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RESEARCH ARTICLE

Drought tolerance indices and path-analysis in long staple cotton genotypes (*G. barbadense*)

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Abstract

Drought stress is a serious abiotic factor that adversely affects cotton yield and fiber properties. The objectives of this study were to screen several genotypes of cotton belong to *Gossypium barbadense* L. for drought tolerance, study drought indices, correlations, and path-coefficient analysis. Fourteen long- staple kinds of cottons cultivated, and obsolete cultivars were screened for drought tolerance at normal irrigation and drought- stressed experiments for two years. Mean squares indicated significant ($p \leq 0.01$) differences among genotypes in the separate and combined analysis. The effect of years showed significant ($p \leq 0.05$ to $p \leq 0.01$) differences in most cases. The interaction of genotypes by years was significant for all traits except few cases. The reduction % caused by drought stress in SCY/P ranged from 31.44 to 39.39 with an average of 33.93. Among ten tolerant indices STI, MP, GMP, HM and DI could be considered the best tolerant indices to detect both of tolerant and susceptible genotypes. The correlation of SCY/P under normal irrigation was high with LY/P, Lint %, NB/P, LI and BW, moderate with NS/B and upper half mean length, and low with DFF, Pressley index and negative with Micronaire reading. However, the picture was different under drought stress, in which drought affected lint rather than seeds. The direct and indirect effects of SCY/P components varied greatly under both environments, and LY/P, NB/P and NS/B should be considered as selection indices under normal irrigation, NB/P and NS/B under stress when selection practiced for SCY/P.

Keywords: Correlation; Drought indices; Drought tolerance; G. barbadense**;** Path-analysis.

1. Introduction

Drought stress is a serious abiotic factor limits crop production worldwide. Egypt suffers from water scarcity required for agriculture. Furthermore, it has become necessary to grow cotton in newly reclaimed soil and leave the old valley for other crops that cannot bear the lack of water. The drought stress significantly affects many agronomic traits like reduction in size and number of bolls per plant, plant height, above- ground fresh weight, seed cotton yield etc. (Malik *et al.*, 2006). The yield and fiber traits of cotton are adversely influenced by moisture stress. Thus, it is a great issue for cotton physiologists and breeders to develop water stress tolerable genotypes (Veesar *et al.*, 2018). Mahdy *et al.* (2008) studied three irrigation treatments: 80, 100 and 120% evapotranspiration (Et) at sandy calcareous and clay soils. The effect of irrigation treatments was significant ($p \leq 0.01$), Dandara and Giza 83 were the best tolerant cultivars for all traits. The interaction of irrigation x cultivars was highly significant for all traits except for lint %, seed and lint indices at both locations and boll weight at the sandy soil. Turkey (2012) noted genotypic variation Between locations. Drought stress

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adversely affected all the growth and yield and its components (Alishah and Ahmadikhah, 2009 ; Mahdi *et al.,* 2014 ; Sahito *et al.,* 2015 ; Hamoud *et al.,* 2016 ; Bakhsh *et al.,* 2019). Furthermore, fiber quality was significantly affected by drought levels (Gao *et al.,* 2020).

Geometric mean productivity (GMP), mean productivity (MP), and stress tolerance (STI) index indices were able to discriminate drought-sensitive and tolerant genotypes (Singh *et al.,* 2016). In wheat found that STI, MP and GMP were the more efficient drought tolerance indicators in identifying high yielding genotypes under normal and drought stress conditions (Fouad, 2018). Yehia (2020) stated that the indices of MP, GMP, STI, YI and HM (harmonic mean) were considered as a better predictor of yield under stress (Ys) and under normal condition (Yp) than the other indices. Many authors reported positive correlations between yield and its components in most cases, and correlations among yield traits were higher in normal irrigation as compared with water stress (Farooq *et al.,* 2014; Reddy *et al.,* 2015; Joshi and Patil, 2018; Khokhar *et al.,* 2017; Abdel-Monaem *et al.,* 2018; Nawaz *et al.,* 2019; Amein, 2020). The true picture of that correlation between seed cotton yield and its contributing traits was reflected from direct and indirect effects to perceive the most influencing characters to be utilized as selection criteria in the cotton breeding program (Tulasi *et al.,* 2012). Bolls plant-^{1} had maximum direct effect followed by boll weight, seed index and lint index (Ahsan *et al.,* 2015; Reddy *et al.,* 2015). Nawaz *et al.* (2019) found that the maximum direct positive effect of lint weight was (2.6005) on seed cotton yield followed by fiber fineness (1.2628), seed index (1.1449) and bolls/plant (1.0027). The objectives of this study were to screen several genotypes of cotton belong to *Gossypium barbadense* L. for drought tolerance, the ability of ten selection indices to identify drought-resistant cultivars under normal irrigation and drought stressful environmental conditions, and study correlations and path-coefficient analysis among seed cotton yield and its components.

2. Materials and methods

The experiments were carried out at Shandaweel Research Station, Sohag, Agricultural Research Center (A.R.C), Egypt during the two-summer successive growing seasons of 2018 and 2019. Fourteen cotton varieties (*Gossypium barbadense* L.) and promising lines were evaluated under water stress and normal irrigation conditions.

2.1. Evaluation

2.1.1. Season 2018 (first season)

The genotypes shown in Table 1 were evaluated under normal irrigation and water stress conditions. All these genotypes are long - staple fiber. Pure seeds of these genotypes were obtained from Cotton Research Institute, Agricultural Research Center at Giza, Egypt.

The fourteen genotypes shown in Table 1 were sown on March 25th in a randomized complete block design of three replications. Each plot consisted of one row, four-meter-long, 0.6 m apart and 40 cm between hills within a row. One stripe five meters in width was left without planting between the normal irrigation (irrigation as required) and drought- stressed (irrigation just before wilting point) experiments to prevent water seepage. After full emergence, seedlings were thinned to one plant per hill.

Table 1. The name, pedigree, and the main characteristics of these genotypes.

Genotype	Pedigree	Characteristics
Giza 80	G. 66×G. 73	Long- staple variety. It is high yield and Lint percentage.
Giza 83	G.72×G.67	A long- staple variety, early maturity, good yarn and tolerant to high temperature
Giza 85	G. 67×CB 58	A long- staple variety, characterized by high yield and earliness variety.
Giza 90	Dandara×G.83	A long- staple cotton variety, early maturity, high yield, good yarn, and tolerant to high temperature.
Giza 95	[(G. 83 × (G.75 × 5844)) × G. 80]	A long- staple cotton variety, high yield, high lint percentage, early maturity, and heat tolerance.
Dandara	Selected from Giza-3	Long- staple variety (obsolete).
Ashmouni	Giza 1	Long- staple variety (obsolete).
Australian		From Australia belong to Gossypium barbadense L.
Krashinki		From Russia belong to Gossypium barbadense L.
Giza 90×Australian	G. 90×Australian	A long- staple cotton variety, early maturity, high yield, high L% and tolerant to high temperature
[(Giza 91×Giza 90) × Giza 80] (A)		Promising line in 12 generation
[(Giza 90× Australian) ×Giza 85] (B)		Promising line in 14 generation
[(Giza 90× Australian) × {(Giza 83×Giza 72) × Dandara}] (C)		Promising line in 13 generation
[(Giza 90× Australian) × {(Giza 83×Giza 75) × 5584}] (D)		Promising line in 12 generation

2.1.2. *Soil Samples*

Disturbed and undisturbed soil samples were collected from plots of each irrigation level at vertical depths of 0-15, 15-30, 30-45 and 45-60 cm before and after irrigation. Measurement of soil moisture content was carried out using the difference in the soil moisture content in each layer before and after irrigation using the gravimetric method. The sum of the soil moisture deficits of the four layers were added in the next irrigation to reach the field capacity.

2.1.2.1. *Soil physical and chemical properties*

The soil physical and chemical properties were measured at Shandaweel Research Station Lab., Sohag, Agricultural Research Center (A.R.C), Egypt as the following.

Particle size distribution according to Gee and Bauder (1986). Field capacity was determined according to Cassel and Nielsen (1986). Available water was calculated from the values of field capacity and wilting point. Bulk density was determined according to (Blake and Hartge, 1986). The soil moisture constant of the experimental field i.e., field capacity, wilting point and available soil moisture were determined and were 30.69 %, 12.63%, and18.06 % respectively. The soil was clay loamy in texture with a bulk density of 1.22 g/cm^3 and pH 7.9. Soil samples were taken from each 15 cm depth up to 60 cm from the ground surface. The amount of water consumed during each irrigation period was obtained from the difference between soil moisture content before the following irrigation and that of the preceding one according to the following formula as described by Israelsen and Hansen (1962). Soil moisture constants and Soil physical and chemical properties were measured and recorded in Tables 2 and 3.

2.1.2.2. Actual water consumptive use 'WCU' (Actual evapotranspiration)

Water consumptive use (actual evapotranspiration) was computed as the difference in soil moisture in the soil samples taken before and after irrigations. It was affected by the amounts and intervals of irrigation. It was calculated according to the equation of Israelsen and Hansen (1962) as follows:

CU=D x Bd x (Q2-Q1/100)

Where:

CU= actual water consumptives use in (mm).

D = irrigation soil depth

Bd=bulk density of soil (g cm $^{-3}$)

Q1 = soil moisture percent before next irrigation.

Q2 = soil moisture percent after irrigation by 48 h.

CU (m^3 fed^{-1}) = CU (mm) x 4.2

To obtain the actual water consumptive use CU, the soil moisture percentage was determined gravimetrically on a dry basis just before irrigation. Soil samples for moisture determination were taken from each 15 cm depth up to 60 cm from the soil surface by a regular auger. The samples were weighted and then oven- dried. The amount of water consumed in each irrigation interval was obtained from the difference between soil content before the following irrigation and field capacity.

At flowering self-pollination was done for the best plants in the plot, days to first flower (DFF) was recorded for five plants/row. Before picking, 10 open sound bolls were picked from each plot to measure boll weight (BW, g), seed index (SI, g), lint index (LI, g).

Table 2. Soil profile and physical analysis of the experimental site at Shandaweel Agricultural Research Station.

depth (cm)	Particle distribution%				Texture	Hydraulic Conductivity , cm/h	Bulk density, gm/cm^3	Soil water content, %		
	Course sand	Fine sand	Silt	Clay				Saturation	Field Capacity	Permanent wilting point
A (1-15)	7.80	16.20	38.20	37.80	Clay Loam	2.90	1.34	56	27.60	15.50
B (15-30)	6.90	15.50	39.50	38.10	Clay loam	2.90	1.36	50	28	14.1
C (30-45)	10.00	35.50	45.20	9.30	Loam	11.50	1.56	27.1	12.2	7.2
D (45-60)	15.50	33.90	42.10	8.50	Loam	10.70	1.57	29.3	15.1	6.4

Table 3. concentration of soil available macro-and microelements, electrical conductivity (EC), PH, and calcium carbonate in the site at Shandaweel Agricultural Research Station.

Season	Concentration, mg/100g soil										
	HCO-3	Cl^-	$SO4^=$	Ca^{++}	Mg^{++}	Na^+	K^+	EC, Ds/m(1:5)	pH	N%	$CaCO_3$%
2018	0.30	0.88	1.02	0.52	0.26	1.26	0.16	0.263	7.3	0.20	1.26
2019	0.26	0.79	1	0.50	0.24	1.17	0.14	0.246	7.8	0.17	1.41
2020	0.22	0.70	0.98	0.48	0.22	1.08	0.12	0.229	8.3	0.14	1.56

At the end of the season the following characters were recorded for each plot: seed cotton yield /plant (SCY/P, g), lint yield /plant (LY/P, g), lint percentage (Lint %), number of bolls/plant (NB/P), and number of seeds/boll (NS/B). The technological properties were determined for a mixed sample from each replicate; Micronaire reading (MR), fiber strength as Pressley index (PI) measured by the H.V.I instrument and Upper half mean length, mm as measured by the H.V.I instrument (UHM)

Season 2019 (second season), the genotypes evaluated under water stress and normal irrigation conditions as in the previous season 2018.

2.2. Statistical analysis

Statistical analysis was performed on plot mean basis and significance tests as outlined by Steel *et al.,* 1997. The analysis of variance and covariance was calculated by Miller *et al,* (1958). The path coefficient analysis was done as outlined by Dewey and Lu (1959). Ten drought tolerance indices were calculated based on grain yield under drought (Ys), irrigated (Yp) conditions and the stress intensity SI = 1− (Ys/Yp).

1- Stress susceptibility index (SSI) = [1- (Ys/ Yp)]/SI (Fischer and Maurer, 1978)
2- Stress tolerance index (STI) = Ys.Yp/$(Yp)^2$ (Fernandez, 1992)
3- Mean productivity (MP) = (Ys + Yp)/2 (Rosielle and Hamblin, 1981)
4- Geometric mean productivity (GMP) = √ Ys.Yp (Fernandez, 1992)
5- Tolerance index (TOL) = Yp – Ys (Rosielle and Hamblin, 1981)
6- Yield stability index (YSI) = Ys/Yp (Bouslama and Schapaugh, 1984)
7- Harmonic mean (HM) = [2(Yp Ys)]/(Yp + Ys) (Chakherchaman *et al.,* 2009)
8- Sensitivity drought index (SDI) = (Yp - Ys)/Yp (Farshadfar and Javadinia, 2011)
9- Drought resistance index (DI) = [Ys (Ys/Yp)]/ Ys (Lan, 1988)

10- Relative drought index (RDI) = (Ys/Yp) (Ys/ Yp) (Fischer *et al.,* 1998)

3. Results and discussion

3.1. Tolerance of Egyptian cotton genotypes to water stress condition

Mean squares of all the studied traits under normal and stressed conditions in year1 and year2 and their combined (Tables 4 and 5) indicated significant ($p \leq 0.01$) differences among genotypes in the separate and combined analysis. The effect of years showed significant ($p \leq 0.05$ to $p \leq 0.01$) differences between the two seasons for all traits except NB/P, NS/B, DFF and Micronaire reading under normal irrigation, and for all traits except for LY/P and lint% under stressed condition. These results show that the stability of cotton characters differed from year to year. Furthermore, the interaction of genotypes by years was significant for all traits except for staple length and strength under normal irrigation, and for all traits except for lint% under drought stress. Except for fiber length and strength, most of the variability was caused by genotypes rather than years and their interactions with genotypes. These results indicate the differential response of most cotton traits to soil moisture and seasons. Mahdi *et al.* (2014) noted that seed cotton yield was reduced by drought stress (%47.03), Sahito *et al.* (2015) showed that all the growth and yield components of cotton were significantly ($P < 0.01$) affected by varieties and irrigation frequencies, Hamoud *et al.* (2016) found significant ($p \leq 0.01$) genetic differences between cotton well-watered and water-stressed treatments, Gao *et al.* (2020) noted that fiber quality was significantly affected by drought level, Shilpa and Chandrasekhar (2020) found that fiber fineness and bundle strength decrease in inferior direction as reduction of soil moisture levels.

Means of all traits at normal irrigation and drought stress conditions in both years, their combined, and reduction% are shown in Table 6. The combined means indicated that Giza95 showed the highest SCY/P (127.32 g) and C-genotype was the lowest (68.89 g) under normal irrigation. The reduction % caused by drought stress in SCY/P ranged from 31.44 (D-genotype) to 39.39 (karashinki) with an average of 33.93. Giza 95 showed the best performance under both environments for SCY/P, LY/P, Lint%, NB/P, SI, and LI, while Giza 90 was the best for fiber length (upper half mean length), and the Australian genotype was the best in fiber strength as measured in Pressley index. The reduction% in LY/P caused by drought stress was slightly higher than in SCY/P indicating that lint was more affected than seeds. In consequence, the lint index was more affected by drought than the seed index. Lint% was slightly affected due to that drought stress affected both of lint and seeds. The reduction in yields could be mainly due to the decrease in lint index, boll weight and seed index rather than a decrease in bolls/plant. None of the genotypes was the best in all traits. These results confirm the significant differences obtained among genotypes. Many authors reported the effect of the environment on cotton traits. Turkey (2012) noted genotypic variation between locations. Mahdi *et al.* (2014) found that seed cotton yield was reduced by drought stress (%47.03) and added that it was probably due to a decrease of bolls/plant. Sahito *et al.* (2015) showed that all the growth and yield components of cotton were significantly ($P < 0.01$) affected by varieties and irrigation frequencies. Bakhsh *et al.* (2019) noted that water stress caused a reduction of 14% in days to first flower formation, 27% in number of bolls/ plants, 14% in boll weight and 37% in seed cotton yield.

3.2. Drought Tolerance Indices

The drought tolerance indices (SSI, STI, MO, GMP, TOL, YSI, HM, SDI, DI and SDI) were calculated based on the combined mean of SCY/P under irrigation (Yp) and under drought stress (Ys) and ranked (Table 7). The low rank indicates tolerance and the high indicates susceptibility to drought. The ranks mean was the lowest for Giza 95 followed by Giza 90 and Giz90 × Aus indicating tolerance to drought stress. These genotypes rank the first, second, and the third for drought tolerance indices STI, MP, GMP, HM and DI. Conversely, the highest ranks mean (towards susceptibility) was for Dandara, Ashmouni and Karashinki, their ranks ranged from 9 to 14 for SSI, STI, MP, GMP, YSI, HM, DI and RDI drought indicators. Therefore, STI, MP, GMP, HM and DI detected both of tolerant and susceptible genotypes and could be considered the best tolerant indices. Furthermore, for the 14 studied genotypes, the simple correlation between the ranks of Yp and Ys with ranks mean were 0.999 and 0.993, respectively indicating that the information concerning to drought tolerance could be derived from the performance of a genotype under normal and stress environments. Fouad (2018) found that STI, MP and GMP were the more efficient drought tolerance indices in identifying high-yielding genotypes under normal and drought stress conditions. Yehia (2020) studied the ability of 13 drought tolerance indicators in 24 cottons (*G. barbadense* L.) and noted that MP, GMP, STI, YI (yield index) and HM were the best indicators to detect drought tolerance genotypes.

3.3. Phenotypic correlations among traits

The phenotypic and genotypic correlations among traits over the two years under normal irrigation and under stressed conditions were estimated**.** The genotypic correlation under stressed condition, exceeded the unity in many cases because of the mean squares of genotype by years was larger than mean squares of genotypes (BW, SI, NS/B and DFF- Table5), which diminished the genetic variance (denominator of correlation). Therefore, the genotypic correlations among traits were omitted. The phenotypic correlations are shown in Table 8. The correlation of SCY/P under normal irrigation was high with LY/P, Lint %, NB/P, LI and BW, moderate with NS/B and upper half mean length, and low with DFF, Pressley index and negative with Micronaire reading.

Table 4. Mean squares of the studied traits under normal irrigation in the two years and their combined.

S.O.V.	df	SCY/P	LY/P	L%	NB	BW	SI	LI	NS/B	D.F.F.	MIC	Length	Strength
Year 1													
Reps	2	14.54	0.17	2.09	2.27	0.01	0.01	0.13	0.61	1.60	0.01	0.04	0.001
Genotypes (G)	13	961.57**	183.99**	3.89**	47.86**	0.19**	0.72**	0.47**	8.71**	55.20**	0.69**	30.59**	1.21**
Error	26	15.91	2.69	0.52	1.72	0.004	0.01	0.04	0.14	0.70	0.01	0.31	0.007
Year 2													
Reps	2	21.32	2.99	0.08	5.88	0.003	0.07	0.02	0.13	3.43	0.01	2.43	0.05
Genotypes (G)	13	877.64**	193.79**	9.54**	43.18**	0.17**	0.82**	1.09**	4.60**	57.73**	0.55**	28.90**	230.14**
Error	26	16.02	2.87	0.90	3.37	0.01	0.02	0.08	0.49	0.66	0.01	0.27	0.01
Combined													
Years (Y)	1	181.75**	65.02**	12.45 **	0.02	0.14**	0.09*	1.04**	0.97	0.78	0.02	9.94**	0.26**
Reps/Year	4	14.94	1.58	1.09	4.07	0.01	0.04	0.07	0.37	2.51	0.01	1.23	0.02
Genotypes (G)	13	1791.95**	368.96**	11.46**	84.13**	0.34**	1.44**	1.43**	11.64**	108.97**	1.20**	59.31**	2.52**
G × Y	13	47.26**	8.82**	1.97**	6.91**	0.03**	0.10**	0.13*	1.66**	3.97**	0.04**	0.17	0.01
Error	52	15.96	2.78	0.71	2.55	0.01	0.02	0.06	0.31	0.68	0.01	0.29	0.01
Pheno. Var.	-	298.66	61.02	1.91	14.02	0.06	0.24	0.24	1.94	18.16	0.20	9.89	0.42
Geno. Var.	-	290.78	60.02	1.58	12.87	0.05	0.22	0.22	1.66	17.50	0.19	9.86	0.42

*, **, significant at 0.05 and 0.01 level of probability, respectively.

Table 5. Mean squares of the studied traits under water stress in the two years and their combined.

S.O.V.	df	SCY/P	LY/P	L%	NB	BW	SI	LI	NS/B	D.F.F.	MIC	Length	Strength
Year 1													
Reps	2	105.42	10.27	0.72	27.70	0.001	0.004	0.04	0.03	0.45	0.07	0.72	0.002
Genotypes (G)	13	461.78**	93.69**	12.00**	63.02**	0.14**	0.64**	0.74**	7.00**	34.83**	0.37**	24.15**	0.94**
Error	26	19.49	2.26	1.10	6.48	0.006	0.01	0.05	0.48	0.71	0.005	0.26	0.008
Year 2													
Reps	2	113.35	7.85	2.43	46.93	0.01	0.04	0.03	0.66	2.17	0.02	0.05	0.02
Genotypes (G)	13	414.61**	87.30**	13.50**	64.51**	0.15**	0.75**	0.91**	11.30**	23.52**	0.34**	15.39**	0.83**
Error	26	18.14	1.80	1.18	15.11	0.01	0.01	0.05	0.79	0.63	0.003	0.26	0.01
Combined													
Years (Y)	1	331.00**	3.18	74.53	66.63**	3.48**	0.11**	11.17**	8.97**	3574.39**	66.76**	93.25**	12.85**
Reps/Year	4	98.57	9.45	46.19	29.85	0.00	0.01	0.12	0.31	6405.89	0.06	0.28	0.02
Genotypes (G)	13	1002.65**	194.32**	15.25**	194.27**	4.80**	1.32**	13.07**	44.41**	128.92**	70.53**	63.13**	9.74**
G × Y	13	152.01**	20.74**	2.96	96.82**	4.91**	1.49**	8.77**	62.59**	613.44**	70.11**	40.14**	9.02**
Error	52	19.48	2.44	42.10	5.89	0.01	0.01	0.11	0.57	40.34	0.01	0.26	0.01
Pheno. Var.	-	167.11	32.39	2.54	32.38	0.80	0.22	2.18	7.40	21.49	0.07	10.52	0.12
Geno. Var.	-	141.77	28.93	2.05	16.24	- 0.02	- 0.03	0.72	- 3.03	- 80.49	11.76	3.83	1.62

*, **, significant at 0.05 and 0.01 level of probability, respectively.

Table 6. Minimum (Min) and maximum (Max) combined means and reduction% (Red%), the best (BG) and the lowest performance genotype (LG) under normal irrigation(N) and drought stress(S) for the studied traits.

Item	SCY/P,g			BG	LG	LY/P, g			BG	LG	Lint%			BG	LG
	Min	Max	Average			Min	Max	Average			Min	Max	Average		
N	68.89	127.32	96.00	G.95	C-g	25.04	51.44	36.41	G.95	C-g	35.28	40.41	37.71	G.95	Kar.
S	46.51	85.12	63.48	G.95	C-g	15.87	33.49	23.13	G.95	Kar.	33.21	39.34	36.18	G.95	Aus.
Red%	31.44	39.39	33.93			30.34	43.15	36.65			-2.03	9.01	4.07		
Item	NB/P			BG	LG	BW, g			BG	LG	SI, g			BG	LG
	Min	Max	Average			Min	Max	Average			Min	Max	Average		
N	27.73	39.80	35.14	G.95	C-g	2.41	3.20	2.72	G.95	Aus.	9.19	10.64	9.91	G.80	C-g
S	24.44	40.77	30.26	G.90×Aus.	C-g	1.84	2.45	2.10	G.95	Kar.	7.27	8.77	7.94	G.80	G.83
Red%	-5.21	23.10	14.01			14.07	36.94	22.67			17.92	27.78	20.79		
Item	LI, g			BG	LG	NS/B			BG	LG	DFF			BG	LG
	Min	Max	Average			Min	Max	Average			Min	Max	Average		
N	5.26	7.19	6.01	G.95	C-g	15.46	19.33	17.09	G.90	Kar.	56.84	70.67	65.40	Aus.	Ashm.
S	3.83	5.64	4.47	G.95	G.83	14.46	19.98	17.07	G.83	G.80	52.00	62.50	56.48	Kar.	Ashm.
Red%	17.89	33.75	25.71			-19.88	18.77	-0.16			-	25.47	13.43		
Item	Micronair reading			BG	LG	Length, mm			BG	LG	Strength (PI)			BG	LG
	Min	Max	Average			Min	Max	Average			Min	Max	Average		
N	3.42	4.85	4.17	C-g	Ashm.	24.12	34.12	29.35	G.90	Aus.	8.65	10.77	9.68	A-g	Aus.
S	2.89	4.05	3.54	B-g	D-g	23.29	31.28	27.32	G.90	Kar.	8.20	9.90	9.01	C-g	Aus.
Red%	-7.16	25.46	14.57			-1.80	11.20	6.75			-0.15	11.75	6.93		

G.=Giza, C-g= C- genotype, Ashm.= Ashmouni, Aus.= Australian genotype, Kar.= Karashinki.

Table 7. Ranks (R), ranks mean ($\bar{R}$), the standard deviation of ranks (SDR) and rank-sum (RS) of drought tolerance indices.

Genotype	Rank												R means	SDR	RS
	Yp	Ys	SSI	STI	MP	GMP	TOL	YSI	HM	SDI	DI	RDI			
Giza 80	7	6	3	6	6	6	7	2	6	12	6	1	5.67	2.81	8.47
Giza 83	4	4	9	4	4	4	11	9	4	6	4	6	5.75	2.53	8.28
Giza 85	6	7	12	7	7	7	10	12	7	3	8	12	8.17	2.79	10.96
Giza 90	2	2	6	2	2	2	13	6	2	10	2	7	4.67	3.77	8.44
Giza 95	1	1	7	1	1	1	14	7	1	8	1	8	4.25	4.39	8.64
Giza90*Aus	3	3	10	3	3	3	12	10	3	5	3	9	5.58	3.55	9.14
Ashmouni	10	11	13	11	11	11	6	13	11	2	12	13	10.33	3.23	13.56
Dandara	9	9	11	9	9	9	8	11	9	4	10	11	9.08	1.88	10.96
Karashinki	12	13	14	13	13	13	5	14	13	1	14	14	11.58	4.14	15.73
Austuraly	13	12	1	12	12	12	2	3	12	13	11	2	8.75	5.03	13.78
A	5	5	8	5	5	5	9	8	5	7	5	10	6.42	1.88	8.30
B	8	8	4	8	8	8	4	4	8	12	7	3	6.83	2.59	9.42
C	14	14	5	14	14	14	1	5	10	14	13	4	9.92	4.83	14.75
D	11	10	2	10	10	10	3	1	10	14	9	5	7.92	4.10	12.02

Yp= yield under non-stress, Ys = yield under stress, Stress susceptibility index (SSI), Stress tolerance index (STI), Mean productivity (MP), Geometric mean productivity (GMP), Tolerance index (TOL) , Yield stability index (YSI), Harmonic mean (HM), Sensitivity drought index (SDI), Drought resistance index (DI), Relative drought index (RDI).
Correlation of rank with scy/p under irrigation = 0.999 and under drought stress = 0.993

However, the picture was different under drought stress in which drought affect lint rather than seeds as mentioned above, the correlation of SCY/P was moderate with lint% (0.5897), fiber length (0.7248), low and negative with LI (-0.1488) and Micronaire reading (-0.4090) indicating that drought-affected deposition of cellulose which slightly lowered Micronaire and increase fiber strength. Under normal irrigation LY/P showed correlations with other traits as SCY/P did. While under drought stress the correlation of LY/P was high with lint%, moderate with NB/P, BW and LI and negative with DFF. The correlation of lint% under irrigation was high with NBV/p, BW and LI, moderate with NS/B and fiber length, and low with the other traits. However, under stress it was moderate only with LI and low with NB/P (0.3010), BW (0.3788) and NS/B (0.3229). Under irrigation the correlation of NB/P was high with LI (0.8123) and moderate with BW (0.6978) and fiber length (0.5401). While under drought NB/P gave negative correlations with BW, LI, NS/B, and Micronaire reading, and positive moderate with DFF, fiber length and strength.

The increase in BW under both environments increased NS/B and LI. Concerning fiber length it was increased under irrigation and decreased under drought with increasing BW. It is known that drought stress decrease fiber length.

Micronaire instrument measures fineness and maturity in combined, it measures fineness between genotypes and maturity within a genotype. Low Micronaire reading of a genotype means large number of fibers in unit weight, which increase fiber strength to some extent. Therefore, Micronaire reading negatively correlated with Pressley index under both environments. The results of correlation in general are in line with many researchers (Farooq *et al.*, 2014; Reddy *et al.*, 2015; Khokhar *et al.*, 2017; Nawaz *et al.*, 2019) noted that seed cotton yield has positive genotypic correlation with bolls/plant, boll weight, staple length, strength, and earliness index. Abdel-Monaem *et al.* (2018) observed positive correlations between yield and each of its components in most cases, while correlations among yield traits were higher in normal irrigation as compared with water stress.

Table 8. Phenotypic correlation among traits over two years under normal irrigation (above) and under drought stress (below diagonal).

Traits	SCY/P	LY/P	Lint%	NB/P	BW	SI	LI	NS/B	DFF	MIC.	Length.	Strength.
SCY/P	-	0.9970	0.9199	0.9320	0.8930	0.2339	0.8126	0.5804	-0.0227	-0.2031	0.6190	0.1170
LY/P	0.7517		0.9458	0.9162	0.9007	0.2135	0.82	0.5933	-0.0245	-0.231	0.622	0.1043
Lint%	0.5897	0.8633	-	0.8194	0.8567	0.0886	0.7976	0.5922	0.0679	-0.3236	0.6373	0.1005
NB/P	0.8468	0.4104	0.3010		0.6978	0.3653	0.8123	0.3279	0.0363	-0.1374	0.5401	0.1731
BW	-0.2292	0.4518	0.3788	-0.5776	-	0.0833	0.6667	0.7328	-0.0383	-0.2739	0.6231	0.0630
SI	0.3150	-0.0037	0.0000	0.2848	-0.4052		0.6667	-0.5862	-0.2635	0.4108	0.0779	-0.0945
LI	-0.1488	0.5331	0.5142	-0.4820	0.9768	-0.2888	-	0.0879	0.1150-	0.0	0.5128	0.0
NS/B	-0.1285	0.4567	0.3229	-0.5207	0.9206	-0.5800	0.8266		0.1213	-0.4174	0.4566	0.1219
DFF	0.2146	-0.3699	-0.2978	0.4322	-0.8297	0.2346	-0.8474	-0.6550	-	-0.2151	0.3552	0.4707
MIC	-0.4090	0.2828	0.2598	-0.6585	0.9683	-0.4601	0.9441	0.8404	-0.8467		-0.256	-0.5866
Length	0.7248	0.3164	0.2940	0.5359	-0.4619	0.4141	-0.4448	-0.2607	0.5773	-0.6473		0.4612
Strength	0.3331	-0.3009	-0.2317	0.5261	-0.8784	0.3183	-0.8833	-0.6932	0.7322	-0.9141	0.6274	-

3.4. Path - coefficient analysis

Path-coefficient analysis is an effective method to partition a correlation to direct and indirect effects and helps the breeder to restrict selection for few important traits and reduce time and effort (Wadeyar and Kajjidoni, 2014). The phenotypic correlation coefficients of seed cotton yield with its contributing traits were partitioned to direct and indirect effects and shown in Table 8. Seed cotton yield/plant is a result of lint yield/plant, bolls/plant, number of seeds/boll and seed index.

The correlation coefficient of lint yield / plant with seed cotton yield / plant (Table 8) was positive and very large in magnitude (0.9970) under normal irrigation, and 0.7517 under drought stress. However, the direct effect of LY/P on SCY/P was high (0.6540) under normal irrigation, and low (0.0891) under drought stress (Table 9). The analysis indicated that under normal irrigation selection should be paid on LY/P, NB/P and NS/B, and for NB/P and NS/B under drought stress. The indirect effect of LY/P via SI was low and negligible.

Partitioning the correlation coefficient NB/P with seed cotton yield to their direct and indirect effects indicated that the direct effect of NB/P was the highest (0.9991) under stress rather than under normal irrigation (0.2376). The indirect effect of NB/P on SCY/P was high under irrigation via LY/P (0.5991) and low under drought (0.0365). The indirect effects of NB/P via NS/B and SI were low. Therefore, selection for NB/P under stress and for LY/P under irrigation should be considered.

Partitioning correlation of NS/B and SI with SCY/P indicated that the direct and indirect effects differed greatly under both environments. The direct effect of NS/B and SI were high under drought and low under irrigation, and vice versa concerning LY/P.

It could be concluded that the direct and indirect effects of SCY/P components varied greatly under both environments, and LY/P, NB/P and NS/B should be considered as selection indices under normal irrigation, NB/P and NS/B under stress when selection practiced for SCY/P. Farooq *et al* (2014) found positive direct effect of boll weight on seed cotton yield / plant. Ahsan et al (2015) found that bolls plant-^{1} had maximum direct effect (0.945) followed by the boll weight (0.062), seed index (0.007) and lint index (0.040). Wadeyar and Kajjidoni (2014) and latif *et al*. (2015) noted that the correlation and path analysis together indicated that number of bolls / plant and boll weight should be considered when selection practiced for seed cotton yield / plant. Joshi and Patil (2018) found that number of bolls/plants had positive indirect effect on seed cotton yield/plant, seed index, lint index, fiber strength etc. Boll weight was responsible for high yield through seed index and lint index.

Table 9. Path coefficient analysis under normal irrigation and water stress conditions.

	Normal irrigation	Drought stress
SCY/P *vs* LY/P	r=0.9970	r=0.7517
Direct effect, P15	0.6540	0.0891
Indirect effect, NB/P (r12P25)	0.2177	0.4100
Indirect effect, NS/B (r13P35)	0.1029	0.2539
Indirect effects, SI (r14P45)	0.0224	-0.0013
Total	0.9970	0.7517
SCY/P *vs* NB/P	r=0.9320	r=0.8468
Direct effect, P25	0.2376	0.9991
Indirect via LY/P (r12P15)	0.5991	0.0365
Indirect via NS/B (r23P35)	0.0570	-0.2894
Indirect via SI (r24P45)	0.0383	0.1006
Total	0.9320	0.8468
SCY/P *vs* NS/B	r=0.5804	r=-0.1285
Direct effect, P35	0.1735	0.5559
Indirect via LY/P (r13P15)	0.3879	0.0406
Indirect via NP/B (r23P25)	0.0780	-0.5202
Indirect via SI (r34P45)	-0.0590	-0.2048
Total	0.5804	-0.1285
SCY/P *vs* SI	r=0.2339	r=0.3150
Direct effect, P45	0.1050	0.3532
Indirect via LY/P (r14P15)	0.1396	-0.0003
Indirect via NB/P (r24P25)	0.0868	0.2845
Indirect via NS/B (r34P35)	-0.0975	-0.3224
Total	0.2339	0.3150
Residual effect	0.0360	0.2171

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