

Relationship between Yield, Fiber Length and other Fiber-Related Traits in Advanced Cotton Strains

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Abstract

The objective of this study was to determine the relationship between yield, fiber length and other fiber related traits in advanced cotton strains, derived from a cotton breeding program. The experiments were conducted in the Southeastern Anatolia Agricultural Research Institute's experimental area according to randomized complete block design (RCBD) with four replications during 2007 and 2008 cotton growing season. In the study, 9 advanced cotton strains and 2 check varieties ('GW-Teks' and 'Stoneville 468') were used as plant materials. The results of the statistical analysis indicated that the advanced cotton strains had significant differences in terms of the investigated characteristics when compared to the check varieties. The highest seed cotton yield (4087.0 kg ha⁻¹) and fiber yield (1632.2 kg ha⁻¹) were obtained from 'SET-34' cotton strain which had acceptable fiber quality properties. However, the highest fiber length (32.33 mm) was obtained from 'ERA-85'. The correlation analysis indicated that there were significant negative correlations between fiber length and seed cotton yield, lint yield and ginning percentage, while there were positive and significant correlations between fiber length and fiber strength.

Keywords: Cotton, yield, correlation, fiber length, fiber technological properties

Introduction

Cotton is the world's most important fiber crop and the second most important oil seed crop. The primary product of cotton plant is the lint that covers the seeds (Freeland *et al.*, 2006). Cotton fibers grow from the epidermis of the seedcoat cells and begin to elongate from the day of anthesis flowering. This growth is completed in 15-25 days (Chaudhry and Guitchounts, 2003).

Fiber length is one of the most important technological properties of cotton fibers in both marketing and processing. Technological changes in the textile industry show that priorities associated with fiber properties have also changed, so the cotton breeders have to concentrate on the improvement in fiber traits to meet the demands of textile industry. Currently, most cotton programs are focused on breeding for longer fibers alone because the current premium and discount schedule reward this type of cotton. The average length of all fibers in a sample or the average length of a given percentage is related to other cotton fiber characteristics such as strength, fineness, maturity and uniformity (Braden, 2005).

Conventional breeding studies have shown that fiber properties tend to be moderately to highly heritable (Meredithe and Bridge, 1972). Environmental conditions within a growing year affect the length distribution of cotton fibers. The length of cotton fibers varies not only among

cultivars but also within a cultivar due to the growth environment, within the same plant due to position of the boll, within the same boll due to individual seed nutrients, and within the same seed due to the positions of fibers on the seed (Bradow *et al.*, 1997; Clouvel *et al.*, 1998; Braden and Smith, 2004; Davidonis *et al.*, 2004; Copur *et al.*, 2010). Abiotic factors such as rainfall, temperature, and irradiance can alter seed and fiber development (Bradow and Davidonis, 2000). Temperature fluctuations before anthesis and during fiber development have been implicated in changes in fiber quality (Davidonis *et al.*, 2004). Under inadequate moisture conditions and increasing temperatures, fiber length decreases and fiber micronaire values increase (Reddy *et al.*, 1999).

The previous studies indicate that seed cotton yield has significant negative correlation with fiber fineness, fiber strength and fiber length (Cheng and Zhao, 1991; Khan *et al.*, 1991). Azhar *et al.* (2004) reported that the association between fiber length and seed cotton yield was negative at phenotypic and genotypic levels, but significant only at phenotypic level. Similarly, the relationship between fiber fineness and fiber length were found to be negative at phenotypic and genotypic levels and also significant only at phenotypic level.

Braden and Smith (2004) reported that breeding for long staple genotypes has been successful, resulting in lines that possess improved yield and fiber quality but without

unduly delaying crop maturity. In contrast, some researchers explained that the development of cotton varieties with improved fiber traits has been very difficult due to the quantitative inheritance of these traits, which can be mitigated using new genomic tools like molecular markers for marker assisted selection in molecular breeding programs (Rahman, 2002; Asif *et al.*, 2006; Jauhar, 2006). Braden *et al.* (2009) suggested that most U.S. cotton breeding programs could improve fiber length by using 'TAM 94L-25' and 'TAM 94M-14' in combination with their breeding lines.

In recent years, the cotton breeders in Turkey have made a great effort to improve on fiber quality addition to seed cotton yield and fiber yield. The objective of this study was to determine the relationship between yield and fiber related traits in advanced cotton strains, derived from the cotton breeding program of the Southeastern Anatolia Agricultural Research Institute (SAARI).

Materials and methods

The experiment was conducted on the Southeastern Anatolia Agricultural Research Institute's experimental area during 2007-2008 cotton growing season in Diyarbakır/Turkey. In the study, eleven cotton strain/cultivars were observed in terms of seed cotton yield, fiber yield and fiber quality properties. Nine advanced cotton strains which developed for fiber quality and two check varieties ('GW-Teks' and 'Stoneville 468') were compared for yield and fiber quality traits.

The experiment was laid out as randomized complete block design (RCBD) with four replications. Each plot consisted of four rows of 12 m length, between and within the row spacing were 0.70 m and 0.20 m respectively. Seeds were planted with combine cotton drilling machine on 10th May, 2007 and on 6th May, 2008 and all plots were treated with 20-20-0 composite fertilizer to provide 70 kg ha⁻¹ N and 70 kg ha⁻¹ P₂O₅. Just before the flowering, 70 kg ha⁻¹ N was applied as ammonium nitrate to the trial as an additional N source. The experiment was thinned and hoed three times by hand and four times with a machine. Herbicides were used only once before sowing. In both years, insect were monitored throughout the experiment and no insect control was necessary during growing season. Experimental plots were irrigated for the first time, five weeks after sowing, and repeated seven times at ten to twelve-days interval in both years. Furrow irrigation was applied.

Plots were harvested twice by hand and the harvests from the four rows of the plot were weighed and calculated for seed cotton yield and fiber yield. The first harvest was done on 22nd October, 2007 and 24th October 2008 and the second harvest was done on 15th November, 2007 and 7th November, 2008. After the harvest, seed cotton samples were ginned on a mini-laboratory roller-gin for lint percentage. Fiber samples were then analyzed for fi-

ber quality properties by High Volume Instrument (HVI Spectrum). Statistical analysis were performed using JMP 5.0.1 statistical software (<http://www.jmp.com>) and the means were grouped with LSD_(0.05) test.

Results and discussion

The analysis of variance of the investigated characteristics and the findings from the cotton genotypes are presented in Tab. 1 and Tab. 2, and relationship between the investigated characteristics are presented in Tab. 3. Significant differences between the genotypes were obtained for seed cotton yield, fiber yield and all fiber traits measured.

The differences between the genotypes and years with respect to seed cotton yield were highly significant ($p < 0.01$), but variety x year interaction were non significant for this trait. According to the Tab. 1, seed cotton yield ranged between 3356.4-4647.3 kg ha⁻¹, 2713.5-3564.0 kg ha⁻¹, in 2007 and 2008, respectively. The average seed cotton yield of genotypes was 4161.3 kg ha⁻¹ in 2007, and 3331.7 kg ha⁻¹ in 2008. The combined values of the two years also ranged from 3034.9 to 4087.0 kg ha⁻¹. The highest seed cotton yield were obtained from 'SET-34' (4087.0 kg ha⁻¹) and 'SER-45-2' (3927.6 kg ha⁻¹), and the lowest yields were obtained from 'ERA-85' (3034.9 kg ha⁻¹) cotton strain (Tab. 1).

In terms of fiber yield, variety and year differences were found to be significant, but variety x year interactions were non significant. The average fiber yield was 1644.3 kg ha⁻¹ in 2007, and 1308.1 kg ha⁻¹ in 2008 (Tab.1). Fiber yield values of cotton genotypes in 2007 were higher than in 2008. The differences observed in the fiber yield between the years were probably related to ambient conditions (Copur, 2006). On average the highest fiber yield was obtained from 'SET-34' (1632.2 kg ha⁻¹) and 'Stoneville 468' (1616.5 kg ha⁻¹) and lowest fiber yields were obtained from 'ERA-85' (1075.5 kg ha⁻¹) for both years.

This study indicated that seed cotton yield and fiber yield were affected both in terms of year and genotypes. Krieg (1997) reported that the current estimates are that, about 70% of the variation in yield from year to year is dependent upon the environment and only 30% of the variation is subject to management.

The differences between genotypes with respect to the ginning percentage were found significant. Variety x year interaction was also significant ($p < 0.05$), but the year differences were non-significant. Averaged over two years, the ginning percentage of genotypes varied from 35.39 to 42.08%. The highest ginning percentage were obtained from 'Stoneville 468' (42.08%), 'GW-Teks' (41.60%), 'SET-35-2' (40.19%) and 'SET-34' (39.91%) check varieties and strains, respectively but the lowest ginning percentage were obtained from 'ERA-85' (35.39%) which had the lowest seed cotton yield and fiber yield. Arshad *et al.* (1993) and Iqbal *et al.* (2003) also studied the same agronomic characteristics of upland cotton cultivars using

Tab. 1. Mean of seed cotton yield, fiber yield, ginning percentage and fiber length

Strains/ Varieties	Seed cotton yield (kg ha ⁻¹)			Fiber yield (kg ha ⁻¹)			Ginning percentage (%)			Fiber length (mm)		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
'ERA-811'	4167.4	3486.2	3826.8 ab	1615.5	1368.8	1492.1 a-c	38.72	39.25	38.98 ce	31.37	30.46	30.91 bc
'ERA-85'	3356.4	2713.5	3034.9 c	1176.8	974.2	1075.5 d	35.03	35.76	35.39 f	33.01	31.65	32.33 a
'SET-34'	4610.1	3564.0	4087.0 a	1846.0	1418.6	1632.2 a	40.05	39.79	39.91 bc	29.94	29.95	29.94 de
'SER-45-2'	4647.3	3208.0	3927.6 ab	1794.9	1226.4	1510.6 a-c	38.61	38.20	38.40 de	30.71	31.00	30.85 bc
'ERD-114'	4238.8	3466.5	3852.6 ab	1661.0	1319.1	1490.0 a-c	39.19	38.03	38.61 de	30.64	30.72	30.68 b-d
'SET-35-2'	4261.1	3281.6	3771.3 ab	1755.2	1288.8	1522.0 a-c	41.16	39.22	40.19 b	30.34	30.37	30.36 cd
'MAY-73-1'	4018.6	3307.7	3663.1 ab	1600.6	1275.3	1437.9 bc	39.84	38.55	39.19 b-e	30.46	31.06	30.76 b-d
'MET-16-2'	3979.1	3115.7	3547.4 b	1592.5	1217.9	1405.1 c	39.86	39.03	39.44 b-d	31.25	30.47	30.86 bc
'ERD-119-1'	4206.8	3480.7	3843.7 ab	1601.7	1342.8	1472.2 a-c	38.08	38.58	38.32 e	31.13	31.62	31.37 b
'GW-Teks'	4079.6	3535.4	3807.4 ab	1713.8	1454.4	1584.1 a-c	42.04	41.16	41.60 a	29.95	30.56	30.25 c-e
'Stoneville 468'	4209.1	3490.3	3849.7 ab	1729.2	1503.9	1616.5 ab	41.08	43.10	42.08 a	30.16	28.77	29.46 e
Mean	4161.3 a	3331.7 b		1644.3 a	1308.1 b		39.42	39.15		30.81	30.60	
CV (%)		11.62			12.48			2.72			2.86	
LSD (0.05)												
Variety		43.35 **			18.32 **			1.05 **			0.87 **	
Year		18.48 **			7.82 **			ns			ns	
Variety x Year		ns			ns			1.51 *			ns	

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

correlation and reported that ginning out-turn percentage had a negative direct effect on seed cotton yield.

Varieties were highly significant for fiber length, but year differences and variety x year interaction were non significant for this trait. The average of the two years of genotypes ranged from 29.46 to 32.33 mm. Among the genotypes, the longest fiber lengths were obtained from 'ERA-85' (32.33 mm) and 'ERD-119-1' (31.37 mm) strains and the lowest fiber length were obtained from 'Stoneville 468' (29.46 mm) check varieties. The lack of a significant effect of variety x year interaction on fiber length supports the premise that there is a strong genetic basis for this trait (May, 2000). Most of the previous genetic studies have indicated that fiber length is moderately to highly heritable. Quisenberry and Kohel (1975) reported that variations in fiber length and the fiber elongation period were associated with heat-unit accumulation. Cheatham *et al.* (2003) reported that genes for improved yield and fiber quality are available in Australian cultivars and wild accessions of cotton (*Gossypium hirsutum* L.). However, their combining ability with U.S. cultivars is unknown and they recommended 'Paymaster 1560' variety for yield and 'Fibermax 975' variety for fiber length. Braden and Smith (2004) revealed that 'TAM 94L-25' and 'TAM 94M-14' exhibited Lw (length by weight) fibers longer than the three cultivars and two other genotypes. On the other hand, Smith *et al.* (2008) reported that 'Extra-long staple' (ELS) upland cotton (*Gossypium hirsutum* L.) germplasm lines were developed and several strains exceeded 34.8 mm.

The means values of 2007, 2008 and combined years for fiber fineness, fiber strength, fiber elongation and fiber

uniformity ratio obtained from cotton genotypes are presented in Tab. 2.

The differences between varieties and years with respect to fiber fineness were found to be significant, but variety x year interaction were non significant for this trait. Fiber fineness values ranged between 3.76 - 4.38 mic. in 2007, and 3.61 - 4.17 mic. in 2008, respectively. The average fiber fineness was 4.10 mic. in 2007, and 3.89 mic. in 2008. Among the genotypes, the mean of fiber fineness ranged from 3.75 to 4.35 mic, and the fiber fineness values for all the genotypes were found to be at an acceptable level for the textile industry. The thinnest fibers were obtained from 'MAY-73-1' (3.75 mic.), 'MET-16-2' (3.78 mic.) and 'ERA-85' (3.82 mic.), respectively.

In terms of fiber strength, the variety and year differences were found significant, but the variety x year interaction was non significant. The average fiber strength was 33.38 g tex⁻¹ in 2007, and 34.30 g tex⁻¹ in 2008. Among the genotypes, this trait changed from 31.30 to 36.77 g tex⁻¹. 'GW-Teks', 'MAY-73-1' and 'ERA-85' had the highest fiber strength of 36.77, 35.67 and 35.20 g tex⁻¹, respectively. The lowest fiber strength was obtained from 'Stoneville 468' (31.30 g tex⁻¹) check variety. In general, lack of a significant effect of variety x year interaction on fiber strength supports the fact that there is a strong genetic basis for this trait. Dever and Gannaway (1987) reported that fiber strength is influenced more by genotype than by environment.

Variety, year and variety x year interaction were significant for fiber elongation. The average fiber elongation was found to be 5.97% in 2007 and 5.10% in 2008. On an average of two years of the genotypes for this trait, the values

Tab. 2. Mean of fiber fineness, fiber strength, fiber elongation and fiber uniformity

Strains/ Varieties	Fiber fineness (micronaire)			Fiber strength (g tex ¹)			Fiber elongation (%)			Fiber uniformity (%)		
	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean	2007	2008	Mean
'ERA-811'	4.17	4.03	4.10 a-d	32.25	32.60	32.42 ef	6.02	5.15	5.58 c	85.10	83.90	84.50 c-e
'ERA-85'	3.76	3.88	3.82 cd	35.97	34.43	35.20 a-c	5.32	4.65	4.98 f	84.70	82.98	83.83 e
'SET-34'	4.54	4.17	4.35 a	32.12	33.53	32.82 d-f	6.35	5.43	5.88 ab	85.92	84.43	85.17 b-d
'SER-45-2'	4.17	4.04	4.10 a-d	32.72	34.75	33.73 c-e	5.80	5.18	5.48 cd	85.17	85.00	85.08 b-d
'ERD-114'	4.04	3.71	3.87 b-d	34.05	35.08	34.56 bc	5.82	4.73	5.27 de	85.45	85.78	85.61 bc
'SET-35-2'	3.94	3.76	3.85 b-d	31.77	33.33	32.55 ef	6.20	5.00	5.60 c	85.95	83.85	84.90 b-e
'MAY-73-1'	3.91	3.61	3.75 d	34.32	37.03	35.67 ab	6.25	4.90	5.57 c	86.02	84.80	85.41 bc
'MET-16-2'	3.89	3.68	3.78 d	32.22	33.48	32.85 d-f	5.50	5.00	5.25 e	84.07	84.18	84.12 de
'ERD-119-1'	4.18	3.82	4.00 b-d	33.20	35.63	34.41 b-d	5.92	5.23	5.57 c	86.15	85.13	85.63bc
'GW-Teks'	4.16	4.17	4.16 a-c	36.85	36.70	36.77 a	6.25	5.13	5.68 bc	87.92	87.55	87.73 a
'Stoneville 468'	4.38	3.97	4.17 ab	31.75	30.85	31.30 f	6.22	5.78	6.00 a	85.95	85.70	85.82 b
Mean	4.10 a	3.89 b		33.38 b	34.30 a		5.97 a	5.10 b		85.67 a	84.84 b	
CV (%)		8.75			4.81			3.97			1.37	
LSD (0.05)												
Variety		0.33 *			1.61 **			0.21 **			1.15 **	
Year		0.13 **			0.67 *			0.07 **			0.47 **	
Variety x Year		ns			ns			0.31 **			ns	

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

ranged from 4.98% ('ERA-85' strain) to 6.00% (for 'Stoneville 468' commercial cotton variety). Significant variety x year interaction indicated that this trait is susceptible to environmental conditions. Similar results were reported by Stewart (1986), who indicated that environmental conditions from 3 to 25 days postanthesis impacted fiber elongation and conditions from 15 to 45 days postanthesis impacted secondary-wall deposition.

Variety and year were significant for fiber uniformity, but variety x year interaction was non significant for this trait. The average fiber uniformity was 85.67% in 2007, and 84.84% in 2008. Among the genotypes, the average of the fiber uniformity varied from 83.83% (for ERA-83) to 87.73% (for GW-Teks).

Correlation Analysis

Correlation analysis indicated that a number of traits were positively associated with each other, but significant

and negatively correlations were also observed between some of the traits (Tab. 3). Seed cotton yield was highly significantly correlated with fiber yield, ginning percentage, fiber fineness, fiber elongation and fiber uniformity. The highest correlation was found between seed cotton yield and fiber yield ($r=0.968^{**}$) and followed by seed cotton yield and fiber elongation ($r=0.667^{**}$). However seed cotton yield was negatively and significantly correlated with fiber length ($r=-0.185^*$) and fiber strength ($r=-0.273^*$). These findings confirm the previous studies reported by Cheng and Zhao (1991), Khan *et al.* (1991), Gomma (1995), Ulloa and Meredith (2000).

Fiber yield was positive and significantly correlated with ginning percentage, fiber fineness, fiber elongation and fiber uniformity, but negatively correlated with fiber length and fiber strength. Similar results were obtained by Desalegn *et al.* (2009) who reported strong positive correlation between fiber yield and fiber fineness (micronaire).

Tab. 3. Coefficients of correlation among the investigated traits

	SCY	FY	GP	FL	FF	FS	FE
FY	0.968**						
GP	0.335**	0.557**					
FL	-0.185*	-0.332**	-0.655**				
FF	0.462**	0.489**	0.316**	-0.263*			
FS	-0.273*	-0.339**	-0.367**	0.468**	-0.136		
FE	0.667**	0.718**	0.492**	-0.309**	0.427**	-0.342**	
FU	0.293**	0.340**	0.329**	-0.081	0.211*	0.312**	0.419**

*, ** indicate that the correlation is significant at the 0.05 and 0.01 probability levels, respectively; SCY: Seed cotton yield (kg ha⁻¹); FY: Fiber yield (kg ha⁻¹); GP: Ginning percentage (%); FL: Fiber length (mm); FF: Fiber fineness (micronaire); FS: Fiber strength (g tex⁻¹); FE: Fiber elongation (%); FU: Fiber uniformity (%)

Ginning percentage was significantly and positively correlated with fiber fineness, fiber elongation and fiber uniformity, but negatively correlated with fiber length and fiber strength. Ulloa and Meredith (2000) reported a strongly negative connection between lint percentage and fiber strength.

Fiber length was positively correlated with fiber strength, but negatively correlated with fiber fineness and fiber elongation, such that cultivars with longer fiber had stronger fiber and lower micronaire reading. These results are in agreement with the results obtained by Ulloa and Meredith (2000); Asif *et al.* (2008); Azhar and Naeem (2008); Bařal *et al.* (2009). Mei *et al.* (2004) revealed insignificant correlation between fiber length and fiber elongation, fiber length and fiber fineness.

Positive correlation between fiber length and fiber strength and negative correlation between fiber length and fiber fineness indicated that the three most fiber quality traits (fiber length, fiber strength and fiber fineness) can be improved simultaneously.

Positive and significantly association was detected between fiber fineness and fiber elongation, and also fiber uniformity. Fiber strength was positively correlated with fiber uniformity, but negatively correlated with fiber elongation. Fiber elongation was positively correlated with fiber uniformity.

Conclusions

The result of this study shows that 'SET-34' cotton strain are preferable for high yield capacity and acceptable level for fiber quality traits. It is considered a promising genotype, while 'ERA-85' had the highest fiber length and also lowest for seed cotton yield, fiber yield and ginning percentage. Developing high yield cotton strain with superior fiber length is a priority for most cotton breeding programs, but improving for these traits simultaneously is much more difficult. The narrow genetic base of cotton (*Gossypium hirsutum* L.) germplasm has been a significant impediment to sustained progress in the development of cotton cultivars to meet the needs of cotton growers and textile industry. For this reason, genetic variability must be broadened and new cotton varieties must be used for cotton breeding programs. Highly strongly correlated traits such as fiber length, fiber fineness and fiber strength can be used for improvement simultaneously.

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References

- Arshad, M., M. Hanif, N. Ilahi and S. M. Shah (1993). Correlation studies on some commercial cotton varieties of *G. hirsutum*. Sarhad J. Agric. 9:49-53.
- Asif, M., M. Rahman and Y. Zafar (2006). Genotyping analysis of six maize (*Zea mays* L.) hybrids using DNA fingerprinting technology. Pak. J. Bot. 38(5):1425-1430.
- Asif, M., J. I. Mirza and Y. Zafar (2008). Genetic analysis for fiber quality traits of some cotton genotypes. Pak. J. Bot. 40(3):1209-1215.
- Azhar, F. M., M. Naveed and A. Asif (2004). Correlation analysis of seed cotton yield with fiber characteristics in *Gossypium hirsutum* L. International Journal of Agriculture and Biology. 4:656/658.
- Azhar, F. M. and M. Naeem (2008). Assessment of Cotton (*Gossypium hirsutum*) Germplasm for Combining Abilities in Fiber Traits. Journal of Agriculture and Social Sciences. 4:129-131.
- Bařal, H., A. Unay, O. Canavar and I. Yavař (2009). Combining ability for fiber quality parameters and within-boll yield component in intraspecific and interspecific cotton populations. Span J Agric Res 7(2):364-374.
- Braden, C. A and C. W. Smith (2004). Fiber length development in near-long staple upland cotton. Crop Sci. 44:1553-1559.
- Braden, C. A. (2005). Inheritance of cotton fiber length and distribution, Texas A and M Univ., PhD Diss. Abstr.
- Braden, C. A., C. W. Smith and E. F. Hequet (2009). Combining ability for fiber length in near-long-staple upland cotton. Crop Sci 49:756-762.
- Bradow, J. M., L. H. Wartelle, P. J. Bauer and F. S. Gretchen (1997). Small-sample cotton fiber quality quantitation. J. Cotton Sci. 1:48-60.
- Bradow, J. M. and G. H. Davidonis (2000). Quantitation of fiber quality and the cotton production-processing interface: A physiologists perspective. J. Cotton Sci. 4:34-64.
- Cheng, B. J. and L. Y. Zhao (1991). Multiple correlation analysis of yield, fiber quality and plant characteristics in upland cotton. Acta Agric. Shanghai 7:29-35.
- Clouvel, P., E. Goze., R. Sequeira, J. Dusserre and M. Cretenet. (1998). Variability of cotton fiber quality, pp. 963-966. Proc. of the World Cotton Res. Conf. 2, Athens, Greece.
- Chaudhry, M. R., and A. Guitchounts (2003). Fiber quality, Cotton Facts. International Cotton Advisory Committee Technical Paper 25:85-89.
- Cheatham, C. L., J. N. Jenkins, J. McCarty, C. E. Watson and J. Wu (2003). Genetic variances and combining ability of crosses of american cultivars, australian cultivars, and wild cottons. J. Cotton Sci. 7:16-22.
- Copur, O. (2006). Determination of Yield and Yield Components of Some Cotton Cultivars in Semi Arid Conditions. Pakistan Journal of Biological Science 9(14):2572-2578

- Copur, O., İ. H. Birgül, H. Haliloğlu and V. Beyyavaş (2010). The effect of different harvesting times on seed-set efficiency in cotton (*Gossypium hirsutum* L.) varieties. African Journal of Biotechnology 9(40):6654-6659.
- Davidonis, G. H., A. S. Johnson, J. A. Landivar and C. J. Fernandez (2004). Cotton fiber quality is related to boll location and planting date. Agron. J. 96:42-47.
- Desalegn, Z., N. Ratanadilok and R. Kaveeta (2009). Correlation and heritability for yield and fiber quality parameters of Ethiopian cotton (*Gossypium hirsutum* L.) estimated from 15 (diallel) crosses. Kasetsart J. (Nat. Sci.) 43:1-11
- Dever, J. K. and J. R. Gannaway (1987). Breeding for fiber quality on the high plains of Texas. p. 111. In: Brown, J. M. (Eds.) Proc. Beltwide Cotton Conf. Memphis, TN.
- Freeland, Jr. T. B., B. Pettigrew, P. Thaxton and G. L. Andrews (2006). Agrometeorology and cotton production, pp. 1-17. Chapter 13A in guide to agricultural meteorological practices, 3rd Ed.
- Gomma, N. A. M. (1995). Evaluation of some families derived from two Egyptian cotton crosses. Ann. Agric. Sci. 40:153-164.
- Iqbal, M., M. A. Chang, M. Z. Iqbal, M. Hassan, A. Nasir and N. Islam (2003). Correlation and path coefficient analysis of earliness and agronomic characters of upland cotton in Multan. Agron. J. 2(3):160-168.
- Jauhar, P. P. (2006). Modern biotechnology as an integral supplement to conventional plant breeding: The prospects and challenges. Crop Sci. 46:1841-1859.
- Khan, M. A., H. A. Sadaqat and M. Tariq (1991). Path coefficient analysis in cotton (*G. hirsutum* L.). J. Agric. Res. 29:177-82.
- Krieg, D. R. (1997). Genetic and environmental factors affecting productivity of cotton. Proc. of the Beltwide Cotton Conf. 2:1347.
- May, O. L. (2000). Genetic variation in fiber quality. p. 183-220. In A.S. Basra (ed) Cotton fibers developmental biology, quality improvement, and textile processing Food Products Press, New York
- Mei, M., N. H. Syed, W. Gao, P. M. Thaxton, C. W. Smith, D. M. Stelly and Z. J. Chen (2004). Genetic mapping and QTL analysis of fiber-related traits in cotton (*Gossypium*) Theor Appl Genet. 108:280-291
- Meredith, W. R. and R. R. Bridge (1972). Heterosis and gene action in cotton (*Gossypium hirsutum* L.). Crop Sci. 12:304-310.
- Quisenberry, J. E. and R. J. Kohel (1975). Growth and development of fiber and seed in upland cotton. Crop Sci. 15:463-467.
- Rahman, M. (2002). DNA Markers Studies in Cotton. PhD Thesis, Department of Plant Bred. Genet. Univ. Agric. Faisalabad Pakistan.
- Reddy, K. R., G. H. Davidonis, A. S. Johnson and B. T. Vinyard (1999). Temperature regime and carbon dioxide enrichment alter cotton boll development and fiber properties. Agron. J. 91-851-858.
- Smith, C. W., S. Hague, E. Hequet, P. S. Thaxton, and I. N. Brown (2008). Development of extra- long staple upland cotton. Crop Sci. 48:1823-1831.
- Stewart, J. McD (1986). Integrated events in the flower and fruit. pp. 261-300. In: Manuey, J. R. and J. McD. Stewart (Eds.). Cotton physiology. The Cotton Foundation, Memphis, TN.
- Ulloa, M. and W. R. Meredith (2000). Genetic linkage Map and QTL analysis of agronomic and fiber quality traits in an intraspecific population. Jour. Cotton Sci 4:161-170.