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# Effect of normal irrigation and water stress conditions on some characteristics of cotton in Toshka region -Egypt

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ABSTRACT

Irrigation, water stress, planting dates and planting distances are crucial for obtaining desirable fiber properties for Egyptian cotton, especially under climate change. Two field experiments were carried out at the Water Studies and Research Complex (WSRC) station, National Water Research Center, Toshka, Egypt in the 2021 and 2022 growing seasons, to evaluate some morphological traits and fiber quality properties of the Egyptian cotton cultivar Giza 95 under three planting dates (january, february, and march) and 6 planting distances (10, 15, 20, 25, 30, and 35 cm among plants), comparing them with two irrigation treatments (100% A.W. and 80 % A.W.). The main effects of irrigation treatments, planting dates, and planting distances in both seasons were found to be significant ($P<0.05$ or 0.01) for most morphological and fiber quality properties under study. Also, the first-order interactions of irrigation treatments with planting dates, and planting distances have significant effects ($P<0.05$ or 0.01) on most studied traits in both seasons. In both seasons, positive effects were observed for the number of fruiting branches, plant height, and fiber fineness traits with irrigation treatment (80 % A.W.) and other fiber quality properties with irrigation treatment (100% A.W.). When compared to other planting dates in both seasons, the February planting date produced the best values for the majority of the analyzed traits, however, the January planting date produced a higher number of fruiting branches. Wider plant spacing produced the best results for fiber quality properties, whereas 10 cm spacing between plants resulted in more fruiting branches. Based on mean performances and principle component analysis, the February planting date with wider plant spacing under irrigation treatment (80% A.W) may be a better method to improve fiber quality properties in the experimental region under study. Additionally, these data will help develop plans for better agricultural practices and enhancing Egyptian cotton's fiber quality.

**Keywords**: Irrigation treatments, planting dates, planting distances, fiber quality, principal component analysis.

**INTRODUCTION:** Cotton, the world's most important crop for natural textile fiber, is also a vital local crop for Egypt's textile industry (Yehia et al., 2024). The world average for cotton harvested area, yield, and production in 2023–24 is 31.79 million (M) ha, 1.36 metric tons $ha^{-1}$, and 43.17 M metric tons; in Egypt, the values are 0.10 M ha, 0.94 metric tons' $ha^{-1}$, and 0.09 M metric tons, respectively. Drought stress is one of the most detrimental abiotic pressures on agricultural production (Geng et al. 2024). Drought stress has become a major global concern that affects cotton output due to changing climatic circumstances (Zafar et al. 2023). Fiber length, strength, and micronaire value are all negatively impacted by moisture stress; the effect is more noticeable on upper fruiting branches than on lower ones (Wang et al. 2016a).

Cotton growth and development are significantly impacted by drought stress, particularly in terms of reproductive development, fiber yield, and quality. Shrunken boll size and lower-quality fiber result from drought stress, which also interferes with the plant's ability to assimilate translocation to sink tissues, pollen function, and antioxidant defense system (Ul-Allah et al. 2021). For improved fiber yield and quality, enough water must be available at all phases of the fiber's development (Zhao et al. 2019). Thus, the main issues facing irrigated agriculture today are increasing water use efficiency and putting water conservation measures into place (Zafar et al. 2023). Cotton yields are greatly influenced by climatic conditions and agronomic practices, including plant density, sowing timing, irrigation, and fertilizer (Tuttolomondo et al. 2020). The choice of type, sowing method, date and time, plant spacing, water demand, seed treatment, and appropriate fertilizer administration are all significant factors affecting cotton growth and development. It is essential to plan improved management strategies to maximize cotton output potential (Ibrahim et al. 2022).

The date of planting is crucial since it influences growth, yield, and fiber quality (Iqbal et al. 2020). Selecting the best time to plant can help minimize damage and adverse effects of weather conditions on all plant growth phases, including vegetative and reproductive (Shafighi et al. 2021). Even if the yield components varied, earlier sowing dates produced higher yields (Tlatlaa et al. 2023). Studies on planting dates and blooming dates have documented the impact of temperature on micronaire, with later planting dates resulting in decreased micronaire (Bradow and Davidonis 2000). By reducing a crop's exposure to cool overnight circumstances during cotton's boll formation stage, early planting may reduce the likelihood of low-discounted fiber micronaire (Mauget et al. 2019).

Planting density and appropriate irrigation are the two most significant environmental elements that affect plant productivity. For cotton to have high quality and production, planting density is crucial (Ye et al. 2021). The ideal plant density is another element influencing cotton quality. Typically, growers and producers select plant density based more on custom than variety needs, which may lead to yield losses (Jalilian et al. 2023). Zhang et al. (2016) found that using high plant density under deficit irrigation can be a viable substitute for conserving water without sacrificing cotton yield in arid environments. The seed cotton production increased under deficit irrigation and high plant density because of increased plant biomass, a greater plant population, and a higher harvest index. As water accessibility decreases, fiber length, fiber strength, and fiber fineness all dynamically decrease (Rehman et al. 2021).

Plant attributes were impacted by varying planting density under situations of water deprivation (Yarnia et al. 2011). According to Ali et al. (2009), the two most crucial productivity factors are planting date and planting distance. Since planting dates can be changed to reduce the effects of drought, flowering happens when the danger of drought is seen to be low (Lu et al. 2017). In areas susceptible to drought, planting at lower densities or thinning existing plants should be taken into account as a method to improve resistance to water stress (Honda et al. 2019). An increase in Egyptian cotton output depends on planting at the right dates and distances, especially under irrigation treatments conditions in the Toshka region of Egypt. To enhance the fiber qualities of Egyptian cotton, it is crucial to understand the intricate connections between planting spacing and dates with irrigation treatments.

**OBJECTIVE:** The objective of the current study were to investigate the effects of planting dates and distances under normal and irrigation treatments on the morphological and fiber quality attributes of the Egyptian cotton cultivar Giza 95.

**MATERIAL AND METHODS:** **Study region:** A set of 2 field experiments were carried out in the 2021-22 and 2022-23 growing seasons in the Toshka of Egypt. The Toshka area, which is part of the Aswan Governorate, is situated between latitudes 22°30′ and 23°30′ N and longitudes 30°30′ and 32°00′ E. It covers a total area of 540,000 acres (216,000 ha) in the southern region of the Western Desert. Climatic data of study region as monthly minimum and maximum temperature ($^0$C), sas well as relative humidity (%) during 2021 and 2022 growing winter years, are presented in figure 1.

The Toshka area has characteristics of an arid climate (Aly et al. 2023). The highest temperature usually was found in Jule and August in both growing years. The highest relative humidity was recorded in January and December months in both growing years under study. **Experimental design and treatment details:** Egyptian cotton cultivar Giza 95 was brought from the Cotton Research Institute, Agriculture Research Center, Giza, Egypt, and was planted in the Toshka region conditions of Egypt. In both years, cottonseed was planted on three different planting dates (January

25, February 25, and March 25) with six different planting distances (10, 15, 20, 25, 30, and 35 cm) under with two irrigation treatments (100% A.W. and 80% A.W.).

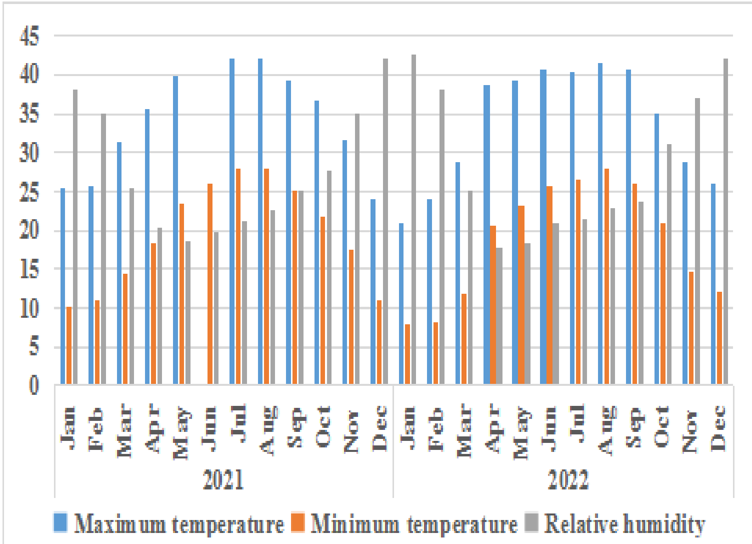


Figure 1: Climatic data at Toshka region, Egypt during the 2021 and 2022 growing years.

Each year, the experimental design was a split-split plot in a randomized complete blocks design with three replicates. Irrigation conditions including two irrigation treatments (100% A.W. and 80% A.W.) were considered as main plots, as shown in table 1.

| Seasons | Planting dates | Irrigation treatments | |
|---|---|---|---|
| | | 100% A.W. | 80% A.W. |
| 2021 | January | 4300 | 3440 |
| | February | 4464 | 3571 |
| | March | 4550 | 3640 |
| 2022 | January | 4350 | 3480 |
| | February | 4500 | 3600 |
| | March | 4610 | 3688 |

Table 1: Total amount of irrigation water ($m^3$) applied to the three planting dates during the 2021 and 2022 seasons.

Three planting dates and six planting distances were assigned to the sub-plots and sub-sub plots, respectively. Each experimental plot included five rows of 4 m long and 0.7 m width, forming a 14 $m^2$ net plot area. To reduce environmental variability as much as possible, all suggested cultural practices for cotton production in the area were followed, including sowing the cottonseed in the same day and maintaining similar field conditions. The guarded plants in each plot from the middle rows were harvested to find the cotton yield and other traits under study in the field and laboratory after the boundary effects were eliminated.

**Irrigation water applied (IWA):** The daily reference evapotranspiration ($ET_o$) values were estimated based on FAO Penman-Monteith method using the latest five-year average of weather data from the meteorological station at Toshka region, where our experiment was conducted (Allen et al. 1998) equation.

$$ET_c = ET_o x K_c$$

where, $ET_o$ and $K_c$, are the reference evapotranspiration (mm $d^{-1}$) and crop coefficient value, respectively, which differs from one growth stage to another. The $K_c$ values for cotton were considered 0.45 for initial (0–25 DAP), 0.75 for developmental stage (26–70 DAP), 1.15 for boll development (71–120 DAP), and 0.7 for maturity stage (121 DAP to harvesting time). The amount of IWA per experimental plot during the irrigation regime was computed ( Allen et al. 1998) equation

$$IWA(m^2) = \frac{ET_c x A x I_i}{Ea x 1000 x (1 - LR)}$$

where $ET_c$, A, $I_i$, Ea, and LR, respectively, are the crop water requirements (mm $d^{-1}$), experimental plot area ($m^2$), irrigation intervals (d), efficiency of irrigation system, which was considered 0.6, and leaching water requirements. Using one PVC (polyvinyl chloride) pipe (50 mm diameter × 1 m length) for each plot, the IWA was transferred to cover the whole plot surface area. The irrigation water quota transferring across each PVC pipe for each plot was calculated (Israelsen and Hansen 1962).

$$Q = \frac{CA\sqrt{2gh}}{1000}$$

where Q, C, A, g, and h, are the irrigation water discharge (l $s^{-1}$), discharge coefficient, PVC pipe's cross section area ($cm^2$), gravity acceleration (cm $s^{-2}$), effective head of water (cm) over the center of piper making flow free, respectively. A guard border of 2 m width between the adjacent experimental plots was in each replication to avoid the border effects. Likewise, another one with 5 m width as a separator under two irrigation treatments (100% A.W. and 75% A.W.) was maintained to avoid water infiltration from one to another treatment.

**Studied traits:** Data were recorded for the studied traits including the number of fruiting branches (NFB); plant height (PH, cm); fiber fineness (FF) micronaire reading; fiber strength (FS, gm/tex); upper half mean length (UHML, mm) and uniformity ratio % (UR%). All fiber properties were measured in the laboratory of the Cotton Technology Research Department, Cotton Research Institute at Giza.

**Statistical approaches:** The measured data were subjected to a three-way ANOVA test and the coefficient of variation (CV%) to determine the significant differences in the effect of experimental factors and their interactions according to the method of Steel and Torrie (1980). The CV% estimates were categorized as very high (CV≥21%), high (15.0%≤CV≤21.0%), moderate (10%<CV≤15%) and low (CV<10%) according to Gomes (2009).

Pearson's correlation coefficient and principal component analysis (PCA) were applied for a better understanding of the relationship among studied traits across experimental factors. The ANOVA, Pearson's correlation coefficient and PCA were performed using the computer software programs SPSS version 20, PAST version 4.03 and Origin Pro 2021 version b 9.5.0.193, respectively.

**RESULTS AND DISCUSSIONS: Analysis of variance (ANOVA):** The ANOVA exhibited that studied traits were significantly ($p < 0.05$ or 0.01) affected by the main effect of irrigation treatments (I) across the two growing seasons, except for the number of fruiting branches and fiber strength in both and 2022 seasons, respectively (table 2). While most studied traits were significantly ($p < 0.05$ or 0.01) affected by the main effects of planting dates (D3), and planting distances (D6) across the two growing seasons, except fiber fineness in the 2021-22 (D3) and 2022-23 (D6) seasons, and upper half mean length in the 2021 season (D6). As for the first-order interactions, morphological and fiber traits were significantly ($p < 0.05$ or 0.01) affected by I x D3 and I x D6 interactions, except plant height in 2022-23 and fiber strength in both seasons (I x D3), as well as the number of fruiting branches and fiber strength in 2022-23 (I x D6). Only the number of fruiting branches was highly significantly affected by D3 x D6 interaction in 2021-22. About the second-order interaction, all studied traits were not significantly affected by the interaction of I x D3 x D3 in both growing seasons. The low coefficient of variation (CV%) was observed for all cotton traits evaluated under 3 investigated factors, except the number of fruiting branches in 2021-22 and 2022-23 with values of 10.55% (moderate) and 17.32% (high), respectively.

| S.O.V | NFB | | PH | | FF | | FS | | UHML | | UR% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| I | 0.55$^{ns}$ | 0.12$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.92$^{ns}$ | 0.03$^{*}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ |
| D3 | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.80$^{ns}$ | 0.04$^{*}$ | 0.00$^{**}$ | 0.01$^{*}$ | 0.06$^{*}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ |
| D6 | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.19$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.12$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ |
| IxD3 | 0.00$^{**}$ | 0.00$^{**}$ | 0.03$^{*}$ | 0.47$^{ns}$ | 0.01$^{*}$ | 0.00$^{**}$ | 0.99$^{ns}$ | 0.54$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ |
| IxD6 | 0.01* | 0.67$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.35$^{ns}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ | 0.00$^{**}$ |
| D3xD6 | 0.09$^{*}$ | 0.99$^{ns}$ | 0.32$^{ns}$ | 0.69$^{ns}$ | 0.77$^{ns}$ | 0.92$^{ns}$ | 1.00$^{ns}$ | 0.79$^{ns}$ | 1.00$^{ns}$ | 1.00$^{ns}$ | 0.97$^{ns}$ | 0.83$^{ns}$ |
| IxD3xD6 | 0.14$^{ns}$ | 0.75$^{ns}$ | 0.44$^{ns}$ | 0.57$^{ns}$ | 0.78$^{ns}$ | 0.92$^{ns}$ | 1.00$^{ns}$ | 0.73$^{ns}$ | 1.00$^{ns}$ | 1.00$^{ns}$ | 0.97$^{ns}$ | 0.83$^{ns}$ |
| C.V.% | 10.55 | 17.32 | 4.66 | 2.59 | 1.52 | 0.93 | 6.75 | 9.22 | 3.25 | 2.33 | 0.76 | 0.65 |

Table 2: Analysis of variance for morphological and fiber traits under irrigation treatments (I), planting dates (D3), and planting distances (D6) at 2021 and 2022 growing seasons.

Statistically significant differences at $^*p \leq 0.05$ and $^{**}p \leq 0.01$; ns: indicate the non-significant difference. NFB: number of fruiting branches; PH: plant height (cm); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

**Experimental factors effects on morphological and fiber traits:** Average irrigation treatments, planting dates, and planting distances for morphological and fiber traits across 2021-22 and 2022-23 (table 3). Irrigation treatments, planting dates, and planting distances significantly affected most studied traits in 2021-22 and 2022-23 g. Cotton plant height was significantly higher in irrigation treatment (80% A.W.) than in irrigation treatment (100% A.W.) in both seasons, while the opposite is true for all cotton fiber quality traits in both seasons. For planting dates in both seasons, the fiber quality traits and the number of fruiting branches increased and decreased significantly at the February planting date, respectively, and plant height increased at the March planting date. Across the planting distances, the number of fruiting branches under 10 cm spacing as well as plant height and fiber quality traits under 35 cm spacing were significantly higher than across other studied plant spacing in both seasons. Generally, the February planting date with wide plant spacing under irrigation treatment (100% A.W.) produced the best fiber quality traits.

| Factors | | NFB | | PH | | FF | | FS | | UHML | | UR% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 | 2021 | 2022 |
| Irrigation treatments | | | | | | | | | | | | | |
| 100% A.W. | | 13.32 | 11.87 | 82.96 | 89.50 | 4.49 | 4.69 | 10.89 | 10.64 | 30.43 | 31.49 | 83.17 | 83.17 |
| 80% A.W. | | 13.48 | 12.51 | 93.04 | 97.38 | 4.30 | 4.38 | 9.99 | 10.65 | 30.01 | 30.50 | 82.48 | 82.42 |
| LSD | 0.05 | NS | NS | 1.57 | 0.93 | 0.03 | 0.02 | 0.27 | NS | 0.38 | 0.28 | 0.24 | 0.21 |
| at | 0.01 | NS | NS | 2.09 | 1.23 | 0.04 | 0.03 | 0.36 | NS | NS | 0.37 | 0.32 | 0.28 |
| Planting Dates | | | | | | | | | | | | | |
| January | | 15.70 | 13.99 | 85.01 | 89.11 | 4.39 | 4.54 | 10.40 | 10.75 | 30.14 | 30.75 | 82.53 | 82.69 |
| February | | 11.81 | 11.24 | 88.69 | 94.26 | 4.40 | 4.55 | 10.83 | 10.94 | 30.53 | 31.33 | 83.10 | 83.10 |
| March | | 12.67 | 11.35 | 90.30 | 96.96 | 4.40 | 4.53 | 10.09 | 10.25 | 30.00 | 30.90 | 82.85 | 82.58 |
| LSD | 0.05 | 0.66 | 0.99 | 1.93 | 1.14 | 0.04 | 0.02 | 0.33 | 0.46 | 0.46 | 0.34 | 0.30 | 0.25 |
| at | 0.01 | 0.88 | 1.32 | 2.56 | 1.51 | 0.05 | NS | 0.44 | NS | NS | 0.45 | 0.39 | 0.34 |
| Planting Distances | | | | | | | | | | | | | |
| 10 cm | | 15.76 | 14.75 | 80.33 | 83.46 | 4.45 | 4.54 | 10.18 | 10.56 | 30.52 | 30.33 | 82.58 | 81.95 |
| 15 cm | | 14.48 | 13.24 | 86.27 | 89.37 | 4.45 | 4.53 | 9.61 | 9.62 | 29.93 | 30.50 | 81.98 | 82.33 |
| 20 cm | | 13.41 | 12.07 | 85.67 | 90.07 | 4.41 | 4.54 | 9.88 | 10.30 | 30.04 | 30.93 | 82.61 | 82.39 |
| 25 cm | | 12.71 | 11.61 | 92.03 | 88.25 | 4.35 | 4.53 | 10.96 | 10.97 | 30.11 | 31.12 | 83.00 | 83.16 |
| 30 cm | | 12.36 | 10.93 | 86.76 | 101.57 | 4.35 | 4.56 | 10.99 | 11.11 | 30.02 | 31.02 | 83.17 | 82.97 |
| 35 cm | | 11.64 | 10.57 | 96.95 | 107.94 | 4.37 | 4.53 | 11.01 | 11.31 | 30.71 | 32.06 | 83.61 | 83.95 |
| LSD | 0.05 | 0.94 | 1.40 | 2.72 | 1.61 | 0.04 | NS | 0.47 | 0.65 | NS | 0.48 | 0.42 | 0.36 |
| at | 0.01 | 1.25 | 1.86 | 3.62 | 2.14 | 0.06 | NS | 0.62 | 0.87 | NS | 0.64 | 0.56 | 0.48 |

Table 3: Average morphological and fiber traits at irrigation treatments, planting dates, and planting distances across 2021 and 2022 growing seasons.

**The first-order interactions effect on morphological and fiber traits:** Compared with irrigation treatment (80% A.W), the number of fruiting branches, fiber fineness, fiber strength, upper half mean length, and uniformity ratio % were recorded the highest values at the three planting dates under irrigation treatment (100% A.W). While the opposite is true for plant height. The highest average number of fruiting branches on the January planting date, as well as fiber strength, upper half mean length, and uniformity ratio on the February planting date were obtained under irrigation treatment (100% A.W) in both seasons (table 4). The highest and lowest values of plant height and fiber fineness in March and January planting dates were observed under irrigation treatment (80% A.W) in both seasons, respectively. During irrigation treatment (80% A.W), the best performance of the Egyptian cotton variety Giza 95 for all studied traits were found by January and February planting dates in both seasons.

| Irrigation | Planting Dates | NFB | | PH | | FF | | FS | | UHML | | UR% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Y1 | Y2 | Y1 | Y2 | Y1 | Y2 | Y1 | Y2 | Y1 | Y2 | Y1 | Y2 |
| 100%A.W | January | 17.04 | 15.50 | 78.67 | 84.92 | 4.52 | 4.72 | 10.84 | 10.60 | 29.83 | 30.87 | 82.48 | 83.16 |
| | February | 11.26 | 9.83 | 83.60 | 90.18 | 4.49 | 4.69 | 11.29 | 11.04 | 31.06 | 32.13 | 83.72 | 83.18 |
| | March | 11.65 | 10.30 | 86.61 | 93.42 | 4.48 | 4.68 | 10.53 | 10.27 | 30.41 | 31.47 | 82.48 | 83.16 |
| 80 % A.W | January | 14.36 | 12.48 | 91.35 | 93.31 | 4.26 | 4.36 | 9.96 | 10.90 | 30.44 | 30.64 | 82.56 | 83.03 |
| | February | 12.37 | 12.88 | 93.78 | 98.35 | 4.31 | 4.42 | 10.36 | 10.83 | 30.00 | 30.53 | 82.49 | 82.22 |
| | March | 13.70 | 12.18 | 93.99 | 100.49 | 4.32 | 4.38 | 9.64 | 10.23 | 29.58 | 30.34 | 83.23 | 82.00 |
| LSD | 0.05 | 0.94 | 1.40 | 2.72 | NS | 0.04 | 0.03 | NS | NS | 0.65 | 0.48 | 0.42 | 0.36 |
| at | 0.01 | 1.25 | 1.86 | NS | NS | 0.06 | 0.04 | NS | NS | 0.87 | 0.64 | 0.56 | 0.48 |

Table 4: Average morphological and fiber traits at irrigation conditions and planting dates across 2021 and 2022 growing seasons.

Averages irrigation treatments and planting distances interaction significantly affected most studied traits in both seasons (table 5). Compared with other interactions of irrigation treatments and planting distances, the number of fruiting branches with 10 cm spacing, plant height, fiber fineness, and uniformity ratio traits with 35 cm spacing were recorded as the best values under drought stress conditions in both seasons. While fiber strength and upper half mean length traits exhibited the highest values with 10 cm and 35 cm distances in 2021-22 and 2022-23 sunder irrigation treatment (100% A.W), respectively. At high plant density under drought irrigation treatment (80% A.W) in both seasons, the best performances of the Egyptian cotton variety Giza 95 were observed for all studied traits except a number of fruiting branches, which recorded the highest values with low plant density (10 cm).

Average morphological and fiber traits were not significantly affected by planting dates and planting distance interaction in both seasons (table 6). In both seasons, the January and February planting dates with all planting distances were recorded as the best morphological and fiber quality traits, respectively. The January planting date produced the largest number of fruiting branches and the shortest plant height with a spacing of 10 cm in both seasons. On the other hand, the February planting date produced the best fiber quality traits with a spacing of 35 cm in both seasons. Diverse tendencies were seen in all of the first-order interactions, but statistical analysis revealed that, for the February planting date in both seasons, the broadest plant spacing produced the best values of cotton fiber traits under irrigation conditions. While morphological traits under study showed the opposite tendency.

**The second-order interactions effect on cotton traits:** All studied traits were not significantly influenced by interaction among irrigation treatments, planting dates, and planting density in both seasons; their averages are given in table 7. In both seasons and all planting distances, the number of fruiting branches in irrigation treatment (100% A.W.) was higher than in irrigation treatment (80% A.W.) at the January planting date, and the opposite is true at other planting dates. At all planting dates and distances, there was more plant height under 80% A.W. than under 100% A.W. in the 2022 season. During all planting dates and distances in both seasons, fiber fineness in drought-stress conditions was lower than in normal irrigation conditions. On the other hand, other studied traits do not have a fixed direction through the second-order interaction effect. Generally, from the results of the effect of experimental factors as well as the first and second-order interactions, the narrowest and widest plant spacing of the variety Giza 95 produced the best morphological and fiber quality traits at the January and February planting dates, respectively.

**Principal component analysis (PCA):** PCA analysis was carried out (figure 2) to comprehend the relationships among irrigation treatments, planting dates, and planting distances that led to variations for the examined traits over both seasons. Among PCs, the extracted eigenvalues of the first two principal components analysis (PCA1 and PCA2) were higher than unity with values of 3.18 and 1.75 in 2021-22 and 3.76 and 1.26 in 2022-23 eigenvalue >1, respectively.

| Irrigation | Planting Distances | NFB 2021 | NFB 2022 | PH 2021 | PH 2022 | FF 2021 | FF 2022 | FS 2021 | FS 2022 | UHML 2021 | UHML 2022 | UR% 2021 | UR% 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100% A.W | 10 cm | 14.98 | 14.29 | 88.02 | 80.69 | 4.53 | 4.53 | 11.54 | 10.53 | 31.93 | 31.73 | 83.64 | 83.19 |
| | 15 cm | 14.66 | 12.41 | 89.59 | 85.93 | 4.43 | 4.58 | 10.59 | 9.58 | 30.20 | 30.96 | 81.89 | 83.14 |
| | 20 cm | 12.72 | 11.59 | 79.12 | 85.40 | 4.53 | 4.68 | 10.33 | 9.83 | 30.35 | 31.22 | 82.99 | 82.74 |
| | 25 cm | 12.56 | 11.38 | 88.02 | 78.59 | 4.43 | 4.73 | 10.84 | 11.14 | 30.04 | 31.42 | 82.14 | 83.49 |
| | 30 cm | 12.48 | 10.63 | 72.31 | 101.11 | 4.48 | 4.83 | 11.14 | 11.29 | 29.53 | 31.22 | 82.09 | 82.59 |
| | 35 cm | 12.50 | 10.95 | 80.69 | 105.30 | 4.58 | 4.83 | 10.89 | 11.44 | 30.55 | 32.39 | 82.14 | 83.84 |
| 80%A.W | 10 cm | 16.54 | 15.21 | 72.64 | 86.24 | 4.37 | 4.55 | 8.82 | 10.59 | 29.10 | 28.93 | 81.53 | 80.71 |
| | 15 cm | 14.31 | 14.06 | 82.94 | 92.82 | 4.47 | 4.49 | 8.62 | 9.66 | 29.67 | 30.04 | 82.06 | 81.51 |
| | 20 cm | 14.11 | 12.55 | 92.22 | 94.73 | 4.29 | 4.40 | 9.42 | 10.77 | 29.73 | 30.65 | 82.24 | 82.03 |
| | 25 cm | 12.87 | 11.83 | 96.04 | 97.90 | 4.26 | 4.34 | 11.09 | 10.79 | 30.17 | 30.82 | 83.86 | 82.82 |
| | 30 cm | 12.25 | 11.24 | 101.21 | 102.03 | 4.22 | 4.30 | 10.84 | 10.92 | 30.51 | 30.83 | 84.25 | 83.35 |
| | 35 cm | 10.79 | 10.19 | 113.21 | 110.58 | 4.15 | 4.23 | 11.14 | 11.19 | 30.86 | 31.73 | 85.09 | 84.06 |
| LSD | 0.05 | 1.33 | NS | 3.85 | 2.28 | 0.06 | 0.04 | 0.66 | NS | 0.92 | 0.68 | 0.59 | 0.51 |
| at | 0.01 | 1.76 | NS | 5.12 | 3.02 | 0.08 | 0.05 | 0.88 | NS | 1.23 | 0.90 | 0.79 | 0.68 |

Table 5: Average morphological and fiber traits at irrigation treatments and planting distances across 2021 and 2022 growing seasons.

| Planting Dates | Planting Distances | NFB 2021 | NFB 2022 | PH 2021 | PH 2022 | FF 2021 | FF 2022 | FS 2021 | FS 2022 | UHML 2021 | UHML 2022 | UR% 2021 | UR% 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 10 cm | 18.85 | 16.15 | 77.00 | 79.75 | 4.42 | 4.54 | 10.15 | 10.63 | 30.50 | 30.19 | 82.47 | 82.45 |
| | 15 cm | 17.80 | 15.61 | 81.75 | 85.25 | 4.44 | 4.52 | 9.55 | 10.05 | 29.80 | 30.39 | 81.67 | 82.68 |
| | 20 cm | 16.09 | 14.05 | 83.17 | 85.38 | 4.39 | 4.54 | 9.85 | 10.30 | 29.97 | 30.65 | 82.09 | 82.60 |
| | 25 cm | 14.50 | 13.53 | 88.82 | 83.53 | 4.33 | 4.53 | 10.93 | 11.05 | 29.92 | 30.77 | 82.74 | 83.60 |
| | 30 cm | 14.23 | 12.64 | 83.96 | 96.92 | 4.37 | 4.57 | 10.95 | 11.19 | 30.01 | 30.79 | 82.83 | 83.24 |
| | 35 cm | 12.75 | 11.98 | 95.35 | 103.85 | 4.39 | 4.52 | 10.98 | 11.29 | 30.62 | 31.73 | 83.35 | 84.05 |
| February | 10 cm | 14.07 | 14.31 | 78.76 | 82.85 | 4.48 | 4.54 | 10.57 | 10.69 | 30.89 | 30.52 | 82.67 | 81.65 |
| | 15 cm | 12.32 | 12.17 | 86.60 | 90.53 | 4.47 | 4.55 | 9.93 | 10.31 | 30.37 | 30.84 | 82.28 | 82.20 |
| | 20 cm | 11.63 | 11.33 | 87.14 | 91.82 | 4.42 | 4.57 | 10.25 | 10.55 | 30.29 | 31.28 | 82.91 | 82.29 |
| | 25 cm | 11.48 | 10.22 | 92.69 | 89.88 | 4.34 | 4.55 | 11.38 | 11.20 | 30.42 | 31.44 | 83.37 | 82.97 |
| | 30 cm | 11.00 | 10.25 | 87.92 | 102.57 | 4.34 | 4.58 | 11.41 | 11.33 | 30.28 | 31.45 | 83.56 | 82.85 |
| | 35 cm | 10.39 | 9.82 | 99.03 | 107.92 | 4.35 | 4.53 | 11.43 | 11.52 | 30.92 | 32.46 | 83.82 | 84.16 |
| March | 10 cm | 14.36 | 13.79 | 85.23 | 87.79 | 4.46 | 4.54 | 9.83 | 10.36 | 30.16 | 30.29 | 82.61 | 81.76 |
| | 15 cm | 13.33 | 11.93 | 90.45 | 92.35 | 4.44 | 4.52 | 9.33 | 8.49 | 29.64 | 30.27 | 81.99 | 82.11 |
| | 20 cm | 12.52 | 10.82 | 86.70 | 93.00 | 4.41 | 4.51 | 9.54 | 10.05 | 29.86 | 30.88 | 82.84 | 82.27 |
| | 25 cm | 12.16 | 11.07 | 94.58 | 91.33 | 4.37 | 4.52 | 10.58 | 10.64 | 29.97 | 31.15 | 82.89 | 82.90 |
| | 30 cm | 11.85 | 9.92 | 88.39 | 105.23 | 4.34 | 4.54 | 10.61 | 10.80 | 29.77 | 30.83 | 83.13 | 82.82 |
| | 35 cm | 11.79 | 9.90 | 96.46 | 112.04 | 4.37 | 4.53 | 10.63 | 11.14 | 30.57 | 32.00 | 83.67 | 83.64 |
| LSD | 0.05 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| at | 0.01 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

Table 6. Average morphological and fiber traits at planting dates and planting distances across 2021 and 2022 growing seasons.

The PCA1 and PCA2 explained 82.12% and 83.64% of the total

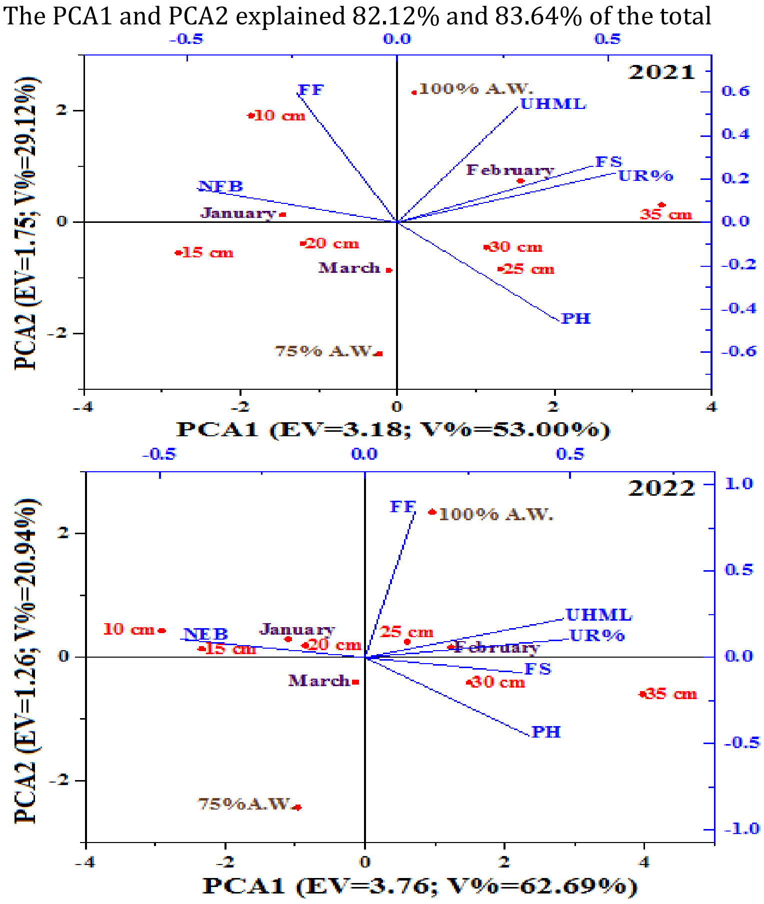


Figure 2. Relationships among the studied traits and treatments (irrigation conditions, planting dates and planting distances) across the 2021 and 2022. EV: eigenvalues; V%: variance %.

variations among studied variables in the 2021 and 2022 seasons, respectively. In the growth seasons of 2021 and 2022, the PCA1 and PCA2 contributed 53.00% and 62.69% of the total variations under study, respectively. Whilst, about 29.12% and 20.94 of the total variability of the measured data under investigation is explained by PCA2 in the 2021 and 2022 growing seasons. The results of the PCA1 and PCA2 can be used to explain the overall variance and PCAs collection, as well as to give an overview of the original variables in any further data analysis.

The angles between NFB and FF in the 2021 season, FF and UR% in the 2022 season, FF and UHML, and PH, FS, UHML, and UR% in both seasons were all less than 90° (sharp angles), indicating a positive association between these traits. Compared to the 2021 season, these positive associations were stronger in the 2022 season. Conversely, there is a negative association between the traits under examination when the obtuse angles (more than 90°). For example, the number of fruiting branches is negatively associated with most and all studied traits in the 2021 and 2022 seasons, respectively. Except for fiber fineness in the 2021 season and the number of fruiting branches in both seasons, PCA1 had a positive connection with all examined characteristics. These findings suggested that PCA1 was influenced by the positive variables of fiber quality properties under treatments under study. As for PCA2, all traits studied have the largest positive loadings, except FS in the 2022 season and PH in both seasons under experimental conditions.

Different patterns were observed during the two growing seasons in the relationships between irrigation treatments, planting dates, and planting distances with all examined variables (Figure 2). February planting date with planting distances of 25, 30, and 35 cm under 100% A.W. contributed to a great proportion of the total variation for PH, FS, UHML, and UR% in both seasons, which were related to PCA1 in the first and fourth quarters. While, the overall variation for NFB and FF was largely attributed to the January planting date with a distancing of 10 cm in the 2021 season and with a distancing of 10, 15, and 20 cm in the 2022 season under 100% A.W. These variables were associated with PCA2 in the second quarter. In both seasons, the March planting date and 80% A.W. were the main factors, that related to PCA2 in the third quarter. In both growing seasons, the February planting date with 35 cm spacing under 100% A.W. was located near the most cotton quality traits.

| Planting Dates | Planting Distances | NFB | | | | PH | | | | FF | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2021 | | 2022 | | 2021 | | 2022 | | 2021 | | 2022 | |
| | | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% |
| January | 10 cm | 19.80 | 17.90 | 19.10 | 13.20 | 83.50 | 70.50 | 76.50 | 83.00 | 4.55 | 4.28 | 4.55 | 4.53 |
| | 15 cm | 20.00 | 15.60 | 16.40 | 14.81 | 85.00 | 78.50 | 81.50 | 89.00 | 4.45 | 4.43 | 4.60 | 4.44 |
| | 20 cm | 17.50 | 14.67 | 14.93 | 13.17 | 75.00 | 91.33 | 81.00 | 89.75 | 4.55 | 4.23 | 4.70 | 4.38 |
| | 25 cm | 15.66 | 13.33 | 14.77 | 12.28 | 83.50 | 94.13 | 74.50 | 92.55 | 4.45 | 4.22 | 4.75 | 4.30 |
| | 30 cm | 15.80 | 12.67 | 14.17 | 11.10 | 68.50 | 99.43 | 96.00 | 97.84 | 4.50 | 4.24 | 4.85 | 4.28 |
| | 35 cm | 13.50 | 12.00 | 13.62 | 10.33 | 76.50 | 114.20 | 100.00 | 107.71 | 4.60 | 4.17 | 4.85 | 4.20 |
| February | 10 cm | 12.50 | 15.63 | 11.80 | 16.82 | 88.68 | 68.85 | 81.32 | 84.39 | 4.52 | 4.44 | 4.52 | 4.56 |
| | 15 cm | 11.90 | 12.74 | 10.33 | 14.00 | 90.26 | 82.94 | 86.58 | 94.47 | 4.42 | 4.52 | 4.57 | 4.54 |
| | 20 cm | 10.20 | 13.05 | 9.72 | 12.95 | 79.74 | 94.54 | 86.05 | 97.59 | 4.52 | 4.32 | 4.67 | 4.47 |
| | 25 cm | 10.90 | 12.07 | 9.17 | 11.27 | 88.68 | 96.69 | 79.21 | 100.54 | 4.42 | 4.25 | 4.72 | 4.37 |
| | 30 cm | 10.70 | 11.30 | 8.70 | 11.80 | 72.89 | 102.95 | 101.84 | 103.30 | 4.47 | 4.21 | 4.82 | 4.33 |
| | 35 cm | 11.33 | 9.44 | 9.23 | 10.41 | 81.32 | 116.74 | 106.05 | 109.80 | 4.57 | 4.12 | 4.82 | 4.25 |
| March | 10 cm | 12.64 | 16.09 | 11.98 | 15.61 | 91.88 | 78.58 | 84.25 | 91.33 | 4.51 | 4.40 | 4.51 | 4.57 |
| | 15 cm | 12.07 | 14.59 | 10.49 | 13.37 | 93.51 | 87.38 | 89.70 | 95.00 | 4.41 | 4.47 | 4.56 | 4.48 |
| | 20 cm | 10.45 | 14.59 | 10.12 | 11.51 | 82.61 | 90.79 | 89.15 | 96.85 | 4.51 | 4.31 | 4.66 | 4.36 |
| | 25 cm | 11.12 | 13.21 | 10.20 | 11.95 | 91.88 | 97.28 | 82.07 | 100.60 | 4.41 | 4.32 | 4.71 | 4.33 |
| | 30 cm | 10.93 | 12.78 | 9.02 | 10.81 | 75.53 | 101.24 | 105.50 | 104.96 | 4.46 | 4.22 | 4.81 | 4.28 |
| | 35 cm | 12.67 | 10.92 | 9.98 | 9.82 | 84.25 | 108.68 | 109.86 | 114.23 | 4.56 | 4.17 | 4.81 | 4.24 |
| LSD | 0.05 | NS | | NS | | NS | | NS | | NS | | NS | |
| at | 0.01 | NS | | NS | | NS | | NS | | NS | | NS | |

| Planting Dates | Planting Distances | FS | | | | UHML | | | | UR% | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2021 | | 2022 | | 2021 | | 2022 | | 2021 | | 2022 | |
| | | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% | 100% | 80% |
| January | 10 cm | 11.50 | 8.80 | 10.50 | 10.75 | 31.30 | 29.70 | 31.10 | 29.27 | 83.65 | 81.29 | 83.20 | 81.69 |
| | 15 cm | 10.50 | 8.60 | 9.55 | 10.54 | 29.60 | 29.99 | 30.35 | 30.43 | 81.90 | 81.44 | 83.15 | 82.20 |
| | 20 cm | 10.30 | 9.40 | 9.80 | 10.80 | 29.75 | 30.19 | 30.60 | 30.69 | 83.00 | 81.19 | 82.75 | 82.45 |
| | 25 cm | 10.80 | 11.05 | 11.10 | 11.00 | 29.45 | 30.40 | 30.80 | 30.74 | 82.15 | 83.34 | 83.50 | 83.69 |
| | 30 cm | 11.10 | 10.80 | 11.25 | 11.12 | 28.95 | 31.08 | 30.60 | 30.98 | 82.10 | 83.56 | 82.60 | 83.87 |
| | 35 cm | 10.85 | 11.10 | 11.40 | 11.17 | 29.95 | 31.30 | 31.75 | 31.71 | 82.15 | 84.55 | 83.85 | 84.26 |
| February | 10 cm | 11.99 | 9.14 | 10.93 | 10.45 | 32.59 | 29.20 | 32.38 | 28.67 | 83.64 | 81.71 | 83.19 | 80.11 |
| | 15 cm | 10.93 | 8.93 | 9.93 | 10.70 | 30.82 | 29.92 | 31.60 | 30.09 | 81.89 | 82.67 | 83.14 | 81.26 |
| | 20 cm | 10.72 | 9.78 | 10.20 | 10.90 | 30.97 | 29.61 | 31.86 | 30.70 | 82.99 | 82.84 | 82.74 | 81.84 |
| | 25 cm | 11.25 | 11.51 | 11.57 | 10.84 | 30.66 | 30.18 | 32.07 | 30.82 | 82.14 | 84.60 | 83.49 | 82.46 |
| | 30 cm | 11.57 | 11.25 | 11.72 | 10.94 | 30.14 | 30.43 | 31.86 | 31.05 | 82.09 | 85.03 | 82.59 | 83.12 |
| | 35 cm | 11.30 | 11.57 | 11.88 | 11.15 | 31.18 | 30.67 | 33.05 | 31.87 | 82.14 | 85.50 | 83.84 | 84.49 |
| March | 10 cm | 11.14 | 8.51 | 10.17 | 10.56 | 31.91 | 28.41 | 31.70 | 28.87 | 83.64 | 81.59 | 83.19 | 80.33 |
| | 15 cm | 10.35 | 8.32 | 9.24 | 7.75 | 30.17 | 29.10 | 30.94 | 29.59 | 81.89 | 82.08 | 83.14 | 81.08 |
| | 20 cm | 9.97 | 9.10 | 9.49 | 10.62 | 30.33 | 29.40 | 31.19 | 30.56 | 82.99 | 82.69 | 82.74 | 81.81 |
| | 25 cm | 10.46 | 10.70 | 10.75 | 10.53 | 30.02 | 29.92 | 31.40 | 30.91 | 82.14 | 83.65 | 83.49 | 82.31 |
| | 30 cm | 10.75 | 10.46 | 10.90 | 10.70 | 29.51 | 30.03 | 31.19 | 30.47 | 82.09 | 84.17 | 82.59 | 83.05 |
| | 35 cm | 10.51 | 10.75 | 11.05 | 11.23 | 30.53 | 30.62 | 32.37 | 31.62 | 82.14 | 85.21 | 83.84 | 83.44 |
| LSD | 0.05 | NS | | NS | | NS | | NS | | NS | | NS | |
| at | 0.01 | NS | | NS | | NS | | NS | | NS | | NS | |

Table 7: Average morphological and fiber traits at irrigation treatments (100% A.W and 75% A.W), planting dates, and planting distances across 2021 and 2022 growing seasons.

**DISCUSSION:** The molecular-level water balance in plants is upset by drought stress, and extreme water shortage in cotton plants can be lethal (Wang *et al.* 2024). When cotton is subjected to prolonged drought stress, it can withstand drought better than other field crops, although unfavorable outcomes such as a reduction in fiber quality can happen (Parida *et al.* 2007). To evaluate the morphological and fiber quality traits of the Egyptian cotton variety Giza 95 under sand soil conditions in Toshka region of Egypt, the roles of the factors that were investigated, including 2 irrigation treatments (100% A.W. and 80% A.W.), 3 planting dates, and 6 planting distances, as well as their interactions, during 2021-22 and 2022-23. The irrigation treatments, planting dates, and planting distances all had a significant impact ($P < 0.05$ or $0.01$) on morphological and fiber quality traits under investigation in both growth seasons, based on p-value results of the three-way ANOVA. These findings imply that there may be variability among investigated experimental treatments, which implies that it may be possible to improve the qualities of cotton fiber under sand soil conditions in Toshka region of Egypt, especially under drought stress conditions. The fiber quality traits were significantly affected by drought stress conditions (Zafar *et al.* 2023). Dates of sowing significantly affected fiber quality properties (Qamar *et al.* 2016). In tested seasons, early planting had a substantial impact on the qualities of fiber quality (Yehia 2022). Cotton fiber quality properties were significantly impacted by planting density (Khan *et al.* 2019). Fiber quality properties are affected by many interrelated elements, including crop management, irrigation, planting treatments, climate during the growing season, and cultivar selection (Pinnamaneni *et al.* 2021).

Regarding the interactions among the experimental components, numerous noteworthy trends emerged, the foremost being the significant influence of irrigation conditions in conjunction with planting dates and planting distances on all the traits examined in both growing seasons. These results indicated that the combined impacts of the weather, planting dates, and planting distances under irrigation conditions are what led to the significant changes in morphological and fiber quality attributes of the Giza 95 variety under examination. Strength, UHML, and micronaire were all significantly impacted by planting geometry and irrigation, with micronaire being the only variable where these effects were statistically significant (Ibrahim *et al* 2022). According to Awan *et al.* (2011), the interaction of sowing timings and plant spacing was significant for fiber strength but not significant for plant height, fiber fineness, staple length, and uniformity index traits.

The Giza 95 variety produced the best values for NFB and FF traits under 80% A.W. and for other studied traits under 100% A.W. in both seasons. According to Zafar et al. (2023), the combined stress had a greater detrimental effect on cotton fiber quality than did the individual strains. There was a steady loss in fiber length and strength as water supply decreased, while, there was no discernible impact of drought on micronaire (Wang *et al.* 2016b). Where low assimilate translocation towards reproductive tissues in drought-

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stressed cotton plants results in lower-quality fiber (Ul-Allah et al. 2021). It is possible to maintain high fiber quality in low-water situations or lessen the impact of low water on quality, according to genotypes that respond differently to drought (Ulloa *et al.* 2020). The planting date is very important since it affects fiber quality properties (Iqbal et al. 2020). Also, the Giza 95 variety performed best on the February planting date for most evaluated traits in both seasons. Our results were confirmed by Zhang et al. (2017), who reported that the middle planting date was superior to the other planting dates for every variable evaluated. While shorter and weaker fibers were identified at the earliest planting date in 2021, no significant changes in fiber length and strength were observed among planting dates in 2019-20 and 2020-21 (Guo et al. 2023). The date of planting has a major impact on the expansion of cotton leaves, internode elongation, generation of dry matter, and the distribution of assimilates among various plant sections, which ultimately influences yield and fiber quality (Dai and Dong 2014). Cotton productivity is affected by the planting date; therefore, choose an appropriate planting date will enhance cotton yield and fiber quality (Guo et al. 2023).

To maximize the quality of cotton fiber, plant population density must be regulated (Zhang et al. 2023). The widest plant spacing (35 cm) produced the best fiber quality properties in both seasons. Our findings are consistent with those of Khan et al. (2019), Zaman et al. (2021), and Zhi et al. (2022), who found that in comparison to high-density, the low or moderately dense-plants (wider plant spacing) increased monopodial branches, longer fiber length, strength, and higher micronaire values. According to Khan et al. (2019), a decreased photosynthetic rate may have contributed to the lower fiber quality at high density by resulting in a lesser supply of carbohydrates during fiber formation. High-density planting increases cotton productivity but leads to lower-quality cotton fiber results from inadequate canopy ventilation and light penetration brought on by a greater population leaf area index (Zuo et al. 2024). To put it simply, when there are enough plants in a given area, the population of plants will receive optimal lighting and ventilation, which will raise the concentration of chlorophyll and promote photosynthesis in the leaves of the main stem. This will ultimately improve properties related to fiber quality (Zhang et al. 2023). Broader and narrower plant spacing had a mixed influence on fiber quality compared with narrow plant spacing (Zaman et al. 2021). Along with light interception, moisture availability, nutrient uptake, humidity, and weed infestation, plant density also affects plant height and fruiting behavior (Ibrahim et al. 2022). Our findings demonstrated that, under typical irrigation treatments in both seasons, the February planting date with the wide plant spacing enhanced FS, UHML, and UR% traits based on the effects of first and second-order interactions. As for the January planting date in both seasons, a better number of fruiting branches and fiber fineness traits were observed with narrow and wide plant spacing under 100% A.W. and 75% A.W. treatments, respectively. Through non-significant interactions, we can say that different environmental conditions can reduce the effects of planting dates, planting distances, and irrigation treatments. The impact of the planting date may be mitigated by a deteriorated environment (Guo et al. 2023). Given the effects of climate change, planting earlier might be a viable method to increase cotton productivity (Deho 2023). According to Yehia et al. (2024), the Toshka region of Egypt's sand soil yields the finest fiber quality qualities when planted on February 25th, with a plant spacing of 10 cm.

In this study, we used PCA analysis to comprehend the relationships among irrigation conditions, planting dates, and planting distances that resulted in variations for the examined traits. The PCA model was built with the PCA1 and PCA2 that extracted eigenvalues higher than unity and explained more than 82% of the total variations among studied variables in both seasons. Similar results were reported by Sarwar et al. (2021) and Jalilian et al. (2023), who noted that only the PCA1 and PCA2 had more than one eigenvalue and roughly 60.90% and 66.80% cumulative variability. As a result, these two PCs were employed to provide additional context and further explanation (Yehia and El-Hashash 2021; Ullah et al. 2022). Since PCA1 accounted for more than half of the variation overall, it was determined that it was the most crucial factor in understanding the experimental treatments in both seasons. Based on the angles in the PCA biplot, strong positive associations were observed between FF and UHML traits, and among PH, FS, UHML, and UR% traits in both seasons. Positive or negative correlations among fiber quality traits were observed under different sowing dates (Khalid et al. 2018), plant density (Jalilian et al. 2023), and drought stress conditions (Zafar et al. 2023). Our results suggested that PCA1 may play a major role in the improved fiber quality attributes when planting in February with wide plant spacing under normal irrigation conditions in both seasons. Conversely, under drought stress treatment (75% A.W.), PC2 seems to exhibit NFB and FF traits with narrow plant spacing at the January planting date. As a result, PCA1 and PCA2 can be viewed as reactions to the experimental treatments that affect fiber quality properties in both good and negative ways. In both seasons, PH, FS, UHML, and UR% traits were more closely related to the February planting date with the wide plant spacing under normal irrigation treatment (100% A.W.). These results indicated that the February planting date with the wide plant spacing under normal irrigation conditions contributed much more proportion to the variances of PH, FS, UHML, and UR% traits, which showed that these treatments played a more important role in the formation of fiber quality properties. Several indicators, such as plant height, the number of fruit branches, and fiber quality, can be used to determine whether a cotton germplasm line is tolerant to drought (Sun et al., 2023). Temporary drought stress or modest water shortages could strengthen crop tolerance (Wang et al. 2024). Generally, our findings showed that the Egyptian cotton variety Giza 95 may provide good fiber characteristics under sand soil conditions in the Toshka region of Egypt when planted in February with broad plant spacing under drought treatment (80 % A.W.).

**CONCLUSIONS:** The majority of the morphological and fiber quality characteristics under investigation showed statistically significant improvements as a result of the main effects of irrigation treatments, planting dates, and planting distances as well as their first-order interactions in both seasons. Since the February planting date with wider plant spacing under drought stress can improve fiber quality properties, these practices are probably appropriate for the Egyptian cotton variety Giza 95 in the Toshka region of Egypt. Understanding the association between planting dates and density across drought-stressed environments can be a useful tool to assist management choices for Egyptian cotton and help improve fiber quality properties. Therefore, in the experimental location under investigation, we suggested doing long-term investigations under drought stress conditions regarding planting dates and broader plant spacing.

**CONFLICT OF INTEREST:** Author has no conflict of interest.

**LIFE SCIENCE REPORTING**: In current research article no life science threat was reported

**ETHICAL RESPONSIBILITY:** This is original research, and it is not submitted in whole or in parts to another journal for publication purpose.

**INFORMED CONSENT:** The author(s) have reviewed the entire manuscript and approved the final version before submission.

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