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GENOTYPIC VARIATION FOR DROUGHT TOLERANCE IN COTTON (*GOSSYPIUM HIRSUTUM* L.): SEED COTTON YIELD RESPONSES

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Abstract

Instability of cotton yield is partly caused by drought susceptibility. The purpose of this study was to assess genotypic variation for drought tolerance in a set of cotton germplasm using geometric mean (*GM*) and drought susceptibility index (*DSI)* as selection criteria and to determine association of these measures with some productivity and physiological attributes. Thirty-two cotton cultivars were evaluated under well-watered (W_1) and water-limited (W_2) regimes in the field during 2003 and 2004. Drought stress determined by the drought intensity index was more sever in 2004 (0.43) as compared to 2003 (0.21). Genotypic variation was detected for both indices in both the years. Significant negative association of *DSI* with seed cotton yield, boll number and certain physiological attributes conferring drought tolerance in W_2 ($P<0.01$) suggested *DSI* as a useful predictor of drought tolerance in cotton. However, selection based solely on *DSI* may be misleading as it does not differentiate between potentially drought-tolerant genotypes and those that possessed low overall yield. Substantial variation in *GM* ranging from 28.9 to 63.9 and 20.7 to 66.7 g was found among the cotton cultivars in 2003 and 2004, respectively. Significant correlation between *GM* and physio-economic traits under water stress provides support for using *GM* as a stress tolerance predictor. Non association between *DSI* and *GM* suggested that each index is a potential indicator of different biological responses to drought and selection for genotypes with low to moderate *DSI* and high *GM* will resulted in combing different traits associated with each index and thus helping to improve tolerance against drought in cotton.

Key words: *Gossypium hirsutum* L., drought tolerance, geometric yield, drought susceptibility index, physiological attributes

Introduction

Cotton is one of the most important cash crops for smallholder in many of Asian, African and Latin American countries including Pakistan (Fortucci, 2002). Rainfed cotton accounts for 47% of the total world cotton acreage but contributes only 27% in total production. Irrigated cotton is mainly grown in regions with Mediterranean, arid or semi-arid climates stretching from Spain to central Asia and Australia (Gillham *et al*., 1995) where freshwater is in short supply. Thus, the development of drought tolerant cotton genotypes is a practical solution to lessen the negative effects of drought on crop productivity.

Significant efforts have been made during the last two decades to improve drought tolerance in cotton using empirical selection for seed cotton yield *per se* as well as analytical approaches. There has been controversy of environment for selection and breeding for yield traits. One approach is to screen germplasm by conducting trials in dry seasons to select productive genotypes. However, these high yielding genotypes under

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water stress could likely to be low yielding under well-watered environment (Rosielle & Hamblin, 1981). Moreover, the too dry selection sites probably do not reflect the conditions of natural drought which more commonly occur as low water availability in a normally reasonably wet period. Other approach suggests testing of germplasm under stress and non-stress conditions and ranking genotypes for drought tolerance / susceptibility on reduction of the yield (Blum, 1988). However, values are confounded with differential yield potential of genotypes. Other yield-based estimates of drought tolerance are geometric mean and (*GM*; Fernandez, 1993) and drought susceptibility index (*DSI*; Fischer & Maurer, 1978). *GM* is often used by breeders interested in relevant performance since drought stress may vary in severity in field environments over the years. *DSI* is a measure of the reduction in the yield of a genotype under drought conditions with respect to the mean reduction of all the genotypes under consideration. Genotypic differences in *GM* and *DSI* have been demonstrated in different crop species (Ramirez-Vallejo & Kelly, 1998; Frahm *et al*., 2004). Fisher & Wood (1979) reported a significant positive correlation between *DSI* and potential yield in wheat suggesting that direct selection under optimum conditions would increase drought susceptibility.

Genotypic variation for physiological attributes had been reported in cotton. Inhibition of photosynthesis and stomatal conductance due to water stress is well documented (Pettigrew, 2004; Athar & Ashraf, 2005). Osmotic adjustment had also been proposed as a potential trait conferring drought tolerance in cotton (Saranga *et al*., 2001). Cell membrane stability has been widely exploited as an indicator of tolerance against water stress in wheat (Ashraf *et al*., 1992), rice, (Tripathy *et al*., 2000) and sorghum (Premachandra, 1992). Photochemical activity of photosystem II (PS-II) calculated as F_v/F_m and chlorophyll are reliable indicators for the selection of genotypes/cultivars for drought tolerance in canola (Kauser *et al*., 2006).

However, in addition to genotypic variation and high heritability estimates, any secondary trait to be included in breeding program must be directly related to yield. It has been suggested that relationship between *DSI* and physiological attributes like osmotic adjustment (Moinuddin *et al*., 2005) and canopy temperature (Rashid *et al*., 1999) might provide a more effective mean to assess drought tolerance in cereals.

The genetic variation for yield indices including *DSI* and *GM* and their relationship with productivity and physiological attributes in cotton are not well documented. Therefore, the objective of the present study was to assess genotypic variation for drought tolerance in a set of germplasm comprising commercial varieties as well as newly developed elite cotton lines using *GM* and *DSI* as selection criteria and to determine association of these measures with some productivity and physiological attributes.

Materials and Methods

Plant material: The experimental material consisted of 32 upland cotton (*Gossypium hirsutum* L.) cultivars and promising bred lines (hereafter referred to as cultivars) selected on the basis of putative differences in yield under drought conditions. Seed of the cultivars was obtained from their respective breeding stations located at different ecological regions of Pakistan (Table 1).

Experimental design: Thirty-two cotton cultivars were evaluated under two irrigation regimes, well-watered (W_1) and water-limited (W_2) in the field during 2003 and 2004 at the research area of the National Institute for Biotechnology and Genetic Engineering

(NIBGE), Faisalabad, Pakistan. Daily rainfall during each growing season was recorded. The two water regimes were described as:

> **W_1.** One sowing irrigation and 5 subsequent irrigations as required for normal crop growth and development, total water applied including rainfall was 823 and 783 mm in 2003 and 2004, respectively.
>
> **W_2.** One sowing irrigation and one supplement irrigation 40 days after sowing (DAS), total water applied including rainfall was 473 and 457 mm in 2003 and 2004, respectively.

The experimental design was a quadruplicated split-plot with water regimes assigned in main plot and cultivars in sub-plots. During both cotton-growing seasons, sowing was completed during the 1^{st} week of April. Four rows 6 m long and 0.75 m apart were sown of each cultivar with a hand drill. A commercial chemical fertilizer was applied at the rate of 100-50-50 kg N-P_2O_5-K_2O ha^{-1} at the time of seedbed preparation. Plant population was maintained at 4-plant m^{-2} by hand-thinning 25 days after germination. Appropriate control measures were adopted for insect-pest and weed infestation and applied evenly to all the plots.

Measurement of physiological attributes: Net assimilation rate (P_n), stomatal conductance (g_s) and transpiration rate (E) were determined with a Cl-301PS Photosynthesis System (CID, Inc Vancouver USA). All physiological measurements were performed between 1000 and 1300 hours at $PAR \geq 1700$ µmol/m^2/s during cloud free days. A youngest fully expanded main stem leaf (16-18 days old) was exposed to direct sunlight to determine the gas exchange parameters. Measurements were recorded on four randomly selected plants per plot 75 to 78 DAS each year. Mean of four observations per plot was used for the statistical analysis.

Osmotic adjustment was measured by the rehydration method as proposed by Blum (1988). Leaves were sampled from both treatments. For rehydration, petioles of detached leaves were inserted into water and incubated at 10 ^{0}C for four hours in dark. Upon rehydration a 5x5 piece of leaf tissue was excised, avoiding midrib, and placed immediately in a 5ml disposable plastic syringe and stored at –20 ^{0}C. After 2 weeks, samples were thawed and tissue sap was collected in 0.2 ml tubes. After centrifugation (13000 rpm) for 5 min, the sap was directly used to determine osmotic potential (OP) with a vapor pressure osmometer (Wescor, model 5200 Wescor, Loga, UT).

CMS was calculated as reciprocal of relative cell injury (Blum & Ebercon, 1981) with the formula,

$$CMS\% = \{(1-(T_1/T_2))/ (1-(C_1/C_2))\} \text{ x}100$$

Where T_1= Stress sample conductance before autoclaving.
T_2= Stress sample conductance after autoclaving.
C_1= control sample conductance before autoclaving.
C_2= control sample conductance after autoclaving.

There was no effective rainfall up to 92 DAS in 2003 and 81 DAS in 2004 at experimental site.

Measurement of productivity traits: Seed cotton yield (*SCY*) was measured on central two rows from both regimes each year and transformed to per plant for harvest index (*HI*) estimation. Seed cotton was hand picked from all the plots 180 DAS and was sun dried for one day after removing trash and dry carpels before weighing. Average seedcotton weight of 40 bolls picked from each plot was used to appraise boll weight (*BW*). The total number of bolls per plant (*BN*) was calculated by dividing seedcotton yield per plant by boll weight. Plant height (*PH*) was recorded in centimeters from the first cotyledonary node to the apical bud.

Above ground parts of five plants per plot were harvested at 50% boll opening and sun- dried in a glasshouse to a constant weight before weighing for biological yield (*BY*) and averaged to per plant for statistical analysis. *HI* was calculated as the ratio of *SCY* to the total above ground *BY*.

Drought intensity index (*D*) for each year was calculated as $D = 1-(Xd/Xp)$, where *Xd* and *Xp* are mean *SCY* of all cultivars in W_2 and W_1 regimes, respectively.

Geometric mean yield of each cultivar was calculated as $= (Yp*Yd)^{1/2}$

The formula proposed by Fisher & Maurer (1978) was used to calculate drought susceptibility index (*DSI*) for each cultivar. $DSI = [1-(Yd/Yp)]/D$ Where where *Yd* and *Yp* are mean yields of a given cultivar in W_2 and W_1 regimes, respectively and *D* is drought intensity.

Statistical analysis: Analysis of variance (ANOVA), appropriate for the specified experimental design, was performed with MSTAT-C software to evaluate the effects of water regime and cultivars on productivity and physiological attributes. Statistical significance was assumed at 5 and 1% levels of probability. Differences among means were tested by least significant difference (LSD) test at 5% probability level. Simple linear regression and correlation analyses were performed to assess relationship among the variables of interest.

Results and Discussion

The magnitude of water stress varied between two years (2003 & 2004). The stress was more sever in 2004 indicated by the high DII value (0.43) as compare to the lower value of 0.20 in 2003. Positive association between *Yp* and *Yd* supported the hypothesis that genotypic advantages selected under near-optimum growing conditions may be obtained under less favorable growing environments (Quisenberry *et al*., 1980), however, the correlation was comparatively stronger in 2003 (r: 0.92) under mild stress than in 2004 (r: 0.52). Genotypic variation for *DSI* and *GM* was found in both years (Table 1). In 2003, *DSI* ranged from 0.46 to 1.72. Eighteen cultivars showed tolerance (*DSI* value less than one) whereas 14 were found susceptible (*DSI* values greater than one).

In 2004, previous ranking of the cultivars for drought tolerance assessed by *DSI* was affected, however, 12 cultivars including RH-510, FH-1200, FH-930, CIM-1100 and CIM-707 again ranked in drought tolerant group. *DSI* was not correlated with none of the productivity or physiological attribute in 2003 when the drought stress was moderate. Non significant correlation between *DSI* and *Yp* was also observed (data not shown), however, significant negative association of *DSI* with *Yd* ($P<0.01$) in 2004 suggested *DSI* as a useful predictor of drought tolerance in cotton (Table 2). Moreover, significant negative correlation of *DSI* with number of bolls per plant (P<0.01) and certain physiological attributes conferring drought tolerance including net photosynthetic rate, stomatal conductance and osmotic adjustment in 2004 (Table 2) further elucidated its use in identification of drought tolerant genotypes. However, authenticity of *DSI* as a selection criterion for drought tolerant coupled with yield potential is controversial in common bean (Schneider *et al*., 1997; White & Singh, 1991) and wheat (Clark *et al*., 1992).

Substantial variation in *GM* ranging from 28.9 to 63.9 and 20.7 to 66.7 g was found among the cotton cultivars in 2003 and 2004, respectively. Thirteen cultivars showed above average *GM* each in both the seasons. The cultivars RH-510, N-Karishma, CIM-707, MHN-554, FH-2000, CIM-473, CIM-1100 and BH-160 produced comparatively

Table 1. Drought susceptibility index (*DSI*) and geometric mean yield (*GM*) of 32 cotton cultivars/genotypes during 2003 and 2004.

Cultivar	Origin[§]	*DSI*[a]		*GM*[b]	
		2003	2004	2003	2004
BH-160	CRS, BWP	1.47	0.97	58.1	61.7
CIM-1100	CCRI, MN	0.80	0.62	52.3	66.7
CIM-443	CCRI, MN	1.66	1.00	42.7	39.9
CIM-473	CCRI, MN	0.64	0.89	52.4	54.9
CIM-497	CCRI, MN	0.79	0.34	41.4	31.4
CIM-499	CCRI, MN	0.50	1.08	38.9	43.8
CIM-501	CCRI, MN	0.69	0.94	34.4	45.4
CIM-707	CCRI, MN	0.91	0.75	45.3	55.9
FH-1000	CRI, FSD	1.72	0.77	45.5	41.6
FH-1200	CRI, FSD	0.65	0.54	36.4	48.1
FH-2000	CRI, FSD	1.39	1.59	52.8	45.0
FH-634	CRI, FSD	0.66	0.93	28.9	44.0
FH-682	CRI, FSD	1.16	1.57	30.7	39.0
FH-87	CRI, FSD	0.89	0.87	36.3	58.3
FH-900	CRI, FSD	1.09	0.88	37.2	62.2
FH-901	CRI, FSD	1.18	1.71	63.9	35.5
FH-925	CRI, FSD	1.06	0.85	38.2	39.0
FH-930	CRI, FSD	0.61	0.61	39.4	42.0
MNH-147	CRS, MN	1.27	1.34	48.5	40.1
MNH-552	CRS, MN	0.58	1.54	41.4	36.4
MNH-554	CRS, MN	0.98	1.43	55.7	53.6
MNH-642	CRS, MN	0.46	1.15	31.5	33.9
NIAB-111	NIAB, FSD	1.12	0.54	36.2	56.0
NIAB-78	NIAB, FSD	0.67	0.87	49.4	41.8
NIBGE-1	NIBGE, FSD	0.80	1.06	34.9	28.6
NIBGE-160	NIBGE, FSD	1.55	1.40	30.0	20.7
NIBGE-2	NIBGE, FSD	1.30	0.61	33.6	29.2
NIBGE-4	NIBGE, FSD	1.36	0.97	35.1	34.2
N-Karishma	NIAB, FSD	0.79	0.88	53.3	53.4
RH-510	CRS, RYK	0.46	0.47	52.4	66.1
SLH-257	CRS, SWL	0.74	1.25	57.3	39.9
VH-142	CRS, VR	1.41	0.89	40.0	24.3

[a] Drought susceptibility index = $(1 – Yd/Yp)/(1 – Xd/Xp)$. [b] Geometric mean yield = $(Yd*Yp)^{1/2}$

[§] CRS= Cotton Research Station, CCRI= Central Cotton Research Institute, CRI= Cotton Research Institute, NIAB= Nuclear Institute for Agriculture & Biology, NIBGE=National Institute for Biotechnology and Genetic Engineering, BWP= Bahawalpure, MN=Multan, FSD=Faisalabad, RYK= Rahim Yar Khan, SWL= Sahiwal and VR= Vehari

Table 2. Correlation coefficients between drought susceptibility index, geometric mean with productivity traits and physiological attributes of 32 cotton genotypes grown under drought stress 2003 and 2004.

Trait	*DSI*[a]		*GM*[b]	
	2003	2004	2003	2004
Seed cotton yield	-0.16	-0.63**	0.98**	0.93**
Boll number	-0.18	-0.63**	0.93**	0.90**
Boll weight	0.11	-0.22	0.04	0.38
Biological yield	-0.03	-0.26	0.43	0.68**
Plant height	-0.35	0.00	0.08	0.54*
Harvest index	-0.14	-0.44	0.24	0.12
Photosynthetic rate	-0.26	-0.55*	0.52*	0.69**
Stomatal conductance	-0.16	-0.50*	0.42	0.52*
Transpiration rate	-0.46	-0.33	0.31	0.45
Osmotic adjustment	-0.36	-0.71**	0.47*	0.59*
Cell membrane stability	-0.24	-0.24	0.29	0.15

*P<0.05, **P<0.01

[a] Drought susceptibility index = $(1 - Yd/Yp)/(1 - Xd/Xp)$. [b] Geometric mean yield = $(Yd*Yp)^{1/2}$

higher *GM* in both years. Significant positive correlation of *GM* was found with *Yd*, number of bolls per plant (P<0.01), net photosynthetic rate and osmotic adjustment (P<0.05) in both years in W_2 (Table 2) condition. Biological yield, plant height and stomatal conductance were also significantly associated with *GM* in 2004 under W_2, condition, however, the level of these association was not significant in 2003 (Table 2). Significant correlation between *GM* and *Yp* (r=0.98 in 2003; r= 0.83 in 2004) provides additional support for using *GM* as a stress tolerance predictor. Non significant correlation was observed between *DSI* and *GM* (r=0.04 in 2003; r= -0.032 in 2004) indicating that each index is a potential indicator of different biological responses to drought and selection for genotypes with low to moderate *DSI* and high *GM* will result in combing different traits associated with each index which helps in improving drought tolerance.

DSI and *GM* estimates in 2003 and 2004 were utilized to generate a biplot (Fig. 1). Cultivars were grouped into four quadrants when the biplot was truncated at moderate *DSI* (1.0) and high *GM* (50). Quadrant-I contained cultivars with high *DSI* and high *GM*. Cultivars with high *DSI* and low *GM* were grouped in quadrant-II. Cultivars characterized with low *DSI* and high *GM* were clustered in quadrant-III whereas quadrant-IV included cultivars with low *DSI* and low *GM*. Seven cultivars in 2003 and nine cultivars in 2004 were placed in quadrant-III. The cultivars, RH-510, CIM-1100, CIM-707 and N-Karishma grouped in quadrant-III in both years, which were identified as the most drought tolerant using both indices as selection criteria.

The results reported here indicate substantial genotypic variation for *DSI* and *GM* among the cotton cultivars examined and supported the hypothesis that selection for combination of *DSI* and *GM* indices might be more useful in improving drought tolerance in cotton instead of using a single yield basis criterion. Moreover, the cotton cultivars, RH-510, CIM-1100, CIM-707 and N-Karishma, came out as drought tolerant cultivars and could be exploited in breeding programs aiming to improve drought tolerance.

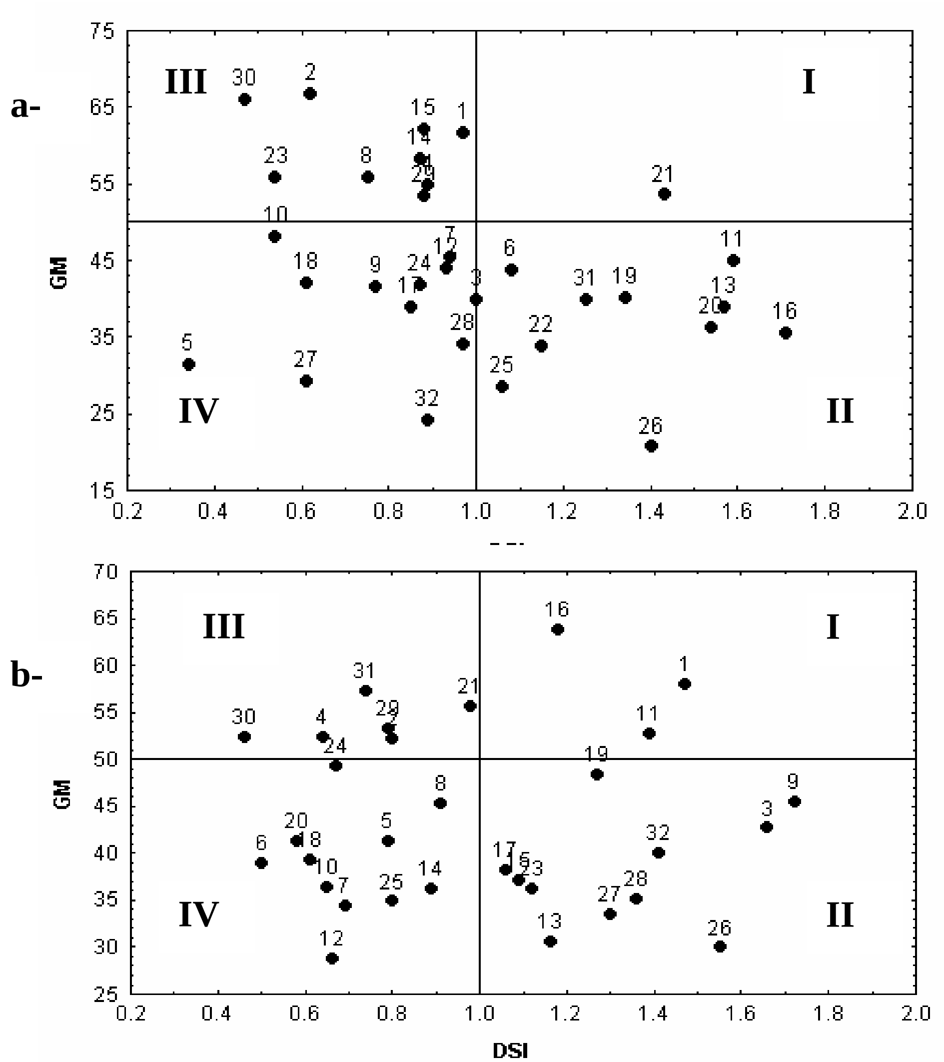

Fig. 1. Biplot between drought susceptibility index (*DSI*) and geometric mean yield (*GM*) for 32 cotton cultivars/genotypes for 2003 (a) and 2004 (b).

1-BH-160, **2**-CIM-1100, **3**-CIM-443, **4**-CIM-473, **5**-CIM-497, **6**-CIM-499, **7**-CIM-501, **8**-CIM-707, **9**-FH-1000, **10**-FH-1200, **11**-FH-2000, **12**-FH-634, **13**-FH-682, **14**-FH-87, **15**-FH-900, **16**-FH-901, **17**-FH-925, **18**-FH-930, **19**-MNH-147, **20**-MNH-552, **21**-MNH-554, **22**-MNH-642, **23**-NIAB-111, **24**-NIAB-78, **25**-NIBGE-1, **26**-NIBGE-160, **27**-NIBGE-2, **28**-NIBGE-4, **29**-N-Karishma, **30**-RH-510, **31**-SLH-257, **32**-VH-142

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