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COMPARATIVE PERFORMANCE AND GENETIC ATTRIBUTES OF UPLAND COTTON GENOTYPES FOR YIELD-RELATED TRAITS UNDER OPTIMAL AND DEFICIT IRRIGATION CONDITIONS

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SUMMARY

Water scarcity is a stress factor that drastically affects and reduces crop productivity. The objective of this study was to explore the influence of water deficiency on seed cotton yield and its associated traits and to study the coefficient of variances, heritability, and GG for various traits in upland cotton (*Gossypium hirsutum* L). Four cotton cultivars, i.e., Ishonch, Navbakhor-2, C-6524, and Tashkent-6, and their F_1 diallel hybrids were grown in a randomized complete block design with factorial arrangement and four replications under optimal and deficit irrigation conditions during 2018–2019 in the Tashkent region of Uzbekistan. Significant ($P \leq 0.01$) differences were observed among the parental genotypes and their F1 hybrids for boll weight, 100-seed weight, seed cotton yield, and lint%. The genotypes exhibited significant ($P \leq 0.05$) and nonsignificant differences for bolls per plant under water deficit and optimal irrigation conditions, respectively. Overall, deficit irrigation conditions negatively affected the yield-contributing traits and eventually the seed cotton yield. The parental cultivars Ishonch and Navbakhor-2 and their F1 diallel hybrids were found to be more stable and performed better than the other genotypes under both water regimes. On average, the genotypic and phenotypic variances for various traits were greater under water deficit conditions than under the optimal irrigation regime. Broad-sense heritability estimates were the highest for boll weight, 100-seed weight, seed cotton yield, and lint% but were low for bolls per plant. Seed cotton yield revealed highly significant positive associations with all traits under optimal irrigation and water deficit conditions but not with 100-seed weight under deficit conditions. The parental genotypes and their hybrids can be used as source materials for developing genotypes with drought tolerance.

Keywords: Genetic variability, coefficient of variances, heritability, genetic gain, correlation coefficient, upland cotton (*Gossypium hirsutum* L.)

Key findings: Overall, the deficit irrigation condition negatively affected yield-contributing traits and eventually seed cotton yield. Two parental cultivars, viz., Ishonch and Navbakhor-

2, and their F1 diallel hybrids were found to be more stable and performed better for various traits than other genotypes under optimal and deficit irrigation conditions.

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INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most important economic crop grown for textile fibers in more than 70 countries worldwide. Cotton fibers and their by-products have dominated the economy of developing and developed countries (Khokhar *et al.,* 2017). Promising cotton genotypes show only enhanced seed cotton yield and lint (%), and improving fiber quality will eventually improve the cotton trade worldwide (Amanov *et al.,* 2020).

Water deficit conditions affect and decrease the total plant stature by up to 35% and leaf area index by 8% due to the interception of solar radiation (Pettigrew, 2004). Saranga *et al.* (1991) observed that the change in water potential accounts for 87% of the change in plant height. The combined phenomenon of abiotic stress and growth reduction affects seed cotton yield and fiber quality (Pettigrew, 2004; Babar *et al.,* 2009; Shavkiev *et al.,* 2019a, Marguba *et al.,* 2020). In cotton, boll formation and fiber development are the most critical stages that are mainly affected by drought stress (Radin *et al.,* 1992; Tohir *et al.,* 2018). Krieg (2000) revealed that the flowering period is the most critical period to drought stress. In cotton, drought tolerance is genetically controlled through various physiological processes (Ahmad *et al.,* 2011; Shavkiev *et al.,* 2019b). Cotton cultivars display varied genetic responses as reflected by their morphophysiological and biochemical parameters under water deficit environments (Hinze *et al.,* 2012; Patil *et al*., 2017; Jaloliddin *et al.*, 2020).

Locally adapted germplasm can be used for the development of new genotypes through different breeding programs. Population structures are of great importance for the utilization of genetic diversity in the development of superior cultivars that combine the positive traits conditioned by diverse cotton germplasm. The majority of cotton cultivars have been developed under irrigation conditions and have experienced intensive selection to increase seed cotton yield and desirable fiber quality (Rosenow *et al.,* 1983). Xamidov (2019) reported that cotton crops need an adequate amount of water for normal growth and development. Under irrigation water shortage, the crop experiences severe water deficiency, thereby exhibiting reductions in crop yield (Nabiev *et al*., 2020). This situation may become increasing critical due to the excessive withdrawal of ground water, which will definitely affect irrigation water resources in the near future (Ullah *et al.,* 2008; Bozorov *et al.,* 2016).

Cotton breeders have continued their efforts to create high-yielding cotton cultivars with improved fiber quality by using existing cotton germplasm. Peohlman and Selper (1995) clarified that yield-contributing and fiber-quality traits are quantitatively heritable. Thus, seed cotton yield and its contributing components and fiber quality can be improved by utilizing new cross combinations developed through appropriate breeding programs. Breeders are mostly interested in possessing sufficient knowledge on genetic components, such as genetic variability, coefficient of variation, heritability, and genetic gain, to devise breeding plans that are appropriate for achieving specific breeding goals (Ali and Khan, 2007; Dhamayanathi *et al.,* 2010). Cotton breeders have always encouraged genetic variability in breeding populations and suggested that screening breeding materials for tolerance to different biotic and abiotic stresses is an initial requirement. Great genetic variability, along with genotypic, phenotypic, and environmental coefficients of variation, has been reported among various upland cotton populations for quantitative and qualitative traits (Dhivya *et al.*, 2014; Dahiphale *et al.*, 2015; Shao *et al.*, 2016; Adsare *et al.*, 2017).

Heritability is an effective statistical tool that helps cotton breeders assess environmental impacts on various traits in a breeding nursery. It is an effective indicator for determining the level at which parental traits are passed down from generation to generation. Thus, heritability and GG can be a powerful tool for plant breeders to select appropriate breeding schemes (Chandio *et al.,* 2003; Baloch *et al.,* 2004). Abbas *et al.* (2013) provided information on high heritability coupled with GG for yield and yield component traits in upland cotton. Moderate to high heritability has been reported for bolls per plant, boll weight, seed cotton yield, lint percentage, fiber length, and strength in upland cotton genotypes (Aziz *et al.,* 2014; Srinivas *et al.*, 2014; Ahsan *et al.*, 2015; Waqar *et al.*, 2016; Nizamani *et al.,* 2017).

Therefore, cotton improvement via selection largely depends on the discovery of genetic variability. Often, selection is based solely on phenotypic expression, which is often misleading because of environmental influence. Thus, data on genotypic, phenotypic, and environmental variances are of great importance for effective selection. However, the genotypic coefficient of variation does not provide an exact idea of the total heritable variation. Magadum *et al.* (2012) stated that the amount of genetic variation can be related by heredity. Heritability has to be estimated to estimate the proportion of phenotypic variance attributable to genetic variance. Such an estimation is vital because it also provides the basis for effective selection. Magadum *et al.* (2012) also pointed out that genetic variability, along with the heritability of a character, will indicate the possibility and extent to which improvement is feasible through selection on a phenotypic basis. The heritability value alone may not provide clear predictability of the breeding value (Mishra *et al.,* 2015). Hence, combination with GG over means is more effective and reliable in predicting the resultant effect of selection (Patil *et al.,* 1996; Ramanjinappa *et al.,* 2011). In presence of the highest magnitude of genetic variability, knowledge on heritability and GG helps the breeder select the desired characters to achieve objectives. Therefore, a thorough knowledge of genetic variability, heritability, and genetic development is necessary to improve the valuable economic traits of crop plants (Burton, 1952; Svarup and Chaugle, 1962).

The development of high-yielding cotton cultivars requires a comprehensive study of the relationship among growth traits, resistance to adverse environmental factors, and productivity in cotton. Heredity and physiological processes in crop plants depend on biological characteristics and environmental conditions. In other words, the probability of inheritance is determined by the degree of the main environmental factors (Bozorov *et al.,* 2016, Nabiev *et al.,* 2020). However, identifying the most precise indexes for evaluating plant drought tolerance remains a requirement. Therefore, identifying drought-tolerant traits and potential indexes and inducing them through different breeding schemes for crop improvement are necessary.

Keeping in view the above discussion, the importance of genetic studies, and the relationships among various quantitative and qualitative traits, the present study was performed to study the genetic variability, coefficient of variation, heritability, and GG in four parental genotypes (Ishonch, Navbakhor-2, C-6524, and Tashkent-6) and their F1 diallel hybrids for seed cotton yield and its component traits under optimal and deficit irrigation conditions.

MATERIALS AND METHODS

Genetic material, experimental site, and irrigation conditions

This study was conducted during 2018–2019 in the Tashkent region of Uzbekistan (41.389°N and 69.465°E). This region experiences cold winters and long hot and dry summers. The annual photoperiod (light/dark) is 16/8 h. This study involved the genetic potential and genetic aspects of four upland cultivars, i.e., Ishonch, Navbakhor-2, Tashkent-6, and S-6524, and their 12 F_1 diallel hybrids under optimal and deficit irrigation conditions. These parental cultivars have an average fiber production (2.0–2.2 tons/hm^2) but varied levels of drought tolerance. The parental cultivars and their F1 diallel hybrids were grown in a randomized complete block design with factorial arrangement and four replications under optimal and deficit irrigation conditions. The cotton genotypes were planted with plant and row spacings of 10 and 60 cm in 50 m long furrows. The soil moisture content was 70% under optimal irrigation conditions and 42% under deficit irrigation conditions as calculated with a moisture tester. Full (optimal) and deficit irrigation conditions were separated by a specified distance.

The temperature increases in April during the cotton sowing season and decreases in late September before the harvesting period. Information on maximum and minimum temperatures, air humidity, and total rainfall during the study period is provided in Table 1. Sunny days were between 180–185 days. Rainfall varied from 0 mm to 45 mm during the dry season for a period of 5–6 months. The crop requires intensive irrigation throughout the vegetative period. Cotton is irrigated in accordance with a 1–2–1 (preflowering–flowering–boll opening) sequence with 900 m^3/hm^2 of water applied before flowering, two applications of 1200 m^3/hm^2 each during flowering, and 900 m^3/hm^2 prior to the boll-opening phases (Xamidovand Matyakubov, 2019). This sequence is an optimal irrigation protocol that is widely used in cotton production in Uzbekistan. Soil moisture also contributes water during seed germination. A modified irrigation protocol was also developed for deficient irrigation conditions. This protocol follows a 0–1–0 sequence that limits water availability during the preflowering, flowering, and boll development stages and reduces the total irrigation requirement to 1200 m^3/hm^2 water (Xamidov and Matyakubov, 2019). For crop protection purposes, the insecticides Bi-58 (BASF, Germany) and Hexachloran were applied for the control of sucking (aphids) and chewing (bollworm) insects, respectively. The seasonal application of fertilizers was performed during tillage and before irrigation per annum with 250:180:115 NPK kg/hm^2.

Table 1. Maximum and minimum temperatures, air humidity, and total rainfall during the study period.

Months	Maximum temperature (°C)		Minimum temperature (°C)		Average relative humidity (%)		Total rainfall (mm)	
	2018	2019	2018	2019	2018	2019	2018	2019
April	+31	+28	+3	+5	34%	+35	4.87	42.38
May	+36	+36	+9	+10	26%	+38	1.79	11.25
June	+37	+36	+14	+16	19%	+39	1.00	6.90
July	+42	+42	+19	+20	15%	+39	0.00	2.43
August	+39	+40	+15	+17	14%	+38	0.00	0.08
September	+32	+36	+12	+10	15%	+33	0.16	1.05
October	+31	+28	+1	+6	29%	+24	2.6	2.78

Table 2. Analysis of variance for various traits in upland cotton under optimal and deficit irrigation conditions.

Source of Variation	d.f.	Bolls plant^{-1}		Boll weight (g)		100-seed weight (g)		Seed cotton yield plant^{-1} (g)		Lint (%)	
		Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
Replications	3	5.36	12.19	5.49	0.002	0.05	0.19	0.93	21.19	7.77	0.80
Genotypes	15	6.97^{NS}	10.72*	0.51**	0.60**	1.98**	0.98**	121.52**	207.81**	11.35**	9.47**
Error	45	3.02	2.54	0.003	0.02	0.08	0.19	32.79	18.31	1.26	0.82

**: Significant at $P \leq 0.01$, *: Significant at $P \leq 0.05$, NS: Nonsignificant

Data recorded and statistical analysis

The valuable economic traits of the parental genotypes and their F1 hybrids were studied under optimal and deficit irrigation conditions. The data on boll weight, bolls per plant, seed cotton yield per plant, and lint percentage were recorded. These parameters were used to monitor stress conditions for comparison with irrigated conditions. The data were subjected to analysis of variance (Steel *et al.,* 1997). Genotypic, phenotypic, and environmental coefficients of variances were estimated by following Burton and Devane (1953). Broad-sense heritability was calculated in accordance with Honson *et al.* (1956), and GG was estimated as per Johnson *et al.* (1955). Correlation coefficients were calculated by using the formulae given by Kown and Torrie (1964).

$$V_g = [\text{Genotypes mean squares} - \text{Error mean squares}]/\text{Number of replications}$$

$$V_e = \text{Error mean squares}$$

$$V_p = V_g + V_e,$$

$$\text{Genotypic coefficient of variation (GCV)} = \sqrt{V_g}/GM \times 100$$

$$\text{Phenotypic coefficient of variation (PCV)} = \sqrt{V_p}/GM \times 100$$

$$\text{Environmental coefficient of variation (ECV)} = \sqrt{V_e}/GM \times 100$$

where V_g = Genotypic variance
V_p = Phenotypic variance
V_e = Environmental variance
GM = Grand mean of the trait.

Broad-sense heritability (h^2) on an entry mean basis was calculated as

$$(h^2) = Vg/Vp.$$

The expected GG (GG) for each trait was calculated as follows:

$$GG = k.\ h^2 \sqrt{vp}.$$

The GG as a percentage of mean for each trait was calculated as

$$GG = GG/GM \times 100,$$

where k = 1.40 at 20% selection intensity for a trait
V_P = Phenotypic variance for a trait
h^2 = Broad sense heritability for a trait
GG = GG (expected response to selection)

RESULTS AND DISCUSSION

The analysis of variance showed that parental cultivars and F1 populations exhibited significant ($P \leq 0.01$) differences for boll weight, 100-seed weight, seed cotton yield per plant, and lint% (Table 2). However, for bolls per plant, the genotypes exhibited significant ($P \leq 0.05$) and nonsignificant differences under water deficit and optimum irrigation conditions, respectively. These observations indicated considerable genetic variability and scope among the genotypes for further improvement in yield-related traits. The mean performances of the parents and F_1 hybrids for various traits under study are presented in Tables 3 and 4. The data were further analyzed to estimate the heritability (broad sense), GG, GCV%, PCV%, and ECV% (Table 5). The

Table 3. Mean performance of parental genotypes and their F1 hybrids for various traits in upland cotton under optimal and deficit irrigation conditions.

Parental genotypes and F1 hybrids	Irrigated/ Drought	Bolls plant^{-1}	Boll weight (g)	100-seed weight (g)	Seed cotton yield plant^{-1} (g)	Lint (%)
		M ± SE	M ± SE	M ± SE	M ± SE	M ± SE
Ishonch	Irrigated	16.45 ± 0.63	5.62 ± 0.06	12.20 ± 0.10	60.18 ± 3.00	36.31 ± 0.40
	Drought	11.50 ± 0.89	5.00 ± 0.06	12.09 ± 0.11	42.09 ± 1.69	37.54 ± 0.45
Navbakhor-2	Irrigated	14.80 ± 0.53	5.80 ± 0.06	12.93 ± 0.10	57.18 ± 3.38	36.47 ± 0.56
	Drought	10.30 ± 0.85	5.13 ± 0.06	12.73 ± .013	42.14 ± 1.42	38.80 ± 0.38
Tashkent-6	Irrigated	16.95 ± 0.74	5.75 ± 0.09	12.60 ± 0.16	62.40 ± 2.32	35.77 ± 0.47
	Drought	7.90 ± 057	4.34 ± 0.04	11.44 ± 0.15	27.17 ± 0.80	37.62 ± 0.08
C-6524	Irrigated	17.35 ± 0.85	5.08 ± 0.07	12.20 ± 0.09	63.97 ± 1.73	36.90 ± 0.78
	Drought	8.30 ± 0.65	4.29 ± 0.09	10.99 ± 0.13	27.10 ± 0.93	37.20 ± 0.11
Ishonch ×	Irrigated	15.20 ± 0.69	6.24 ± 0.02	14.23 ± 0.10	69.07 ± 2.28	41.13 ± 0.55
Navbakhor-2	Drought	12.80 ± 0.65	5.34 ± 0.08	12.58 ± 0.13	49.86 ± 3.05	41.17 ± 0.39
Ishonch ×	Irrigated	17.00 ± 1.06	5.73 ± 0.04	14.90 ± 0.08	74.15 ± 2.86	39.68 ± 0.70
Tashkent-6	Drought	8.95 ± 1.05	4.82 ± 0.08	12.18 ± 0.27	46.12 ± 2.11	39.84 ± 0.51
Ishonch × C-	Irrigated	15.50 ± 0.54	5.51 ± 0.08	13.52 ± 0.08	70.74 ± 3.20	36.87 ± 0.49
6524	Drought	11.25 ± 0.45	4.84 ± 0.04	12.02 ± 0.11	43.52 ± 2.00	40.26 ± 0.048
Navbakhor-2	Irrigated	14.50 ± 1.02	5.70 ± 0.07	13.33 ± 0.15	75.65 ± 3.63	39.27 ± 0.44
× Ishonch	Drought	10.30 ± 0.85	5.34 ± 0.05	12.05 ± 0,19	45.37 ± 3.05	42.72 ± 0.48
Navbakhor-2	Irrigated	15.40 ± 0.51	6.22 ± 0.07	13.20 ± 0.07	65.64 ± 2.39	37.08 ± 0.31
× Tashkent-6	Drought	8.00 ± 0.52	5.43 ± 0.05	11.14 ± 0.12	38.49 ± 1.28	41.53 ± 0.65
Navbakhor-2	Irrigated	16.901.29	6.31 ± 0.07	13.23 ± 0.21	66.71 ± 4.75	39.08 ± 0.14
× C-6524	Drought	8.60 ± 0.67	5.56 ± 0.07	11.68 ± 0.95	41.81 ± 2.58	40.59 ± 0.30
Tashkent-6 ×	Irrigated	19.20 ± 0.73	5.45 ± 0.05	13.04 ± 0.17	77.48 ± 2.43	36.24 ± 0.75
Ishonch	Drought	9.10 ± 0.71	4.54 ± 0.07	11.12 ± 0.21	35.04 ± 1.08	40.13 ± 0.51
Tashkent-6 ×	Irrigated	17.30 ± 0.92	5.38 ± 0.06	13.19 ± 0.10	68.62 ± 2.37	36.05 ± 0.93
Navbakhor-2	Drought	7.90 ± 0.63	4.46 ± 0.08	11.06 ± 0.22	33.26 ± 1.65	38.33 ± 0.51
Tashkent-6 ×	Irrigated	14.65 ± 0.65	5.52 ± 0.05	12.67 ± 0.09	64.75 ± 1.94	39.06 ± 0.68
C-6524	Drought	7.05 ± 0.49	4.61 ± 0.08	11.74 ± 0.22	28.44 ± 1.89	39.33 ± 0.45
C-6524 ×	Irrigated	15.20 ± 0.90	5.42 ± 0.06	13.92 ± 0.22	70.24 ± 2.53	37.88 ± 0.51
Ishonch	Drought	7.60 ± 0.34	4.73 ± 0.06	11.81 ± 0.18	32.61 ± 1.45	38.97 ± 0.70
C-6524 ×	Irrigated	16.20 ± 1.00	5.40 ± 0.07	13.07 ± 0.13	67.17 ± 2.45	37.34 ± 0.40
Navbakhor-2	Drought	8.20 ± 0.44	4.64 ± 0.04	11.63 ± 0.21	32.86 ± 0.93	39.27 ± 0.56
C-6524 ×	Irrigated	14.60 ± 0.69	5.23 ± 0.07	12.91 ± 0.09	63.79 ± 1.82	40.45 ± 0.57
Tashkent-6	Drought	8.10 ± 0.35	4.57 ± 0.10	11.49 ± 0.22	32.42 ± 1.22	40.64 ± 0.75

Table 4. Basic statistics in parental cultivars and their F1 hybrids for various traits in upland cotton.

Traits	Irrigated/ Drought	Grand mean	Minimum	Maximum	Variance	CV (%)
Bolls plant^{-1}	Irrigated	16.09	11.60	20.60	4.07	0.12
	Drought	9.12	6.60	14.20	4.95	0.24
Boll weight (g)	Irrigated	5.65	5.03	6.32	0.12	0.06
	Drought	4.88	4.23	5.69	0.16	0.08
100-seed weight (g)	Irrigated	13.20	11.94	15.12	0.53	0.05
	Drought	11.75	10.58	13.27	0.38	0.05
Seed cotton yield plant^{-1} (g)	Irrigated	67.36	50.61	85.41	52.42	0.11
	Drought	37.39	25.66	55.46	63.57	0.21
Lint (%)	Irrigated	37.89	34.25	41.98	3.98	0.05
	Drought	39.62	37.03	44.45	2.88	0.04

Table 5. Genotypic, phenotypic, and environmental variances and coefficient of variation, broad sense heritability, and GG under optimal and deficit irrigation conditions.

Traits	Irrigated /Drought	GV	GCV (%)	PV	PCV (%)	EV	ECV (%)	h^2	GG	GG (%)
Bolls plant^{-1}	Irrigated	0.98	6.17	4.01	12.45	3.02	10.81	0.24	1.01	6.31
	Drought	2.05	15.68	4.58	23.50	2.54	17.50	0.44	1.97	21.60
Boll weight	Irrigated	0.12	6.30	0.13	6.39	0.004	1.06	0.97	0.72	12.82
	Drought	0.14	7.82	0.16	8.34	0.02	2.90	0.88	0.52	10.74
100-seed weight	Irrigated	0. 47	5.23	0.55	5.63	0.08	2.08	0.86	1.32	10.04
	Drought	0.19	3.78	0.39	5.34	0.19	3.77	0.50	0.64	5.52
Seed cotton yield plant^{-1}	Irrigated	22.18	6.99	54.97	11.00	32.79	8.50	0.40	6.17	9.16
	Drought	47.37	18.41	65.69	21.67	18.32	11.44	0.72	12.06	32.25
Lint (%)	Irrigated	2.52	4.19	3.79	5.13	1.26	2.97	0.66	2.67	7.05
	Drought	2.16	3.71	2.98	4.36	0.82	2.29	0.72	2.51	6.51

GV: Genotypic variance; GCV%: Genotypic coefficient of variance; PV: Phenotypic variance; PCV%: Phenotypic coefficient of variance; EV: Environmental variance; ECV%: Environmental coefficient of variance; h^2: Heritability (broad sense); Genetic gain: GG

Table 6. Correlation coefficients among yield-related traits under optimal irrigation (below diagonal) and deficit irrigation (above diagonal) conditions.

Traits	Bolls plant^{-1}	Boll weight	100-seed weight	Seed cotton yield plant^{-1}	Lint%
Bolls plant^{-1}	–	0.467***	0.395**	0.421***	0.033^{NS}
Boll weight	−0.045^{NS}	–	0.327**	0.396**	0.033^{NS}
100-seed weight	−0.099^{NS}	0.372**	–	0.001^{NS}	0.546***
Seed cotton yield plant^{-1}	0.763***	0.554***	0.718***	–	0.350**
Lint (%)	−0.377**	0.425***	0242^{NS}	0.15^{NS}	–

**: Significant at $P \leq 0.01$, *: Significant at $P \leq 0.05$, NS: Nonsignificant

correlation coefficients among various yield related traits are presented in Table 6.

Mean performance

Under optimal irrigation, bolls per plant fell in the ranges of 14.80–17.35 and 14.50–19.20 in parental cultivars and F_1 hybrids, respectively (Tables 3 and 4). Among parental genotypes, the cultivars C-6524 (17.35), Tashkent-6 (16.95), and Ishonch (16.45) produced the maximum bolls per plant, whereas Navbakhor-2 (14.80) presented the lowest bolls per plant. Among the F_1 hybrids, Tashkent-6 × Ishonch (19.20) displayed the maximum bolls per plant, followed by Tashkent-6 × Navbakhor-2 (17.30), whereas the lowest bolls per plant were recorded for the F1 hybrid Navbakhor-2 × Ishonch (14.50) under optimal irrigation conditions.

Under deficit irrigation conditions, the bolls per plant fell in the ranges of 7.90–11.50 and 7.05–12.80 in parental cultivars and F_1 hybrids, respectively (Tables 3 and 4). Among the parental genotypes, Ishonch (11.50) and Navbakhor-2 (10.30) provided the maximum number of bolls per plant, followed by cultivar C-6524 (8.30). However, the lowest number of bolls per plant was recorded for the cultivar Tashkent-6 (7.90). Among F_1 hybrids, Ishonch × Navbakhor-2 (12.80) displayed the maximum bolls per plant, followed by two other F1 hybrids, i.e., Ishonch × C-6524 (11.25) and Navbakhor-2 × Ishonch (10.30). However, the lowest bolls per plant were recorded for the F1 hybrid Tashkent-6 × C-6524 (7.05) under water deficit conditions.

Under optimal irrigation, boll weight ranged from 5.08 g to 5.80 g and from 5.23 g to 6.31 g in parental cultivars and F_1 hybrids, respectively (Tables 3 and 4). The heaviest boll weight in parents was recorded for cultivar Navbakhor-2

(5.80 g), followed by Tashkent-6 (5.75 g) then by Ishonch (5.62 g), whereas the lowest boll weight was observed for cultivar C-6524 (5.08 g). Among F_1 cross combinations, Navbakhor-2 × C-6524 (6.31 g) and Ishonch × Navbakhor-2 (6.24 g), followed by Navbakhor-2 × Tashkent-6 (6.22 g), showed the maximum boll weight. The lowest boll weight was recorded for F1 hybrids, i.e., C-6524 × Tashkent-6 (5.23 g), Tashkent-6 × Navbakhor-2 (5.38 g), and C-6524 × Navbakhor-2 (5.40 g), under optimal irrigation conditions.

Under deficit irrigation, in parental cultivars and F_1 hybrids, boll weight varied from 4.29 g to 5.13 g and to 4.46 g to 5.56 g, respectively (Tables 3 and 4). Among parental genotypes, the bigger bolls were recorded for Navbakhor-2 (5.13 g), followed by Ishonch (5.00 g). The lowest boll weight was observed for Tashkent-6 (4.34 g) and C-6524 (4.29 g). Among F_1 hybrids, the highest boll weight was recorded in hybrid Navbakhor-2 × C-6524 (5.56 g), followed by Navbakhor-2 × Tashkent-6 (5.43) and Ishonch × Navbakhor-2 and its reciprocal (5.34 g). F_1 hybrids i.e., Tashkent-6 × C-6524 (4.61 g) and Tashkent-6 × Ishonch (4.54 g), followed by Tashkent-6 × Navbakhor-2 (4.46 g) showed the minimum boll weight under water deficit conditions.

Under optimal irrigation, 100-seed weight ranged from 12.20 g to 12.93 g and 12.67 g to 14.90 g in parental cultivars and F_1 hybrids, respectively (Tables 3 and 4). The maximum 100-seed weight was displayed by cultivar Navbakhor-2 (12.93 g), followed by Tashkent-6 (12.60 g). The parental genotypes C-6524 and Ishonch showed the minimum and same 100-seed weight. The F1 hybrids i.e., Ishonch × Tashkent-6 (14.90 g) and Ishonch × Navbakhor-2 (14.23 g), followed by C-6524 × Ishonch (13.92 g), exhibited the highest 100-seed weight. However, F1 hybrid Tashkent-6 × C-6524 revealed the lowest 100-weight (12.67 g) with optimum irrigation condition.

Under deficit irrigation condition, the 100-seed weight of the parental cultivars and F_1 hybrids ranged from 10.99 g to 12.73 g and 11.06 g to 12.58 g, respectively (Tables 3 and 4). Among parental cultivars, the highest 100-seed weight was displayed by Navbakhor-2 (12.73 g), followed by Ishonch (12.09 g). The cultivars Tashkent-6 (11.44 g) and C-6524 (10.99 g) showed the least 100-seed weight. Among F1 hybrids, the highest 100-seed weight was revealed by two hybrids i.e., Ishonch × Navbakhor-2 (12.58 g) and Ishonch × Tashkent-6 (12.18 g). The minimum 100-seed weight was recorded in F1 hybrids i.e., Tashkent-6 × Navbakhor-2 (11.06 g) and its reciprocal (11.14 g), and Tashkent-6 × Ishonch (11.12 g) with deficit irrigation condition.

Under optimal irrigation, the seed cotton yield per plant ranged from 57.18 g to 63.97 g and 63.79 g to 77.48 g in parental cultivars and F_1 hybrids, respectively (Tables 3 and 4). The parental cultivar C-6524 (63.97 g) displayed maximum seed cotton yield per plant, followed by two other cultivars, i.e., Tashkent-6 (62.40 g) and Ishonch (60.18 g). The parental genotype Navbakhor-2 (57.18 g) was recorded with the lowest seed cotton yield per plant. Among F_1 hybrids, Tashkent-6 × Ishonch (77.48 g) and its reciprocal (74.15 g) and Navbakhor-2 × Ishonch (75.65 g) showed the maximum seed cotton yield per plant. The lowest seed cotton yield per plant was obtained in the F1 hybrid C-6524 × Tashkent-6 (63.79 g) and its reciprocal Tashkent-6 × C-6524 (64.75 g).

Under deficit irrigation conditions, the seed cotton yield per plant of the parental genotypes and F1 hybrids ranged from 27.10 g to 42.14 g and 28.44 g to 77.48 g, respectively (Tables 3 and 4). Under water deficit conditions, the parental genotype Navbakhor-2 (42.14 g), followed by the cultivar Ishonch (42.09 g), displayed the maximum yield per plant. The cultivar Tashkent-6 (27.17 g), followed by C-6524 (27.10 g), exhibited the lowest seed cotton yield per plant. The F1 hybrids Ishonch × Navbakhor-2 (49.86 g), Ishonch × Tashkent-6 (46.12), and Navbakhor-2 × Ishonch (45.37 g) showed the maximum seed cotton yield per plant. The lowest seed cotton yield per plant was recorded in the F1 populations Tashkent-6 × C-6524 (28.44 g), C-6524 × C-Tashkent-6 (32.42 g), and Tashkent-6 × Navbakhor-2 (33.26 g) under deficit irrigation.

Under optimal irrigation, the lint% of the parental genotypes and F1 hybrids ranged from 35.77% to 36.99% and 36.05% to 41.13%, respectively, (Tables 3 and 4). In parental cultivars, the highest lint% was exhibited by the parental genotype C-6524 (36.90%), followed by Navbakhor-2 (36.47%). The lowest lint% was recorded for the parental cultivar Tashkent-6 (35.77%). Similarly, among F1 hybrids, the cross combinations Ishonch × Navbakhor-2 (41.13%) and C-6524 × C-Tashkent-6 (40.45%) displayed the maximum lint%. The lowest lint% was recorded for the F1 hybrids Tashkent-6 × Navbakhor-2 (36.05%) and Tashkent-6 × Ishonch (36.24%) under optimal irrigation.

Under water deficit conditions, the lint% of the parental genotypes and F1 hybrids varied from 37.20% to 38.80% and from 38.33% to 42.72%, respectively (Tables 3 and 4). The mean performance of the parents for lint% revealed that the parental genotype Navbakhor-2 (38.80%), followed by Tashkent-6 (37.62%), displayed the maximum lint%. The lowest lint% was recorded for the parental cultivar C-6524 (37.20%). Similarly, among F1 hybrids, the cross combinations Navbakhor-2 × Ishonch (42.72%) and Navbakhor-2 × Tashkent-6 (41.53%) displayed the maximum lint%. The lowest lint% was recorded for the F1 hybrids Tashkent-6 × Navbakhor-2 (38.33%) and C-6524 × Ishonch (38.97%).

Overall, the mean performance of the genetic material for various yield-related traits revealed a considerable amount of genetic variability. Under the optimal irrigation condition, no one genotype was superior for all traits. However, under deficit irrigation condition, the parental cultivars Ishonch and Navbakhor-2 and their hybrids were found to be superior for all traits. Previous studies on the assessment of cotton germplasm under various environmental conditions also reported a significant magnitude of genetic variability for seed cotton yield and its components (Islam *et al.*, 2013; Srinivas *et al.*, 2014; Dahiphale *et al.*, 2015; Raza *et al.*, 2016; Nizamani *et al.*, 2017; Marguba *et al.,* 2020).

GCV, PCV, and ECV

The ranges of genotypic, phenotypic and environmental variances for various traits in parental genotypes and their F1 hybrids are presented in Table 5. Under optimal irrigation condition, the GCV and PCV values varied from 4.19% to 6.99% and from 5.13% to 12.45%, respectively. Under deficit irrigation, the estimates of GCV and PCV ranged from 3.71% to 18.41% and 4.36% to 23.50% respectively. Under the optimal irrigation regime, the highest GCV and PCV effects were found for seed cotton yield per plant (6.99% and 11.00%, respectively), followed by bolls per plant (6.17% and 12.45%, respectively) and boll weight (6.30% and 6.39%, respectively). The lowest values of GCV and PCV were observed for 100-seed weight (5.23% and 5.63%, respectively) and lint% (4.19% and 5.13%, respectively).

Under deficit irrigation conditions, the highest GCV and PCV effects were found for seed cotton yield per plant (18.41% and 21.67%, respectively), followed by bolls per plant (15.68% and 23.50%, respectively) and boll weight (7.82% and 8.34%, respectively) (Table 5). The lowest GCV and PCV effects were noted for lint% (3.71% and 4.36%, respectively) and 100-seed weight (3.78% and 5.34%, respectively). Saleem *et al.* (2016) reported the highest genetic variability in segregating populations for economically important traits and declared it as a prerequisite for the success in breeding programs. Adequate information regarding genotypic variances make selection in breeding populations effective given that plant traits are mostly influenced by environmental effects (Mahaingam *et al.,* 2013).

The 100-seed weight and lint% showed low GCV and PCV values, suggesting limited room for the further improvement in these traits. For traits with low estimates of GCV and PCV, the breeders should search for the source of highest genetic variability for further improvement. Cotton breeders must exploit Uzbek germplasm from diverse sources to identify the genetic variability in breeding populations. Moderate PCV and GVC for yield traits suggest that these characters can be improved by using vigorous selection methods (Girase and Mehatne, 2002; Harshal, 2010). Kowsalya and Raveendran (1996) provided similar suggestions in their studies on upland cotton. However, some of the past studies showed higher values of GCV and PCV for seed cotton yield and yield related traits (Ahuja and Tuteja, 2000; Girase and Mehetre, 2002; Ganesan and Raveendran, 2007). In upland cotton genotypes, boll weight showed moderate estimates of PCV and GCV and indicated the possibility of improvement in yield and yield component traits by further selection in segregating populations (Rao and Reddy, 2001; Prasad *et al.,* 2005).

Under optimal and deficit irrigation conditions, the ECV ranged from 2.97% to 10.81% and from 2.29% to 17.50%, respectively (Table 5). The highest ECV values were recorded for bolls per plant (10.81% and 17.50%), followed by seed cotton yield per plant (8.50% and 11.44%) under deficit and optimal irrigation conditions, respectively, suggesting that these traits were considerably influenced by environmental factors. The selection of genotypes in early generations with moderate to high GCV and PCV is also recommended for improvement in yield and yield component traits (Ahsan *et al.*, 2015; Shao *et al.*, 2016; Adsare *et al.*, 2017). Thus, genetic variability with high heritability estimates play an important role in the inheritance and improvement of yield-related traits in upland cotton (Ahmed *et al.*, 2011).

The coefficient of phenotypic variation has the same contribution as the coefficient of genotypic variation. In this study, the GCV and PCV for all the traits showed close resemblance, indicating that these traits were less influenced by the environment. The highest GCV and PCV were observed for boll weight, 100-seed weight, and seed cotton yield per plant under water deficit conditions, and effective selection is recommended to isolate highly promising cotton lines. Past studies also reported similar type of observations for yield-related traits in upland cotton populations (Dheva and Potdukhe, 2002; Preetha and Raveendran, 2007; Amir *et al.,* 2012; Abbas *et al.,* 2013).

Heritability (broad sense)

The present investigation revealed the highest broad sense heritability estimates for boll weight, 100-seed weight, seed cotton yield, and lint% (Table 5). However, low heritability (bs) was reported for bolls per plant. The high heritability estimates highlighted the importance of genetic variance and depicted that variation among the populations for majority of the traits, except bolls per plant, is under the influence of genetic factors. Past studies reported high heritability and greeter genetic variability estimates for seed cotton yield and yield component traits in upland cotton genotypes (Khan *et al.*, 2010; Batool *et al.*, 2010; Ahmed *et al.*, 2011; Aziz *et al.,* 2014; Raza *at al.,* 2016; Nizamani *et al.*, 2017). Additional genetic influence with lower environmental factors predicted that most of the traits are controlled by additive gene action. The present results were also in accordance with the results of Abbas *et al.* (2013) and Dhivya *et al.* (2014) for upland cotton genotypes and were also in agreement with earlier findings of Ahuja and Tuteja (2000), Girase and Mehetre (2002), Prasad *et al.* (2005), and Pujer *et al.* (2014), who reported similar values of broad-sense heritability for seed cotton yield and yield-contributing traits in in upland cotton. For yield-related traits, the greater genetic variance might be effective in selection and improvement because of additive gene action (Rokadia and Vaid, 2003; Eswari *et al.*, 2017).

High heritability is a determinant of genotype flexibility in the selection process. In this investigation, the high heritability coupled with high GG observed for boll weight and seed cotton yield per plant reflected the preponderance of additive gene action in the inheritance of these traits. Johnson *et al.* (1955) and Swarup and Chaugale (1962) indicated that high heritability is not always an indication of high GG. If the transmission of heredity from generation to generation is mainly due to nonadditive gene effects, then the expected GG will be low; however, if some additive gene effects exist, then the expected GG will be high (Panse, 1957). Ahuja and Tuteja (2000), Girase and Mehetre (2002), Kumari and Chamundeshwari (2005), Kale *et. al.* (2006), and Preetha and Raveendran (2007) also reported the highest heritability and GG values for seed cotton yield and yield-related traits in upland genotypes.

In this study, under water deficit conditions and considering genetic variability, heritability and GG, selection would be effective for bolls per plant and boll weight besides yield per plant for developing high-yielding cotton cultivars. Hence, the pedigree breeding method will be the rewarding method for improving the traits under investigation. Characters with high heritability and GG can be used as tools in the selection process, and such traits are controlled by additive gene effects that are less affected by the environment (Panes and Suxhatme, 1995). Under optimal and deficit irrigation conditions, the GG, as the percentage of means for various traits, ranged from 6.31% to 12.82% and 5.52% to 32.25%. A higher GG as the percentage of mean was recorded for seed cotton yield per plant (9.16% and 32.25%), followed by boll weight (12.82% and 10.74%), bolls per plant (6.31% and 21.6%), 100-seed weight (10.04% and 5.52%) and lint% (7.05% and 6.51%) under optimum and deficit irrigation conditions, respectively.

High heritability and GG were observed for seed cotton yield per plant and boll weight and were considered as highly reliable during selection. High heritability and moderate GG were reported for lint% in upland cotton genotypes (Muhammad *et al*., 2004). In present studies, some of the genotypes were identified as potential donors for improvement in different traits. Therefore, direct selection can be more effective for improvement in majority of the traits. Johnson *et al.* (1955) suggested that heritability estimates in conjunction with high GG were usually helpful in predicting its resultant effects for selecting promising genotypes.

Correlation coefficient

Under optimal irrigation condition, bolls per plant revealed a significant ($P \leq 0.01$) positive association with seed cotton yield but negative associations with all other traits (Table 6). Boll weight exhibited significant ($P \leq 0.01$) positive correlations with 100-seed weight, seed cotton yield, and lint%. Hundred-seed weight exhibited a significant ($P \leq 0.01$) positive relationship with seed cotton yield but a nonsignificant positive relationship with lint%. Seed cotton yield showed a nonsignificant positive association with lint%.

Under water deficit conditions, bolls per plant revealed a significant ($P \leq 0.01$) positive association with all the traits except lint% (Table 6). Boll weight exhibited a significant ($P \leq 0.01$) positive correlation with 100-seed weight and seed cotton yield but a nonsignificant positive relationship with lint%. Hundred-seed weight exhibited a significant ($P \leq 0.01$) positive association with lint% but a nonsignificant positive relationship with seed cotton yield. Seed cotton yield showed a significant ($P \leq 0.01$) positive association with lint%. Overall, seed cotton yield revealed highly significant positive associations with all the traits, except for 100-seed weight under water deficit condition, under optimal and deficit irrigation conditions.

Past studies revealed the positive correlation of seed cotton yield with bolls per plant and boll weight (Alkuddsi *et al.*, 2013; Jaloliddin *et al.*, 2020; Zeeshan *et al.*, 2020). Previous studies also reported the positive correlation of seed cotton yield with lint% and boll weight (Amanov *et al.*, 2020). Tohir *et al.* (2018) mentioned the positive correlation of seed cotton yield with bolls per plant, boll weight, and 100-seed weight under water deficit conditions.

CONCLUSIONS

The cotton cultivars Ishonch and Navbakhor-2 and their F1 hybrids were more stable and performed better than other genotypes under both water regimes. These parental genotypes and their hybrids can be used as source materials for developing genotypes with tolerance to drought conditions. Broad-sense heritability was the highest for boll weight, 100-seed weight, seed cotton yield, and lint% but was low for bolls per plant. Genotypic and phenotypic variances for various traits were greater under water deficit conditions than under the optimal irrigation regime. Overall, under optimal and deficit irrigation conditions, seed cotton yield revealed a highly significant positive association with the majority of the traits.

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