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COTTON GENOTYPES APPRAISAL FOR MORPHO-PHYSIOLOGICAL AND YIELD CONTRIBUTING TRAITS UNDER OPTIMAL AND DEFICIT IRRIGATED CONDITIONS

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SUMMARY

In agricultural ecosystems, drought has a detrimental effect on crop production, affecting the growth rate and development of the economically important traits of the crop plants. The presented study aimed to assess the genetic potential and aspects of 20 upland cotton cultivars (*Gossypium hirsutum* L.) for morpho-physiological and yield contributing traits under optimal and deficit irrigated conditions during 2018–2019, at Tashkent, Uzbekistan. With water deficit conditions, the proline content in plant leaves of various cotton genotypes increased (76.36%) compared with the optimal water regime. The chlorophyll a and b, total chlorophyll, and carotenoids can increase and decrease to varying degrees, depending upon the water content in the leaves of cotton genotypes. Results also revealed that upland cotton's leaf relative water content, excised-leaf water loss, total chlorophyll, chlorophyll a and b, carotenoid and proline contents, plant height, sympodial branching, leaf area, bolls per plant, opened bolls plant, and seed cotton yield depended on water supply conditions and the genotypic composition of the genotypes. Based on the analysis of stress tolerance indices for morpho-yield and some physiological traits of cotton genotypes under different irrigation regimes, genotypes Namangan-77, Hapicala-19, 0-30, Zangi-Ota, Saenr Pena-85, S-2025, KK-602, SAD-35-11, and C-417 revealed tolerant to water deficit conditions. However, the cotton cultivars KK-1796, KK-1795, 1000, L-N1, S-9006, KK-1086, Catamarca 811, S-9008, L-N1, 141, C-4769, and L-45 were not good performers and susceptible to water stress conditions. Results concluded that soil drought conditions during the flowering stage disrupted physiological processes, including leaf relative water content and excised-leaf water loss.

Keywords: Upland cotton (*Gossypium hirsutum* L.), water optimal and deficit conditions, drought tolerance, morpho-yield traits, physiological variables, correlation

Key findings: The deficit irrigated conditions negatively affected morpho-physiological and yield contributing traits of upland cotton. Cultivars Namangan-77, Hapicala-19, 0-30, Zangi-Ota, Saenr Pena-85, C-2025, KK-602, SAD-35-11, and C–417 revealed more promising and stable performing better than other genotypes for various traits under optimal and deficit irrigated conditions.

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INTRODUCTION

Cotton is a cash crop grown in many regions of the world. This plant is also an industrial crop produced in developed and developing countries (Imran *et al.,* 2011, 2012). Farming cultivars belonging to *Gossypium hirsutum* L. occur in more than 77 countries. Currently, the world's cotton area is around 35 million ha, with about 1.0 million ha in Uzbekistan, grown under varied climatic conditions (Worldbank.org, 2020). In Uzbekistan in 2020, the total production of cotton fiber was about 610 mt (2,800 bales) (World Markets and Trade, 2022).

Cotton gins and the textile industry are the main sources of employment for millions of people, accounting for a significant share of the gross domestic product in many countries, including Uzbekistan, Australia, Greece, India, China, and Pakistan (www.trendingtopmost.com, 2017). Uzbekistan is the sixth-largest cotton producer in the world, with China, India, the USA, Brazil, Pakistan, and Turkey. Uzbekistan ranks seventh by the volume of cotton consumed in the world, after China, India, Pakistan, Bangladesh, Turkey, and Vietnam. However, Uzbekistan did not rank among the top-eight cotton-exporting countries. In this ranking, the leaders are the US, Brazil, India, Australia, and Benin. According to the study, the world cotton market will reach US$46.5 billion by 2027, with an annual growth rate of 2.74% from 2020 to 2027 (Researchandmarkets.com, 2021; World Markets and Trade, 2022).

Climate change has caused an increase in the environmental temperature, which resulted in modification of the water regimes and precipitation patterns worldwide (Hitz and Smith, 2004). According to experts, global warming will further enhance the frequency of periods of droughts, summer temperatures, and changes in water resource formation. Such extreme signs of climate change can lead to increased scarcity of water resources and increased risks associated with a lack of water, which may decline crop production and a shortage of drinking water in the arid regions of Uzbekistan and the world. Like other countries, Uzbekistan is facing serious drought problems due to a lack of irrigation water. The main problem of declining cotton yields is the lack of irrigation water, so it is necessary to create genotypes that can withstand water deficit conditions.

Current global developments could exaggerate water deficiency in the future. Global climate change will continue, and water deficiency may become a severe obstacle in crop production worldwide (Riaz *et al.,* 2013; Matniyazova *et al.,* 2022). With this, there is a dire need to develop drought-resistant cotton cultivars (Longenberger *et al.,* 2006; Shavkiev *et al.,* 2019b, 2020). According to past studies, a rise in temperature from 2 °C to 4 °C will reduce precipitation by 30%, impacting productivity and water availability in 2050 (Ben-Asher *et al.,* 2007; Gornall *et al.,* 2010). Thus, drought is a global problem for food security, which has highlighted the need to create different crop cultivars that produce good yields under water-deficit conditions (Almeselmani *et al.,* 2015).

Water supply is one of the chief factors determining the value of growth and productivity of crop plant species. At the same time, there is an increase in the demand for water resources in agriculture due to the sharp climate changes and the rise in food demand in connection with the growing population (Reddy *et al.,* 2004; Normamatov *et al.,* 2023). Drought tolerance is one of the most complex agronomic properties, which depends on many factors affecting different systems of crop plants (Cushman and Bohnert, 2000). The depletion of groundwater reserves utilized by crop plants and the high energy consumption relative to water absorption directly impact seed cotton yield in irrigated agriculture. Therefore, the study of drought tolerance is one of the primary issues in the existing genotypes of cotton and other crops (Howard *et al.,* 2001).

Past studies believed that cotton is a drought-tolerant crop; however, drought significantly reduced the seed cotton yields, and lack of irrigation water and biochemical properties have negatively impacted the morpho-physiological and yield traits of the crop (Patil *et al.,* 2011; Jayalalitha *et al.,* 2015). Cotton characterization is through genetic variability in water deficit and high-temperature conditions. Significant genetic variability is a requirement in the germplasm for response to dry conditions, with the belief that this variability gets maintained by genetic factors for drought tolerance (Iqbal *et al.,* 2011; Saba and Azhar, 2015).

The impact of drought on cotton yield directly relates to the period under study, as well as the drought level. Studies have shown that under drought conditions, the leaf surface area, the number of leaf buds, and leaves of cotton plants decreased, which indirectly reduced the photosynthesis efficiency and plant yield (Krieg, 1997). Past results also revealed that in cotton crop, the need for water increases sharply at the flowering stage, while during the mass flowering phase, the plants show the highest sensitivity to drought, which directly affects the boll formation and eventually the seed cotton yield (Pettigrew, 2004).

Water deficit condition adversely impacts the cotton fiber quality, especially during the fiber formation and development period, reducing the fiber length. In the final stage of the flowering phase of the cotton plant, the lack of water slows down the development of the late-formed bolls, shortens the length of the resulting fiber, reducing the fiber strength and increasing the possibility of shedding (McWilliams, 2004). In drought during the flowering period, a sharp decrease emerged in the number of joints producing flower-forming buds in the plant bush and a violation in the balance of phytohormones in cotton bolls, which in turn leads to a decrease in productivity (Guinn and Mauney, 1984).

Chlorophyll is one of the main chloroplast components, which plays a vital role in photosynthesis (Shavkiev *et al.,* 2020). Decreased chlorophyll content under drought stress is a symptom of photooxidation and chlorophyll degradation, with its reduction depending upon the duration and extent of the drought, which eventually declines the yield potential (Anjum *et al.,* 2011; Shavkiev *et al.*, 2021). As water deficiency degrades photosynthetic pigments, chlorophyll amount reduces and disrupts the photosynthetic system. A significant decrease in chlorophyll content and synthesis may be due to systemic disruptive factors, with a reduction in chlorophyll levels recorded due to water scarcity in cotton crops (Shavkiev *et al.*, 2022). Based on the above discussion, the presented study aimed to assess the morpho-yield and physiological traits of cotton genotypes under water optimal and deficit conditions.

MATERIALS AND METHODS

Genetic material, experimental site, and irrigation conditions

The completed study started with cotton cultivar planting during 2020–2021 in the Tashkent region of Uzbekistan (41.389° N and 69.465° E). This region mostly experiences cold winters and long, hot, and dry summers, with annual photoperiod of 16/8 h (light/dark). This study involved the genetic potential and genetic aspects of 20 upland cotton (*G. hirsutum* L.) genotypes (Table 1). These genotypes have an average fiber production (1.5–2.0 t/ha) with varying levels of drought tolerance. The cotton cultivars, grown in a randomized complete block design (RCBD) with a factorial arrangement, had three replications under optimal and deficit irrigated conditions. Planting the cotton genotypes consisted of plant and row spacing of 10 and 60 cm in 50 m long furrows. The soil moisture content was 74% under optimal irrigated conditions, and 45% under deficit irrigated conditions, based on a moisture tester calculation. A specified distance managed and separated the optimal (full) and deficit irrigated conditions.

During the crop season in 2020-2021, the recorded sunny days were around 180–185. The temperature increased in April during the cotton sowing season, while decreasing in late October during the boll formation stage and before the harvesting period. Rainfall varied from 0 mm to 45 mm during the dry season for 5–6 months (Table 2). The crop required intensive irrigation throughout the vegetative period. Cotton irrigation comprised a 1–2–1 (pre-flowering–flowering–boll opening) sequence, with 900 m3/ha of water applied before flowering, two applications of 1200 m3/ha each during flowering, and 900 m3/ha before the boll opening (Xamidov and Matyakubov, 2019). This sequence is an optimal irrigation protocol widely used in cotton production in Uzbekistan. Soil moisture also contributes to water during seed germination. A modified irrigation protocol developed for deficient irrigated conditions also ensued. The irrigation process employed took one time according to the ratio of 0:1:0, with the total volume of water used for irrigation being 1200 m3/ha. In this experimental environment, the cotton plant irrigation

Table 1. Cotton genotypes with their origins used in the present study.

No.	Name	Origin
1	Namangan-77	Uzbekistan
2	KK1796	Uzbekistan
3	KK1795	Uzbekistan
4	L-1000	Uzbekistan
5	C-9006	Uzbekistan
6	KK-1086	Uzbekistan
7	Catamarca 811	Argentina
8	C-9008	Uzbekistan
9	L-N1	Uzbekistan
10	L-141	Uzbekistan
11	Hapicala-19	Australia
12	0-030	Uzbekistan
13	C-4769	Uzbekistan
14	L-45	Uzbekistan
15	Zangi-Ota	Uzbekistan
16	Saenr Pena-85	Argentina
17	C-2025	Uzbekistan
18	KK-602	Uzbekistan
19	SAD-35-11	Mexico
20	C-417	Mexico

Table 2. Maximum and minimum temperatures, air humidity, and the total rainfall during the study period.

Months	Maximum temperature (°C)		Minimum temperature (°C)		Average relative humidity (%)		Total rainfall (mm)	
	2020	2021	2020	2021	2020	2021	2020	2021
April	+27	+29	+4	+4	32%	34%	3.98	4.38
May	+33	+35	+8	+10	30%	33%	2.95	3.36
June	+37	+38	+15	+16	25%	30%	1.15	1.90
July	+43	+40	+20	+19	15%	19%	0.00	0.12
August	+39	+36	+17	+15	14%	18%	0.00	0.05
September	+32	+30	+11	+10	22%	21%	0.36	0.31
October	+29	+26	+3	+4	29%	26%	2.74	2.55

occurred once only during the flowering stage (Xamidov and Matyakubov, 2019). For crop protection purposes, applying the insecticides Bi-58 (BASF, Germany) and Hexachloran proceeded with the control of sucking (aphids) and chewing (bollworm) insects, respectively. The seasonal application of fertilizers was during tillage and before irrigation per annum at the rate of 250:180:115 NPK kg/ha.

Traits measurement

With optimal water supply and water deficit conditions in the field, the assessment of the physiological parameters in the plants ensued during the flowering period. In determining the leaf relative water content (Egert and Tevini, 2002), excised-leaf water loss (Farshadfar *et al.,* 2002), total chlorophyll, chlorophyll a, chlorophyll b, carotenoid content in plant leaves (Sumanta *et al.,* 2014), and the amount of proline in plant leaves followed the standard procedures (Bates *et al.,* 1973). The recorded data were also on the morpho-yield traits, i.e., plant height, the number of sympodial branches per plant, leaf area indicators, the number of bolls per plant, the number of opened bolls per plant, and seed cotton yield per plant.

Statistical analysis

Analysis of the variance of the various traits of the cotton cultivars under two different irrigation regimes progressed according to Steel *et al.* (1997). In this case, the Fisher criterion (F), the standard deviations (SD), the standard error (SE), and the degree of significant difference ($P \leq 0.05$*, $P \leq 0.01$**, and $P \leq 0.001$***) determined the reliability of the differences between the genotypes for each trait. A correlation coefficient determination also went on among the various variables (Kwon and Torrie, 1964). In this case, when r was less than 0.3, the correlation between the characters was weak; when r = 0.3–0.7, then it was average, and r higher than 0.7 has a strong association.

The evaluation of drought tolerance of cotton genotypes proceeded by using the following equations:

Stress Tolerance Index (Fernandez, 1992)
$$STI = (Ys \times Yp) / \bar{Y}p2$$

Stress Susceptibility Index (Fischer and Maurer, 1978)
$$SSI = (1 - [Ys / Yp]) / (1 - [\bar{Y}s / \bar{Y}p])$$

Tolerance Index (Hossain *et al.,* 1990)
$$TOL = Yp - Ys$$

Mean Productivity (MP) (Hossain *et al.,* 1990)
$$MP = (Ys + Yp)/2$$

Yield Index (Gavuzzi *et al.,* 1997)
$$YI = Ys / \bar{Y}s$$

Yield Stability Index (Bouslama and Schapaugh, 1984)
$$YSI = Ys / Yp$$

Where:
Yp = is the average productivity of the genotype in optimal water supply conditions
Ys = is the average plant productivity of the genotype in water deficit conditions
$\bar{Y}p$ = is the average productivity of all the genotypes in optimal water supply conditions
$\bar{Y}s$ = is the average productivity of all the genotypes in water deficit conditions

RESULTS AND DISCUSSION

Under optimal irrigated conditions, the lowest values recorded for seed cotton yield were in the cotton (*G. hirsutum* L.) genotypes 0-30 and L-45 (35.78 ± 0.28 and 38.13 ± 0.29 g, respectively). Under deficit irrigated conditions, the lowest seed cotton yield observed was in the cotton genotype KK-1795 (13.17 ± 0.14 g). Genotype Saenr Pena-85 was the highest yielder than the control and experimental backgrounds (94.91 ± 1.34 and 91.2 ± 2.57 g, respectively). For seed cotton yield, the genotypes, viz., KK-1796, KK-1795, 1000, C-9006, KK-1086, Catamarca-811, and L-N1, showed significant differences under water deficit conditions compared with the optimal irrigation. These genotypes revealed unstable under water deficit conditions based on yield-related traits. Cotton genotypes 0-30, C-4769, L-45, Zangi-Ota, Saenr Pena-85, SAD-35-11, C-417, and the control cultivar (Namangan-77) showed stable compared with other cotton genotypes.

In the case of stress susceptibility index (SSI), the genotypes Namangan-77 (0.09), 0-30 (0.02), Saenr Pena-85 (0.12), SAD-35-11 (0.07), and C-417 (0.14) had the lowest rates of SSI, whereas the highest rates were in genotypes KK-1796 (1.76), KK-1795 (2.33), L-1000 (1.78), C-9006 (1.61), KK-1086 (1.63), Catamarca 811 (2.19), L-N1 (2.31), and 141 (1.220) (Table 3). Researchers have proven that if a plant's stress susceptibility index is SSI ≥ 1, the plant is prone to stress conditions (Fischer and Maurer, 1978). The results also authenticated that cotton genotypes, i.e., KK-1796, KK-1795, L-1000, C-9006, KK-1086, Catamarca 811, L-N1, and L-141, have no tolerance to water deficit conditions compared with other genotypes.

By studying the stress tolerance index (STI) in cotton genotypes, the lowest STI value emerged in cotton genotype KK-1795 (0.17), and the highest STI values were in the cultivars Saenr Pena-85 (2.07) and C-417 (1.30). Previous observations stated that the higher the stress tolerance index, the greater tolerance of the cotton genotype under water deficit conditions (Fernandez, 1992) The results also exhibited that cotton genotypes Namangan-77, Zangi-Ota, Saenr Pena-85, C-2025, and C-417 were resistant to water deficit conditions among all the genotypes. The tolerance index (TOL) is the difference between seed cotton yield under optimal water and water deficit conditions. Among the genotypes, the highest TOL values recorded appeared in the cotton genotypes Catamarca-811 (56.82) and L-N1 (65.71), whereas the lowest was in the genotype 0-30 (0.28). Results also revealed that cotton cultivars KK-1796, KK-1795, 1000, C-9006, KK-1086, Catamarca-811, and L-N1 showed a sharp decline in seed cotton yield with the imposition of water deficit conditions (Table 3).

The mean productivity (MP) index is an average indicator of plant productivity under optimal water and water deficit conditions, with the best performance identified in the Saenr Pena-85 (93.06 g) genotype (Table 3). Cotton genotypes Namangan-77, Zangi-Ota, Saenr Pena-85, C-2025, KK-602, SAD-35-11, and C-417 were the donors for good initial selection in terms of seed cotton yield. Yield Index (YI) was highest in cotton genotypes Namangan-77 (1.50), Zangi-Ota (1.42), Saenr Pena-85 (2.10), and C-417 (1.65). The lowest yield

Table 3. Analysis of various stress selection indices in cotton genotypes.

	(STI)	(SSI)	(TOL)	(MP)	(YI)	(YSI)
Namangan-77	1.05	0.09	2.05	66.12	1.50	0.97
KK-1796	0.55	1.76	42.59	52.40	0.72	0.42
KK-1795	0.17	2.33	42.28	34.31	0.30	0.24
L-1000	0.42	1.78	38.15	46.18	0.62	0.42
C-9006	0.71	1.61	41.62	58.15	0.86	0.47
KK-1086	0.47	1.63	34.83	47.80	0.70	0.47
Catamarca 811	0.42	2.19	56.82	50.73	0.51	0.28
C-9008	0.60	0.70	13.15	50.68	1.01	0.77
L-N1	0.43	2.31	65.71	53.78	0.48	0.24
L-141	0.33	1.22	19.24	38.37	0.66	0.60
Hapicala 19	0.75	0.49	9.89	56.23	1.18	0.84
0-30	0.30	0.02	0.28	35.64	0.82	0.99
C-4769	0.43	0.45	6.76	42.67	0.90	0.85
L-45	0.30	0.41	5.12	35.57	0.76	0.87
Zangi-Ota	0.97	0.20	4.37	63.72	1.42	0.93
Saenr Pena-85	2.07	0.12	3.71	93.06	2.10	0.96
C-2025	0.97	0.61	14.30	64.19	1.31	0.80
KK-602	0.77	0.83	18.19	57.47	1.11	0.73
SAD-35-11	0.88	0.07	1.35	60.67	1.38	0.98
C-417	1.30	0.14	3.56	73.61	1.65	0.95

index came from genotypes KK-1795 (0.30) and L-N1 (0.48).

The yield stability index (YSI) determines the degree of stability of a genotype under water deficit conditions relative to the optimal water supply (Shavkiev *et al.,* 2019a; Shavkiev *et al.,* 2022). The observed highest YSI values were in cotton cultivars Namangan-77 (0.97), 0-30 (0.99), Zangi-Ota (0.93), Saenr Pena-85 (0.96), SAD-35-11 (0.98), and C-417 (0.95), whereas the lowest YSI values were in the cotton genotypes, i.e., Catamarca 811 (0.28), L-N1 (0.24), and KK-1795 (0.24). Results revealed that cotton cultivars Namangan 77, 0-30, Zangi-Ota, Saenr Pena-85, SAD-35-11, and C-417 have significantly higher seed cotton yields under water deficit conditions than other genotypes (Table 3).

Based on the cluster analysis of drought tolerance indices for yield trait in cotton (*G. hirsutum* L.) genotypes under different irrigation regimes, the cultivars Namangan-77, Hapicala-19, 0-30, Zangi-Ota, Saenr Pena-85, S-2025, KK-602, SAD-35-11, and C-417 revealed resistant to water deficit conditions compared with other genotypes (Figure 1).

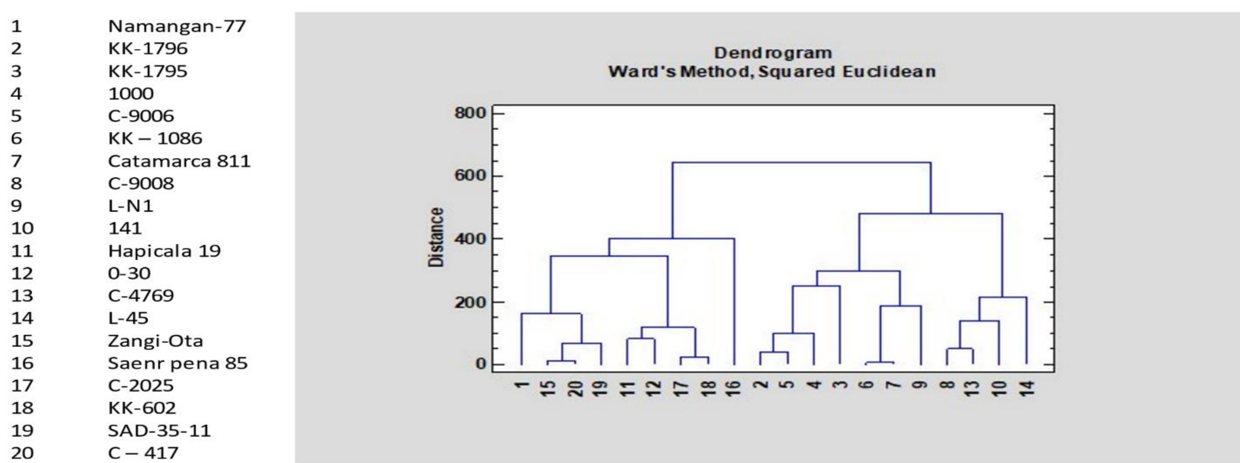

Figure 1. Drought tolerance cluster analysis of the various cotton genotypes.

Irrigation influence on morpho-physiological and yield contributing traits

Drought-tolerant genotypes reduce water loss by enlarging the leaves and lessening the opening of the leaf openings (stomata). The most effective criteria are the physiological traits, i.e., chlorophyll a and relative water content (RWC%), for determining the high-yielding genotypes under drought conditions (Mustafavi *et al.,* 2016). In studying the excised-leaf water loss (ELWL%) of cotton genotype leaves under different water regimes, the highest rate of ELWL observed occurred in genotype KK-1795 (42.82% ± 1.58%), with the lowest in cotton genotypes L-1000, C-9006, and L-141 (30.06% ± 1.68%, 30.13% ± 1.26%, and 30.14% ± 1.22%, respectively) compared with the control cultivar Namangan-77 (34.85% ± 1.72%) under optimal water supply (Table 4). With water deficiency, the highest ELWL was in cotton genotype KK-602 (24.76% ± 1.35%), whereas the lowest in KK-1086 (13.65% ± 0.22%) and L-N1 (13.46% ± 0.69%). Cotton genotypes KK-1795 and L-N1 showed significance, with a sharp decrease under water deficit conditions relative to Namangan-77 and other cultivars in optimal irrigation. The cultivars possessing the ability of low-rate excised leaf water loss showed drought resistance. Therefore, ELWL% recommends as the best measure for tolerance in the genotypes to water stress.

Cotton genotypes Catamarca 811 and L-N1 came out with the lowest relative water content percentage (58.56% ± 2.72% and 59.25% ± 1.44%, respectively) in the leaf under water deficit conditions, with genotypes Namangan-77 and KK-1796 showing the highest RWC% (71.7% ± 0.51% and 70.94% ± 2.82%, respectively) (Table 4). Under optimal water supply, the lowest RWC values observed were in cotton genotypes L-N1 and Catamarca 811 (65.47% ± 1.35% and 65.34% ± 0.68%, respectively), whereas the highest values in genotypes KK-1795 and L-1000 (77.31% ± 0.71% and 79.28% ± 1.84%, respectively). The results further revealed that in the leaves of cotton genotypes Namangan-77, KK-1796, L-45, Zangi-Ota, Saenr Pena-85, and C-2025, the relative water content was non-significantly different than those of other genotypes under water deficit conditions. In genotype KK-1795, the difference for the sharp decrease proved significant. Under drought-stress conditions, the high RWC would be preferable to maintain water balance. An earlier report said higher RWC in leaf was a selection criterion to breed tolerant genotypes to drought stress (Rahman *et al.,* 2000). Moisture stress caused a substantial decline in growth, leaves' water content, and seed cotton yield; however, some cultivars recorded higher growth and yield and sustained higher leaf water content and more photosynthesis (Soomro *et al.,* 2011). Leaf relative water content exhibited as 69% and 45% in transgenic and wild-type plants, respectively, at 10-day drought stress. Similarly, the transgenic cotton genotypes showed better performance due to stress-responsive genes for photosynthesis, stomatal conductance, transpiration, and osmotic potential compared with wild types (Sarwar *et al.,* 2017).

For proline content under deficit irrigated conditions, the lowest values resulted in the leaves of the cotton genotypes Hapicala-19 and Saenr Pena-85 (147.66 ± 5.40 and 151.85 ± 1.39 µg g-1, respectively). Under the optimal irrigated conditions, the lowest values for proline content emerged in the cotton genotypes Saenr Pena-85 and KK-602 (104.52 ± 1.32 and 109.35 ± 0.40 µg g-1, respectively). Under optimal water supply, the highest proline content was in the leaves for 141 and C-4769 genotypes (174.52 ± 5.14 and 170.97 ± 4.21 µg g-1, respectively). Under water deficit conditions, the cotton genotypes KK-1795 and L-141 came with the highest proline content, i.e., 221.05 ± 8.00 and 223.55 ± 1.85 µg g-1, respectively (Table 4). Moreover, results indicated the proline content in genotype C-9006 significantly increased with the optimal water supply compared with cotton control genotype Namangan-77 and other genotypes under water deficit conditions.

The chlorophyll a, b, total chlorophyll, and carotenoid content also underwent scrutiny in the cotton genotypes. Under optimal irrigated conditions, the amount of chlorophyll a in the leaves of cotton genotypes KK-1086 and Catamarca 811 was the highest (21.47 ± 0.24 and 22.02 ± 0.70 mg g-1, respectively), whereas the lowest was in genotypes C-9006 and L-141 (15.85 ± 0.26 and 15.57 ± 0.22 mg g-1, respectively). Under deficit irrigated conditions, the highest amount of chlorophyll a recording showed in cotton genotypes Hapicala-19 and KK-602 (22.11 ± 0.90 and 22.14 ± 0.18 mg g-1, respectively), with the lowest amount of chlorophyll a exhibited by the genotype L-45 (11.33 ± 0.63 mg g-1). For cotton genotypes, L-45, KK-1086, Catamarca-811, C-9008, Zangi-Ota, and SAD-35-11, the decrease in chlorophyll content under the water deficit condition proved significant relative to the optimal irrigated condition.

Table 4. Mean performance of cotton genotypes for physiological traits under water optimal and deficit irrigated conditions.

Genotypes	Excised-leaf water loss			Leaf relative water content			Proline		
	Irrigated ME±SE	Drought ME±SE	Difference	Irrigated ME±SE	Drought ME±SE	Difference	Irrigated ME±SE	Drought ME±SE	Difference
Namangan-77	34.85±1.72	19.3±0.60	15.55	74.89±1.13	71.7±0.51	3.19	137.42±2.11	215.16±5.86	-77.74
KK-1796	33.73±1.83	16.24±0.99	17.49	75.19±0.95	70.94±2.82	4.25	163.55±1.19	197.34±4.17	-33.79
KK-1795	42.82±1.58	14.62±0.14	28.2	77.31±0.71	60.79±1.89	16.52	166.45±2.63	221.05±8.00	-54.6
L-1000	30.06±1.68	20.55±0.97	9.51	79.28±1.84	69±0.27	10.28	112.58±6.19	170.73±3.86	-58.15
C-9006	30.13±1.26	18.99±1.64	11.14	75.32±1.53	65.35±0.86	9.97	135.48±4.74	214.12±6.87	-78.64
KK – 1086	34.89±0.41	13.65±0.22	21.24	71.53±0.a	60.62±0.77	10.91	125.48±0.92	180.81±4.02	-55.33
Catamarca 811	32.48±0.65	16.22±0.30	16.26	65.47±1.35	58.56±2.72	6.91	134.19±2.90	186.94±9.57	-52.75
C-9008	35.98±0.37	15.03±1.16	20.95	70.77±0.82	61.31±1.10	9.46	152.9±2.63	180.16±1.54	-27.26
L-N1	36.18±0.27	13.46±0.69	22.72	65.34±0.68	59.25±1.44	6.09	159.35±2.63	190.08±1.39	-30.73
L-141	30.14±1.22	14.54±1.19	15.6	69.08±1.04	62.61±2.28	6.47	174.52±5.14	223.55±1.85	-49.03
Hapicala 19	31.28±0.95	16.25±0.97	15.03	72.11±1.44	65.97±1.58	6.14	126.77±1.19	147.66±5.40	-20.89
0-30	35.7±0.35	18.92±1.43	16.78	69.55±1.31	59.94±1.12	9.61	130.65±5.93	163.55±4.32	-32.9
C-4769	33.71±0.71	20.85±0.80	12.86	71.75±1.11	64.7±1.74	7.05	170.97±4.21	210.08±0.15	-39.11
L-45	35.28±0.34	21.02±1.23	14.26	72.06±1.05	68.81±0.78	3.25	136.77±2.90	172.34±0.77	-35.57
Zangi-Ota	35.02±0.42	21.12±1.15	13.9	70.56±0.69	69.18±1.31	1.38	150.97±1.58	182.18±1.08	-31.21
Saenr Pena-85	37.83±1.24	21.29±1.82	16.54	71.86±0.69	65.7±2.07	6.16	104.52±1.32	151.85±1.39	-47.33
C-2025	38.23±0.27	21.37±1.06	16.86	68.4±1.32	64.06±0.51	4.34	154.84±0.26	172.02±1.08	-17.18
KK-602	38.87±0.44	24.76±1.35	14.11	71.93±1.43	63.57±0.57	8.36	109.35±0.40	176.53±2.32	-67.18
SAD-35-11	30.12±1.18	19.78±1.13	10.34	70.16±1.38	60.42±0.59	9.74	141.94±2.37	157.74±1.85	-15.8
C – 417	37.58±1.47	21.78±1.10	15.8	76.95±0.40	68.47±1.22	8.48	131.61±0.53	178.06±6.18	-46.45

Under optimal water supply, the amount of chlorophyll b was the highest in the leaves of cotton genotype KK-1086 (7.26 ± 0.32 mg g-1), whereas the lowest value of the said trait in cotton genotype L-141 (4.08 ± 0.22 mg g-1). With water deficit conditions, the maximum chlorophyll b content recorded was in the genotype Saenr Pena-85 (7.11 ± 0.28 mg g-1), with the lowest in genotypes C-9008 and L-45 (3.99 ± 0.06 and 3.49 ± 0.15 mg g-1, respectively). In cotton genotypes: KK-1086 and SAD-35-11, the decrease in chlorophyll b under water deficit conditions relative to the optimal water supply showed significance, and a notable increase appeared in cotton genotypes Hapicala-19 and Saenr Pena-85 genotypes (Table 5). The decrease in chlorophyll a and b under drought conditions might be due to the inhibition of the oxidant during the photooxidation process in cotton and other crop plants (Farooq *et al.,* 2009; Shavkiev *et al.,* 2020, 2021, 2022).

For total chlorophyll content under optimal water supply conditions, the cotton genotypes KK-1086 and Catamarca-811 came out with the highest values (28.73 ± 0.56 and 28.2 ± 0.98 mg g-1, respectively), whereas the lowest value observed was in the genotype 141 (19.65 ± 0.43 mg g-1). Under water deficit conditions, the highest rates for total chlorophyll content surfaced from cotton genotypes Hapicala 19 and KK-602 (29.47 ± 1.29 and 28.28 ± 0.39 mg g-1, respectively), but the lowest was in the cotton genotype L-45 (14.82 ± 0.78 mg g-1). In cotton genotypes: KK-1086, Catamarca-811, C-9008, C-4769, L-45, Zangi-Ota, SAD-35-11, and C-417, the differences for total chlorophyll content proved to be reliable. Results also revealed that the differences in the cotton genotypes Hapicala-19 and Saenr Pena-85 for total chlorophyll content under water deficit conditions relative to optimal water supply were convincing (Table 5).

Concerning carotenoid content in cotton cultivars, under optimal water supply, the highest content occurred in genotypes L-1000, KK-1086, and Catamarca-811 (5.19 ± 0.11, 5.27 ± 0.13, and 5.7 ± 0.17 mg g-1, respectively), whereas the minimum carotenoid content recording was in cultivar L-N1 (3.6 ± 0.07 mg g-1). Under water-deficient conditions, the cotton genotype L-45 resulted in the lowest carotenoid content (2.4 ± 0.16 mg g-1), but cultivars Saenr Pena-85 and C-2025 gave the highest values (5.14 ± 0.15 and 5.03 ± 0.11 mg g-1, respectively). With water scarcity, the reduction in carotenoid content in leaves of the genotypes L-45 and SAD-35-11 relative to the optimal water supply was influencing (Table 5). However, with optimal water supply, increased carotenoid content observed in the genotypes Saenr Pena-85 and C-2025 was also encouraging. Chlorophyll contents play a vital role in the photosynthetic process, ultimately increasing crop growth and yield (Taiz and Zieger, 2006). Drought stress is one of the factors affecting chlorophyll 'a,' 'b,' total chlorophyll, and the ratio of a/b (Massacci *et al.,* 2008; Hamayun *et al.,* 2010). By studying the effect of drought stress on chlorophyll, observations noted that drought stress had decreased chlorophyll 'a,' 'b,' and total chlorophyll (Massacci *et al.,* 2008; Hamayun *et al.,* 2010).

Studies have shown that in cotton genotypes, the amount of pigment in the plant leaves has decreased and increased to varying degrees depending on the origin and genetic makeup of the genotypes (Massacci *et al.,* 2007). Parida *et al.* (2007) revealed that the chlorophyll and carotenoid content in cotton genotypes declined in a low-water environment while enhanced with optimal irrigation. For plant height under different water regime conditions, the genotypes Catamarca 811 and C-417 arrived with a plant height of 115.4 ± 1.44 and 115.4 ± 1.23 cm, respectively, under optimal water supply. However, under water deficit conditions, genotypes Hapicala-19 and Saenr Pena-85 showed the highest values for plant height (77.7 ± 1.67 and 75.55 ± 0.99 cm, respectively), with the lowest values recorded in cotton genotype KK-1795 (78 ± 1.6 and 34.2 ± 0.12 cm) under control and experimental conditions, respectively (Table 6). For water deficit, relative to the optimal water supply conditions, a partial decrease was in cotton cultivars Hapicala and Namangan-77, whereas a sharp fall resulted in the remaining cultivars.

By studying the sympodial branches of cotton genotypes under different water regimes, the highest values occurred in genotypes Namangan-77 and C-9006 (19.4 ± 0.46 and 19.5 ± 0.17 units, respectively) under optimal water supply; under water deficit conditions, the genotypes Zangi-Ota and Saenr Pena-85 recorded with the least number of sympodia per plant (13.1 ± 0.17 and 14.0 ± 0.46 units, respectively). In optimal water supply, the lowest value found was in cotton genotypes Saenr Pena-85 (11.8 ± 1.04), and in the case of water shortage, in genotype KK-1795 (8.2 ± 0.12). In cotton genotypes, Zangi-Ota, Saenr Pena-85, and C-417, no decrease in the number of sympodial branches happened under water shortage relative to the optimal

Table 5. Mean performance of cotton genotypes for chlorophyll traits under water optimal and deficit irrigated conditions.

Genotypes	Chlorophyll a		Difference	Chlorophyll b		Difference	Total chlorophyll		Фарк	Carotenoid		Difference
	Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE	
Namangan-77	17.16±0.65	15.93±0.19	1.23	5.44±0.37	4.85±0.24	0.59	22.6±1.00	20.77±0.26	1.83	4.94±0.15	4.08±0.02	0.86
KK-1796	20.16±0.78	18.54±0.65	1.62	6.63±0.64	4.92±0.35	1.71	26.79±1.41	23.46±0.99	3.33	4.88±0.05	4.48±0.18	0.4
KK-1795	16.34±0.64	17.7±0.50	-1.36	4.83±0.12	5.32±0.06	-0.49	21.17±0.55	23.02±0.55	-1.85	4.9±0.12	4.17±0.15	0.73
L-1000	16.87±0.57	17.98±0.79	-1.11	5.95±0.37	4.93±0.29	1.02	22.83±0.92	22.91±1.08	-0.08	5.19±0.11	4.35±0.19	0.84
C-9006	15.85±0.26	19±0.77	-3.15	6.06±0.05	5.12±0.11	0.94	21.91±0.23	24.12±0.88	-2.21	4.67±0.19	4.94±0.16	-0.27
KK – 1086	21.47±0.24	17.53±0.41	3.94	7.26±0.32	4.6±0.13	2.66	28.73±0.56	22.14±0.53	6.59	5.27±0.13	4.39±0.05	0.88
Catamarca 811	22.02±0.70	17.78±0.59	4.24	6.18±0.29	4.99±0.28	1.19	28.2±0.98	22.78±0.86	5.42	5.07±0.17	4.4±0.13	0.67
C-9008	18.2±0.47	14.42±0.42	3.78	5.51±0.47	3.99±0.06	1.52	23.71±0.87	18.41±0.42	5.3	4.25±0.11	3.54±0.04	0.71
L-N1	16.11±0.30	17.18±0.27	-1.07	4.61±0.32	5.02±0.31	-0.41	20.71±0.58	22.2±0.58	-1.49	3.6±0.07	4.5±0.14	-0.9
L-141	15.57±0.22	18.1±0.60	-2.53	4.08±0.22	5.72±0.12	-1.64	19.65±0.43	23.82±0.68	-4.17	3.76±0.04	4.58±0.11	-0.82
Hapicala 19	17.83±0.93	22.11±0.90	-4.28	4.92±0.19	7.35±0.26	-2.43	22.75±1.11	29.47±1.29	-6.72	3.93±0.13	3.85±0.26	0.08
0-30	17.19±0.68	17.87±0.79	-0.68	5.19±0.26	6.99±0.51	-1.8	22.39±0.94	24.85±1.29	-2.46	4±0.20	4.31±0.07	-0.31
C-4769	18.92±0.83	16.29±0.50	2.63	5.8±0.14	4.31±0.34	1.49	24.72±0.89	20.6±0.84	4.12	4.43±0.12	4.44±0.12	-0.01
L-45	16.61±0.92	11.33±0.63	5.28	5.03±0.24	3.49±0.15	1.54	21.65±1.16	14.82±0.78	6.83	4.06±0.26	2.4±0.16	1.66
Zangi-Ota	18.83±0.70	14.81±0.56	4.02	5.89±0.26	4.15±0.23	1.74	24.72±0.96	18.97±0.71	5.75	4.25±0.22	3.65±0.19	0.6
Saenr Pena- 85	16.01±0.21	19.8±0.60	-3.79	4.46±0.12	7.11±0.28	-2.65	20.47±0.32	26.91±0.87	-6.44	3.78±0.10	5.14±0.15	-1.36
C-2025	16.52±0.69	19.25±0.53	-2.73	4.89±0.12	6.4±0.30	-1.51	21.41±0.60	25.65±0.82	-4.24	3.91±0.15	5.03±0.11	-1.12
KK-602	18.29±0.67	22.14±0.18	-3.85	5.12±0.27	6.14±0.22	-1.02	23.41±0.94	28.28±0.39	-4.87	4.5±0.18	4.92±0.06	-0.42
SAD-35-11	21.21±0.89	16.87±0.41	4.34	6.33±0.17	4.17±0.40	2.16	27.55±1.06	21.05±0.81	6.5	4.81±0.16	3.91±0.05	0.9
C – 417	18.13±0.23	15.28±0.15	2.85	5.17±0.16	4.95±0.48	0.22	23.31±0.08	20.22±0.57	3.09	4.19±0.07	3.59±0.03	0.6

Table 6. Mean performance of cotton genotypes for morphological traits under water optimal and deficit irrigated conditions.

Genotypes	Plant height		Difference	Sympodial branching		Difference	Leaf area		Difference
	Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE	
Namangan-77	84±1	64.8±0.58	19.2	19.4±0.46	12.9±0.52	6.5	90.67±3.31	80.55±1.9	10.12
KK-1796	87±0.53	44±0.58	43	17.0±0.12	9.35±0.03	7.65	71.89±4.83	63.69±1.64	8.2
KK-1795	78±1.6	34.2±0.12	43.8	18.4±0.12	8.2±0.12	10.2	74.75±1.11	64.78±1.9	9.97
L-1000	102±0.53	48.1±3.64	53.9	17.3±0.17	9.0±0.58	8.3	96.88±2.12	90.21±4.12	6.67
C-9006	101±1.87	45±1.62	56	19.5±0.17	11.2±0.23	8.3	86.34±2.4	49.33±2.15	37.01
KK – 1086	99.6±0.69	62.9±0.52	36.7	15.8±0.12	10.7±0.64	5.1	108.08±3.78	100.52±1.7	7.56
Catamarca 811	115.4±1.44	48.8±1.85	66.6	16.3±0.40	10.1±0.29	6.2	101.26±2.14	92.65±2.27	8.61
C-9008	98.2±2.38	50.7±2.48	47.5	15.9±0.29	10.9±0.4	5	98.45±2.59	74.26±3.13	24.19
L-N1	118±0.32	55±0.58	63	15.6±0.23	9.6±0.58	6	102.92±2.08	84.58±3.03	18.34
L-141	88.8±2.62	51.1±1.56	37.7	13.0±0.58	9.4±0.23	3.6	105.19±2.12	80.20±0.66	24.99
Hapicala 19	92.2±2.76	77.7±1.67	14.5	13.6±0.35	11.5±0.29	2.1	90.86±2.19	87.04±3.78	3.82
0-30	102±0.53	65.3±1.64	36.7	12.8±0.23	11.3±0.17	1.5	112.55±2.94	107.62±3.28	4.93
C-4769	95.2±0.8	47.1±1.67	48.1	13.6±0.23	10.1±0.17	3.5	152.22±1.6	108.45±2.7	43.77
L-45	84.2±0.48	42.2±0.81	42	13.1±0.17	9.6±0.12	3.5	89.66±1.9	52.96±1.48	36.7
Zangi-Ota	107.4±1.33	68.4±0.69	39	13.1±0.06	13.1±0.17	0	122.06±2.03	117.55±1.54	4.51
Saenr Pena-85	113.4±0.37	75.55±0.99	37.85	11.8±1.04	14.0±0.46	-2.2	121.13±2.18	111.13±1.42	10
C-2025	109±2	71.2±0.92	37.8	15.1±0.64	13.1±0.29	2	123.76±1.97	82.65±3.17	41.11
KK-602	101.6±1.78	58.6±1.27	43	13.8±0.35	10.5±0.29	3.3	93.68±2.79	80.20±1.73	13.48
SAD-35-11	100±0.27	68.7±1.91	31.3	12.67±0.09	11.4±0.12	1.27	109.38±3.36	101.24±3.51	8.14
C – 417	115.4±1.23	73.1±2.02	42.3	12.72±0.11	14.5±0.52	-1.78	97.65±0.61	97.57±3.29	0.08

water supply (Table 6). In cotton cultivars, KK-1796, KK-1795, 1000, and C-9006, the number of sympodial branches declined compared with the control variety (Namangan 77) under water deficit conditions. Results also revealed that cotton genotypes KK-1796, KK-1795, 1000, and C-9006 experienced a higher decrease in the number of sympodial branches relative to optimal water supply, which was of substantial concern.

While studying the leaf level mark in cotton genotypes, the control background was the highest in the cotton cultivar C-4769 (152.22 ± 1.6 cm^2), with the lowest in the genotypes KK-1796 and KK-1795 (71.89 ± 4.83 and 74.75 ± 1.11 cm^2, respectively). Under water deficit conditions, the genotypes Zangi-Ota and Saenr Pena-85 appeared with higher values (117.55 ± 1.54 and 111.13 ± 1.42 cm^2, respectively). However, cotton cultivar C-9006 displayed the lowest value (49.33 ± 2.15 cm^2). Results revealed a sharp decline due to water scarcity relative to the optimal water supply in leaf level indicator of the cotton genotypes, viz., C-9006, C-4769, L-45, and C-2025 was reliable (Table 6). However, genotypes Hapicala 19, 0-30, Zangi-Ota, and C-417 showed no differences for leaf level marks under both water regimes. Past studies observed that cotton genotypes showed reduced plant leaf surface area under water deficit conditions (Noreen *et al.,* 2013).

Several studies authenticated the adverse effects of water deficit conditions on seed cotton yield and its components in the cotton genotypes (Islam *et al.,* 2013; Srinivas *et al.,* 2014; Dahiphale *et al.,* 2015; Raza *et al.,* 2016; Nizamani *et al.,* 2017). By studying the number of bolls per plant under different water regimes, the highest values observed transpired with the optimal water supply and water deficit in cotton genotype Saenr Pena-85 (23.0 ± 0.92 and 22.5 ± 1, respectively). Under optimal water supply, the lowest numbers of bolls per plant recorded were in genotypes L-141 and 0-30 (8.01 ± 0.12 and 8.7 ± 0.06, respectively), although in the case of water deficit conditions, the cotton genotype KK-1795 gave the least number of bolls per plant (4.0 ± 0.12). In cotton cultivars Hapicala 19, 0-30, L-45, Zangi-Ota, Saenr Pena-85, and SAD-35-11, no sharp decrease occurred for bolls per plant under water deficit conditions after comparing with optimal water supply (Table 7).

The study found that the number of bolls in the samples of this cotton variety was stable in the conditions of water shortage compared with the optimal water supply condition. According to the same mark, the reliability of the difference in water deficit conditions resulted in the samples of KK-1796, KK-1795, L-1000, C-9006, KK-1086, Catamarca-811, and L-N1 cotton cultivars. In plants, a sharp decrease showed in the number of joints in which flower-forming buds emerged in the plant bush up to the flowering stage, caused by drought. Further, earlier research said that water deficiency leads to a disturbance of the balance of phytohormones in the buds and buds of the cotton plant, which in turn leads to a decrease in productivity (Guinn and Mauney, 1984).

Assessing the open bolls in cotton genotypes under different water regimes, the highest numbers observed were in the control and experimental backgrounds of the cultivar Saenr Pena-85 (19.8 ± 0.35 and 19.3 ± 0.4, respectively). As for optimal water supply, the lowest values recorded were in cotton genotypes L-141 and 0-30 (8.01 ± 0.12 and 8.7 ± 0.06, respectively), but with water shortage, the lowest values were in genotypes KK-1795 and L-1000 (4 ± 0.12 and 5 ± 0.69, respectively). Cotton genotypes Namangan-77, Hapicala-19, 0-30, L-45, Zangi-Ota, Saenr Pena-85, and C-417 did not show a sharp decrease in open bolls with water deficit conditions compared with optimal water supply (Table 7). Results also revealed that the number of bolls opened in reduced water conditions was stable in cotton genotypes relative to the optimal water supply conditions. According to this indicator, in cotton cultivars KK-1796, KK-1795, 1000, C-9006, KK-1086, Catamarca-811, and L-N1, a sharp decrease resulted in water shortage relative to the optimal water conditions (Table 8). Past findings enunciated that a significant decline occurred in the number of bolls per plant, the number of seeds per boll, cotton fiber weight per seed, and, eventually, the productivity with water deficit conditions (Abdel *et al.,* 2012).

Correlation analysis

The correlation coefficient determines the relationship between various traits of the cotton (*Gossypium hirsutum* L.) genotypes, determining the properties that are beneficial as selection criteria for enhancing the seed cotton yield. However, the expression and association of different traits often varied with breeding material and environmental conditions. Therefore, the relationship between traits and productivity is crucial for selecting the high-yielding genotypes in the breeding material, and much emphasis needs to study the interdependence of various traits (Afiah and Ghoneim, 2013).

Table 7. Mean performance of cotton genotypes for seed cotton yield and its related traits under water optimal and deficit irrigated conditions.

Genotypes	Bolls plant^{-1}		Difference	Opened bolls plant^{-1}		Difference	Seed cotton yield plant^{-1}		Difference
	Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE		Irrigated ME±SE	Drought ME±SE	
Namangan-77	17±1.27	13.7±0.87	3.3	12.3±0.17	12.4±0.92	-0.1	67.14±1.86	65.09±3.05	2.05
KK-1796	17.3±1.56	8.4±0.92	8.9	14.6±0.07	8.3±0.98	6.3	73.69±4.12	31.11±3.07	42.58
KK-1795	10.4±0.69	4.0±0.12	6.4	9.4±0.23	4±0.12	5.4	55.45±5.62	13.17±0.14	42.28
L-1000	11±1.96	5.5±0.87	5.5	11.25±0.14	5±0.69	6.25	65.26±1.3	27.11±1.96	38.15
C-9006	20.3±0.98	8.8±0.92	11.5	16.9±0.06	8.4±0.81	8.5	78.96±6.79	37.34±3.48	41.62
KK – 1086	16.3±1.21	8.8±1.39	7.5	13.6±0.23	8.8±1.39	4.8	65.22±3.34	30.39±3.32	34.83
Catamarca 811	12.5±0.98	6.8±0.35	5.7	13.7±0.06	6.8±0.35	6.9	79.14±5.04	22.32±0.34	56.82
C-9008	12.5±0.29	9.7±1.44	2.8	10.2±0.35	9.5±1.56	0.7	57.25±0.56	44.11±6.67	13.14
L-N1	14.7±1.67	5.8±0.69	8.9	13.4±0.12	5.4±0.58	8	86.64±4.94	20.92±1.37	65.72
L-141	9.2±0.46	6.5±1.10	2.7	8±0.12	6.5±1.1	1.5	47.99±3.09	28.75±5.44	19.24
Hapicala 19	16.3±0.98	15.9±0.06	0.4	13.7±0.4	13.4±0.23	0.3	61.18±0.91	51.29±0.52	9.89
0-30	10.2±0.23	9.6±0.23	0.6	8.7±0.06	8.4±0.46	0.3	35.78±0.28	35.5±1.29	0.28
C-4769	12.2±0.58	9.2±0.23	3	10.5±0.17	9±0.12	1.5	46.05±0.85	39.29±2.46	6.76
L-45	10.5±0.52	10.4±0.35	0.1	10±0.23	10±0.35	0	38.13±0.29	33.01±1.92	5.12
Zangi-Ota	14.4±1.15	13.9±1.21	0.5	13.5±0.87	12.9±1.1	0.6	65.9±8.70	61.53±4.85	4.37
Saenr Pena-85	23.0±0.92	22.5±1.21	0.5	19.8±0.35	19.3±0.4	0.5	94.91±1.34	91.2±2.57	3.71
C-2025	14.5±1.44	12.9±0.29	1.6	11.1±0.17	10±0.12	1.1	71.34±8.04	57.04±1.08	14.3
KK-602	14.2±0.46	11.2±1.04	3	12.75±0.14	10.8±1.27	1.95	66.56±1.22	48.37±4.58	18.19
SAD-35-11	14.2±0.35	13.7±0.64	0.5	13.8±0.27	12.5±1.21	1.3	61.34±1.45	59.99±0.32	1.35
C – 417	18.8±0.46	17.3±1.33	1.5	16.1±0.17	15.4±0.23	0.7	75.39±0.24	71.83±5.40	3.56

Table 8. Basic statistics for morpho-physiological and economic traits in upland cotton genotypes.

Traits		Mean	Standard deviation	Standard error	Coeff. of variation	Minimum	Maximum
Plant height	Irrigated	99.58	11.13	2.49	11.18%	75.25	117.45
	Drought	57.62	12.64	2.82	21.93%	34.20	77.70
Sympodial branching	Irrigated	15.01	2.37	0.53	15.82%	11.80	19.50
	Drought	11.05	1.74	0.39	15.78%	8.20	14.50
Bolls plant^{-1}	Irrigated	14.47	3.63	0.81	25.06%	9.20	23.00
	Drought	10.73	4.52	1.01	42.17%	4.00	22.50
Seed cotton yield plant^{-1}	Irrigated	64.67	15.20	3.39	23.51%	35.78	94.91
	Drought	43.47	19.64	4.39	45.18%	13.17	91.20
Opened bolls plant^{-1}	Irrigated	12.66	2.91	0.65	22.95%	8.00	19.80
	Drought	9.84	3.72	0.83	37.82%	4.00	19.30
Leaf area	Irrigated	102.47	18.35	4.10	17.91%	71.89	152.22
	Drought	86.36	19.01	4.25	22.02%	49.33	117.55
Excised-leaf water loss	Irrigated	21.74	8.44	1.89	38.81%	10.12	42.82
	Drought	18.89	3.84	0.86	20.35%	13.46	27.29
Leaf relative water content	Irrigated	71.97	3.68	0.82	5.11%	65.34	79.28
	Drought	64.55	4.09	0.91	6.34%	58.56	71.70
Chlorophyll a	Irrigated	17.96	1.95	0.44	10.87%	15.57	22.02
	Drought	17.49	2.51	0.56	14.33%	11.33	22.14
Chlorophyll b	Irrigated	5.47	0.79	0.18	14.47%	4.08	7.26
	Drought	5.58	2.32	0.52	41.52%	3.49	14.56
Total chlorophyll	Irrigated	23.43	2.61	0.58	11.17%	19.65	28.73
	Drought	23.08	4.41	0.99	19.13%	14.82	36.67
Carotenoid	Irrigated	4.42	0.52	0.11	11.73%	3.60	5.27
	Drought	4.23	0.63	0.14	15.01%	2.40	5.14
Proline	Irrigated	141.02	20.31	4.54	14.40%	104.52	174.52
	Drought	185.08	23.80	5.32	12.86%	147.66	228.55

Table 9. Correlation coefficient among morpho-physiological and economic traits under water optimal (below diagonal) and deficit irrigated (above diagonal) conditions.

Traits	Plant height	Sympodial branching	Bolls plant^{-1}	Seed cotton yield plant^{-1}	Opened bolls plant^{-1}	Leaf area	Excised-leaf water loss	Leaf relative water content	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid	Proline
Plant height		0.8483***	0.8127***	0.7840***	0.7672***	0.6293**	0.4083	0.0861	0.2737	0.4821*	0.4086	0.0990	-0.6047**
Sympodial branches	-0.4150		0.8893***	0.9099***	0.8643***	0.4579*	0.5659**	0.3040	0.0326	0.2196	0.1335	0.0384	-0.3923
Bolls plant^{-1}	0.3495	0.0610		0.9600***	0.9891***	0.4169	0.6649***	0.3603	0.1048	0.3414	0.2386	-0.0310	-0.5377*
Seed cotton yield plant^{-1}	0.5779**	0.2170	0.7635***		0.9526***	0.4368	0.7170***	0.3986	0.0611	0.1787	0.1283	0.0431	-0.4159
Opened bolls plant^{-1}	0.5033*	-0.0279	0.9300***	0.8286***		0.4111	0.6467**	0.3741	0.0477	0.2685	0.1680	-0.0793	-0.5003*
Leaf area	0.4309	-0.5303*	-0.0476	-0.0946	-0.0415		0.2782	-0.1511	0.0640	0.0928	0.0853	0.1404	-0.3783
Excised-leaf water loss	-0.5463*	0.8197***	0.0789	0.1504	-0.0065	-0.6596**		0.4050	0.1123	-0.0020	0.0624	0.1628	-0.4025
Leaf relative water content	-0.4500*	0.3714	0.1927	-0.0396	0.1214	-0.4338	0.6091**		-0.1858	-0.0099	-0.1112	-0.2478	0.0730
Chlorophyll a	0.1097	-0.0650	0.0123	0.0442	0.1570	0.0899	-0.1441	-0.2008		0.6734**	0.9217***	0.7632***	-0.1918
Chlorophyll b	-0.0650	0.3262	0.1394	0.0664	0.2128	-0.0421	0.1535	0.1633	0.7816***		0.9075***	0.1668	-0.4071
Total chlorophyll	0.0619	0.0495	0.0509	0.0521	0.1811	0.0543	-0.0614	-0.0996	0.9820***	0.8852***		0.5210*	-0.3230
Carotenoid	-0.3310	0.6010**	-0.0261	0.0387	0.0458	-0.3087	0.5696**	0.4463*	0.5772***	0.7860***	0.6682**		0.1146
Proline	-0.3914	0.1367	-0.4073	-0.2978	-0.4903*	0.0866	0.0617	-0.2117	-0.0588	-0.1024	-0.0754	-0.1581	

Significant at: ***$P \leq 0.001$, **: $P \leq 0.01$, *: $P \leq 0.05$

The presented results revealed a moderately positive correlation between plant height, productivity, and the number of open bolls; also, a moderate negative correlation occurred with the excised-leaf water loss and the relative water content under optimal water irrigation (Table 9). Under water deficit conditions, a strong positive correlation of plant height appeared with the number of sympodial branches, the number of bolls per plant, the number of opened bolls, and plant productivity, while a positive correlation with leaf area and chlorophyll b, and a moderate negative correlation with proline content (Table 9). Abdel *et al.* (2012) studied 21 cotton cultivars and their 15 F_1 hybrids under two irrigation regimes (100% and 60% field capacity) and observed a meaningful correlation of physiological and morphological traits with seed cotton yield.

Under optimal water irrigation, the number of sympodial branches exhibited a moderately negative correlation with leaf area, a strong positive correlation with plant height and relative water content, and a moderate positive correlation with carotenoids. Under water deficit conditions, the sympodial branches indicated a strong association with the number of bolls, the number of open bolls, and plant productivity, but a moderate positive correlation with leaf area and the excised-leaf water loss. The excised-leaf water loss displayed a moderately positive correlation with the relative water content and carotenoids under optimal water irrigation (Table 9). The relative water content implied a moderate positive correlation with carotenoids under optimal water irrigation. Shavkiev *et al*. (2021) findings also revealed the importance of studying the correlation between various yield-related traits to improve the seed cotton yield and its fiber quality traits.

Results further revealed that the bolls per plant were in strong positive correlation with the number of opened bolls and plant productivity under optimal water irrigation, moderately positive with the relative water content, and a moderate negative correlation with proline under water deficit conditions. Plant productivity showed a strong positive correlation with plant height and the number of opened bolls under optimal water irrigation. Under water deficit conditions, plant productivity also indicated a strong positive relationship with the relative water content and leaf area. The number of opened bolls resulted in a moderately negative correlation with proline under optimal water irrigation and a moderately positive with relative water content (Table 9). Leaf areas have a fairly negative correlation with the relative water content under optimal water irrigation. Javed *et al.* (2017) also had findings showing a positive correlation between seed cotton yield with plant height, number of bolls, and boll weight.

Chlorophyll 'a' showed a positive correlation with chlorophyll 'b,' total chlorophyll, and carotenoids under different water regimes. Chlorophyll 'b' has a strong positive correlation with total chlorophyll under both irrigation conditions, while under water deficiency it has a positive correlation with carotenoids (Table 9). Total chlorophyll indicated a positive association with carotenoids under different water regimes. In the past study, 20 cotton genotypes comprising two cultivars and 18 improved lines gained assessment under water stress conditions, providing reliable correlation among the plant height, chlorophyll content, weight boll, fiber index, and fiber yield (Karademir *et al.*, 2009).

CONCLUSIONS

Based on the analysis of drought tolerance indices for morpho-physiological and yield contributing traits in cotton (*Gossypium hirsutum* L.) genotypes under different irrigation regimes, the cultivars Namangan-77, Hapicala-19, 0-30, Zangi-Ota, Saenr Pena-85, S-2025, KK-602, SAD-35-11, and C-417 proved resistant to water deficit conditions compared with other genotypes. Cotton genotypes KK-1796, KK-1795, L-1000, L-N1, C-9006, KK-1086, Catamarca-811, C-9008, L-N1, L-141, C-4769, and L-45 revealed susceptible to water stress conditions. Also, observations noted chlorophyll a and b, total chlorophyll, and carotenoid content could enhance or decline in cotton genotypes with various irrigation regimes.

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