RESEARCH | Egyptian Journal of Agricultural Research | Cotton

Improving the quality and productivity of cotton under a drip irrigation system in Toshka, Egypt

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Received:10-05-2024; **Accepted**:18-08-2024; **Published:** 31-08-2024 **DOI:** 10.21608/EJAR.2024.288608.1543

ABSTRACT

Cotton is the most important natural textile fiber and cash crop in Egypt. Planting dates and planting distances are important determinants of achieving maximum cotton productivity and quality fiber. In the Toshka region conditions of Egypt, two field experiments during the 2021 and 2022 growing years were executed at the Water Studies and Research Complex (WSRC) station, National Water Research Center, Toshka, Egypt, to study the effects of three planting dates (25January, 25 February, and 25 March) and six planting distances (10, 15, 20, 25, 30, and 35 cm among plants) with drip irrigation on the yield, yield components and fiber quality traits of the Egyptian cotton cultivar Giza 95. Growing years, planting dates, planting distances, and their first-order interactions had significant effects (P<0.05 or 0.01) on cotton yield, most of its component traits, and fiber quality properties. Cotton yield and all examined traits had low CV% values. The production and quality of cotton are greatly influenced by the year and climate. The Giza 95 variety under the February planting date with the lowest plant spacing showed the highest cotton yield and most traits under study, especially strength and length fiber. Across the planting dates, 3.55% and 5.09% more seed cotton yield was achieved under the February planting date than the March and January planting dates, respectively. When it comes to planting distances, 10 cm spacing outperformed 15, 20, 25, 30, and 35 cm spacing by 1.09, 2.12, 3.76, 5.05, and 6.58%, respectively, in terms of seed cotton yield. Cotton yield significantly (P<0.05 or 0.01) correlated with some cotton traits under different planting dates and planting distances. The results of the three-way ANOVA, correlation coefficient, and PCA from our study could be useful and used for cotton productivity improvement under planting dates and planting distances. Based on these experiments, it is concluded that the 25 February planting date under 10 cm plant spacing is optimal for high cotton yield and the best fiber quality properties in sand soil at the Toshka region of Egypt.

Keywords: Planting dates, planting distances, cotton yield, fiber quality, correlation, PCA analysis

INTRODUCTION

The most significant crop for natural textile fiber in the world, cotton is also a major local crop for Egypt's textile sector (Yehia *et al*., 2024). Because of its significant contribution to the development of the industrial sector (oil and fiber) and the creation of jobs, cotton is often referred to as "white gold" (Ahmed and Delin, 2019). In February 2023/2024, the total area, yield, and production of cotton are an average of 30.98 and 0.11 million ha, 1.34 and 0.96 metric tons' ha^{-1}, and 41.46 and 0.11 million metric tons in world and Egypt, respectively (USDA, 2024). Geographical locations, growth seasons, years, drought conditions, rainfall, the amount of precipitation received in each season, temperature, and other environmental (non-genetic) elements can all affect genotypes, either positively or negatively (El-Hashash *et al*., 2018).

Climate factors and agronomic techniques, such as plant density, sowing time, irrigation, and fertilization, have a significant impact on cotton yields (Tuttolomondo *et al*., 2020). Important variables influencing cotton growth and development include variety choice, sowing technique, date and time, plant spacing, water demand, seed treatment, and proper fertilizer application. Planning better management techniques to increase the potential production of cotton is crucial (Ibrahim *et al*., 2022).

The planting date is very important since it affects fiber quality as well as growth and yield (Iqbal *et al.*, 2020). According to Khan *et al*., (2017), planting date has an impact on nutrient uptake, root penetration, vegetative growth, and solar energy usage. However, because of environmental factors including soil and air temperatures and solar radiation, choosing the best time to sow can be difficult (Lin *et al*., 2023a). The possible effects on crop establishment, development, and yields further emphasize the need to determine the best dates to plant. Higher yields were obtained with earlier sowing dates, albeit the yield components varied

(Tlatlaa *et al*., 2023). In the current context of a changing environment for cotton crops, planting dates and genotypes had an impact on seed cotton production and related attributes (Deho, 2023). According to Wang *et al*. (2023), late planting in cotton promotes concentrated boll opening for mechanical harvesting and speeds up leaf aging; however, it also delays physiological maturity, which may reduce cotton production. The temperature of the soil and the air affect when to planting (Bozbek *et al*., 2006). The yield of seed cotton was reduced by low soil temperature and delayed emergence, in particular (Norfleet *et al*., 1997).

Planting density is essential to maximizing crop development and output potential. Planting density in cotton significantly influences the growth and yield characteristics of the cotton plant. By forcing competition among plants for resources such as sunlight, nutrients, moisture uptake, and space, the plant population influences crop development dynamics (Zaman, 2021). The cultivar and planting density are thought to be the main factors influencing cotton yield. By altering light interception, photosynthetic capability, nutrient intake, plant establishment pattern, and assimilating metabolism enzyme activity at various canopy positions, planting density also affects crop growth and yield (Khan *et al*., 2017). Plant spacing has been shown to be the most important component in improving the structures and raising the photosynthetic potential of the cotton canopy (An et al., 2023), which is connected to the strategy for cotton production (Ibrahim *et al*., 2022). Plant height, architecture, boll behavior, crop maturity, and crop yield are all impacted by plant density, which also affects light absorption, moisture availability, and wind movement (Khan *et al*., 2019; Fahad *et al*., 2021). Thus, options to attain potential benefits from ecosystem services can be modified by planting density control (Khan *et al*., 2019).

Planting date and planting distance are the two most important productivity parameters (Ali *et al*., 2009). The phenology, growth, and development of a cotton crop can be significantly influenced by the timing of sowing and the density of the plants (Khan *et al*., 2017). The crop's morphological adaptations to its growing environment, such as changes in canopy structure in response to sowing date and plant population density, are a result of its unpredictable growth behavior (Zhang *et al*., 2004). The main factors influencing lint yield and quality are these morphological changes related to canopy development, light interception, source-sink interaction, and integrated partitioning (Yang *et al*., 2014).

For Egyptian cotton yield to increase, particularly in the Toshka region of Egypt, appropriate planting dates and planting distances are essential. It is essential to comprehend the complex interactions between planting distances and dates in order to maximize cotton yield and fiber qualities. Therefore, the present field experiments were conducted to study the effects of planting dates and distances with drip irrigation on the yield, yield components and fiber quality traits of the Egyptian cotton cultivar Giza 95 under the Toshka region conditions of Egypt.

MATERIAL AND METHODS

Study region:

A set of two field experiments were carried out in the 2021 and 2022 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. It is made up of numerous connected depressions. The primary River Nile irrigation water supply is the Sheikh Zayed Canal. It carries water from the Nile through four subbranches to irrigate various areas (Al-Soghir *et al.,* 2022). Besides Lake Nasser, Toshka is a potential place where groundwater-dependent activities are expanding. As such, it is critical to offer a sustainable development strategy and evaluate the environmental effects that follow (Aly *et al.,* 2023). As part of the latest mega project termed the "1.5 million Feddan Project," the Egyptian government wants to extend the project by about 100,000 feddan dependent on surface water irrigation and 25,000 feddan depending on groundwater (via 102 wells) (Sharaky *et al.,* 2018). Enclosed between latitudes 22°30′ N and 23°30′ N and longitudes 31°00′ E and 32°00′ E, the development area spans approximately 25,000 acres (Aly *et al.,* 2023).

Climatic data of study region as monthly minimum and maximum temperature (^{0}C), as well as relative humidity (%) during 2021 and 2022 growing winter years, are presented in **Fig. 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.

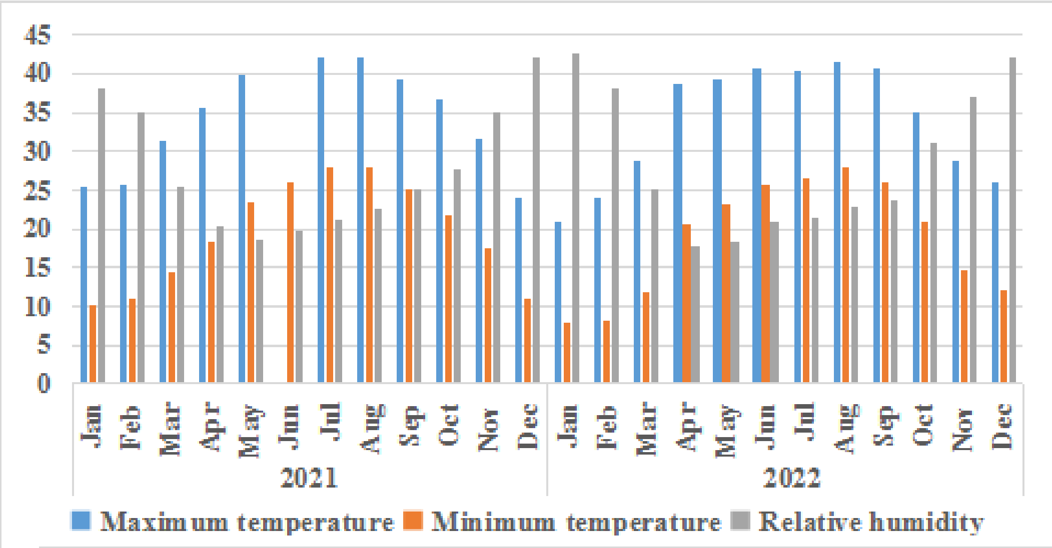

Fig. 1. Climatic data at Toshka region, Egypt during the 2021 and 2022 growing years.

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). At each year, cottonseed was sown in a randomized complete block design with the factorial arrangement in three replicates. Each experimental plot included five rows of 4 m long and 0.7 m width, forming a 14 m2 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.

Agronomic traits and yield components:

Seed cotton yield was determined by manually harvesting three times from each treatment for studied factors. The moisture level of the bolls was decreased to less than 11% after air drying, and seed cotton from 100 bolls was tested for boll weight during the first harvest. Data were recorded for the studied traits including position of the first fruiting node (FFN); the number of fruiting branches (NFB); plant height (PH, cm); seed cotton yield (SCY, K/Feddan); lint cotton yield (LCY, K/Feddan); boll weight (BW, g); lint percentage (L%); seed index (SI, g); fiber fineness (FF) micronair reading; fiber strength (FS, gm/tex); upper half mean length (UHML, mm); 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≤20%) 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

Three-Way ANOVA:

Table (1) shows the comprehensive results of a three-way ANOVA for cotton yield and other studied quantitative traits affected by years, planting dates, and planting distances factors. The results of p-values showed a significant effect ($P < 0.05$ or 0.01) of the years, planting dates, and planting distances on all studied traits, except the years on lint% and fiber strength traits, and the planting dates on seed index, fiber fineness, and uniformity ratio% traits, which had non-significant effects. In terms of first-order interactions, the years x planting distances interaction had significant effects ($P < 0.05$ or 0.01) on all investigated traits except the number of fruiting branches trait. Only the seed and lint cotton yields traits showed highly significant interactions between years and planting dates. The interaction between planting dates and distances only had a significant effect on two traits: the number of fruiting branches ($P < 0.01$) and seed cotton yield ($P < 0.05$). On the other hand, the second-order interaction of the studied factors exhibited no statistically significant effects on seed cotton yield or other studied traits. The coefficient of variation (CV%) for all cotton traits studied across the three evaluated factors was less than 10% (**Table 1**). The uniformity ratio and fiber fineness traits had the lowest CV% values, at 0.69% and 1.26%, respectively. The largest CV% were obtained for the position of the first fruiting node and the number of fruiting branches, with values of 7.84% and 8.06%, respectively.

Table 1. Three-way ANOVA (p-values) for the effect of the years (Y), planting dates (D3), and planting distances (D6) on the evaluated traits of cotton.

S.O.V	FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML	UR%
Y	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.61^{ns}	0.00**	0.00**	0.07^{ns}	0.00**	0.00**
D3	0.03*	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.24^{ns}	0.02^{ns}	0.00**	0.00**	0.99^{ns}
D6	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
Y x D3	0.47^{ns}	0.92^{ns}	0.94^{ns}	0.00**	0.00**	0.92^{ns}	0.10^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}
Y x D6	0.08*	0.25^{ns}	0.00**	0.01*	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.03*	0.00**
D3 x D6	0.84^{ns}	0.00**	1.00^{ns}	0.03*	0.22^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}
YxD3xD6	0.94^{ns}	0.14^{ns}	1.00^{ns}	0.64^{ns}	0.88^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}	1.00^{ns}
C.V.%	7.84	8.06	3.85	1.58	2.69	3.78	2.05	2.49	1.26	6.72	3.12	0.69

Statistically significant differences at $^{*}p \le 0.05$ and $^{**}p \le 0.01$; ns: indicate the non-significant difference. FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

Experimental Factors effects on cotton traits:

As shown in **Table (2)**, the statistical analysis revealed significant differences between the two years, three planting dates, and six planting distances for all studied traits. Boll weight, seed index, fiber fineness (undesirable), upper half mean length, and uniformity ratio traits were significantly higher in 2022 compared to 2021. The opposite is true for the other analyzed traits. Regarding the planting dates, the February planting date showed a considerably lower position of the first fruiting node and significantly higher seed cotton yield, lint cotton yield, lint percentage, fiber strength, and upper half mean length traits than the other planting dates. The March planting date yielded the best results for plant height, boll weight, seed index, and fiber fineness traits. While the highest values for the number of fruiting branches and uniformity ratio traits were recorded in January, but uniformity ratio trait is unaffected by the three planting dates. In terms of planting distances, plant height, seed cotton yield, and lint cotton yield traits under 10 cm spacing, lint percentage, and fiber strength traits under 15 cm spacing, the number of fruiting branches, boll weight, seed index, upper half mean length, and uniformity ratio traits under 35 cm spacing were significantly higher than across other studied plant spacing's. while the lowest values for the position of the first fruiting node and fiber fineness traits (desirable) were found under 35 and 30 cm spacings, respectively. The greatest yields of seed and lint cotton were obtained with a narrow plant spacing of 10 cm, followed by wide-narrow plant spacing in order of 15, 20, 25, 30, and 35 cm among plants. While the wide plant spacing produced the best fiber and earliness traits.

Table 2. Effects of years, planting dates and planting distances on cotton studied traits.

Factors		FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML	UR%
Years													
2021		9.71	13.32	82.96	8.38	10.61	2.88	39.16	9.37	4.49	10.89	30.43	82.48
2022		10.40	11.87	89.50	8.13	10.04	3.24	39.08	10.11	4.69	10.64	31.49	83.17
LSD	**0.05**	0.30	0.39	1.27	0.05	0.11	0.04	NS	0.09	0.02	NS	0.37	0.22
at	**0.01**	0.40	0.52	1.69	0.07	0.14	0.06	NS	0.12	0.03	NS	0.49	0.29
Planting Dates													
25 January		10.26	16.27	81.79	7.71	9.69	2.88	38.26	9.73	4.62	10.72	30.35	82.83
25 February		9.78	10.54	86.89	8.97	11.33	3.05	40.09	9.69	4.59	11.17	31.60	82.82
25 March		10.13	10.97	90.02	8.09	9.95	3.26	39.00	9.79	4.58	10.40	30.94	82.82
LSD	**0.05**	0.37	0.48	1.56	0.06	0.13	0.05	0.38	0.11	0.03	0.34	0.45	NS
at	**0.01**	NS	0.63	2.07	0.08	0.17	0.07	0.50	0.15	NS	0.45	0.60	NS
Planting Distances													
10 cm		11.08	11.72	93.00	9.79	12.21	3.04	39.12	9.77	4.70	11.16	31.47	82.99
15 cm		10.69	11.55	86.71	9.25	11.84	3.02	40.10	9.41	4.65	11.22	30.37	82.34
20 cm		9.95	11.97	83.31	8.74	10.95	2.98	39.21	9.78	4.58	10.99	30.73	82.82
25 cm		10.25	12.15	82.26	7.93	9.86	3.02	38.87	9.66	4.60	10.08	30.78	82.87
30 cm		9.27	13.53	87.76	7.29	9.00	3.11	38.56	9.67	4.50	10.09	30.58	82.52
35 cm		9.08	14.64	84.35	6.53	8.10	3.19	38.83	10.13	4.53	11.04	31.83	83.42
LSD	**0.05**	0.52	0.68	2.20	0.09	0.18	0.08	0.53	0.16	0.04	0.48	0.64	0.38
at	**0.01**	0.70	0.90	2.93	0.11	0.25	0.10	0.71	0.21	0.05	0.64	0.85	0.50

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

The first-order interactions effect on cotton traits:

The highest values across both studied years were recorded in February for the position of the first fruiting node, seed cotton yield, lint cotton yield, lint percentage, fiber strength, and upper half mean length traits; in March for plant height, boll weight, seed index, and fiber fineness traits; and in January for the number of fruiting branches and uniformity ratio traits (**Table 3**). When compared to their values in other years x planting dates interactions, the middle planting date (25 February) of the 2021 growing year registered the best values for the position of the first fruiting node, seed cotton yield, lint cotton yield, and fiber strength traits. During the 2021 growing year, the number of fruiting branches and fiber fineness showed the highest values in January and March, respectively. Plant height, boll weight, and seed index traits in 25 March and lint percentage and upper half mean length in 25 February were recorded at the highest values across the 2022 growing year. A decrease was found for cotton yield and important studied traits in the 25 January planting date across the 2022 growing year compared to other interactions of years and planting dates.

Table 3. The first-order interaction of years and planting dates for cotton studied traits.

Years	Planting Dates	FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML	UR%
2021	**25 January**	9.79	17.04	78.67	7.78	10.23	2.70	38.54	9.36	4.52	10.84	29.83	82.49
	25 February	9.53	11.26	83.60	9.28	11.70	2.87	40.01	9.32	4.49	11.29	31.06	82.48
	25 March	9.81	11.65	86.61	8.07	9.90	3.07	38.92	9.41	4.48	10.53	30.41	82.48
2022	**25 January**	10.74	15.50	84.92	7.64	9.16	3.05	37.98	10.10	4.72	10.60	30.87	83.18
	25 February	10.02	9.83	90.18	8.65	10.96	3.23	40.17	10.05	4.69	11.04	32.13	83.16
	25 March	10.45	10.30	93.42	8.11	10.00	3.44	39.08	10.16	4.68	10.27	31.47	83.16
LSD	**0.05**	NS	NS	NS	0.09	0.18	NS	NS	NS	NS	NS	NS	NS
at	**0.01**	NS	NS	NS	0.11	0.25	NS	NS	NS	NS	NS	NS	NS

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

In **Table (4)**, the greatest values across both studied years were recorded for the position of the first fruiting node and number of fruiting branches traits under 35 cm spacing, as well as seed and lint cotton yields traits under 10 cm spacing. The first fruiting node's position, the number of fruiting branches, fiber strength traits under 35 cm spacing, seed and lint cotton yield traits under 10 cm spacing, and fiber fineness under 30 cm were recorded as the maximum values in the 2021 growing seasons when compared with interactions of years and planting distances. In contrast, the 2022 growing year had the highest levels of plant height, seed index, upper half mean length, and uniformity ratio traits under 10 cm spacing, lint percentage under 15 cm spacing, and boll weight under 35 cm spacing.

Table 4. The first-order interaction of years and planting distances for cotton studied traits.

Years	Planting Distances	FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML	UR%
2021	**10 cm**	10.72	12.50	80.69	9.94	12.53	2.73	39.09	8.97	4.58	10.89	30.55	82.14
	15 cm	10.59	12.48	72.31	9.31	11.89	2.93	39.54	9.00	4.48	11.14	29.53	82.09
	20 cm	9.71	12.56	88.02	8.82	11.08	2.77	38.82	9.39	4.43	10.84	30.04	82.14
	25 cm	10.19	12.72	79.12	8.05	10.32	2.89	39.63	9.12	4.53	10.33	30.35	82.99
	30 cm	8.55	14.66	89.59	7.49	9.54	3.02	39.34	9.58	4.43	10.59	30.20	81.89
	35 cm	8.50	14.98	88.02	6.66	8.31	2.94	38.53	10.15	4.53	11.54	31.93	83.64
2022	**10 cm**	11.45	10.95	105.30	9.63	11.89	3.35	39.15	10.57	4.83	11.44	32.39	83.84
	15 cm	10.79	10.63	101.11	9.20	11.80	3.11	40.66	9.82	4.83	11.29	31.22	82.59
	20 cm	10.19	11.38	78.59	8.66	10.81	3.19	39.60	10.17	4.73	11.14	31.42	83.49
	25 cm	10.31	11.59	85.40	7.82	9.40	3.14	38.12	10.20	4.68	9.83	31.22	82.74
	30 cm	9.99	12.41	85.93	7.09	8.45	3.21	37.78	9.76	4.58	9.58	30.96	83.14
	35 cm	9.67	14.29	80.69	6.39	7.89	3.45	39.14	10.12	4.53	10.53	31.73	83.19
LSD at	**0.05**	NS	NS	3.12	0.12	0.26	0.11	0.75	0.23	0.05	0.68	0.91	0.53
	0.01	NS	NS	4.14	NS	0.35	0.14	1.00	0.30	0.07	0.90	NS	0.71

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

As for interaction of planting dates and planting distances (**Table 5**), the best values across three planting dates were recorded under 35 cm spacing for the position of the first fruiting node, the number of fruiting branches, boll weight, seed index, upper half mean length, and uniformity ratio traits; under 10 cm spacing for plant height, seed cotton yield, and lint cotton yield traits; under 15 cm spacing for lint percentage and fiber strength traits; and under 30 cm spacing for the fiber fineness trait. Compared with other interactions of planting date and planting distances, the first fruiting node's position, the number of fruiting branches, boll weight, and seed index traits under 35 cm spacing, plant height under 10 cm spacing, and fiber fineness under 30 cm were recorded as the best values in the 25 March planting date. The maximum number of fruiting branches and uniformity ratio traits under 35 cm spacing in the 25 January planting date were found. During the 25 February planting date, the seed and lint yields under 10 cm spacing and the lint percentage and fiber strength traits under 15 cm spacing registered the highest values. On the other hand, the lowest values were found for cotton yield under wide plant spacing in all planting dates. Diverse tendencies were seen in all of the first-order interactions, but statistical analysis revealed that, for the 25 January planting date in 2021, the narrowest plant spacing produced the highest values of cotton yield and other significant traits. Conversely, fiber properties showed the opposite tendency.

Table 5. The first-order interaction of planting dates and planting distances for cotton studied traits.

Planting Dates	Planting Distances	FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML	UR%
25 January	**10 cm**	11.23	13.56	88.25	9.26	11.58	2.86	38.28	9.77	4.73	11.13	30.85	83.00
	15 cm	10.95	14.98	82.25	8.70	11.18	2.84	39.25	9.41	4.68	11.18	29.78	82.35
	20 cm	10.31	15.22	79.00	8.15	10.24	2.79	38.31	9.78	4.60	10.95	30.13	82.83
	25 cm	10.63	16.22	78.00	7.34	9.15	2.83	37.86	9.66	4.63	10.05	30.18	82.88
	30 cm	9.23	18.20	83.25	6.74	8.37	2.93	37.65	9.67	4.53	10.03	29.98	82.53
	35 cm	9.23	19.45	80.00	6.07	7.64	3.01	38.23	10.13	4.55	11.00	31.20	83.43
25 February	**10 cm**	10.78	10.28	93.68	10.56	13.34	3.03	40.09	9.72	4.70	11.59	32.12	82.99
	15 cm	10.22	9.70	87.37	10.02	12.96	3.01	41.08	9.36	4.65	11.64	31.00	82.34
	20 cm	9.55	10.03	83.95	9.50	12.03	2.97	40.21	9.73	4.57	11.41	31.36	82.81
	25 cm	9.98	9.96	82.89	8.65	10.89	3.01	39.92	9.61	4.60	10.46	31.41	82.86
	30 cm	9.19	11.12	88.42	7.95	9.92	3.10	39.55	9.62	4.50	10.43	31.21	82.51
	35 cm	8.94	12.15	85.00	7.10	8.87	3.18	39.67	10.08	4.52	11.46	32.48	83.41
25 March	**10 cm**	11.24	11.32	97.05	9.54	11.71	3.23	39.00	9.82	4.69	10.78	31.45	82.99
	15 cm	10.91	9.98	90.51	9.05	11.39	3.22	39.97	9.45	4.64	10.83	30.35	82.34
	20 cm	9.99	10.66	86.97	8.58	10.57	3.17	39.11	9.83	4.56	10.61	30.71	82.81
	25 cm	10.16	10.29	85.88	7.81	9.55	3.21	38.84	9.71	4.59	9.73	30.76	82.86
	30 cm	9.64	11.28	91.60	7.18	8.70	3.31	38.48	9.72	4.49	9.80	30.55	82.51
	35 cm	8.83	12.31	88.06	6.40	7.79	3.39	38.60	10.19	4.51	10.66	31.81	83.41
LSD at	**0.05**	NS	1.17	NS	0.15	NS	NS	NS	NS	NS	NS	NS	NS
	0.01	NS	1.55	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

The second-order interactions effect on cotton traits:

The impacts of the second-order interactions of the experimental factors on the examined traits and cotton yield are given in **Table (6)**. Non-significant differences were found between the single alterations in experimental factors on cotton yield and all examined traits. During the 2021 year, the best values were observed for the position of the first fruiting node and the number of fruiting branches in 25 January under 30 cm spacing, as well as seed and lint cotton yields in 25 February under 10 cm spacing, compared with those of other second-order interactions. As for the 2022-year, better values were noticed for plant height (25 March), seed index, uniformity ratio traits (25 January), fiber strength, and upper half mean length traits (25 February) under 10 cm spacing, for lint percentage (25 February) under 15 cm spacing, and for boll weight and fiber fineness traits (25 March) under 35 cm spacing. Generally, from the results of the effect of experimental factors as well as the first and second-order interactions, the narrowest plant spacing on the 25 February planting date increased cotton yield and most studied traits, especially fiber properties including strength and length fiber. On the other hand, the wide plant spacing produced the best position of the first fruiting node, the number of fruiting branches (25 January), boll weight, and fiber fineness traits (25 March).

Table 6. The second-order interaction of years, planting dates, and planting distances for cotton studied traits.

Planting Dates	Planting Distances	FFN		NFB		PH		SCY		LCY		BW	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
25 January	10 cm	10.93	11.53	13.50	13.62	76.50	100.00	9.38	9.14	12.21	10.95	2.55	3.16
	15 cm	10.70	11.20	15.80	14.17	68.50	96.00	8.69	8.70	11.51	10.84	2.75	2.93
	20 cm	10.00	10.63	15.66	14.77	83.50	74.50	8.16	8.14	10.64	9.85	2.59	3.00
	25 cm	10.40	10.86	17.50	14.93	75.00	81.00	7.41	7.27	9.85	8.45	2.71	2.96
	30 cm	8.36	10.10	20.00	16.40	85.00	81.50	6.97	6.52	9.23	7.50	2.84	3.02
	35 cm	8.37	10.10	19.80	19.10	83.50	76.50	6.09	6.06	7.94	7.35	2.76	3.26
25 February	10 cm	10.43	11.13	11.33	9.23	81.32	106.05	10.94	10.19	13.75	12.92	2.73	3.33
	15 cm	10.37	10.07	10.70	8.70	72.89	101.84	10.28	9.76	13.08	12.85	2.93	3.10
	20 cm	9.62	9.48	10.90	9.17	88.68	79.21	9.80	9.20	12.25	11.81	2.76	3.17
	25 cm	10.07	9.88	10.20	9.72	79.74	86.05	8.95	8.35	11.44	10.33	2.89	3.13
	30 cm	8.10	9.78	11.90	10.33	90.26	86.58	8.30	7.61	10.50	9.34	3.01	3.20
	35 cm	8.60	9.78	12.50	11.80	88.68	81.32	7.44	6.76	9.21	8.53	2.93	3.43
25 March	10 cm	10.79	11.68	12.67	9.98	84.25	109.86	9.51	9.56	11.63	11.79	2.92	3.55
	15 cm	10.71	11.11	10.93	9.02	75.53	105.50	8.94	9.15	11.06	11.72	3.12	3.31
	20 cm	9.51	10.47	11.12	10.20	91.88	82.07	8.52	8.63	10.36	10.78	2.95	3.39
	25 cm	10.11	10.21	10.45	10.12	82.61	89.15	7.78	7.84	9.68	9.43	3.08	3.34
	30 cm	9.18	10.11	12.07	10.49	93.51	89.70	7.22	7.14	8.88	8.52	3.21	3.41
	35 cm	8.54	9.13	12.64	11.98	91.88	84.25	6.47	6.34	7.79	7.78	3.13	3.66
LSD at	0.05	NS		NS		NS		NS		NS		NS	
	0.01	NS		NS		NS		NS		NS		NS	
Planting Dates	Planting Distances	L%		SI		FF		FS		UHML		UR%	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
25 January	10 cm	38.52	38.03	8.97	10.57	4.60	4.85	10.85	11.40	29.95	31.75	82.15	83.85
	15 cm	38.97	39.54	9.00	9.82	4.50	4.85	11.10	11.25	28.95	30.60	82.10	82.60
	20 cm	38.17	38.45	9.39	10.17	4.45	4.75	10.80	11.10	29.45	30.80	82.15	83.50
	25 cm	38.83	36.89	9.12	10.20	4.55	4.70	10.30	9.80	29.75	30.60	83.00	82.75
	30 cm	38.74	36.55	9.58	9.76	4.45	4.60	10.50	9.55	29.60	30.35	81.90	83.15
	35 cm	38.03	38.43	10.15	10.12	4.55	4.55	11.50	10.50	31.30	31.10	83.65	83.20
25 February	10 cm	39.92	40.26	8.92	10.51	4.57	4.82	11.30	11.88	31.18	33.05	82.14	83.84
	15 cm	40.38	41.79	8.95	9.77	4.47	4.82	11.57	11.72	30.14	31.86	82.09	82.59
	20 cm	39.68	40.74	9.34	10.12	4.42	4.72	11.25	11.57	30.66	32.07	82.14	83.49
	25 cm	40.58	39.27	9.07	10.15	4.52	4.67	10.72	10.20	30.97	31.86	82.99	82.74
	30 cm	40.18	38.93	9.53	9.71	4.42	4.57	10.93	9.93	30.82	31.60	81.89	83.14
	35 cm	39.31	40.04	10.10	10.07	4.52	4.52	11.99	10.93	32.59	32.38	83.64	83.19
25 March	10 cm	38.83	39.16	9.01	10.62	4.56	4.81	10.51	11.05	30.53	32.37	82.14	83.84
	15 cm	39.28	40.65	9.04	9.87	4.46	4.81	10.75	10.90	29.51	31.19	82.09	82.59
	20 cm	38.60	39.63	9.43	10.22	4.41	4.71	10.46	10.75	30.02	31.40	82.14	83.49
	25 cm	39.47	38.20	9.16	10.25	4.51	4.66	9.97	9.49	30.33	31.19	82.99	82.74
	30 cm	39.09	37.87	9.63	9.81	4.41	4.56	10.35	9.24	30.17	30.94	81.89	83.14
	35 cm	38.24	38.95	10.20	10.17	4.51	4.51	11.14	10.17	31.91	31.70	83.64	83.19
LSD at	0.05	NS		NS		NS		NS		NS		NS	
	0.01	NS		NS		NS		NS		NS		NS	

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

Pearson's correlation coefficient:

As indicated in **Table (7)**, Pearson's correlation coefficient is used to grasp the links between the features of cotton that are researched throughout three planting dates and six planting distances across two years. A perfect positive correlation (p<0.01) was observed between seed cotton yield and lint cotton yield traits. Seed and lint cotton yields are significantly positively correlated with the position of the first fruiting node, lint percentage, fiber fineness, and fiber strength traits (p<0.05), but non-significant and positive with the plant height trait. A significant positive correlation (p<0.05 or 0.01) was observed among all seed index, upper half mean length, and uniformity ratio traits. Boll weight exhibited a positive and significant association with plant height, seed index, and upper half mean length traits (p<0.05). Lint percentage was positively and significantly associated with fiber strength (p<0.05)

Table 7. Pearson's correlation coefficient among cotton yield and other studied traits across the three experimental factors.

Traits	FFN	NFB	PH	SCY	LCY	BW	L%	SI	FF	FS	UHML
NFB	-0.36										
PH	0.42	-0.55*									
SCY	0.77*	-0.64*	0.42								
LCY	0.74*	-0.61*	0.36	1.00**							
BW	-0.14	-0.36	0.60*	-0.30	-0.35						
L%	0.25	-0.73*	0.23	0.65*	0.68*	0.01					
SI	-0.18	0.13	0.24	-0.45	-0.50	0.68*	-0.34				
FF	0.88**	-0.32	0.48	0.58*	0.55*	0.13	0.23	0.24			
FS	0.23	-0.13	0.11	0.51*	0.55*	-0.24	0.61*	-0.05	0.29		
UHML	-0.11	-0.27	0.45	-0.07	-0.10	0.60*	0.17	0.74*	0.24	0.29	
UR%	-0.13	0.16	0.12	-0.38	-0.42	0.50	-0.30	0.92**	0.24	0.07	0.81**

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

Principal component analysis (PCA):

According to PCA, the eight PCs for all cotton studied traits and the experimental factors are presented in **Table (8)**. Of the eight PCs, the extracted eigenvalues of PC1, PC2, PC3, and PC4 were 4.80, 3.57, 1.42, and 1.33 (eigenvalue >1), respectively, as well as contributing 92.59% of the total variation existing among studied variables. Conversely, the eigenvalues of the remaining four PCs were less than one (eigenvalue <1). While PC1 only accounts for approximately 39.99% of the entire variability of the measured data, its contributions to the total variance were greater than those of PC2 (29.74%), PC3 (11.80%), and PC4 (11.05%). In any additional data analysis, the outcomes of the first two PCs can be utilized to provide an overview of the original variables as well as to explain the overall variance and PCs collection. In **Table (8)**, PC1 had a positive correlation with all studied traits, except the number of fruiting branches, boll weight, seed index, upper half mean length, and uniformity ratio traits. These results indicated that the positive variables of the cotton yield and its components contributed to PC1. Except for the number of fruiting branches, seed cotton yield, and lint cotton production, the PC2 has recognized all investigated traits as having positive loading factors and contributions to the variables. As for PC3 and PC4, most variables studied have the highest positive loadings on these principal components under experimental factors. Also, the narrow plant spacing (10 and 15 cm) in the February planting date across the 2021 growing year influenced PC1. While PC2 is affected by 10 cm and 35 cm spacing at February and March planting dates across the 2022 growing year. On the other hand, the PC3 included 10 cm and 25 cm spacing at the January planting date across the 2022 growing year. PC4 consisted of 35 cm spacing at the February and January planting dates under the 2021 growing year.

Table 8. Results of principal component analysis (PCs) in the first eight PCs for the studied traits during the three experimental factors.

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
FFN	0.35	0.07	0.46	-0.21	-0.12	0.10	0.12	-0.52
NFB	-0.31	-0.18	0.43	0.23	0.41	0.25	0.29	0.12
PH	0.20	0.34	-0.09	-0.35	0.71	-0.07	0.12	0.10
SCY	0.45	-0.01	0.06	0.01	0.05	-0.31	-0.25	0.10
LCY	0.45	-0.04	0.05	0.06	0.04	-0.23	-0.17	0.11
BW	-0.10	0.42	-0.28	-0.32	0.02	0.44	-0.15	-0.30
L%	0.34	0.04	-0.44	0.25	-0.27	0.38	0.30	0.15
SI	-0.21	0.44	0.15	0.09	-0.10	0.07	-0.52	0.45
FF	0.27	0.26	0.47	-0.09	-0.23	0.33	0.22	0.40
FS	0.24	0.08	0.00	0.67	0.36	0.31	-0.27	-0.25
UHML	-0.03	0.47	-0.14	0.28	0.01	-0.38	0.54	0.07
UR%	-0.19	0.42	0.21	0.26	-0.21	-0.27	-0.03	-0.38
Years								
2021	0.07	-3.00	-0.68	0.68	0.39	-0.41	0.02	-0.26
2022	-0.10	2.98	0.64	-0.65	-0.37	0.38	-0.05	0.23
Planting Dates								
25 January	-1.54	-1.87	2.54	0.46	0.17	0.28	0.04	0.12
25 February	1.79	0.78	-1.63	1.25	-0.32	-0.34	0.28	0.30
25 March	-0.21	1.15	-0.86	-1.74	0.12	0.13	-0.29	-0.39
Planting Distances								
10 cm	3.08	1.92	1.37	-0.06	0.92	-0.72	0.12	-0.11
15 cm	3.39	-1.36	-0.35	0.05	-0.02	1.21	0.14	-0.06
20 cm	0.54	-0.64	-0.02	0.80	-0.50	-0.27	-0.81	0.14
25 cm	-0.78	-0.78	0.46	-0.98	-1.45	-0.47	0.35	-0.14
30 cm	-2.37	-1.24	-1.00	-1.63	0.83	-0.09	0.08	0.38
35 cm	-3.86	2.08	-0.45	1.82	0.23	0.31	0.11	-0.22
Eigenvalues	4.80	3.57	1.42	1.33	0.44	0.29	0.10	0.06
Variance %	39.99	29.74	11.80	11.05	3.64	2.42	0.83	0.52
Cumulative%	39.99	69.74	81.54	92.59	96.23	98.64	99.47	100.00

FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

In **Fig. (2)**, PC1 and PC2 primarily distributed and discriminated the variables and examined attributes in various groups based on all measurable data. Consequently, a biplot was created using the first two PCs. The biplot diagram showed how planting distances and dates varied throughout the course of growing years, contributing to variability in all traits that were examined. In PC1, the position of the first fruiting node, plant height, seed cotton yield, lint cotton yield, lint percentage, fiber fineness, and fiber strength traits were highly and positively correlated with narrow plant spacing at the February planting date in the 2021 growing year, which fell in the first and fourth quarters. While boll weight, seed index, upper half mean length, and uniformity ratio traits had a positive correlation with 35 cm spacing in the March planting date of the 2022 growing year, which was located in the second quarter according to PC2. The 10 cm spacing under the February planting date was located near the cotton yield and most important traits. Based on PCA, a positive correlation between the majority of the traits under study was displayed by the data about the contribution of experimental factors, which showed a sharp angle between them (**Fig. 2**). However, there were differences in terms of amount and degree of consistency. Highly positive correlations were observed among the position of the first fruiting node, plant height, seed cotton yield, lint cotton yield, lint percentage, fiber fineness, and fiber strength traits, as well as among boll weight, seed index, upper half mean length, and uniformity ratio traits. On the other hand, the obtuse angles between the traits under investigation show a negative correlation between them; their degree and consistency in amount varied. For instance, there was a negative correlation between the number of fruiting branches and some traits, including plant height, seed cotton yield, and lint cotton yield.

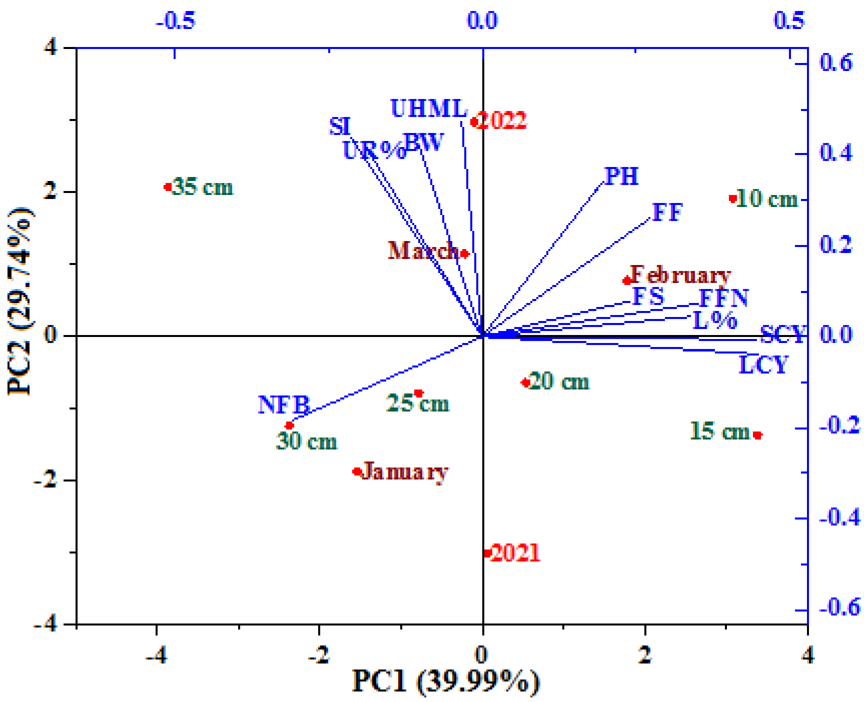

Fig. 2. Biplot diagram between PC1 and PC2 shows relationships between the studied traits during the years, planting dates and planting distances. FFN: position of the first fruiting node; NFB: number of fruiting branches; PH: plant height (cm); SCY: seed cotton yield (K/F); LCY: lint cotton yield (K/F); BW: boll weight (g); L%: lint percentage; SI: seed index (g); FF: fiber fineness; FS: fiber strength (gm/tex); UHML: upper half mean length (mm); UR%; uniformity ratio %.

DISCUSSION

In the current study, six planting distances and three planting dates in each of the growing years 2021 and 2022 were used to assess the cotton yield, component traits, and fiber properties of the Egyptian cotton variety Giza 95 under sand soil conditions in the Toshka region of Egypt. According to the three-way ANOVA, the p-value results indicated that the years, planting dates, and planting distances had a significant effect ($P < 0.05$ or 0.01) on the cotton yield and the majority of the attributes that were evaluated. These results suggest the existence of variability among the studied experimental factors, which means that cotton production in the Toshka region of Egypt under sand soil conditions can be improved. Similar findings to ours were found in earlier studies, including those by Guzman *et al*., (2019), Khan *et al*., (2020), Ye *et al*., (2021), Jalilian *et al*., (2023) and Patel *et al*., (2023). As for the interactions between the experimental factors, there were many trends in terms of significance, the most important of which was the significant effect of the interactions of years with both planting dates and planting distances on seed and lint cotton yields traits. These results are consistent with the results of Khan *et al*.,(2017), who reported that the interaction of sowing date and plant density was non-significant for all cotton studied traits. We can infer from the results of the three-way ANOVA that the substantial differences observed in cotton yield, its component traits, and fiber properties of the Giza 95 variety under investigation were caused by the weather, planting dates, and planting distances. Many factors, such as soil, microclimate, planting pattern, irrigation type, fertilizer administration technique, cultivar, and farmer's field management, affect the ideal cotton plant density (Khan *et al*., 2020). The results of the coefficient of variation (CV%) revealed that the experiment had a high level of precision due to the environmental influence being found to be low (<10%) for all measured traits. That would imply that the experimental factors under study differ significantly from one another. Li *et al*., (2020) found that the CV% values in cotton were greater than 10%; however, Yehia and El-Hashash (2021), El-Hashash and Yehia (2021) and Patel *et al.,* (2023) found that they were less than 10%.

The production and quality of cotton are greatly influenced by the year and climate. According to Darawsheh *et al*., (2022), the year effect outweighed the environment by a factor of two to six. Thus, choosing high-yielding cultivars with good fiber quality requires understanding how they respond to different environmental circumstances (Yaşar, 2023). The Giza 95 variety produced the best cotton yield and earliness, as well as length and strength of fibers, under the planting date in February. February planting date increased seed cotton yield by 3.55% and 5.09% as compared to the March and January planting dates, respectively. The date of planting has a significant impact on the yield of seed cotton. An earlier planting date could be a successful strategy to boost seed cotton yield due to climate change (Deho, 2023). In cotton, Zhang *et al.*, (2017) discovered that the middle planting date outperformed other sowing dates for every variable that was assessed. Khan *et al.*, (2017) discovered that the yield of cotton lint from early sowing was higher than that from late planting. They attributed this increase to the crop remaining in the field for a longer period during the cropping season, which maximizes the amount of time available to use growth resources. According to Mohamed *et al*., (2007), delaying the planting date decreased the seed index, lint yield, boll weight, and seed cotton yield per plant. Late planting in cotton promotes concentrated boll opening for mechanical harvesting and speeds up leaf aging; however, it also delays physiological maturity, which may reduce cotton production (Wang *et al.*, (2023). The date of planting has an impact on cotton production; thus, choosing the right date to sow is crucial for maximizing yield and growth (Tlatlaa *et al*., 2023).

The narrowest plant spacing produced the highest yields of lint cotton and seed. The best fiber and earliness traits were obtained with wide plant spacing. When it comes to planting dates, 10 cm spacing outperformed 15, 20, 25, 30, and 35 cm spacing by 1.09, 2.12, 3.76, 5.05, and 6.58%, respectively, in terms of seed cotton yield. These results are consistent with those of Ali *et al.*, (2010), Zaman *et al*., (2021) and Zhi *et al*., (2022), who reported that narrow plant spacing produced the best results for seed cotton yield, monopodial and sympodial branch traits, and that wider plant spacing increased monopodial branches, boll weight, staple length, and fiber fineness traits. Taller plants with more leaves per plant were produced by cotton planted at lower plant densities, but higher densities produced more branches, fruiting nodes, and bolls per unit of the ground surface (Khan *et al*., 2020). In contrast to narrow plant spacing, there was a mixed effect of broader and narrower plant spacing on cotton productivity and fiber quality (Zaman *et al*., 2021). The tendency for boll weight decreased as plant spacing shrank. Less competition between plants resulted in a greater number of branches per plant and a higher boll weight in wider spaces (Zaman *et al*., 2021; Alsalem *et al*., 2022; Zhi *et al*., 2022). Wider spacing between heavier bolls could indicate reduced competition among cotton plants, leading to efficient use of available resources (Zaman *et al.*, 2021). Plant height, fruiting behavior, maturity, and ultimate production are all impacted by plant density, along with light interception, moisture availability, nutrient uptake, humidity, and weed infestation (Stephenson *et al*., 2011; Ibrahim *et al*., 2022). According to Parlawar *et al*., (2017), a high plant population is the reason for the maximum seed cotton yield with narrow spacing. Narrower plant spacing resulted in the maximum seed cotton yield, according to studies by Ali *et al.*, (2010); Zaman *et al.*, (2021) and Li *et al.*, (2023b). Closer spacing results in a larger yield since the plant grows taller in vertical space and generates more leaves and sympodial branches per plant, additionally, more plants are produced per unit area (Zaman *et al*., 2021). In comparison to high plant densities, an ideal plant density not only boosts productivity but also uses fewer inputs without reducing yield (Zhi *et al*., 2016; Khan *et al*., 2020).

Based on the effects of first- and second-order interactions, our results showed that the February planting date with the smallest plant spacing boosted cotton yield and most examined traits, especially fiber properties like strength and length fiber. Conversely, the better position of the first fruiting node, the number of fruiting branches (in 25 January), boll weight, and fiber fineness traits (in 25 March) were observed by the wide plant spacing under study. For strength, fineness, and uniformity, there was a planting date-by-year interaction, though, with late planting producing more uniform fibers in growing years and early planting producing lower lint yield, fiber strength, and higher fiber fineness values than late planting (Sarah, 2023). The maximum production was found in plots with narrow plant spacing sown on an early planting date; this may be because these plots had the ideal plant population per unit area. The interaction between plant spacing and planting dates was similarly important for seed cotton yield (Awan *et al.*, 2011). Under conditions of high plant density, reproductive dry matter had the greatest direct impact on seed cotton yield. Thus, it can be inferred that an early planting date contributed to the mobilization of photosynthates, whereas a high plant density contributed to the formation of more reproductive dry matter (Ali *et al*., 2009). According to Iqbal and Khan (2011), high seed cotton production can be attained by early planting at high plant spacing and late planting at low plant spacing.

During the planting dates and planting distances spread over two years, the reciprocal relationships among the majority of the variables under study were positive and either significant or insignificant ($p < 0.05$ or 0.01). Our correlation results agreed with many previous studies on planting dates and planting distances. Seed cotton yield was positively and significantly correlated with some cotton traits under different sowing dates (Huang 2016; Khalid *et al*., 2018; Ishaq *et al.*, 2022), and under plant density (Jalilian *et al*., 2023). Under plant spacings, a positive association was observed between boll weight and all other parameters (Zaman *et al*., 2021). Under certain sowing date and plant density conditions, crop corn seed yield exhibited a positive and substantial link with several quantitative features (Rabbani and Safdary, 2021).

To determine the correlations between the cotton traits across experimental factors under study, principal component analysis (PC) has been employed. More than 69.74% of the variance in all the variables examined under planting dates and planting distances during the growth seasons is explained by PC1 and PC2. Likewise, the first two PCs contributed 60.90% and 66.80% towards variability under planting dates and plant density, according to Sarwar *et al*., (2021) and Jalilian *et al.,* (2023), respectively. About 39.99% of the overall variability in the measured data for the original variables was explained by PC1. Increases in seed cotton yield, lint cotton yield, lint percentage, fiber fineness, and fiber strength properties under narrow plant spacing at the February planting date are thought to be highly dependent on PC1. On the other hand, PC2 appears to reflect the traits of uniformity ratio, upper half mean length, boll weight, and seed index with a 35 cm spacing during the March planting date. Therefore, PC1 and PC2 can be understood as responses to the experimental conditions that have both positive and negative effects on cotton yield, its component traits, and fiber quality properties. These results are consistent with those by Sarwar *et al.*, (2021). The biplot analysis of the relationship between the variables studied revealed that the Egyptian cotton variety Giza 95 under narrow plant spacing at the February planting date gave the highest cotton yield in sand soil conditions at the Toshka region of Egypt.

CONCLUSION

A three-way ANOVA revealed significant differences between the years, planting dates, planting distances, and their first-order interactions for the cotton yield and the majority of the traits assessed. The production and quality of cotton are greatly influenced by the year and climate. Seed cotton yield was positively and significantly correlated with some cotton traits under different planting dates and planting distances. Based on the three-way ANOVA and PCA, our results showed that the February planting date with the smallest plant spacing boosted cotton yield and most examined traits, especially fiber properties like strength and length fiber. Ultimately, to maximize the yield and quality fiber of Egyptian cotton in the Toshka region of Egypt, it is advised to sow the Egyptian cotton variety Giza 95 with narrow plant spacing on the 25 February planting date.

Funding: Not applicable.
Conflict of Interest: The authors declare no conflict of interest

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تحسين جودة وإنتاجية القطن تحت نظام الري بالتنقيط بمنطقة توشكي، مصر

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يعد القطن من أهم ألياف النسيج الطبيعية ومحصول نقدي في مصر. تعد مواعيد الزراعة ومسافات الزراعة من العوامل المهمة لتحقيق أقصى قدر من إنتاجية القطن وجودة الألياف. في ظروف منطقة توشكي بمصر، تم تنفيذ تجربتين حقليتين خلال موسمي النمو 2021 و2022 بمحطة مجمع الدراسات والبحوث المائية بالمركز القومي لبحوث المياه، توشكي، مصر، لدراسة تأثير ثلاثة مواعيد زراعة (25 يناير، 25فبراير، 25 مارس) وستة مسافات زراعة (10، 15، 20، 25، 30، 35 سم بين النباتات) مع الري بالتنقيط على المحصول ومكونات المحصول وصفات جودة الألياف لصنف القطن المصري جيزة 95. أظهرت النتائج أن سنوات النمو ومواعيد الزراعة ومسافات الزراعة وتفاعلاتها من الدرجة الأولى كان لهم تأثيرات معنوية (P<0.05 or 0.01) على صفات المحصول ومعظم صفات مكونات المحصول وجودة الألياف. كما أوضحت النتائج أن قيم معامل الاختلاف كانت منخفضة لمحصول القطن وجميع الصفات المدروسة. كما يتأثر إنتاج ونوعية القطن بشكل كبير بالسنة والمناخ. أظهر الصنف جيزة 95 في موعد زراعة فبراير مع أقل مسافة للزراعة أعلى إنتاجية لمحصول القطن ومعظم الصفات قيد الدراسة وخاصة صفتي متانة وطول الألياف. بالنسبة لمواعيد الزراعة، تم تحقيق زيادة في إنتاج محصول القطن الزهر بنسبة 3.55% و5.09% في ميعاد زراعة شهر فبراير مقارنة بمواعيد زراعة شهري مارس ويناير، على التوالي. وفيما يتعلق بمسافات الزراعة، تفوقت مسافة الزراعة 10 سم على مسافات 15، 20، 25، 30، 35 سم بمقدار 1.09، 2.12، 3.76، 5.05، و6.58% على التوالي من حيث محصول القطن الزهر. أشارت النتائج الى أن محصول القطن الزهر قد ارتبط معنويا (P<0.05 or 0.01) ببعض صفات القطن المدروسة تحت مواعيد ومسافات الزراعة المختلفة. يمكن أن تكون نتائج تحليل التباين الثلاثي ومعامل الارتباط وتحليل المكون الرئيسى (PCA) من دراستنا مفيدة وتستخدم لتحسين إنتاجية القطن في ظل مواعيد الزراعة ومسافات الزراعة. بناءً على هذه التجارب، نستنتج أن موعد الزراعة في 25 فبراير تحت مسافة 10 سم بين النباتات هو الأمثل للحصول على إنتاجية عالية من محصول القطن وأفضل خصائص جودة للألياف في التربة الرملية بمنطقة توشكي في مصر.

الكلمات المفتاحية: مواعيد الزراعة، مسافات الزراعة، محصول القطن، جودة الألياف، الارتباط، تحليل المكون الرئيسي.