly significant in all traits under study ($P < 0.01$). All parameters were therefore analyzed by pooling the data over the 2 years for each temperature regime.

Results

The genetic variability, broad sense heritability and genetic advance estimates were high under the heat-stress regime as compared to the non-stress regime, for all traits under study, except FW/UL, in which the broad sense heritability estimate was high under the non-stress regime. Among the basic lint yield traits, F/S showed the highest genetic variability and genetic advance (Table 2).

The phenotypic correlation coefficients were determined for all the possible character combinations with the objective to derive information about the nature and intensity of the relationship among the different character combinations (Table 3).

Table 2. Genetic variability, broad sense heritability, and genetic advance estimates under the heat-stress and non-stress regimes.

Parameters	LW/B		LW/S		F/S		F/USA		LW/USA		FW/UL		FL	
	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS	HS	NS
Genetic variability (σ^2G)	0.02	0.01	0.00	0.00	806.96	685.56	775.89	616.23	0.00	0.00	0.00	0.00	0.62	0.57
Broad sense heritability	0.78*	0.61*	0.75*	0.59*	0.72**	0.68**	0.59**	0.52*	0.67*	0.41*	0.78**	0.90**	0.92**	0.49*
Genetic advance	0.24	0.16	0.006	0.004	1570.04	1409.73	1302.40	1243.94	0.005	0.004	0.00	0.00	1.40	1.09

*, **significant at 5% and 1% level of probability, respectively.

Table 3. Phenotypic correlation coefficients among all possible combinations of 8 different lint yield components under the heat-stress (diagonal) and non-stress (anti-diagonal) regimes.

	FL 1	FW/UL 2	F/USA 3	F/S 4	LW/USA 5	LW/S 6	LW/B 7	LY/P 8
				(Heat Stress)				
1		–0.19*	–0.26**	–0.37**	–0.04 NS	–0.24**	0.10 NS	0.05 NS
2	–0.31**		–0.61	–0.57**	0.13 NS	0.06 NS	–0.37**	–0.23*
3	–0.09 NS	–0.56**		0.95**	0.60**	0.67**	0.33*	0.27**
4	0.09 NS	–0.78**	0.84**		0.51**	0.71**	0.27**	0.34**
5	–0.03 NS	0.21*	0.63**	0.28**		0.90**	0.13 NS	0.18 NS
6	0.26**	0.06 NS	0.46**	0.48**	0.77**		0.11 NS	0.32**
7	0.17 NS	0.26**	–0.20*	–0.19*	0.07 NS	0.15 NS		0.73**
8	–0.04 NS	0.44**	–0.33**	–0.37**	–0.001 NS	–0.009 NS	0.62**	
				(Non-Stress)				

*, **: significant at 5% and 1% level of probability respectively.
NS: non-significant (P > 0.05).

The association between LW/B and LY/P was both positive and the strongest under both temperature regimes; however, under the non-stress regime its magnitude was reduced (Table 3). The correlation between LY/P and LW/S was positive; however, its estimate was negative under the non-stress regime. Similar types of trends were observed for F/S, LW/USA FL, and F/USA, which were positive under the heat-stress regime, but were negative under the non-stress regime (Table 3).

Path coefficient analysis was used to determine the effects of lint yield components on LY/P under both regimes. The effect of LW/B on lint yield was positive and moderately high under both regimes (Figures 1 and 2). The effect of FL on lint yield was positive and moderate under the non-stress regime (Figure 1), while its effect was negative and moderate under the heat-stress regime (Figure 2). F/S showed a strong and positive effect on lint yield under both regimes (Figures 1 and 2). The effect of FW/UL on lint yield was strong under both regimes, but it was only positive under the non-stress regime (Figure 1 and 2). F/USA and LW/USA had a negligible effect on lint yield under the non-stress regime (Figure 1); however, under the heat-stress regime, LW/USA showed a strong positive effect on lint yield, in contrast to F(USA, which had a strong negative effect on lint yield (Figure 2). The effect of LW/S was very strong and negative on lint yield under both regimes (Figures 1 and 2).

The variability in lint yield due to the basic lint yield components was significant under the non-stress regime ($P < 0.10$), while under the heat-stress regime the variability in lint yield due to independent variables was significant at $P < 0.01$. The relationship of lint yield to basic lint yield traits was weak under the non-stress regime ($R^2 = 0.27$), while it was strong under the heat-stress regime ($R^2 = 0.77$).

Multiple regression analysis was used to estimate LY/P under both regimes. LY/P was estimated by solving the equation given in Figures 3 and 4. The equation suggests that if selection is based on high LW/B a maximum LY/P of 49.78 g could be obtained under the non-stress regime (Figure 3). Similarly, with selection on the basis of high LW/USA or FL, a LY/P of 49.08 or 51.94 g can be obtained under the non-stress regime (Figure 3). LY/P of 62.06 g can be obtained if selection is performed on the basis of maximum FW/UL within these 23 genotypes (Figure 3). A maximum LY/P of 67.10 g can be obtained if selection is based on the maximum F/S under the non-stress regime (Figure 3).

A review of the data depicted in Figure 4 suggested that a LY/P of 42.76 or 57.02 g can be obtained if selection is based on high LW/B or genotypes with a maximum LW/USA. However, a LY/P of 88.71 g can be obtained if selection is based on the maximum F/S (Figure 4).

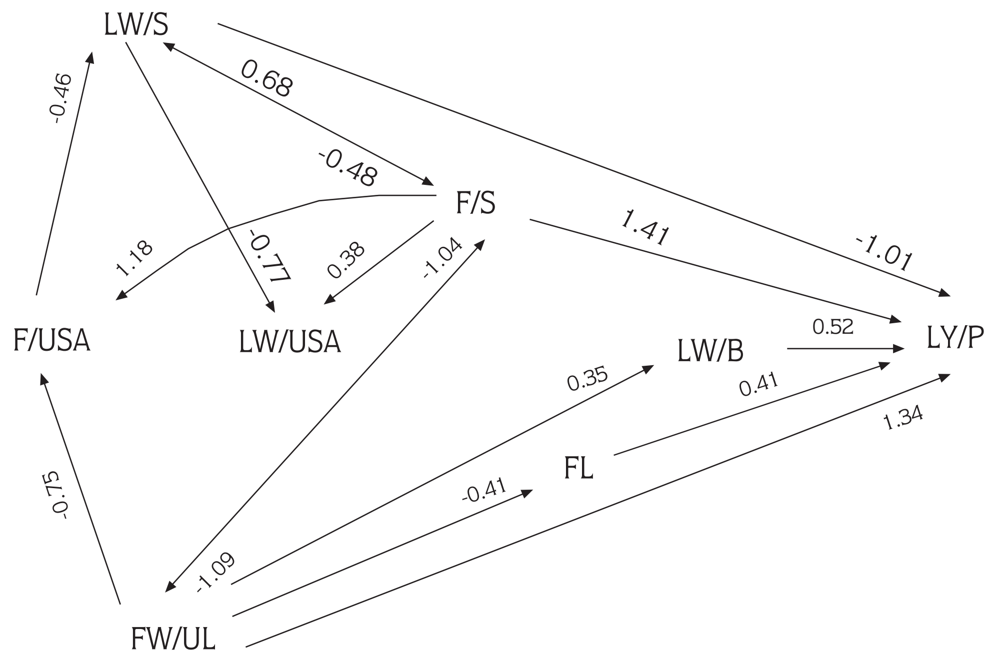

Figure 1. Path coefficient diagrams showing the interrelationships among LW/S, F/USA, LW/USA, FW/UL, LW/B, F/S, FL, and LY/P under normal conditions.

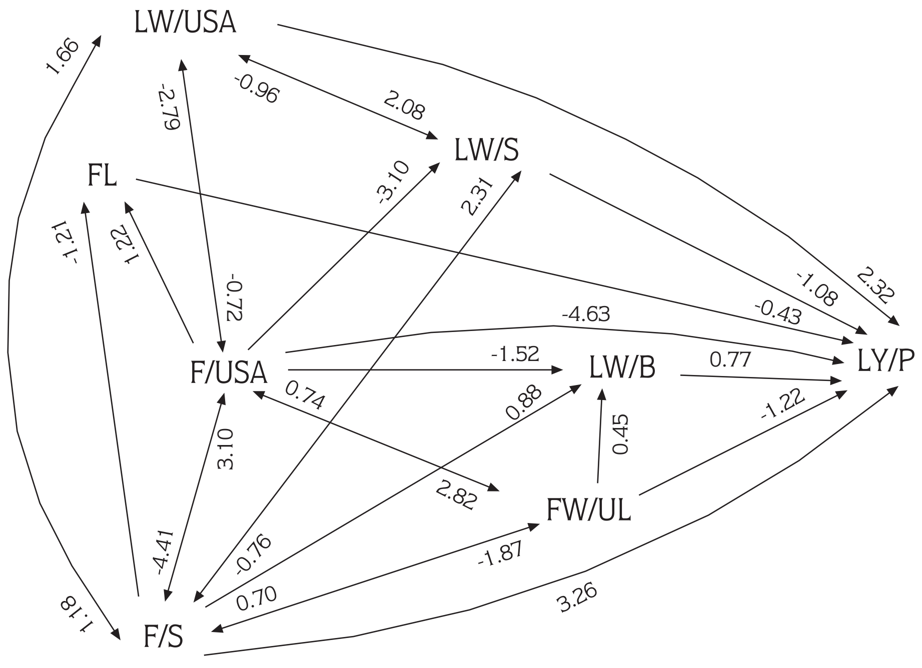

Figure 2. Path coefficient diagrams showing the interrelationships among LW/S, F/USA, LW/USA, FW/UL, LW/B, F/S, FL, and LY/P under the heat-stress regime.

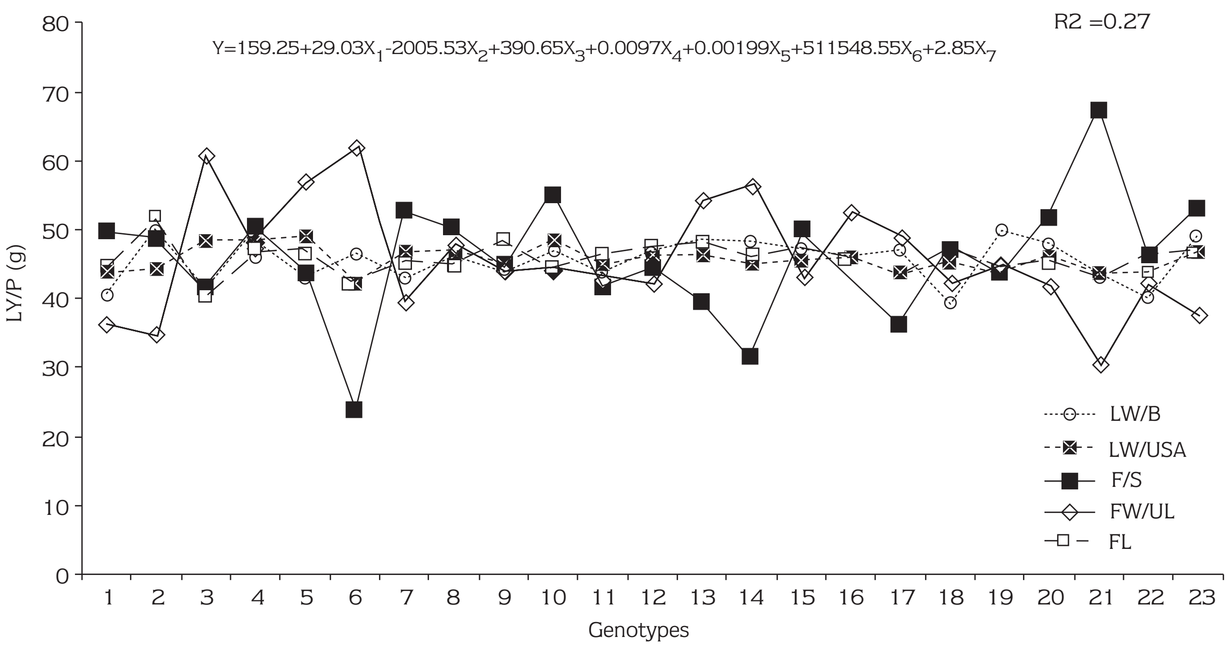

Figure 3. Estimated LY/P under the non-stress regime, on the basis of means of LW/B, LW/USA, F/S, FW/UL and FL of 23 genotypes used in this study, based on the equation's solution.

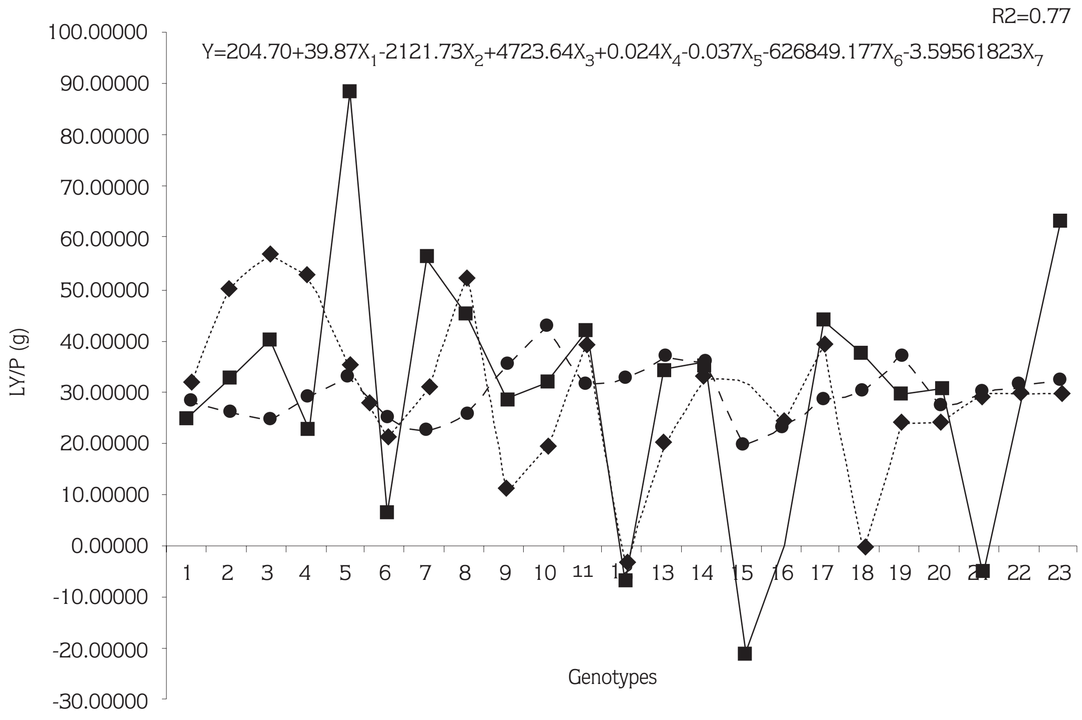

Figure 4. Estimated LY/P under the heat-stress regime, on the basis of means of LW/B (●), LW/USA (◆), and F/S (■) of 23 genotypes used in this study, based on the equation's solution.

Discussion

The results of the present study revealed higher genetic variability, broad sense heritability, and genetic advance among genotypes under the heat-stress regime with respect to basic lint yield traits. Heritability and genetic variability has been reported to increase with the extremity of environmental conditions and is interpreted as evidence of the expression of new genes under stress conditions (17,18).

Heat stress altered phenotypic correlations between the basic lint yield components, such as FW/UL, F/USA, F/S, LW/S, and LY/P. For instance the heat-stress regime showed a negative correlation between FW/UL and LY/P, and a positive correlation under the non-stress regime. In contrast, the heat-stress regime favored positive associations between F/USA, F/SA, and LY/P, while negative associations were observed under the non-stress regime. It may have been due to the relative sensitivity of these fiber traits to the temperature regimes, which eventually altered their associations with lint yield, while temperature influence on these fiber traits may have been due its effect on the expression of genes that control the development of fiber. This conclusion finds support in the work by Lewis (19), who evaluated 2 upland cotton varieties, genetically defined for the fiber maturity gene (imim), in the field to check the effects of temperature on fiber gene expression during early plant growth. The results of these experiments showed that F/S for both genetic types was influenced significantly by temperatures to which they were exposed during early true leaf elaboration. Changes in temperature during early plant development accounted for 74%-85% of the variation in F/S. These results were then verified in controlled growth chamber experiments, which not only confirmed the field results, but also demonstrated that brief exposure of 2nd-3rd true leaf plants to low temperatures also significantly impacted ultimate FL, micronaire value, and weight per fiber. A major effect on genetic short fiber content was found, resulting in a decrease in short fiber content as temperatures increased (19).

In the present study temperature regimes also modified lint yield path; however, F/S had the strongest positive direct effect on lint yield under both regimes. Therefore, the F/S criterion may be used for the evolution of high yielding cotton varieties under both regimes. The strongest effect of F/S on lint yield was also confirmed by predicting lint yield through the multiple regression equation. Although the equation in both regimes suggested that the highest LY/P could be obtained by selecting genotypes with maximum F/S under both regimes, better response may be obtained under the heat-stress regime. This may be due to the preponderance of additive genes under this regime. Rahman et al. (21) also found heat stress a more favorable environment for selection due to the prevalence of additive gene action and concluded F/S and F/USA are more useful traits from a breeding point of view.

F/S also posed a positive effect on other basic lint yield traits, such as LW/S, F/USA, and LW/USA, under both regimes. These findings are also supported by Lewis (20), who previously reported that approximately 99% of the increase in LW/S is accounted for by increased F/S, and an increase of 309 fibers per seed would result in a weight increase of about 1 mg of lint per seed. In Pakistani cultivars, F/S ranged between 1200 and 21,000 (5). Keeping other factors constant, an increase of 309 fibers per seed would increase lint yield by 10 kg/ha in the cotton belt of Punjab Province, Pakistan.

Corresponding author:
Saeed RAUF
Department of Plant Breeding and Genetics,
University of Agriculture,
Faisalabad 38040 Pakistan
Email: saeedbreeder@hotmail.com

References

1. Wells R, Meredith Jr. WR. Comparative growth of obsolete and modern cotton cultivars. III. Relationship of yield to observed growth characteristics. Crop Sci 24: 868-872, 1984.
2. Coyle GG, Smith W. Combining ability for with in boll yield components in cotton Gossypium hirsutum L. Crop Sci 37: 1118-1122, 1997.
3. Stewart JM. Integrated events in the flower and fruit. In: Mauney JR, Stewart JM. ed. Cotton physiology. The Cotton Foundation, Memphis, TN; 1986: pp. 261-300
4. Oosterhuis DM. Special research report, Arkansas Agricultural Experiment station, Arkansas; 1999: pp. 2-4.

5. Rahman H, Genetic basis of heat resistance in upland cotton (PhD thesis), Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan, Pakistan, 2004.

6. Rahman H, Malik SA, Saleem M et al. Heat tolerance of upland cotton during the fruiting stage evaluated using cellular membrane thermostability. Field Crop Res 85: 149-158, 2004.

7. Bradow JM, Davidonis GH. Quantitation of fiber quality and the cotton production processing interface: A physiologist's perspective. J Cot Sci 4: 34-64, 2000.

8. Hall AE. Crop Responses to Environment. CRC Press. Boca Raton, FL; 2001.

9. Ragsdale Pl. Diallel analysis of within-boll seed yield components and fiber properties in upland cotton (Gossypium hirsutum L.) and breeding potential for heat tolerance, (Ph.D. thesis), Texas A & M University, USA, 2003.

10. Stenier JJ, Jacobsen TA. Time of planting and diurnal temperature effects on cotton seedling field emergence and rate of development. Crop Sci 32: 238-244, 1992.

11. Morrison MJ, Stewart DW. Heat stress during flowering in summer brasica. Crop Sci 42: 797-803, 2002.

12. Hodson EA. Lint frequency in cotton with a method for determination. Arkansas Agric Exp Stn Bull, 168, 1920.

13. Falconer DS. Introduction to Quantitative Genetics. Longman Press. New York; 1981.

14. Kwon SH, Torrie, JH. Heritability and interrelationship among traits of two soyabean population. Crop Sci 13: 505-507, 1964.

15. Steel RGD, Torrie JH. Principles and procedures of statistics: A biometrical approach. McGraw Hill Inc. New York; 1980.

16. Dewey DR, Lu KH. A correlation and path coefficient analysis of components of crested wheat grass and seed production. Agron J 51: 515-517, 1959.

17. Waddington CH. Genetic assimilation. Adv Genet 10: 257–293, 1961.

18. Pál C. Plasticity, memory and the adaptive landscape of the genotype, Proc R Soc London. 265: 1319-1323, 1998.

19. Lewis H. Cotton yield and quality - where are we going and what do we need to do to get there? 14th EFS® System Conference 113-122, 1996.

20. Lewis H. Environmental regulation of yield and quality components in American Upland cotton. Genetic Control of Fiber and Seed Quality Conference 8-36, 2005.

21. Rahman H. Number and weight of cotton lint fibres: variation due to high temperatures in the field. Aust J Agric Res 57: 583-590, 2006.