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Full Length Article

Genetics of Physiological, Fiber and Yield Contributing Traits in Cotton Grown under Normal and Water Stress Conditions

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Abstract

Drought is the primary constraint to achieve the goal of sustainable crop production. Drought severely affects the production and fiber quality of cotton. To overcome this problem, development of drought resilient cotton cultivars with better lint quality and yield is a sustainable solution. Therefore, an experiment was conducted to evaluate the genetics of yield and quality traits of cotton under drought. Seventy cotton genotypes were screened against drought stress in glass house using completely randomized design based on cell membrane thermostability (CMT), relative water contents, excise leaf water loss, fresh and dry shoot weight, fresh and dry root weight and root-shoot ratio. On basis of mean performance eight genotypes (05 lines and 03 testers) were selected. Selected lines and testers were crossed to obtain 15 F1 hybrids. Eight parents and 15 hybrids were sown in pots in glasshouse under two water levels *i.e*., normal and drought. Data regarding various physiological, yield and fiber quality parameters *viz*., CMT, ELWL, RWC, chlorophyll contents (CC), plant height (PH), number of monopodial branches per plant (NMBP), number of sympodial branches per plant (NSBP), number of bolls per plant (NBP), seed index (SI), fiber fineness (FF), fiber strength (FS) and staple length (SL) were collected. Degree of dominance revealed that all parameters were highly influenced by non-additive gene action under both water regimes except for NMBP under stress environment. Parental genotypes FH-682, 149-F and CIM-240, CRIS-134 were good general combiner for most of the studied traits under normal and drought conditions and could be used in a breeding program for development of cotton variety. Due to non-additive types of gene action for most of the traits, it is suggested to delay selection for latter generations in developing drought tolerant high yielding genotypes. © 2020 Friends Science Publishers

Keywords: Seed cotton yield; Fiber quality; Physiological traits; Yield traits

Introduction

Cotton (*Gossypium hirsutum* L.) is an important fiber cash crop of Pakistan and usually cultivated for fiber, livestock feed and edible oil. Cotton is cultivated over a large area in Sindh and Punjab Provinces. Pakistan is the 4th largest producer of cotton in the world after India, China and USA. However, Pakistan ranks 3rd among cotton consuming countries of the world (GOP 2018).

Water is a key factor for plant growth, development and yield attributes. Cotton plant is a glycophytic in nature and show medium tolerance to abiotic stresses *e.g*., drought, as compared to other major crops. Harsh climatic conditions badly effect the growth, quality and yield of cotton crop (Papastylianou and Argyrokastritis 2014; Iqbal *et al*. 2017). Critical stages which are highly responsive to drought are flowering and boll formation, as moisture stress not only reduce bool retention but quality of fiber is also affected (Iqbal *et al*. 2018;). Moderate water stress enhances yield and fiber quality of crop (Papastylianou and Argyrokastritis 2014). A significant reduction in PH, NMBP, NSBP, NBP, FL, FS and SI of cotton plant was observed under drought conditions (Iqbal *et al*. 2017; Bakhsh *et al*. 2019). Abrupt drought episodes resulted in drastic yield reduction and poses threat for sustainable production in plants (Wang *et al*. 2016; Hussain *et al*. 2018). Timely irrigation not only helpful for sustainable yield but also enhance stress tolerance capability of cotton plant (Zahoor *et al*. 2017; Farooq *et al*. 2019). Depending upon the severity and duration of stress, 50–70% yield losses were observed in cotton (Berry *et al*. 2014).

In water limited environment, synthesis and translocation of carbohydrates to reproductive parts of plant is reduced, while depletion of reserved starch is fastened (Galmes *et al*. 2007; Abid *et al*. 2016). This phenomenon ultimately resulted in malnutrition of the plant reproductive organs due to which boll size and weight is decreased (Hearn 1980; Iqbal *et al*. 2017). Final impact of this

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malnutrition is dropping of leaves and fruits from plant and final yield is drastically reduced (Pettigrew 2004). Basic purpose of cotton breeders under stress environment is to improve the quality and quantity of lint to meet the demand of high grade fiber (Wendel and Cronn 2002). Water availability during growth and development of fiber cell has direct impact on fiber quality (Girma *et al*. 2007).

Yield stability and improvement under normal and stress environment is necessary for cotton crop. Different environmental (rainfall, temperature and sunlight) and physiological factors (RWC, ELWL, CMT & CC) determine the complexity of drought tolerance in cotton. Genetic variability among the genotypes is considered as key factor for plant breeders (Ul-Allah *et al*. 2019). To cope with drought, better understanding of morpho-physiological mechanisms *i.e*., escapes, avoidance and tolerance, and their response to confer drought tolerance in plant is necessary. Additive and non-additive genetic attributes play significant role in inheritance of traits from parents to off springs. High magnitude of specific Combining ability (SCA) than general combining ability (GCA) depicted predominance of over-dominance gene action for FF, FS and SL (Saravanan *et al*. 2010). PH, NBP and SI were highly influenced by partial dominance with additive genetic effects (Iqbal *et al*. 2008). Magnitude of GCA variance was greater than SCA variance for CC, PH, NMBP, NBP, FS and SL. So, these traits were influenced by additive genetic effects while NSBP and SI were under influence of non-additive genetic attributes due to GCA > SCA variance (Saeed *et al*. 2017). But all these findings do not cover environmental effects into the account. Due to climate change, change in the environment, especially drought, is expected, due to reason we have planned this experiment, with selection for drought followed by inheritance studies.

The basic objective of this research was to study the effect of water stress on nature of gene action and inheritance pattern of different physiological, fiber quality and yield related attributes in cotton under varying level of moisture stress. This study will be helpful not only for choosing an appropriate breeding programme, but also for selection of superior parents and F_1's, which can perform best under water deficit environment.

Materials and Methods

Experimental site and location

The study was conducted at experimental farm of Department of Plant Breeding and Genetics, Bahauddin Zakariya University, Multan.

Selection of parents

Seventy (70) genotypes of cotton collected from various national cotton research stations were screened in glasshouse at seedling stage. Genetic material was equally divided into two groups each comprised of 70 genotypes. Three seeds/pot of each genotype were sown in glasshouse using Complete Randomize Design. One group of genotypes was irrigated at regular intervals (control) to meet full water requirements, while 2nd group was exposed to two successive drought cycles. First stress cycle was initiated at first true-leaf stage and after 12 h of visual symptoms of wilting, plants was irrigated to field capacity. Plants from both (normal & stress) groups were uprooted after completion of 2nd cycle of drought. Data related to seedling parameters *i.e*., CMT, RWC, ELWL, FSW, FRW, DSW, DRW and RSR were measured and subjected to statistical analysis. On the basis of seedling performance eight genotypes were ear-marked for hybridization and evaluation of F_1's in the field. Out of this experiment, five line (good performer under drought) and three testers (poor performer under drought) were selected for further studies.

Development of line × tester population

The seeds of eight (8) genotypes comprising five lines (CIM-446, FH-682, MNH-814, LINE-A-100, 149-F) and three testers (CIM-240, CRIS-134 and Sadori) were sown in the pots. Nine (9) pots were assigned to each genotype and six seeds per pot were planted to have three plants per pot after germination. All necessary practices were exercised to have a vigorous crop. At blooming stage, hybridization/ crossing were attempted carrying 5 accessions (female) as lines and three accessions (male) as tester. Self-fertilized bolls from eight parents and crossed bolls from 15 F_1 hybrids of each combination (fully opened) were picked out in order to get seed cotton. F_1 seed was obtained after Ginning. Extreme attention was given to avoid the seeds of different genotypes from mixing during process of ginning.

Parental seed along with F_1's was planted in the field in two plots using triplicate randomized complete block design. One plot was irrigated 100% (irrigation every week) and 2nd plot was given half number of irrigations (irrigated after two weeks) at different growth stages. At maturity ten (10) fully guarded plants per replication were selected and data for the following parameters were recorded.

Physiological traits

For excise leaf water loss (ELWL), the leaves were weighed at three stages, *viz*., immediately after sampling (fresh weight), placing leaves in an incubator at 28ºC at 50% R.H. for 3 h & 6 h and then dried in an oven for 24 h at 70ºC as proposed by Clark and McCaig (1982);

$$\text{ELWL } (0-3\text{h}) = {}^{FW_0 - FW_3}/_{FW_0 - DW} \quad (1)$$

$$\text{ELWL } (3-6\text{h}) = {}^{FW_3 - FW_6}/_{FW_3 - DW} \quad (2)$$

$$\text{ELWL } (0-6\text{h}) = {}^{FW_0 - FW_6}/_{FW_0 - DW} \quad (3)$$

Where FW_0, FW_3 and FW_6 are fresh weight after 0, 3 and 6

h, respectively, and DW is dry weight after drying at 70°C.

Fresh, mature and fully extended leaves were cut from three random plants and immediately placed in ice box. Fresh weight was taken immediately. Leaves were than soaked in distilled water for 24 h and after 24 h turgid weight was recorded. After that leaves were kept in oven at 80°C for 24 h to record dry weight. The relative water content (RWC) was recorded using following formula (Barrs and Weatherly 1962).

$$RWC(\%) = \frac{(FW - DW)}{(TW - DW)} \times 100 \quad (4)$$

For cell membrane thermos-stability (Sullivan 1972), three mature leaves were random Ly taken from each treatment and were cut into 3.5 cm long pieces. After washing, two sets of test tubes were made each containing 10 mL of water and a piece of leaf. One set was used as control and other was used for drought treatment. The treatment set of test tubes was wrapped with paraffin film and heated in water bath at 45°C for 1 h (T1) while control was kept at room temperature (25°C). The tubes were kept at 10°C for 24 h to allow leakage of electrolytes form leaves. After 24 h tubes were shifted to room temperature shaken well and electric conductivity (C1) was recorded. The tubes were than heated at 100°C for 30 min (T2) to release all electrolytes and then cooled at room temperature. After shaking, the final electric conductance was measured (C2). Membrane stability was calculated by following formula;

$$CMS(\%) = \{1 - \left[\frac{1-T_1/T_2}{1-C_1/C_2}\right]\} \times 100 \quad (5)$$

Chlorophyll content (CC) was determined during and after anthesis by using a SPAD 502 (Minolta Spectrum Technologies Inc., Plainfield, IL, USA) portable leaf chlorophyll meter.

Yield contributing traits

Among yield related traits, plant height (cm), number of monopodial and sympodial branches per plant, number of bolls per plant and seed index were measured from guarded tagged plant as descried by Ul-Allah *et al*. (2019) and averaged for statistical analysis.

Fiber traits

Total seed cotton of all tagged (10) plants in each entry were ginned with a single roller electrical gin in the laboratory on individual plant basis. Lint was conditioned by placing at 65% humidity and 18–20°C temperature in an air-conditioned room using humidifier before fibre testing. Quality characteristics of Fiber *i.e*., fiber fineness (FF), fiber strength (FS) and staple length (SL) were measured in μg/inch, g/tex and mm respectively, using High Volume Instrument (HVI-900-SA; Zelwiger, Uster, Switzerland) at textile college Bahauddin Zakariyia University, Multan.

Statistical analysis

The data were analysed by following Steel *et al*. (1997) to find out the significance of genetic dissimilarities among generations used in the experiment under two moisture levels. The 3×5 line × tester analysis was performed following the procedure given by Kempthorne1957.

The statistical model used to obtain the different effects was as follows:

$$Y_{ijk} = \mu + g_i + g_j + S_{ij} + e_{ijk} \quad (6)$$

Where: Yijk is the performance of the cross between the ith and jth genotypes in the kth replication;
μ is the overall mean; gi and gj are GCA effects for the ith and j th parents respectively; sij is the SCA effect for the cross between the ith and jth genotypes and eijk is the error term associated with the cross evaluated.

General combining ability (GCA) and specific combining ability (SCA) were computed for characters that showed significant differences among crosses following Line × Tester analysis Kempthorne (1957). Estimation of GCA of line and tester and SCA of crosses was performed using the following expression:

$$g_i = X_{itr} - X_{ltr} \quad (7)$$

$$g_j = X_{jtr} - X_{ltr} \quad (8)$$

$$S_{ij} = X_{ijr} - X_{ltr} - X_{jlr} + X_{ltr} \quad (9)$$

Where g_i is the GCA of line, g_j is the GCA of tester, S_{ij} is SCA effects, X_i is the total of the ith line, X_j is the total of the jth tester; X_{ij} is the crossing of the ith line and jth tester; X is grand total; r is the number of replications, l is number of lines; t is number of tester.

Results

Data analyses depicted highly significant ($P \leq 0.05$) differences among all genotypes and between both water treatments for all the studies traits (Table 1). Results revealed that for CMT, RWC, CC, PH, NSBP, NBP and FS, GCA variances were negative and SCA variances were positive under both experimental conditions. Such results depicted that these traits are highly influenced by non-additive type of gene action. However, GCA and SCA variances were positive for ELWL, NMBP, SI, FF and SS (Table 2). These results depicted the predominance of both additive and non-additive genetic effects for inheritance of these traits under both experimental conditions.

Regarding contribution of lines & testers, contribution of lines was higher as compared to testers for all parameters under both experimental conditions, except for CMT and SI. Results regarding degree of dominance depicted the

Table 1: Analysis of variance for physiological, yield contributing and fiber traits under control and drought conditions in cotton

SOV	DF	Tr	CMT	ELWL	RWC	CC	PH	NMBP	NSBP	NBP	SI	FF	FS	SL
Replication	2	C	696	1.56	128.	0.770	0.930	0.280	14.6	4.75	0.220	0.101	1.84	0.890
		D	908	0.350	2.33	1.91	1.87	0.820	6.04	3.64	0.020	0.003	9.80	0.100
Genotypes	22	C	525	2.12	95.1	92.1	536	1.69	117	104	2.38	0.620	44.3	2.57
		D	596	0.220	201	131	2299	0.510	45.5	39.4	1.51	0.910	64.9	3.31
Parents	7	C	49.2	0.110	109	118	785	1.42	60.3	44.8	3.03	0.770	40.7	3.52
		D	162	0.180	458	120	1367	0.610	40.7	30.2	1.37	0.420	61.8	1.39
Crosses	14	C	706	3.24	84.2	77.7	354	1.82	149	140	2.22	0.450	48.9	2.13
		D	361	0.250	52.4	119	2110	0.410	45.8	41.9	1.61	1.10	67.6	3.98
P. *vs.* crosses	1	C	1336	0.610	150	107	1331	1.76	74.2	19.3	0.140	1.84	5.53	2.05
		D	6932	0.070	479	381	11476	1.30	75.7	67.2	1.02	1.61	47.3	7.36
Lines	4	C	1704	3.17	83.4	117	566	1.77	190	138	1.60	0.850	80.7	0.900
		D	98.8	0.540	60.3	148	3201	0.740	46.8	105	3.99	2.17	143	5.95
Testers	2	C	788	2.28	25.5	65.2	26.0	2.74	75.4	192	5.58	0.530	35.6	1.53
		D	290	0.002	2.04	19.1	3041	0.820	6.76	7.36	0.510	1.46	33.1	0.880
L × T	8	C	186	3.51	99.3	60.9	331	1.62	147	128	1.69	0.230	36.4	2.90
		D	510	0.170	61.1	129	1332	0.140	55.1	19.0	0.690	0.480	38.3	3.77
Error	44	C	570	1.91	61.9	2.98	2.94	0.890	1.01	5.10	0.070	0.040	1.33	0.530
		D	353	0.210	121	0.220	2.37	0.160	0.840	2.45	0.020	0.040	1.22	0.180
Total	68	C	559	1.97	74.6	31.7	175	1.13	39.1	37.2	0.820	0.230	15.2	1.20
		D	448	0.220	143	42.7	745	0.300	15.6	14.4	0.500	0.320	22.0	1.19

Here SOV= source of variation; DF= degree of freedom; Tr= treatments; CMT= cell membrane thermo stability; ELWL= excise leaf water loss; RWC= relative water contents; CC= chlorophyll contents; PH= plant height; NMBP= number of monopodial branches per plants; NSBP= number of sympodial branches per plants; NBP= number of boll per plants; SI= seed index; FF= fiber fineness; FS= fiber strength; SL= staple length; L= lines; T= testers; C= control; D= drought

Table 2: Estimates of genetic components and percent contribution of line and testers for physiological, yield contributing and fiber traits under control and drought conditions

Genetic components	Tr	CMT	ELWL	RWC	CC	PH	NMBP	NSBP	NBP	SI	FF	FS	SL
σ^2gca	C	-0.568	0.084	-0.050	-0.134	-0.087	0.035	-0.079	-0.093	0.050	0.009	-0.158	0.026
	D	-0.024	0.005	-0.054	-0.062	-0.174	0.010	-0.050	-0.408	0.039	0.026	-0.242	0.140
σ^2sca	C	-128	0.533	12.4	19.3	109	0.244	48.7	41.1	0.541	0.064	11.6	0.787
	D	52.5	0.013	-20.3	43.1	443	0.009	18.0	5.52	0.222	0.148	12.3	1.198
σ^2D	C	-2.27	0.336	-0.200	-0.536	-0.348	0.140	-0.316	-0.372	0.200	0.036	-0.632	0.104
	D	-0.096	0.020	-0.216	-0.248	-0.696	0.040	-0.200	-1.632	0.156	0.104	-0.968	0.560
σ^2H	C	-512	2.132	49.8	77.2	437	0.976	194	164	2.164	0.256	46.7	3.148
	D	210	0.052	-80.1	172	1772	0.036	72.3	22.0	0.888	0.592	49.4	4.792
Contribution of lines	C	510	2069	222	437	170	402	102	2873	462	183	5836	175
	D	5.70	3152	50.3	155	111	229	247	625	1559	540	1213	323
Contribution of tester	C	118	745	33.9	121	3.91	311	203	1991	8058	57	1288	149
	D	8.38	6.36	0.853	10.0	53.0	125	17.8	21.8	100	181	140	23.9
Degree of dominance	C	0.004	0.158	-0.004	-0.007	-0.001	0.143	-0.002	-0.002	0.092	0.141	-0.014	0.033
	D	0.0005	0.385	0.003	-0.001	0.0004	1.111	-0.003	-0.074	0.176	0.176	-0.020	0.117

Here σ^2gca=variance of GCA; σ^2sca=variance of SCA; σ^2D= additive variance; σ^2H= dominance variance; CMT= cell membrane thermo stability; ELWL= excise leaf water loss; RWC= relative water contents; CC= chlorophyll contents; PH= plant height; NMBP= number of mono podial branches per plants; NSBP= number of sympodial branches per plants; NBP= number of boll per plants; SI= seed index; FF= fiber fineness; FS= fiber strength; SL= staple length; L= lines; T= testers; C= control; D= drought

importance of non-additive gene action for inheritance of all traits except NMBP, which was governed by additive genetic effects under stress environment.

Parental line CIM-446 proved to be poor combiner for most of the studied traits under both experimental conditions (Table 3). Parental line FH-682 proved to be good general combiner for CC, PH, SI, NMBP, FS and SL under normal and drought conditions. MNH-814 was good combiner for NMBP, NBP and SI under both environments, while for CC and FF under stress environment. Line-A-100 proved to be good combiner for CMT, ELWL and NBP under normal and drought environments. Results of general combining ability revealed that parental line 149-F proved to be good combiner for RWC, NMBP, NSBP, NBP and FS under normal and drought conditions.

Among testers, CIM-240 proved to be good general combiner for CC, NMBP, FF and FS under both experimental conditions. CRIS-134 was good combiner for CMT, ELWL, NMBP and SI under both experimental conditions. Results of GCA revealed that SADORI was a poor combiner among testers for studied parameters, except for RWC and NBP (Table 3).

Specific combining ability results (Table 4) revealed that F_1 CIM-446 × CIM-240 proved to be a good cross combination for RWC, CC and NMBP under normal and drought conditions. Cross combination CIM-446 × CRS-134 proved to be good combiner for NSBP, NBP, FS and SL under both experimental conditions. Cross combination

Table 3: General combining ability estimates depicting the breeding value of lines and testers of physiological, yield contributing and fiber traits under control and drought conditions in cotton

Lines (L)	Tr	CMT	ELWL	RWC	CC	PH	NMBP	NSBP	NBP	SI	FF	FS	SL
CIM-446	C	-4.22	-0.260	0.485	2.18	1.77	-0.230	-2.23	-4.46	0.527	0.278	-0.600	-0.258
	D	-1.55	0.216	2.16	2.22	-21.3	0.089	-2.38	-5.01	-0.055	0.429	0.156	-0.171
FH-682	C	9.13	1.02	-4.48	5.26	-9.00	0.363	-3.56	-3.59	0.087	0.222	3.06	0.153
	D	-1.02	-0.264	-2.80	5.24	-15.2	0.311	0.726	-1.59	0.556	-0.082	5.15	0.084
MNH-814	C	-5.58	-0.328	-1.33	-1.578	11.5	-0.341	5.65	3.59	0.172	-0.489	-3.60	0.398
	D	-3.75	0.155	-0.844	0.156	6.53	-0.356	-2.34	3.58	0.727	0.251	-4.84	-0.127
LINE-A-100	C	18.01	-0.420	3.24	-2.76	-5.66	0.585	-4.11	3.94	-0.602	-0.078	-1.93	-0.380
	D	4.94	-0.270	-1.75	-2.31	25.9	0.200	1.28	2.41	-0.914	0.218	-2.84	1.240
149-F	C	-17.3	-0.020	2.10	-3.11	1.33	-0.378	4.25	0.516	-0.184	0.067	3.06	0.087
	D	1.38	0.163	3.23	-5.30	4.08	-0.244	2.72	0.607	-0.314	-0.816	2.37	-1.027
Testers(T)	Tr	CMT	ELWL	RWC	CC	PH	NMBP	NSBP	NBP	SI	FF	FS	SL
CIM-240	C	-6.44	0.449	0.337	2.33	1.17	-0.459	-0.911	3.91	0.325	0.218	1.44	0.340
	D	0.465	-0.004	-0.099	1.28	-16.3	-0.237	0.711	-0.798	-0.036	0.262	1.68	-0.133
CRIS-134	C	7.85	-0.250	-1.439	-0.665	0.244	0.385	2.55	-0.807	0.379	-0.109	0.178	-0.047
	D	4.15	-0.010	-0.309	-0.461	6.35	0.230	-0.622	0.516	0.200	0.082	-0.578	0.280
SADORI	C	-1.41	-0.199	1.10	-1.67	-1.42	0.074	-1.64	-3.10	-0.704	-0.109	-1.622	-0.293
	D	-4.616	0.014	0.409	-0.826	9.956	0.007	-0.089	0.282	-0.164	-0.344	-1.111	-0.147

Here Tr= treatments; CMT= cell membrane thermo stability; ELWL= excise leaf water loss; RWC= relative water contents; CC= chlorophyll contents; PH= plant height; NMBP= number of monopodial branches per plants; NSBP= number of sympodial branches per plants; NBP = number of boll per plants; SI= seed index; FF= fiber fineness; FS= fiber strength; SL= staple length; L= lines; T= testers;
C= control; D= drought

Table 4: Specific combining ability estimates depicting the breeding value of 15 F_1's of physiological, yield contributing and fiber traits under control and drought conditions in cotton

Crosses	Tr	CMT	ELWL	RWC	CC	PH	NMBP	NSBP	NBP	SI	FF	FS	SL
CIM-446 × CIM-240	C	-2.40	-0.462	6.58	3.68	-4.51	-0.170	-2.12	-3.99	-0.325	0.016	-0.667	-0.329
	D	-8.92	0.351	7.67	4.80	16.0	-0.244	0.585	0.309	-0.205	-0.396	-1.36	-0.356
CIM-446 × CRIS-134	C	-7.28	0.085	-2.61	-0.998	10.0	-0.126	9.07	3.46	-0.445	-0.158	2.60	0.024
	D	-7.47	-0.190	-1.39	-1.28	4.42	0.178	3.91	1.52	0.093	0.151	3.91	0.098
CIM-446 × Sadori	C	9.68	0.377	-3.97	-2.69	-5.578	0.296	-6.94	0.529	0.770	0.142	-1.933	0.304
	D	16.3	-0.160	-6.28	-3.51	-20.5	0.067	-4.50	-1.83	0.113	0.244	-2.55	0.258
FH-682 × CIM-240	C	-3.93	2.19	0.686	-1.94	6.60	0.570	-2.79	0.342	-0.240	-0.096	0.667	-0.707
	D	13.2	-0.336	-4.31	-2.12	12.3	0.089	2.36	0.853	0.395	0.416	0.644	0.622
FH-682 × CRIS-134	C	5.7	-0.912	-1.48	3.61	0.200	-0.607	-2.92	-3.60	0.429	0.098	0.267	-0.420
	D	-6.35	0.213	2.14	4.71	-14.0	-0.156	-3.74	-1.82	-0.041	-0.338	-0.089	-0.558
FH-682 × Sadori	C	-1.76	-1.283	0.797	-1.66	-6.80	0.037	5.71	3.26	-0.189	-0.002	-0.933	1.12
	D	-6.93	0.123	2.16	-2.58	1.71	0.067	1.38	0.973	-0.354	-0.078	-0.556	-0.064
MNH-814 × CIM-240	C	-4.48	-0.295	1.74	-1.06	-15.9	-0.059	-6.68	-5.24	0.119	0.216	-2.66	0.616
	D	0.377	-0.081	0.933	-0.054	-35.1	0.089	-0.896	-1.89	-0.798	0.016	-2.35	1.73
MNH-814 × CRIS-134	C	-0.789	0.200	-5.89	1.09	6.64	-0.348	1.18	3.90	0.888	-0.291	2.60	0.369
	D	-10.1	0.007	-1.42	0.573	15.5	-0.156	-5.00	0.996	0.622	0.262	2.24	-0.213
MNH-814 × Sadori	C	5.27	0.095	4.14	-0.024	9.31	0.407	5.49	1.34	-1.007	0.076	0.067	-0.984
	D	9.75	0.074	0.493	-0.519	19.6	0.067	5.90	0.896	0.176	-0.278	0.111	-1.52
LINE-A-100 × CIM-240	C	-2.34	0.338	2.08	-5.74	-8.46	1.39	-1.59	-2.81	-0.971	0.331	-4.40	0.247
	D	13.7	-0.172	2.57	-6.69	6.75	0.289	3.80	2.96	-0.326	0.262	-3.75	0.187
LINE-A-100 × CRIS-134	C	-1.01	0.402	3.43	0.376	-0.133	-0.963	-5.17	-8.88	0.333	-0.436	-0.933	-1.30
	D	-11.1	0.022	0.224	-0.956	-14.1	-0.156	-0.948	-2.20	-0.039	-0.378	-1.22	0.347
LINE-A-100 × Sadori	C	7.45	-0.698	-3.50	-6.04	5.26	0.089	4.83	-2.80	-0.192	-0.240	-2.66	-0.640
	D	-2.13	-0.083	-1.49	-10.2	-0.689	0.200	0.807	1.48	0.243	-0.151	-1.91	-1.46
149F × CIM-240	C	4.72	0.289	7.90	2.03	-8.46	-0.311	-5.74	-0.949	0.099	0.020	-1.06	-0.220
	D	10.1	0.141	-1.90	2.69	-12.6	-0.156	1.03	-3.66	-0.348	-0.338	-2.31	0.487
149F×CRIS-134	C	-12.1	0.409	-4.40	4.00	3.20	0.222	0.904	3.75	0.093	0.220	3.73	0.860
	D	-8.05	-0.058	3.40	7.57	13.3	-0.044	-1.83	2.1	0.105	0.489	4.22	0.980
149F × Sadori	C	3.36	-0.740	-5.51	5.36	8.60	-0.430	6.76	11.6	0.638	0.104	5.33	1.06
	D	-2.61	0.150	-2.79	7.65	7.42	-0.133	-2.85	-0.758	0.365	0.116	4.97	-0.533

Here CMT= cell membrane thermo stability; ELWL= excise leaf water loss; RWC= relative water contents; CC= chlorophyll contents; PH= plant height; NMBP= number of monopodial branches per plants; NSBP= number of sympodial branches per plants; NBP= number of boll per plants; SI= seed index; FF= fiber fineness; FS= fiber strength; SL= staple length; L= lines; T= testers; C= control; D= drought

CIM-446 × Sadori was a good combiner for CMT, PH, SI, FF and SL under both environmental conditions. Cross combination FH-682 × CIM-240 was good specific combiner for CMT, ELWL, NSBP, SI, FF and SL under drought conditions. Cross combination FH-682 × Sadori was good combiner for RWC, NSBP and NBP under both

environments.MNH-814 × CIM-240 proved to be a good specific combiner for ELWL, RWC, PH, FF and SL under both experimental conditions. MNH-814 × CRIS-134 was a good specific combiner for CC, NMBP, NBP, SI and FS under normal and stress environment. MNH-814 × Sadori proved to be a good specific combiner for CMT, RWC, NSBP, NBP and FS under normal and drought environments.

Line-A-100 × CIM-240 was a good specific combiner for CMT, ELWL, RWC, NSBP, NBP, FF and SL under normal and stress environment (Table 4). Line-A-100 × Sadori proved to be a good specific combiner for ELWL and NSBP under both environments, while for PH, NBP and SI under stress environment. Cross combination 149-F × CIM-240 was a good combiner for CMT, CC and NMBP under normal and stress environment. Cross combination 149-F × CRIS- 134 proved to be a good specific combiner for CC, NBP, SI, FF, FS and SL under both environments. Cross combination 149-F × Sadori was good combiner for CC, NMBP, SI, FF and FS under normal and drought conditions.

Discussion

Fiber quality of cotton crop is reduced under water deficit environment, as plant utilizes its all assimilates for seed yield (Shareef *et al*. 2018). ANOVA revealed existence of high genetic variability among parents, crosses, lines, testers and their relevant cross combinations with each other, as mean squares were highly significant for all parameters under normal and stress environment (Table 1). Additive variance was negative for most of the traits under normal and stress environment. It could be possible only due to absence of epistasis in genetic model, existence of significant environmental variation or due to assortative mating technique (Bridges and Knapp 1987). Negative additive variance also depicts that selection in early generation can mislead the selection (Zhang *et al*. 2017); therefore, selection must be delayed till further generations.

GCA effects of parents and SCA effects of crosses were highly affected by stress environment. Magnitudes of GCA and SCA effects were high under control condition as compared to water deficit environment, indicating that parents and crosses with positive effects were more under normal environment (Shiri *et al*. 2010). Existence of variability in performance of parents and F_1's is due to genetic dissimilarity among parents and G × E interaction existing during the experiment (Pettersen *et al*. 2006). The genetic mechanism in maize (*Zea mays* L.) and cotton working under normal conditions is different from stress conditions (Chattha *et al*. 2018). Similarly, in this study we have observed combining ability effects under stress conditions were different as compared to normal conditions. So, it is suggested that selection for best combiner for stress environments should be screened under stress condition.

Environmental variance was high in comparison with partitioned genotypic (lines & tester) variance. To resolve this problem, assume negative variance equal to zero. Specific combining ability variance was very high under both experimental conditions revealing that all studied parameters were influenced by non-additive gene action except NMBP (additive) under stress environment. These results suggested heterosis breeding for improvement of physiological, fiber quality and yield related attributes under normal and stress environment. However, direct selection could be done for NMBP under water deficit conditions. Negative GCA and SCA values are preferred for ELWL and NMBP. High positive values revealed that parental genotypes showed excessive water loss from plant under normal and drought conditions, which is undesirable. In same way, monopodial branches are desirable for high yield, but this trait also enhance insect infestation on plant, which ultimately reduce fiber quality and yield of plant (Munir *et al*. 2018).

This study is very helpful in understanding of genetic mechanism involved in inheritance pattern of different morpho-physiological traits in cotton under normal and water deficit conditions. Knowledge of nature of gene action (additive, non-additive & epistasis) for different parameters is helpful for execution of useful breeding program. On the basis of studied parameters, germplasm could also be evaluated for other abiotic stresses like heat tolerance in cotton (Azhar *et al*. 2005; Karademir *et al*. 2016).

Conclusion

There was high genetic variability among lines (females) and testers (males) for all studied parameters under normal and drought stress environment. Combining ability variance analysis revealed that both GCA and additive variances were negative in magnitude except for ELWL, NMBP, SI, FF and SL under both normal and stress conditions. SCA and dominance variances were positive and higher than GCA in magnitude under both normal and stress conditions except for RWC. As most of the traits are being controlled by non-additive type of gene action, therefore, heterosis breeding is recommended. In case of development of cotton variety, crop selection must be delayed to latter generations until the fixation of segregating genes.

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