Research Article

Evaluation of Cotton Genotypes for Seed Cotton Yield and Fiber Quality Traits Under Water Stress and Non-Stress Conditions

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Abstract | Cotton is an important commodity that runs the textile industry of Pakistan. Under the present scenarios of climate change and water security cotton production is under threat so, it is imperative for plant breeders to develop cotton lines that can grow on minimum water availability. In this study performance of 23 cotton genotypes was compared for seed cotton yield and fiber quality traits under water stress and non-stress conditions. All the genotypes depicted significant differences for days to first square formation, days to first flower formation, plant height, monopodial branches per plant, sympodial branches per plant, number of bolls per plant, boll weight, fiber length, fiber strength, uniformity index, fiber fineness, ginning out turn and seed cotton yield per plant in both watering treatments. Water stress on an average, caused a reduction of 13% in days to first square formation, 14% in days to first flower formation, 19% in plant height, 18% in monopodial branches, 26% in sympodial branches, 27% in number of bolls per plant, 14% in boll weight, 4% in ginning out turn and 37% in seed cotton yield. GeFH-326 showed better performance for sympodial branches, bolls per plant, fibre strength and seed cotton yield under water stress and non-stress conditions. Sitara-15 recorded higher number of bolls formed, fibre length, fibre strength and seed cotton yield under moisture stress and NIAB-1048 and Zakaria-1 attained higher sympodial branches, maximum bolls per plant, fiber length, GOT and seed cotton yield per plant under non-stress treatment.

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Introduction

Cotton (*Gossypium hirsutum* L.) is a known as major fiber and cash crop. It is predominantly cultivated in more than hundred countries of the world with the major share from USA, China, India and Pakistan. Being high economic value crop, cotton provides livelihood to rural people and a major share to the textile sector. Cotton offers 1.0 percent in national GDP and adds 5.2 percent in agriculture esteem value addition of Pakistan (GOP, 2016-17). Pakistan is moving from water abundant to water scarce country. The present scenarios of rising population and climate change are drawing very bad picture of water availability. Cotton is grown in dry areas where its production has deep effect on the water supply systems. During 2015-16, the availability of water was 65.5 million acre feet (MAF) showing a decline of 5.5 % over 2014 and 2.4 % over normal supplies of 67.1 MAF. Current shortage is 11.69 MAF which is likely to increase to 30 MAF by the year 2025 (GOP, 2016-17).

Links Researchers

Cotton is said to be problematic crop because all the biotic and abiotic factors cause yield losses in cotton (Choudhury et al., 2017; Nachimuthu and Webb, 2017). Water stress is the most devastating abiotic factor that adversely effects the plant growth, seed cotton yield and fiber quality attributes in cotton (Makbul et al., 2011). Water stress affects all the morpho-physiological processes that ultimately lead to reduced crop yield and productivity. It negatively affects photosynthesis, respiration and plant assimilate synthesis. Seed cotton yield has close association with formation and retention of bolls. Significant reductions were observed in plant height, bolls per plant, sympodial branches and seed cotton yield when adequate amount of water was not applied at most sensitive growth stages such as bud formation, flowering and boll formation. (Jayalalitha et al., 2015; Zonta et al., 2015; Zhang et al., 2016). Fiber quality traits including fiber length, fiber strength and fiber fineness were also decreased under water stress conditions (Karademir et al., 2011; Sahito et al., 2015; Amin et al., 2016). Under these circumstance, it is imperative for plant breeders to develop cotton genotypes that can produce better yield under water limited conditions.

Cotton is successfully grown when either plenty of irrigation water is available or genotypes under cultivation have the ability to compensate yield losses under moisture stress conditions (Sahito et al., 2015). Success in breeding for drought tolerant cotton depends upon the identification of morphological traits related to drought tolerance (Rahman et al., 2008). Availability of genetic variation is prerequisite for result oriented breeding program. Existence of genetic variability for drought tolerance in cotton germplasm has been reported by several workers. (Pettigrew and Meredith, 1994; Lacape et al., 1998). Loka et al. (2011) reported numerous morphological traits as best selection criteria for drought tolerance in cotton. Keeping in view the importance of cotton sector, water status of the country and effects of moisture stress on cotton production, present research was planned to evaluate the performance of newly bred cotton genotypes under water stress and non-stress conditions.

Materials and Methods

Current research was conducted at the experimental farm of Ghazi University, Dera Ghazi Khan during 2016. The climate of the experimental area was arid to semi-arid. Seasonal rainfall, average temperature, and humidity are presented in Figure1. The soil of experimental location was clay loam with pH of 7.5 and a saturation percentage of 48.5%. Twenty-three cotton genotypes including BPC-10, BS-151, CEMB-88, CIM-625, CIM-632, CRIS-600, Crystal-12, CYTO-313, FH-152, FH-326, GH-Mubarak, IR-NIBGE-8, IR-NIBGE-9, NIAB-1048, NS-18, SAU-1, Sitara-15, SLH-12, Thakar-808, Weal-AG-1606, Weal-AG-Gold, Weal-AG-Shahkar and Zakaria-1 were evaluated under two water treatments (water stress and normal irrigation) using randomized complete block design with split plot arrangements in three replications. Water treatments comprised of main plots and cotton genotypes as sub-plots entries. Each genotype was grown in 3 rows of 5-meter length, with 75 cm spacing between rows and 30 cm within the rows. Recommended doses of fertilizers and cultural practices were applied throughout the growing season. For normal irrigation treatment, eight irrigations -one at sowing and seven other irrigations with an interval of 15 days were applied at various crop growth stages. Water stressed plot was irrigated four times with one at the time of sowing and other three irrigations were applied with an interval of 30 days.

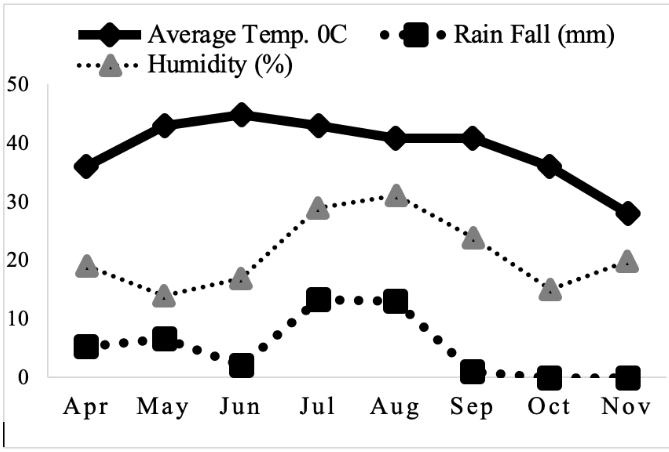

Figure 1: *Average Temperature (^{0}C); Rain fall (mm) and Humidity (%) of experimental site during the study period (Source: http://www.worldweatheronline.com).*

Five plants were selected within each genotype and labeled with wax coat. Data were collected for traits including days to first square formation, days to first flower formation, plant height, monopodial branches per plant, sympodial branches per plant, number of bolls per plant, boll weight, fiber length, fiber strength, uniformity index, fiber fineness, ginning out turn (%) and seed cotton yield per plant. The data collected were analyzed using statistical package SAS 9.2 version (SAS Institute, Cary NC, 2004). Significance of differences for analysis of variance were detected as ** p < 0.01 and * p < 0.05. Significance of differences among genotypes under different water treatments were determined using Fisher's protected LSD at α = 0.05.

Results and Discussion

The analysis of variance (Table 1a and b) revealed significant variability among water treatments and cotton genotypes for all the measured traits. Noteworthy, genotype × water treatment interaction was observed for number of days to first square formation, number of days to first flower formation, monopodial branches per plant, sympodial branches per plant, number of bolls per plant, boll weight and seed cotton yield per plant. These types of results can be helpful in cotton breeding program to develop new water stress tolerant germplasm (Volkan et al., 2015). Similar findings were reported by Veesar et al. (2018) about variations in cultivar performance evaluated under moisture stress and normal irrigation conditions.

Days to first square formation

Early square formation is required in cotton (Tolk and Howell, 2010). On an average, water stress caused 13% reduction in number of days taken to first square formation as compared to normal irrigation. Cotton genotype Weal-AG-1606 (30.0 and 34.3 days) and Zakaria-1 (27.0 and 34.3 days) were identified with minimum days taken to first square formation under both water stress and non-stress conditions. Among others, NIAB-1048 (30.0 days) was earlier under water stress and Crystal-12 (33.1 days) took less days for square development under normal irrigation conditions (Table 2a). Patil et al. (2004), Pettigrew (2004) and Alishah and Ahmadikhah (2009) also found significant variation for early square formation in cotton genotypes when exposed to water treatments.

Days to first flower formation

A significant reduction of 14% was observed for days to first flower formation under moisture stress as compared to non-stressed condition. Genotype FH-152 (43.6 days), IR-NIBGE-8 (45.0 days) and NIAB-1048 (46.6 days) were found early flowering as they took less days for first flower formation under moisture stress condition. Under normal irrigation Zakaria-1 (52 days), SAU-1 (54.0 days) and Weal-AG-1606 (54.2 days) took less days to first flower formation. Water stress clearly distinguished early flowering cotton

Table 1a: *Means squares for days to first square formation (DFSF), days to first flower formation (DFFF), plant height (PH), monopodial branches per plant (MBP), sympodial branches per plant (SBP), number of bolls per plant (NB) and boll weight (BW) of 23 cotton genotypes grown under water stress and non-stress conditions.*

Sources	DF	DFSF	DFFF	PH	MBP	SBP	NB	BW
Replication	2	20.55	6.15	442.6	0.98	0.68	22.11	0.06
Treatment	1	954.84**	2446.09**	17811.57**	6.26**	906.03**	2847.39**	6.90**
Replication × Treatment	2	2.43^NS	1.22^NS	92.66^NS	0.04^NS	0.26^NS	8.47^NS	0.01^NS
Genotype	22	60.06**	41.93**	975.51**	1.24**	50.59**	75.59**	0.13**
Genotype × Treatment	22	7.84*	10.59**	39.37^NS	0.07**	7.06**	29.23**	0.14**
Error	88	3.61	3.88	68.11	0.02	0.76	6.76	0.03

**: Significant at 5% level of probability; **: Significant at 1% level of probability; NS: non-significant.*

Table 1b: *Means squares for fiber length (FL) fiber strength (FS), uniformity index (UI), fiber fineness (FF), ginning out turn% (GOT), and seed cotton yield (SCY) of 23 cotton genotypes grown under water stress and non-stress conditions.*

Sources	DF	FL	FS	UI	FF	GOT	SCY
Replication	2	0.13	1.00	1.07	0.04	0.01	323.30
Treatment	1	14.87**	18.99**	185.73**	1.87**	80.80**	52710.16**
Replication × Treatment	2	0.83^NS	1.33^NS	0.56^NS	0.01^NS	0.64^NS	87.01^NS
Genotype	22	3.85**	4.79**	8.16**	0.52**	10.12**	726.13**
Genotype × Treatment	22	0.38^NS	0.89^NS	1.00^NS	0.02^NS	0.40^NS	440.39**
Error	88	0.28	0.56	0.82	0.03	0.7	95.73

**: Significant at 5% level of probability; **: Significant at 1% level of probability; NS: non-significant.*

genotypes. Similar findings have been reported been reported by Patil et al. (2004) and Alishah and Ahmadikhah (2009) about early flowering in cotton genotypes when grown under water deficit condition.

Plant height (cm)

Cotton genotypes with medium tallness are preferred for suitable height of flowers and boll formation. On an average, a reduction of 19% was observed in the height of cotton plants under stress condition. Average plant height was 109.5 cm under moisture stress and 132.2 cm under-non stress condition. Cotton genotypes NS-181 (108.2 cm and 133.0 cm) and Cyto-313 (110.4 cm and 134.2 cm) achieved medium height under stress and non-stress conditions. SAU-1 (107.7 cm) and Weal-AG-1606 (112.0 cm) were identified with medium tallness under moisture deficit conditions. Under normal irrigation BS-15 (129.4 cm) and NIAB-1048 (132.0 cm) were around the average height. Lack of genotype × water treatment interaction indicated that response of genotypes was similar to water stress and non stress conditions but differences among genotypes were prominent (Table 1a). A decrease of 38.3% in plant height of cotton genotypes was noticed by Ninganur et al. (2008). These findings are similar to those reported by Jayalalitha et al. (2015).

Monopodial branches per plant

Cotton genotypes with minimum monopodial branches per plant are required for selection of high yielding cultivars (Khokhar et al., 2018). A significant reduction of 18% for monopodial branches per plant under water stress condition indicated noteworthy variation for this trait (Table 2a). Genotypes that produced lowest monopodial branches under moisture stress and non-stress conditions were Weal-AG-Gold (1.0 and 1.3), SAU-1 (1.0 and 1.5) and CIM-625 (1.1 and 1.5). This indicates moisture tolerance of these genotypes as compared to others. Presence of considerable variation in cotton for monopodial branches in response to water treatments were observed by Ratnakumari and Subbaramamma (2006) and Ghongane et al. (2009).

Sympodial branches per plant

Sympodial branches are the fruit bearing branches and positively associated with yield in cotton (Bozorov et al., 2018). The number of sympodial branches per plant was reduced by 26% under water stress conditions. Higher number of sympodial branches under moisture deficit and normal irrigation conditions was documented in FH-326 (19.4 and 24.8) followed by Weal-AG-Shahkar (18.8 and 24.6), Zakaria-1 (18.3 and 25.7) and CIM-632 (18.2 and 24.2). Other genotypes with higher sympodial branches were IR-NIBGE-8 (18.6) under water deficit and SLH-12 (24.9) and NIAB-1048 (24.2) under normal moisture conditions. Similar results were reported by Jayalalitha et al. (2015), Sahito et al. (2015) and Veesar et al. (2018) who observed that cotton genotypes with different genetic makeup produce larger variation for sympodial branches in response to various water regimes.

Number of bolls per plant

Number of bolls per plant is an important trait to determine seed cotton yield. Soil moisture deficiency significantly restricts the developing capacity of each cotton boll (Stewart, 1986). Number of bolls per plant was markedly lowered (27%) under water deficit condition. Cotton genotype FH-326 produced higher bolls per plant (30.2 and 39.0) under both water stress and non-stress conditions. Other genotypes that produced maximum bolls per plant under moisture stress conditions were SLH-12 (29.2), IR-NIBGE-8 (29.0) and Sitara-15 (28.7) (Table 2a). Genotypes that produced highest number of bolls under well water condition were Zakariya-1 (42.5) NIAB-1038 (40.5) and FH-326 (39.0). Similar to current findings, Pettigrew (2004) and Veesar et al. (2018) stated that response of cotton genotypes for number of bolls was different to non-stressed and stressed conditions.

Boll weight (g)

Boll weight is considered as a significant trait that directly influences the final yield of cotton. Cotton genotypes under water stress conditions recorded 14% decline in mean boll weight as compared to well-watered condition (Table 2a). Maximum boll weight (2.9 g) under water stress condition was recorded in each of Zakaria-1, FH-326 and FH-152. Genotypes producing bolls with maximum weight under water stress condition are considered better choice to develop high yielding stress tolerant breeding material (Veesar et al., 2018). Under normal irrigations, maximum boll weight was obtained by FH-152 (3.7 g) and BS-15 (3.5 g). Varied response of cotton genotypes to different water regimes was also reported by Grimes et al. (1969), Gerik et al. (1996) and Wang et al. (2016).

Table 2a: *Mean days to first square formation (DFSF), days to first flower formation (DFFF), plant height (PH), monopodial branches per plant (MBP), sympodial branches per plant (SBP) number of bolls per plant (NB) and boll weight (BW) of 23 cotton genotypes grown under water stress and non-stress conditions.*

Genotypes	DFSF		DFFF		PH(cm)		MBP		SBP		NB		BW(g)	
	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
BPC-10	33.6^{l-p}	42.6^{ab}	50.3^{i-n}	59.6^{b-d}	116.8^{j-p}	145.6^{a-d}	2.0^{i-m}	2.7^{b-d}	11.5^{w-y}	17.1^{k-p}	21.6^{r-u}	32.6^{f-i}	2.8^{h-n}	3.0^{f-h}
BS-15	40.0^{b-g}	42.3^{a-c}	56.0^{ef}	64.3^{a}	100.0^{r-t}	129.4^{f-j}	1.7^{n-p}	2.0^{i-m}	12.7^{u-w}	16.8^{l-p}	20.0^{tu}	27.4^{j-n}	2.7^{l-o}	3.5^{ab}
CEMB-88	35.6^{h-l}	42.0^{a-c}	50.0^{j-n}	60.3^{b}	123.7^{f-m}	151.0^{a}	2.2^{f-i}	2.8^{a-c}	15.8^{p-s}	19.3^{f-i}	27.2^{j-o}	32.3^{f-i}	2.8^{h-n}	3.2^{c-f}
CIM-625	37.3^{f-j}	41.3^{a-d}	52.0^{g-k}	61.3^{ab}	79.9^{v}	100.5^{r-t}	1.1^{st}	1.5^{pq}	10.4^{y}	16.4^{o-r}	20.2^{t-u}	33.0^{e-h}	2.5^{o-q}	3.3^{b-d}
CIM-632	35.0^{i-n}	43.0^{ab}	50.3^{i-n}	60.3^{b}	119.5^{i-o}	136.8^{b-f}	2.1^{h-l}	2.5^{de}	18.2^{i-l}	24.2^{bc}	25.6^{k-r}	36.9^{b-e}	2.4^{p-r}	2.7^{l-o}
CRIS-600	35.3^{i-m}	42.6^{ab}	51.0^{h-m}	62.0^{ab}	104.1^{p-t}	124.2^{f-l}	1.9^{l-n}	2.0^{i-m}	13.2^{t-v}	16.9^{k-p}	27.8^{j-k}	29.4^{h-k}	2.7^{l-o}	2.7^{l-p}
Crystal-12	30.6^{pq}	33.0^{l-q}	48.0^{m-p}	56.6^{de}	113.2^{l-r}	122.5^{g-m}	2.1^{h-l}	2.8^{a-c}	15.9^{p-s}	20.8^{de}	22.7^{p-u}	35.9^{c-f}	2.5^{o-q}	3.3^{b-d}
Cyto-313	35.6^{h-l}	37.6^{e-i}	51.3^{h-l}	57.0^{c-e}	110.4^{r-m}	134.2^{c-g}	2.0^{i-m}	2.9^{ab}	10.9^{xy}	20.8^{de}	20.2^{j-o}	36.4^{b-d}	2.8^{h-n}	3.2^{c-f}
FH-152	34.6^{i-o}	41.0^{b-d}	43.6^{q}	59.3^{b-d}	125.1^{f-l}	149.6^{ab}	2.0^{i-m}	2.2^{f-i}	15.3^{q-s}	18.0^{i-m}	22.2^{q-u}	26.6^{j-p}	2.9^{g-k}	3.7^{a}
FH-326	34.0^{k-o}	42.6^{ab}	53.3^{f-i}	60.0^{bc}	121.7^{g-m}	146.8^{a-c}	2.2^{f-i}	2.6^{c-e}	19.4^{e-g}	24.8^{ab}	30.2^{g-j}	39.0^{a-c}	2.9^{g-k}	3.2^{c-f}
GH-Mubarak	37.6^{e-i}	42.0^{a-c}	51.6^{h-l}	60.3^{b}	84.7^{uv}	113.0^{l-r}	1.3^{q-s}	1.9^{l-n}	12.0^{v-x}	17.9^{i-n}	20.4^{tu}	26.6^{j-p}	2.6^{n-p}	2.7^{l-o}
IR-NIBGE-8	32.3^{m-q}	40.3^{b-f}	45.0^{pq}	56.6^{de}	120.3^{h-o}	147.1^{a-c}	2.1^{h-l}	2.3^{f-h}	18.6^{g-j}	23.0^{c}	29.0^{h-l}	36.5^{b-f}	2.6^{n-p}	3.2^{c-f}
IR-NIBGE-9	37.6^{e-i}	40.6^{b-e}	51.3^{h-l}	59.6^{b-d}	96.8^{s-u}	123.6^{f-m}	1.3^{q-s}	1.7^{n-p}	13.5^{tu}	15.1^{rs}	23.2^{n-u}	34.3^{d-g}	2.3^{qr}	3.2^{c-f}
NIAB-1048	30.0^{qr}	35.3^{i-m}	46.6^{o-q}	55.0^{e-g}	104.4^{p-s}	132.0^{e-i}	2.0^{i-m}	2.7^{b-d}	16.6^{m-q}	24.2^{bc}	23.7^{m-t}	40.5^{ab}	2.5^{o-q}	3.2^{c-f}
NS-181	37.0^{g-k}	41.6^{a-d}	49.0^{k-o}	60.0^{bc}	108.2^{n-s}	133.0^{d-h}	1.6^{op}	1.9^{l-n}	14.5^{st}	17.4^{j-o}	21.2^{s-u}	26.6^{j-p}	2.2^{r}	3.4^{bc}
SAU-1	32.0^{n-q}	35.3^{i-m}	49.6^{j-o}	54.0^{e-h}	107.7^{o-s}	121.6^{g-n}	1.0^{t}	1.5^{pq}	12.5^{u-w}	15.8^{p-s}	22.1^{q-u}	26.0^{j-q}	2.8^{h-n}	2.9^{g-k}
Sitara-15	35.0^{i-n}	41.6^{a-d}	50.3^{i-n}	59.3^{b-d}	114.9^{h-q}	136.1^{c-f}	2.0^{i-m}	2.1^{h-l}	15.8^{p-s}	19.8^{d-g}	28.7^{i-l}	35.0^{c-f}	2.7^{l-o}	2.8^{h-n}
SLH-12	31.0^{o-q}	35.6^{h-l}	48.6^{l-o}	55.0^{e-g}	113.0^{l-r}	129.2^{f-j}	2.2^{f-i}	2.8^{a-c}	17.2^{k-p}	24.9^{ab}	29.2^{h-k}	38.0^{b-d}	2.7^{l-o}	3.0^{f-h}
Thakar-808	35.0^{i-n}	42.3^{a-c}	51.0^{h-m}	59.6^{b-d}	102.4^{q-t}	127.1^{f-k}	2.1^{h-l}	2.4^{e-g}	16.5^{n-r}	20.9^{d}	27.7^{j-m}	32.8^{e-i}	2.8^{h-n}	3.0^{f-h}
Weal-AG-1606	30.0^{qr}	34.3^{j-o}	47.6^{n-p}	54.2^{e-h}	112.0^{l-r}	129.6^{f-j}	1.7^{n-p}	1.8^{m-o}	16.8^{l-p}	19.2^{f-i}	23.1^{o-u}	27.8^{j-m}	2.6^{n-p}	3.1^{d-g}
Weal-AG-Gold	39.3^{c-g}	44.3^{a}	52.3^{g-j}	59.6^{b-d}	90.8^{t-v}	114.6^{k-q}	1.0^{t}	1.3^{q-s}	10.9^{xy}	20.1^{d-f}	19.2^{u}	32.5^{f-i}	2.7^{l-o}	2.9^{g-k}
Weal-AG-Shahkar	38.6^{d-h}	40.0^{b-g}	55.6^{ef}	60.0^{bc}	120.2^{h-o}	143.4^{a-e}	2.0^{i-m}	2.4^{e-g}	18.8^{f-i}	24.6^{ab}	25.1^{l-s}	35.8^{c-f}	2.6^{n-p}	3.3^{b-d}
Zakaria-1	27.0^{r}	34.3^{j-o}	47.6^{n-p}	52.0^{g-k}	128.7^{f-j}	150.2^{a}	2.4^{e-g}	3.0^{a}	18.3^{i-k}	25.7^{a}	25.4^{k-s}	42.5^{a}	2.9^{g-k}	3.0^{f-h}
Mean	34.5	39.8	50.1	58.4	109.5	132.2	1.8	2.2	15.1	20.1	24.1	33.7	2.7	3.1
Reduction	13%		14%		19%		18%		26%		27%		14%	
Increase	---		---		---		---		---		---		---	
LSD	3.0		3.1		13.4		0.2		1.4		4.2		0.2	

Means with same letter are not significantly different.

Fiber length (mm)

Fiber length is considered as the major quality characteristic. Cotton varieties with longer fiber are highly desired for commercial production. Absence of significant genotype × water treatment interaction (Table 1b) indicated similar response of cotton genotypes to different moisture treatments. Significant genotypic differences revealed the presence of considerable variability for drought tolerance. Genotype CIM-632 (28.6 mm and 28.9 mm) and IR-NIBGE-8 (28.2 mm and 28.6 mm) produced lint with longer fibres under water deficit and full irrigation regimes. Fibre length of Sitara-15 (28.8 mm) was higher under stress condition. NIAB-1048 (28.6 mm) and IR-NIBGE-9 (28.2 mm) recorded higher fibre length under non stress conditions. Previous studies conducted by Luz et al. (1997) and Karademir et al. (2011) revealed no significant differences in fiber length due to water treatments. However, some researchers reported that water stress adversely decreased the fiber length in cotton (Pettigrew, 2004; Mahmood et al. 2006; Osborne et al. 2006). These contradictory consequences may be because of differences in genotypes and also because of different year of experiments.

Fiber strength (g/tex)

Fiber strength is a key quality parameter in cotton that has ultimate impact on durability of the fibre

Table 2b: *Mean fiber length (FL), fiber strength (FS), uniformity index (UI), fiber fineness (FF), ginning out turn% (GOT) and Seed cotton yield (SCY) of 23 cotton genotypes grown under water stress and non-stress conditions.*

Genotypes	FL(mm)		FS(g/tex)		UI(%)		FF(µg/inch)		GOT(%)		SCY(g)	
	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
BPC-10	26.5^{l-q}	27.1^{i-n}	27.1^{n-r}	28.4^{e-l}	81.1^{k-o}	82.8^{f-j}	4.1^{d-g}	3.9^{g-l}	38.2^{e-k}	39.5^{a-d}	67.9^{n-r}	98.7^{f-i}
BS-15	26.4^{n-r}	27.2^{h-l}	28.6^{e-l}	28.5^{e-l}	82.0^{h-m}	84.6^{a-c}	4.5^{ab}	4.1^{d-g}	37.5^{i-p}	39.1^{a-f}	55.9^{r-t}	96.2^{g-j}
CEMB-88	27.4^{f-l}	27.6^{e-j}	27.9^{i-p}	27.9^{i-p}	80.6^{m-p}	82.9^{e-i}	4.0^{e-i}	3.8^{h-m}	36.7^{m-s}	37.7^{g-n}	77.7^{l-o}	104.5^{d-g}
CIM-625	25.9^{q-s}	27.4^{f-l}	26.9^{o-r}	28.9^{e-j}	77.3^{r}	80.5^{m-q}	3.6^{l-p}	3.4^{op}	35.9^{q-t}	37.0^{k-r}	52.2^{st}	110.4^{c-f}
CIM-632	28.6^{a-c}	28.9^{a}	30.4^{ab}	30.6^{a}	82.1^{h-l}	83.6^{b-g}	3.8^{h-m}	3.7^{i-n}	38.8^{b-i}	40.1^{ab}	63.9^{o-s}	103.1^{e-h}
CRIS-600	25.9^{q-s}	26.9^{j-p}	27.2^{m-r}	27.4^{l-r}	81.1^{k-p}	82.2^{h-l}	4.0^{e-i}	3.8^{h-m}	35.7^{s-t}	37.3^{j-p}	75.8^{m-p}	81.9^{k-n}
Crystal-12	26.1^{p-s}	27.4^{f-l}	26.4^{r}	27.8^{j-q}	80.0^{o-q}	82.3^{g-k}	4.1^{d-g}	3.9^{g-l}	37.8^{f-m}	39.0^{b-g}	58.2^{r-t}	120.1^{ac}
Cyto-313	26.6^{k-q}	27.8^{c-h}	26.7^{q-r}	28.8^{e-k}	80.4^{n-p}	83.2^{d-h}	3.7^{i-n}	3.7^{i-n}	36.5^{n-t}	38.1^{e-k}	57.8^{r-t}	117.9^{a-d}
FH-152	27.1^{i-n}	27.7^{d-i}	28.4^{e-l}	28.6^{e-l}	82.8^{f-j}	84.8^{ab}	4.0^{e-i}	3.5^{n-p}	35.5^{s-t}	36.7^{m-s}	63.9^{o-s}	98.1^{f-i}
FH-326	28.0^{b-g}	28.2^{a-f}	28.9^{e-j}	28.9^{e-j}	81.7^{i-n}	82.9^{e-i}	3.7^{i-n}	3.5^{n-p}	33.8^{v}	35.2^{tu}	87.1^{i-m}	127.5^{ab}
GH-Mubarak	27.4^{f-l}	27.9^{b-h}	27.9^{i-p}	27.9^{i-p}	81.6^{i-n}	83.0^{e-i}	4.5^{ab}	4.0^{e-i}	35.9^{q-t}	37.7^{g-n}	53.1^{st}	73.4^{m-q}
IR-NIBGE-8	28.2^{a-f}	28.6^{a-c}	29.4^{a-f}	29.7^{a-e}	82.6^{g-j}	85.4^{a}	4.2^{c-f}	3.9^{g-l}	36.0^{q-t}	37.7^{g-n}	75.4^{m-p}	118.4^{a-d}
IR-NIBGE-9	28.0^{b-g}	28.2^{a-f}	28.0^{h-n}	29.9^{a-d}	82.1^{h-l}	84.1^{a-f}	4.2^{c-f}	3.8^{h-m}	37.2^{k-q}	38.3^{d-k}	55.9^{r-t}	110.6^{c-f}
NIAB-1048	27.0^{j-o}	28.4^{a-d}	28.2^{g-n}	28.3^{f-m}	80.1^{o-q}	83.3^{c-h}	4.1^{d-g}	3.9^{g-l}	38.9^{b-h}	40.4^{a}	60.5^{q-t}	130.3^{a}
NS-181	26.3^{n-s}	27.3^{g-l}	28.3^{f-m}	29.2^{c-h}	82.8^{f-j}	84.8^{ab}	4.4^{b-d}	4.3^{b-e}	35.8^{r-t}	36.6^{n-s}	47.9^{t}	90.1^{h-l}
SAU-1	25.4^{s}	26.1^{p-s}	26.5^{qr}	26.6^{p-r}	79.2^{q}	81.7^{i-n}	4.7^{a}	4.5^{ab}	36.3^{p-t}	37.5^{i-p}	62.0^{p-s}	76.5^{l-o}
Sitara-15	28.8^{ab}	28.2^{a-f}	29.3^{b-g}	30.4^{ab}	82.7^{f-j}	83.6^{b-g}	4.0^{e-i}	3.6^{l-p}	37.5^{i-p}	38.5^{d-j}	77.3^{l-o}	98.3^{f-i}
SLH-12	27.4^{f-l}	27.9^{b-h}	28.5^{e-l}	29.4^{a-f}	80.0^{o-q}	82.4^{g-k}	3.3^{p}	3.3^{p}	34.1^{uv}	37.1^{k-r}	83.6^{j-m}	116.2^{b-e}
Thakar-808	26.0^{q-r}	27.1^{i-n}	27.6^{k-r}	27.8^{j-q}	80.8^{l-p}	82.9^{e-i}	4.2^{c-f}	4.0^{e-i}	37.5^{i-p}	39.2^{a-e}	77.5^{l-o}	98.4^{f-i}
Weal-AG-Shahkar	25.6^{rs}	25.9^{q-s}	27.1^{n-r}	29.3^{b-g}	81.1^{k-p}	85.2^{a}	3.8^{h-m}	3.6^{l-p}	36.8^{l-s}	38.1^{e-k}	65.8^{o-s}	119.0^{a-c}
Weal-AG-Gold	27.0^{j-o}	27.2^{h-l}	28.4^{e-l}	29.1^{d-i}	81.4^{j-o}	82.9^{e-i}	4.1^{d-g}	3.9^{g-l}	38.5^{d-j}	38.9^{b-h}	53.6^{st}	94.7^{g-k}
Weal-AG-1606	26.5^{l-q}	27.4^{f-l}	27.6^{k-r}	28.7^{e-k}	79.8^{pq}	83.3^{c-h}	3.8^{h-m}	3.7^{i-n}	36.4^{o-t}	38.3^{d-k}	67.8^{o-r}	86.6^{i-m}
Zakaria-1	27.2^{h-l}	27.9^{b-h}	28.4^{e-l}	28.6^{e-l}	81.6^{i-n}	84.3^{a-d}	3.8^{h-m}	3.6^{l-p}	38.7^{c-i}	39.9^{a-c}	75.4^{m-p}	130.8^{a}
Mean	26.9	27.6	28.0	28.7	81.0	83.7	4.1	3.8	36.6	38.2	65.3	104.4
Reduction	2%		3%		3%			---	4%		37%	
Increase		---		---		---	6%			---		---
LSD	0.8		1.2		1.4		0.3		1.3		14.0	

Means with same letter are not significantly different.

during harvesting, ginning and manufacturing of the yarn. Differences due to genotype × water treatment interaction were not significant. However, significant variability was found among genotypes under water stress and non-stress conditions. Comparison of performance revealed highest fiber strength in CIM-632 (30.4 and 30.6 g/tex), IR-NIBGE-8 (29.4 and 29.7 g/tex) and Sitara-15 (29.3 and 30.4 g/tex) under water stress and non-stress conditions (Table 2b). Fibre strength of FH-326 (28.9 g/tex) was also high and remained unchanged under both irrigation regimes. Pettigrew (2004) reported that irrigation treatments did not affect fiber strength. On the other hand, variation in fiber strength of cotton genotypes due to different water treatments was reported by Osborne et al. (2006) and Karademir et al. (2011).

Uniformity index (%)

Significant differences were recorded among genotypes for uniformity index (UI). Higher UI values under both water regimes were recorded by FH-152 (82.8 and 84.8%), NS-181 (82.7 and 84.8%) and IR-NIBGE-8 (82.6 and 85.4%). Genotype Sitara-15 (82.7%) also achieved higher uniformity index under stress conditions. Other genotypes that attained larger values for UI under non stress conditions were Weal-AG-Shahkar (85.2), Zakaria-1 (84.3%) and IR-NIBGE-9 (84.1%). Lack of significant genotype × water treatment interaction indicated that fibre uniformity was not affected by water treatments. These results

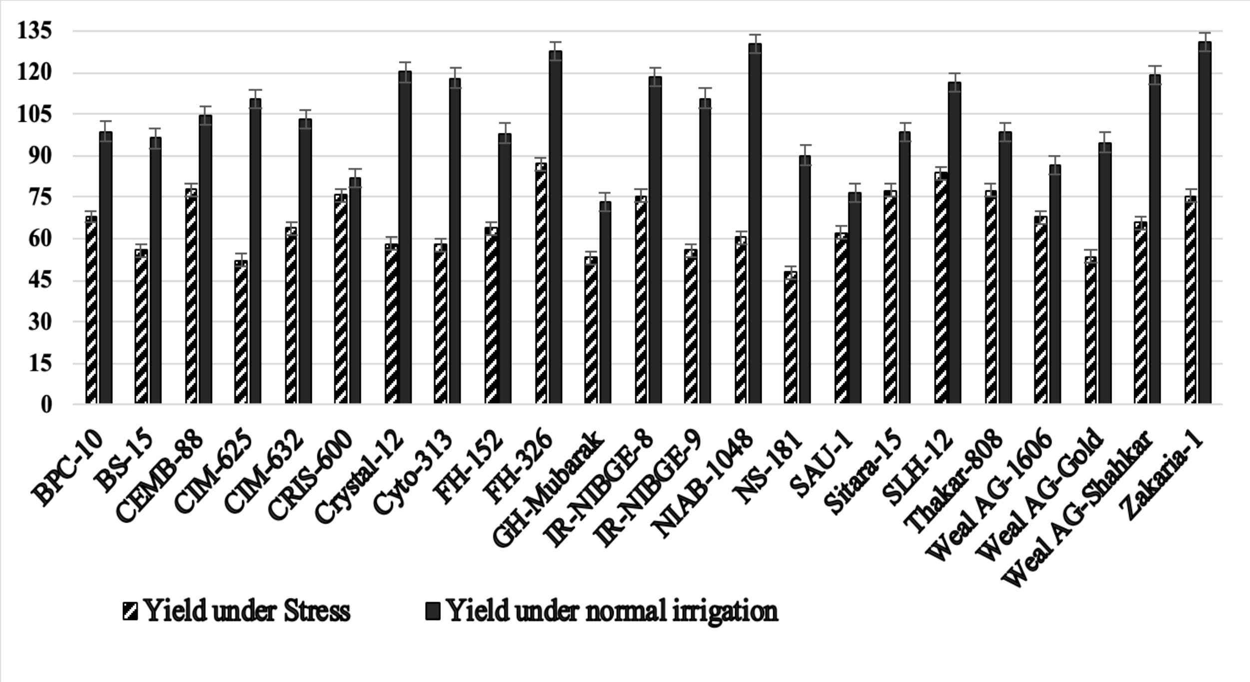

Figure 2: *Seed cotton yield per plant (g) of cotton genotypes grown under water stress and non stress condition.*

are in line with those of Marur (1991), Luz et al. (1997), Pettigrew (2004) and Karademir et al. (2011).

Fiber fineness (µg/inch)

It is measured as the micronaire value of lint. Finer fibers affect the end product quality in cotton. Although absence of significant genotype × water treatment interaction revealed effect of water treatments on this trait however, differences among genotypes under each treatment were prominent (Table 1b). The mean fiber fineness showed a non-significant increase of 6% under water stress condition. Highest fiber fineness was recorded in SAU-1 (4.7 and 4.5 µg/inch) and NS-181 (4.4 and 4.3 µg/inch)) under stress and non-stress conditions (Table 2b). These results are in line with the findings of Davis et al. (2014), Lokhande and Reddy (2014) and Wiggins et al. (2014). Osborne et al. (2006) suggested that moisture stress in cotton triggered a trend of increased fiber fineness as compared to non-stressed condition.

Ginning out turn (%)

Ginning out turn (GOT) is a polygenic trait and highly influenced by the environment. Cotton genotypes with higher GOT are preferred by the ginners. Individually the response of water treatments and cotton genotypes was significantly different for GOT. However, lack of significant genotype × water treatment interaction indicated no response of cotton genotypes to different moisture treatments. Under water deficit conditions, highest GOT under water stress and non-stress conditions was recorded in NIAB-1048 (38.9 and 40.4%), CIM-632 (38.8 and 40.1%) and Zakaria-1 (38.8 and 39.8%). The mean ginning out turn under water stress condition was lower (4.0%) as compared to normal irrigation (Table 2b.). This reduction might be due to reduction in lint yield that ultimately effects GOT percentage. Mahmood et al. (2006), Osborne et al. (2006) and Karademir et al. (2009) reported that ginning out turn was remarkably reduced due to water stress.

Seed cotton yield per plant (g): Increase in seed cotton yield per plant is ultimate objective of plant breeders. This trait is highly influenced by the environmental factors. On an average 37.43 % reduction in mean seed cotton yield was recorded in genotypes grown under water stress condition (Table 2b and Figure 2). Reduction in seed cotton yield due to water stress was also observed by Karademir et al. (2011) and Jayalalitha et al. (2015). Genotype FH-326 (87.8 g and 127.5 g) was identified with highest seed cotton yield under moisture stress and non-stress conditions. Among other genotypes, SLH-12 (83.6 g), CEMB-88 (77.7 g) Thakar-808 (77.5 g) and Sitara-15 (77.3 g) produced highest yield under water stress regime. Zakaria-1 (130.8 g), NIAB-1048 (130.3 g) and Crystal-12 (120.1 g) were the highest yielder under normal irrigation. Presence of substantial amount of variation among cotton genotypes suggested the possibility of selection for the development of drought tolerant cotton germplasm.

Conclusions and Recommendations

From this study it is evident that cotton genotype FH-326 performed better under water stress and non-stress conditions. The performance of Sitara-15 was superior under moisture stress treatment. NIAB-1048 and Zakaria-1 presented enhanced yield attributes under normal irrigation treatment. Therefore, these genotypes are suggested to be included in further breeding for drought tolerance programs.

Author's Contribution

Ali Bakhsh and Mashal Rehman: Planned research experiment and recorded data from field and prepared the manuscript.
Said Salman and Rehmat Ullah: Contributed in data analysis, results interpretation and manuscript preparation.

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