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# Genetic Analysis of Some Morpho-Physiological Traits Related to Drought Stress in Cotton (*Gossypium hirsutum*)

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## ABSTRACT

To develop cultivar, yielding better under drought stress, breeder needs the information about the gene action of the traits related to yield and quality responsible for drought tolerance. The objective of the study was to generate genetic information, which can help in breeding cotton cultivars with improved drought tolerance. Six genotypes of *Gossypium hirsutum* (S-12, NIAB-78, CIM-240, Karishma, CP-1521 & ACALA-15/17) were selected to make cross combinations. The parents $F_1$, $F_2$ and backcross generations of six crosses were studied under drought conditions in the field to find gene action of the traits, plant height, number of monopodial branches per plant, number of sympodial branches per plant, number of bolls per plant, boll weight, ginning out-turn, staple length, fiber strength, fiber fineness, relative water content and excised leaf water loss. The generation means analysis indicated that all three kinds of gene effects (additive, dominance & interactions) were involved in the inheritance of the studied traits. The plants selected in early segregating generation may not breed true thus selection at later segregating generations may show good results.

**Key Words:** Cotton; Gene action; Generation means analysis; Drought stress

## INTRODUCTION

Cotton plays a pivotal role in the agriculture-based economy of Pakistan. Cotton is grown on an area of about 3.1 million hectares with production of about 12.4 million bales in Pakistan (Anonymous, 2006-2007). Pakistan is the fourth largest cotton producing country after China, USA and India. It generates significant proportion of foreign exchange. In addition to fiber, cotton is also an important source of vegetable oil in Pakistan. Poor yields of cotton are due to different biotic and abiotic stresses. Precipitation and river flow are the two major sources of surface water used to meet the requirements of agriculture in Pakistan. Most of the rainfall is received during July to September, which is hardly available for crop production, because of rapid runoff due to torrential showers. There is shortage of water during the growing season of cotton. So we need to breed cotton variety, which may produce relatively better yield under drought stress condition.

Drought stress or water deficit is a complex phenomenon affecting the physiology of cotton plant. There are number of plant traits like relative water content (RWC), excised leaf water loss (ELWL), stomatal frequency, stomatal size, osmotic adjustment etc., which are related to drought resistance (Basal *et al*., 2005; Malik *et al*., 2006; Parida *et al*., 2008). Dhillon and Singh (1980) analyzed genetic control of different traits in cotton using $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$ and $BC_2$ generations. They found that expression of different components of genetic variation was much influenced by the environmental effects. Effect of environment on gene action suggests that gene action for the traits need to be improved should be analyzed under the environment in which breeding has to be undertaken. A number of studies regarding gene action of agronomic traits are reported in the literature (Babar & Khan, 1999; Murtaza, 2005; Rahman & Malik, 2008), however; only a few studies are conducted under drought stress.

Present study was initiated to investigate the inheritance of RWC, ELWL, plant height, number of monopodial branches, number of sympodial branches, number of bolls per plant, boll weight, staple length, fiber fineness, fiber strength and ginning out- turn under drought stress. The information generated by this study would be helpful for plant breeder to tailor high yielding drought tolerant cotton strains.

## MATERIALS AND METHODS

The experimental material was selected from the gemplasm available at different research stations of Pakistan, including Cotton Research Station (CRS) Multan, Central Cotton Research Institute (CCRI) Multan, Nuclear Institute for Agriculture and Biology (NIAB) Faisalabad, Cotton Research Institute, AARI, Faisalabad and the University of Agriculture, Faisalabad, Pakistan. Twenty each of drought resistant and susceptible genotypes were selected using the

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data available on the field response of varieties/genotypes under drought stress in the respective institutes.

Drought response of selected varieties/genotypes was further assessed by growing them under drought stress through measurement of relative water content (RWC) and excised leaf water loss (ELWL). The varieties/genotypes were grown during the normal crop season of 2004 in a randomized complete block design with three replications in the area of the Department of Plant Breeding and Genetics to select contrasting parents for making crosses. To select pair of contrasting parents for a cross, it was made sure that both the parents in the cross had relatively same phenology. Crossing was started in the field during the normal cropping season, 2005. Sufficient numbers of flowers were selfed and crossed to produce seeds. During the December, 2005 the seed of selected varieties/genotypes and their $F_1$s was planted in pots filled with loamy soil under glasshouse conditions to make further crosses. Some flower buds of $F_1$ plants were used for backcrossing and the others were selfed to produce seed for $F_2$ population. List of crosses are shown in Table I.

Parental, $F_1$, $F_2$ and backcross ($BC_1$ & $BC_2$) generations for each of the crosses were raised in field as separate experiment during the year 2006. The crop was sown in a randomized complete block design having three replications. In each replication there were two rows for each of the parents and $F_1$, 12 rows for each of the $F_2$ and 10 rows for each backcross generation. The length of row was 4 m. Row to row and plant-to-plant distance was 75 and 30 cm, respectively. Control plants were irrigated five times during the experiment. For drought stress the plants were irrigated only twice up to the maturity. At maturity 30 guarded plants from each of the parents and $F_1$, 45 plants from each of the backcross populations and 150 plants from each of the $F_2$ populations were selected at random to record the data on individual plant basis.

**Relative water content (RWC).** Three fully developed leaf sample were taken from each of the selected plants during the month of September when the plants showed the symptoms of drought stress. The samples were covered with polythene bags soon after excision and fresh weight was recorded. The leaf samples were dipped in water overnight for recording the turgid leaf weight. The samples were oven dried at 70°C for taking dry weight. RWC was calculated using the following formula as by Clarke and Townley-Smith (1986).

$$RWC = [(\text{Fresh weight}-\text{Dry weight})/(\text{Turgid weight}-\text{Dry weight})] \times 100$$

**Excised leaf water loss (ELWL).** Three fully developed leaf sample were taken from each of the selected plant, during the month of September when the plants were showing symptoms of drought stress. The samples were covered with polythene bags soon after excision and fresh weight was recorded using electronic balance. The leaf samples were left on laboratory bench. After six hours the weight of the wilted leaf samples were taken. The samples were oven dried at 70°C for taking oven dry weight. Excised leaf water loss was calculated by the following formula by Matin *et al.* (1889).

$$ELWL = (\text{Fresh weight}-\text{wilted weight})/\text{Dry weight}$$

During the end of November, when the plants were fully mature, the data about the traits, plant height, number of monopodial branches per plant, number of sympodial branches per plant, number of bolls per plant, boll weight, ginning out-turn (GOT), staple length, fiber strength and fiber fineness were recorded. Standard analysis of variance technique, described by Steel *et al.* (1997) was applied to test the significance of differences among the generations used in the experiment. Generation means analysis was performed following the method described by Mather and Jinks (1982). Means of each population (parents, backcrosses, $F_1$ & $F_2$) used in the analysis were calculated from individual plants pooled over replications. Coefficients of genetic components of generation means used in the analysis are shown in the Table II. A weighted least square analysis was performed on the generation means commencing with the simplest model using parameter *m* only. Further models of increasing complexity (*md, mdh*, etc.) were fitted if the chi-squared value was significant. The best model was chosen as the one, which had significant estimates of all parameters along with non-significant chi-squared value. For each trait the higher value parent was always taken as $P_1$ in the model fitting.

## RESULTS AND DISCUSSION

Analysis of variance revealed significant differences among the generations for various traits including plant height, number of monopodial branches, number of sympodial branches, number of bolls per plant, boll weight, ginning out-turn (GOT), fiber length, fiber strength, fiber fineness, relative water contents and excised leaf water loss in some crosses, while the traits were not significantly different in the other crosses. Means and LSD values of traits showing significant differences ($P \leq 0.05$) among generation means for various crosses used for genetic analysis are shown in Table III. The $F_2$ population for the traits was almost normally distributed showing quantitative inheritance of the traits. Transgressive segregation was also observed for the traits in some crosses.

**Plant height.** In the case of plant height the simple model with two parameters m and [d] provided a good fit to the data in the two crosses suggesting presence of additive genetic effects for inheritance of this trait. Singh *et al.* (1980) reported that in *G. hirsutum,* quantitative characters like plant height, number of branches in different cross combinations were affected by additive type of gene action. Tyagi (1988) investigated genetic architecture of yield and its components in upland cotton and reported that genetic control appeared additive for plant height. In the cross CP-1521 x Acala-15/17 the model with two parameters m and [i] was fit showing the presence of interaction i.e., additive x additive. Similar results were reported by Kalsey and Vithal

**Table I. List of crosses and backcrosses made in the study**

| Population | Parents |
|---|---|
| $F_1$, $F_2$ | S-12 x NIAB-78 |
| BC1 | (S-12 x NIAB-78) x S-12 |
| BC2 | (S-12 x NIAB-78) x NIAB-78 |
| $F_1$, $F_2$ | CIM-240 x Karishma |
| BC1 | (CIM-240 x Karishma) x CIM-240 |
| BC2 | (CIM-240 x Karishma) x Karishma |
| $F_1$, $F_2$ | Karishma x ACALA-15/17 |
| BC1 | (Karishma x ACALA-15/17) x Karishma |
| BC2 | (Karishma x ACALA-15/17) x ACALA-15/17 |
| $F_1$, $F_2$ | CP-1521 x ACALA-15/17 |
| BC1 | (CP-1521 x ACALA-15/17) x CP-1521 |
| BC2 | (CP-1521 x ACALA-15/17) x ACALA-15/17 |
| $F_1$, $F_2$ | ACALA-15/17 x CIM-240 |
| BC1 | (ACALA-15/17 x CIM-240) x ACALA-15/17 |
| BC2 | (ACALA-15/17 x CIM-240) x CIM-240 |
| $F_1$, $F_2$ | Karishma x CP-1521 |
| BC1 | (Karishma x CP-1521) x Karishma |
| BC2 | (Karishma x CP-1521) x CP-1521 |

**Table II. Coefficients of the mean (*m*), additive (*d*), dominance (*h*), additive × additive (*i*), additive × dominance (*j*) and dominance × dominance (l) parameters for the weighted least squares analysis of generation means (Mather and Jinks, 1982)**

| Generations | Components of genetic effects | | | | | |
|---|---|---|---|---|---|---|
| | m | [d] | [h] | [i] | [j] | [l] |
| $P_1$ | 1 | 1.0 | 0.0 | 1.00 | 0.00 | 0.00 |
| $P_2$ | 1 | -1.0 | 0.0 | 1.00 | 0.00 | 0.00 |
| $F_1$ | 1 | 0.0 | 1.0 | 0.00 | 0.00 | 1.00 |
| $F_2$ | 1 | 0.0 | 0.5 | 0.00 | 0.00 | 0.25 |
| $BC_1$ | 1 | 0.5 | 0.5 | 0.25 | 0.25 | 0.25 |
| $BC_2$ | 1 | -0.5 | 0.5 | 0.25 | -0.25 | 0.25 |

(1980). Their studies revealed additive x additive interactions for inheritance of plant height. Kalsay and Garg (1988) performed generation mean analysis for yield components including plant height. The results showed that additive gene action and epistasis was important in the inheritance of plant height. Randhawa *et al.* (1986) revealed the presence of additive and epistasis for plant height. Singh *et al.* (1983) estimated gene action and observed epistasis for the character.

Plant height is related to yield and drought tolerance in cotton. Taller plant results due to faster growth and hence require more water due to higher water loss. So, medium height cotton varieties may perform better under limited water conditions. The results of present studies showed that gene action was different in the crosses. Hence segregating populations of different cross combination may be exploited differently depending upon their gene actions. The variation of gene action in the crosses may be expected under drought stress. However, well watered plants also showed such a variation (Singh *et al.,* 1983; Kalsy & Garg, 1988). In the crosses where the additive gene action was present the selection in early generation may be fruitful however, in the cross showing epistasis, selection may be postponed to later segregating generations.

**Number of monopodial branches.** For number of monopodial branches two parameter model m, [h] provided a satisfactory fit to the data in the cross S-12 x NIAB-78 showing the presence of dominance. However, in the cross Acala-15/17 x CIM-240 two parameter model m, [d] was fit showing additive variance and in the cross, Karishma x CP-1521 three parameter model m, [d] and [i] provided a satisfactory fit to the data showing additive and additive x additive interactions, as reported in other studies as well (Singh *et al.,* 1971; Silva & Alves, 1983). Larger number of monopodial branches may negatively affect plant growth under drought. Monopodial branches increase vegetative growth resulting in more water loss. The presence of interaction in the crosses in the present and earlier studies shows that in manipulating monopodial branches selection of plants in early generations would not be effective. Selection in later generations would be more effective.

**Number of sympodial branches.** In the cross, Karishma x Acala-15/17 simple model with two parameter m and [d] was found fit with additive type of gene action, whereas in the cross CIM-240 x Karishma, a model with three components m, [d] and [i] and in the cross S-12 x NIAB-78 model with four parameters m [d], [h] and [i], which revealed that additive and dominance as well as additive × additive interaction were involved in the inheritance. Singh *et al.* (1971) reported additive and dominance genetic variance along with interactions for number of sympodial branches in cotton. Silva and Alves (1983) reported the involvement of additive and dominance as well as epistasis for number of fruiting branches (sympodial branches) in cotton. The presence of interaction in two crosses in the present study and in the earlier reports suggested that in the improvement of sympodial branches, selection of plants later rather than earlier generations would be effective.

**Numbers of boll per plant.** In crosses, S-12 x NIAB-78 and Acala-15/17 x CIM-240, model with two parameters m and [i] provided a good fit to the data suggesting presence of additive x additive variance. In the cross CP-1521 x Acala-15/17, a model with m, [h] and [i] provided a good fit to the data, suggesting the presence of dominance and additive x additive variance. Pathak and Singh (1970) investigated the inheritance of number of bolls in cotton and reported dominance and additive effects as well as epistasis for number of bolls. Singh *et al.* (1971) also reported additive and dominance genetic variances along with the genetic interactions for the character. El-Fawal *et al.* (1974) studied gene action in interspecific crosses of cotton and observed dominant genetic variance, while Gad *et al.* (1974) reported additive gene action for boll number. Randhawa *et al.* (1986) also observed the presence of epistasis for number of bolls. Kalsy and Garg (1988) showed that additive and dominance as well as epistasis were important for inheritance of boll number in cotton. The presence of interactions in the inheritance of number of bolls per plant in the present and earlier studies indicated that the trait is not simply inherited. The plants selected in early segregating generation may not be expected to breed true. So, selection

**Table III. Estimates of the best fit model for generation means parameters (±, standard error) by weighted least squares analysis in respect of plant height (PH, cm), monopodia (Mon), sympodia (Sym), boll number (BN), boll weight (BW, g), ginning outturn (GOT, %), fiber fineness (FF. Mic), fiber strength (FS, g tex$^{-1}$), fiber length (FL, mm), relative water contents (RWC, %), excised leaf water loss (ELWL, g g$^{-1}$) in six crosses S-12 x NIAB-78 (1), CIM-240 x Karishma (2), Karishma x Acala-15/17 (3), CP-1521 x Acala-15/17 (4), Acala-15/17 x CIM-240 (5), Karishma x CP-1521 (6) of cotton**

| Traits | Cross # | Genetic Effects | | | | | | $X^2$ |
|---|---|---|---|---|---|---|---|---|
| | | m | [d] | [h] | [i] | [j] | [l] | df |
| PH | 1 | 96.59±0.27 | 0.91±0.43 | - | - | - | | 3.11(4) |
| | 3 | 98.47±0.31 | 1.07±0.15 | - | - | - | - | 2.23(4) |
| | 4 | 98.37±0.21 | - | - | 1.53±0.73 | - | - | 2.19(4) |
| MONO | 1 | 2.92±0.07 | - | 0.28±0.14 | | - | | 3.04(4) |
| | 5 | 2.63±0.16 | 1.01±0.44 | - | | | | 2.28(4) |
| | 6 | 2.72±0.05 | 0.16±0.06 | - | 0.28±0.09 | | | 2.95(3) |
| SYM | 1 | 8.07±0.45 | 0.39±0.12 | 1.46±0.63 | 1.73±0.48 | - | - | 3.60(2) |
| | 2 | 7.52±0.06 | 0.40±0.09 | - | 0.44±0.13 | - | - | 3.39(3) |
| | 3 | 7.55±0.07 | 0.38±0.13 | - | - | - | - | 2.93(4) |
| NB | 1 | 18.42±0.26 | - | - | 1.69±0.47 | - | - | 3.54(4) |
| | 4 | 15.25±0.39 | - | 3.57±0.75 | 3.20±0.59 | - | - | 3.21(3) |
| | 5 | 14.1±0.18 | - | - | 0.91±0.36 | - | - | 2.51(4) |
| BW | 1 | 3.86±0.033 | 0.23±0.04 | - | - | - | 0.30±0.08 | 3.60(3) |
| | 4 | 2.97±0.15 | 0.29±0.02 | - | - | 0.27±0.05 | - | 4.84(3) |
| | 6 | 2.96±0.019 | 0.38±0.03 | - | - | 0.45±0.07 | - | 5.94(3) |
| GOT | 1 | 36.02±0.16 | - | - | 1.48±0.35 | - | - | 4.16(4) |
| | 3 | 35.93±0.20 | - | - | 1.02±0.37 | - | - | 2.72(4) |
| | 5 | 36.25±0.19 | 0.49±0.24 | - | 0.83±0.35 | - | - | 3.35(3) |
| FF | 4 | 4.69±0.04 | - | 0.59±0.20 | - | - | 0.48±0.20 | 2.34(3) |
| | 5 | 4.57±0.08 | - | 0.35±0.09 | - | - | - | 3.54(4) |
| | 6 | 4.78±0.14 | 0.12±0.05 | 1.03±0.21 | 0.97±0.16 | - | - | 3.99(2) |
| FS | 1 | 26.62±0.13 | - | - | 0.87±0.26 | - | - | 3.22(4) |
| | 2 | 26.62±0.15 | - | - | 0.62±0.29 | - | - | 2.15(4) |
| | 3 | 25.86±0.14 | - | - | 1.08±0.22 | - | - | 4.75(4) |
| | 4 | 26.50±0.09 | - | - | 0.15±0.06 | - | - | 3.49(4) |
| FL | 2 | 27.55±0.15 | - | - | 0.77±0.28 | - | - | 2.67(4) |
| | 3 | 27.54±0.14 | - | - | 0.63±0.26 | - | - | 3.38(4) |
| | 4 | 27.36±0.08 | 0.38±0.15 | - | - | - | - | 2.53(4) |
| | 5 | 27.93±0.14 | - | - | 0.60±0.22 | - | - | 3.64(4) |
| RWC | 1 | 75.43±2.10 | | 0.36±0.09 | | - | 0.37±0.08 | 4.23(3) |
| | 4 | 74.34±2.06 | | 0.63±0.10 | | - | 0.53±0.11 | 4.81(3) |
| | 6 | 70.65±2.04 | | 0.54±0.09 | | | 0.58±0.10 | 5.58(3) |
| ELWL | 1 | 1.75±0.14 | - | 6.04±0.60 | 1.05±0.23 | - | 4.91±0.39 | 2.44(2) |
| | 3 | 1.41±0.08 | - | 2.94±0.34 | - | - | 2.77±0.35 | 7.86(3) |
| | 4 | 1.71±0.06 | - | - | 0.17±0.03 | - | | 5.57(4) |

in later segregating generations may show good results.

**Boll weight.** All the crosses showed additive as well as interactions for inheritance of boll weight. Three parameter model m and [d] and [j] with additive type of gene action with additive x dominance interactions provided fit to the data was observed in the crosses CP- 1521 x Acala-15/17 and Karishma x CP-1521. However, in the cross S-12 x NIAB-78, three parameter model m [d] and [l] with additive and dominance x dominance was fit. Additive, additive and epistatic effects or dominance genetic variance along with the genetic interactions have been reported in cotton for boll weight (Pathak & Singh, 1970; El-Adl & Miller, 1971; Singh *et al.,* 1971; Gad *et al.,* 1974; Kaseem *et al.,* 1984; Kalsy & Garg, 1988). However, Tyagi (1988) reported dominance and additive variance for boll weight. The results of present study and earlier reports, the trait is not simply inherited.

**Ginning out-turn (GOT).** All the crosses revealed epistasis for the inheritance of GOT. In the crosses S-12 x NIAB-78 and Karishma x Acala-15/17 two parameters model m and [i], whereas in the cross Acala-15/17 x CIM-240 with three parameters model m, [d] and [i] provided good fit to the data. Dhillon and Singh (1980) studied genetic control of ginning out-turn in $P_1$, $P_2$, $F_1$, $F_2$, $BC_1$ and $BC_2$ generations of the cross, J34 x SS167 grown at two locations with additive dominance and interactions for the inheritance of GOT. They further observed that expression of different components of variation was much influenced by the environmental effects. The finding of Pavasia *et al.* (1999) and Singh and Yadavendra (2002) corroborates the results of present study. So breeding for this trait may be relatively difficult.

**Fiber fineness.** In the case of fiber fineness the model with four parameters m, d, [h] and [l] provided a good fit to the data in the cross, Kasihma x CP-1521, suggesting the presence of complex genetic variance for inheritance of this trait. However, in the crosses CP-152 x Acala-15/17 and Acala-15/17 x CIM-240 two parameter m and [h] provided a good fit to the data, suggesting presence of only dominance variance for the trait. Gad *et al.* (1974) reported additive and dominance gene action for fineness. Ma *et al.* (1983) studied inheritance of fiber fineness in $P_1$, $P_2$, $F_1$, $F_2$,

$BC_1$ and $BC_2$ of a cross between Loumain I and Acala Sj-3 and found dominance effects for fiber fineness. Lin and Zhao (1988) in a study of three intervarietal crosses of cotton estimated genetic effects of fiber fineness. The results showed that inheritance of the trait fitted a modified additive dominance epistatic model. The effects of dominance and epistasis varied significantly in different years and different hybrids. Nadarajan and Rangasamy (1990) reported that fiber fineness was governed by additive gene action. Nadarajan and Rangasamy (1992) opined that in general fiber fineness was governed by additive, dominance and digenic non-allelic interaction. In concurrence with earlier studies, the presence of epistatic interactions in the present studies showed that the inheritance of the traits is complex. Hence, selection for improved fiber fineness cannot be started in early segregating generations.

**Fiber strength.** For fiber strength two parameter model m and [i] provided a satisfactory fit to the data in all the crosses. The results showed that all the variance was due to additive × additive interaction. Lin and Zhao (1988) in a study on inter-varietal crosses of cotton showed that inheritance of fiber traits fitted a modified additive dominance epistatic model. The effects of epistasis varied significantly in different years and in different hybrids. The presence of interaction in all the crosses in this study showed that the variance noted in the segregating generation may be due to interactions. So the selection of plants to improve fiber fineness would be effective in later generations.

**Staple length.** In the cross, CP-1521 x Acala-15/17 simple two parameter model m and [d] gave a good fit to the data suggesting the presence of only additive type of gene action. However, in the crosses CIM-240 x Karishma, Karishma x Acala-15/17 and Acala-15/17 x CIM-240 two parameter model m and [i] with additive x additive effects was found to be most appropriate. Lin and Zhao (1988) in a study of three inter varietial-crosses of cotton estimated genetic effects of fiber length. The results showed that inheritance of the trait fitted a modified additive dominance epistatic model. Nadarajan and Rangasamy (1990) concluded that staple length was governed by additive gene action. Additive, dominance, additive × additive and additive × dominance genetic effects as well as epistatic effects for staple length have also been recorded previously (Singh & Yadavendra, 2002; Nimbalkar *et al*., 2004; Murtaza *et al*., 2004). Different types of gene actions for the trait in different crosses in the present study and in the studies reported earlier may be due to difference of genetic backgrounds of the parents involved. In the present study only one cross showed additive variance and absence of interactions, while three crosses showed interactions. The presence of interactions in the inheritance of staple length revealed that the trait may not be simply inherited. So, selection in later segregating generations may be suitable.

**Relative water content (RWC).** In all the crosses, model with three parameters m, [h] and [l] was a good fit to data showing dominance along with the dominance x dominance interaction of relative water content. Schonfeld *et al.* (1988) reported additive, dominance as well as additive x additive genetics effects for RWC in wheat. The presence of interactions in the inheritance of relative water contents showed that the trait was not simple in heritance the plants selected in early segregating generation may not be expected to breed true. So, selection in later segregating generations may show good results. Trends towards higher RWC at a give water potential has been observed in species, which are better adopted to dry environments (Weatherley & Slatyer, 1957; Jarvis & Jarvis, 1963; Malik *et al*., 2006; Parida *et al*., 2008). Sorghum, for instance, suffered a smaller decrease in RWC per unit change in leaf water potential than cotton (Ackerson & Krieg, 1977) and maize (Levitte, 1980). Similarly, un-irrigated plants showed a much smaller change in water content per change in water potential, than the irrigated ones (Levitt, 1980). Maintenance of higher relative water content has been suggested as screening criterion for drought resistance (Matin *et al*., 1989; Schonfeld *et al*., 1988; Ritchie *et al*., 1990).

**Excised leaf water loss (ELWL).** In the cross S-12 x NIAB-78, model with four parameter, (m, [h], [i] & [l]) provided a good fit to the data suggesting presence of dominance mode of gene action along with the additive x additive and dominance x dominance type of interactions. In the cross Karishma x Acala-1517 three parameters m, [h] and [l] provided a good fit to the data, suggesting the presence of dominance gene action along with the dominance x dominance type of interaction. In the cross, CP-1521 x Acala-15/17, model with two parameter m and [i] provided a good fit, suggesting the presence of additive x additive interaction. Genetic variation in ELWL has been reported in crop species and FLWL has been suggested as selection criterion for drought resistance (Salim *et al.,* 1969; Dedio, 1975; Clarke & McCaig, 1982a & b; Clark, 1983; Clarke & Townley-Smith, 1986; Clarke, 1987; Clarke *et al*., 1992). Difference in ELWL of the genotypes may be due to cuticular thickness as stomata close about two minutes after leaf excision. Most of the water lost from the leaf would be from the epidermis (except for a small loss from the cut end) so differences in cuticular thickness would result in difference of ELWL. It has been reported that cuticular thickness and waxiness of leaf surfaces are genetically controlled and affect transpiration (Haque *et al*., 1992). Different types of gene actions for the trait in different crosses showed a wide genetic diversity for the genes. The presence of interactions in the inheritance shows that the trait is not simply inherited.

## CONCLUSION

Additive dominance and interactions were involved for agronomic (plant height, number of monopodial branches per plant, number of sympodial branches per plant, number of bolls per plant, boll weight, ginning out-turn), fiber quality (staple length, fiber strength, fiber fineness) and physiological traits (relative water content & excised leaf water loss) under drought stress environments. Hence for breeding drought tolerant cotton, selection of plants would be appropriate for later segregating generations.

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