

Influence of Variable Thermal Regimes and Locations on Growth, Yield and Fiber Quality Dynamics of Cotton

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ABSTRACT

Sowing time and different ecological conditions affect cotton growth, yield, fiber quality, and economic returns. The current study was established to uncover the effects of different sowing dates of cotton grown under the different ecological conditions of Pakistan. A two-year (2016-2017) experiment was done with different sowing dates (S₁: March 01, S₂: March 15, S₃: April 01, S₄: April 15, S₅: May 01, and S₆: May 15) and ecological conditions (Faisalabad, Khanpur, Sakrand, and Dera Ismail Khan) with the randomized complete block design using split plot design with three replications. Results showed that the highest leaf area index, leaf area duration, crop growth rate were noted at Sakrand location while net assimilation rate was maximum at Faisalabad location. The highest plant height, total bolls plant⁻¹, and sympodial branches plant⁻¹, 100-seed weight and seed cotton yield were noted at Sakrand location and monopodial branches plant⁻¹ Dera Ismail Khan Location. Moreover, fiber uniformity index, micronaire value, staple length, and staple strength were best at Khanpur location followed by Sakrand, Dera Ismail Khan and Faisalabad locations. While the best time of sowing for getting higher growth, fiber quality and yield related attributes as 15th of April where seed cotton yield was producing 26.5% and 31.5% higher cotton yield than early (1st March) as well as late (15th May) sowing dates, respectively. The maximum seed cotton yields and better-quality fiber were attained when the temperature during the growth season of the crop was warm in nature along with little rainfall creating a warm-dry climate in arid to semi-arid areas of Pakistan.

Keywords: cotton, fiber, quality, sowing dates, ecology, yield.

INTRODUCTION

Cotton has been associated with ancient civilizations and has made significant contributions to the industrial and economic growth of many countries (Tokel et al., 2022). Cotton is the most valuable significant cash crop in the world, despite intense competition from man-made fibres, the demand for cotton goods has secured its longevity as one of the world's most extensively grown crops (Broadberry and Gardner, 2022). The planting time is a major concern which plays a key role in high

production and good quality of cotton. Fiber value count depends on cotton fiber yield and quality (Mathangadeera et al., 2020). The inheritance enhancements in yield and quality indicators by cotton breeders have contributed to more attractive lint to textile industry, however, the poor management practices and climate conditions badly influence the fiber quality (Anu et al., 2022). The occurrence of high temperatures (45-48°C) during the cotton-growing season, particularly in the early and mid-season, reduces the cotton crop's potential output in the arid to semi-arid climatic conditions (Shah et al., 2017;

Majeed et al., 2019). It is widely assumed that flowers blooming in July and August cannot give good quality lint due to the improper opening of bolls caused by the high temperatures prevalent during this growth period (Shah et al., 2017; Tariq et al., 2017; Ahmad et al., 2018). As a result, early planting in March may lessen the risk of detrimental impacts from early and mid-season high temperatures (Abbas and Ahmad, 2018; Brar and Singh, 2022). Cotton planting during high temperatures increases the risk of exposing cotton seedlings to heat stress, resulting in a low plant population (Virk et al., 2021). Under late sown cotton, the growing degree days to emergence, square formation, flower initiation, bolls formation and opening were high. Moreover, early sown cotton the sympodial branches, bolls plant⁻¹ and yield were more than late sown crop (Shah et al., 2017).

Previous study exhibited that the late cultivation of cotton decreases the yield and fiber quality (Usman and Ayatullah, 2016; Çopur et al., 2019). Callose and cellulose have the same structure but the ratio of callose in the cell wall of fiber increased the quality of fiber was decreased. The photosynthetic CO₂ fixation along with cellulose synthesis is influenced by ecological factors, making the fiber wall thick (Zhao et al., 2012). Moreover, sucrose and cellulose play vital role in fiber quality that is determined by different dates of sowing in cotton crop (Hu et al., 2016). The sowing date influences the quality indicators of cotton (Khan et al., 2017; Shah et al., 2017; Ahmad et al., 2018). Recently, Rezaei et al. (2024) also demonstrated that planting date significantly affects cotton lint yield and several fiber quality traits, including fiber length, strength, fineness and uniformity under contrasting environmental conditions. Their findings further emphasize that optimizing sowing time is an effective agronomic strategy for improving both productivity and fiber quality. Early sowing of cotton gets benefit of favorable environmental conditions before high temperature and low rainfall at flowering and fruiting stages (Afzal et al., 2020).

Late sowing of cotton significantly influenced micronaire and increased fiber length (Abbas and Ahmad, 2018). Seven days after anthesis the fiber and outer most covering of seed take maximum photosynthates and sharing photosynthates between reset of cotton seed and maintained the same fiber quantity (Abbas and Ahmad, 2018). In cotton seed, the length of fiber starts two days after anthesis and goes on till twenty-eight days (Rehman and Farooq, 2019). The cellulosic wall deposition commences after fifteen days that control fiber maturation (Zhang et al., 2020). Moreover, the extent of secondary wall deposition influences fiber micronaire and fineness (Niu et al., 2019). The increase in temperature fifty days after sowing have negatively impacted the micronaire and 150 days after sowing displayed the best results related to micronaire (Saleem et al., 2023). Hence, it is the dire need to produce high yielding and good quality cotton. Therefore, this study was done to determine the influence of the sowing dates on growth, yield and fiber quality of cotton at different cotton growing regions of Pakistan.

MATERIAL AND METHODS

Study site

Field trials were carried out during 2016 and 2017 at four diversified locations throughout cotton growing zone of Pakistan, i.e., Agronomy Research Area, University of Agriculture, Faisalabad [E° 73° 04, N° 31° 26, Altitude 184 m, Dry semi-arid (annual rainfall 346 mm)], Cotton Research Station (CRS) Khanpur, Rahim Yar Khan [(E° 70° 18, N° 28° 25, Altitude 80 m, Dry semi-arid (annual rainfall 231 mm)], Central Cotton Research Institute (CCRI) Sakrand [(E° 68° 27, N° 26° 14, Altitude 36 m, Dry arid (annual rainfall 72 mm)] and Cotton Research Station (CRS), D.I. Khan [(E° 70° 54, N° 31° 49, Altitude 165 m, Dry semi-arid (annual rainfall 268 mm)] and further details are given in Figure 1. The soil samples at depth 0 to 30 cm were collected with the help of soil auger before the sowing of experiments at all locations and composite samples were sent to soil fertility laboratories at respective sites for their physico-chemical

attribute determination. Various soil chemical attributes were determined following Homer and Pratt (1961). Soil texture as well as chemical properties were varied among the experimental sites such as Faisalabad [pH 8.0, organic matter (OM) 1.08%, available P 3.4 mg kg⁻¹, available K 182 mg kg⁻¹], Khanpur (pH 8.2, OM 0.84%, 10.8 mg kg⁻¹, available K 183 mg kg⁻¹), Sakrand (pH 7.76, OM 0.66%, available P 2.54 mg kg⁻¹, available K 154 mg kg⁻¹), and Dera Ismail Khan (pH 7.8, OM

0.89%, available P 7.8 mg kg⁻¹, available K 180 mg kg⁻¹). The experiment was executed in RCBD with split plot arrangement considering the four locations (Faisalabad, Khanpur, Sakrand, Dera Ismail Khan) as main plot and 6 sowing dates (S₁: March 01, S₂: March 15, S₃: April 01, S₄: April 15, S₅: May 01, S₆: May 15) as sub plots. The treatments were repeated thrice for statistical evaluation with net plot size of 7 m × 4.5 m. The Bt. cotton variety FH 142 was used as a test variety in the study.

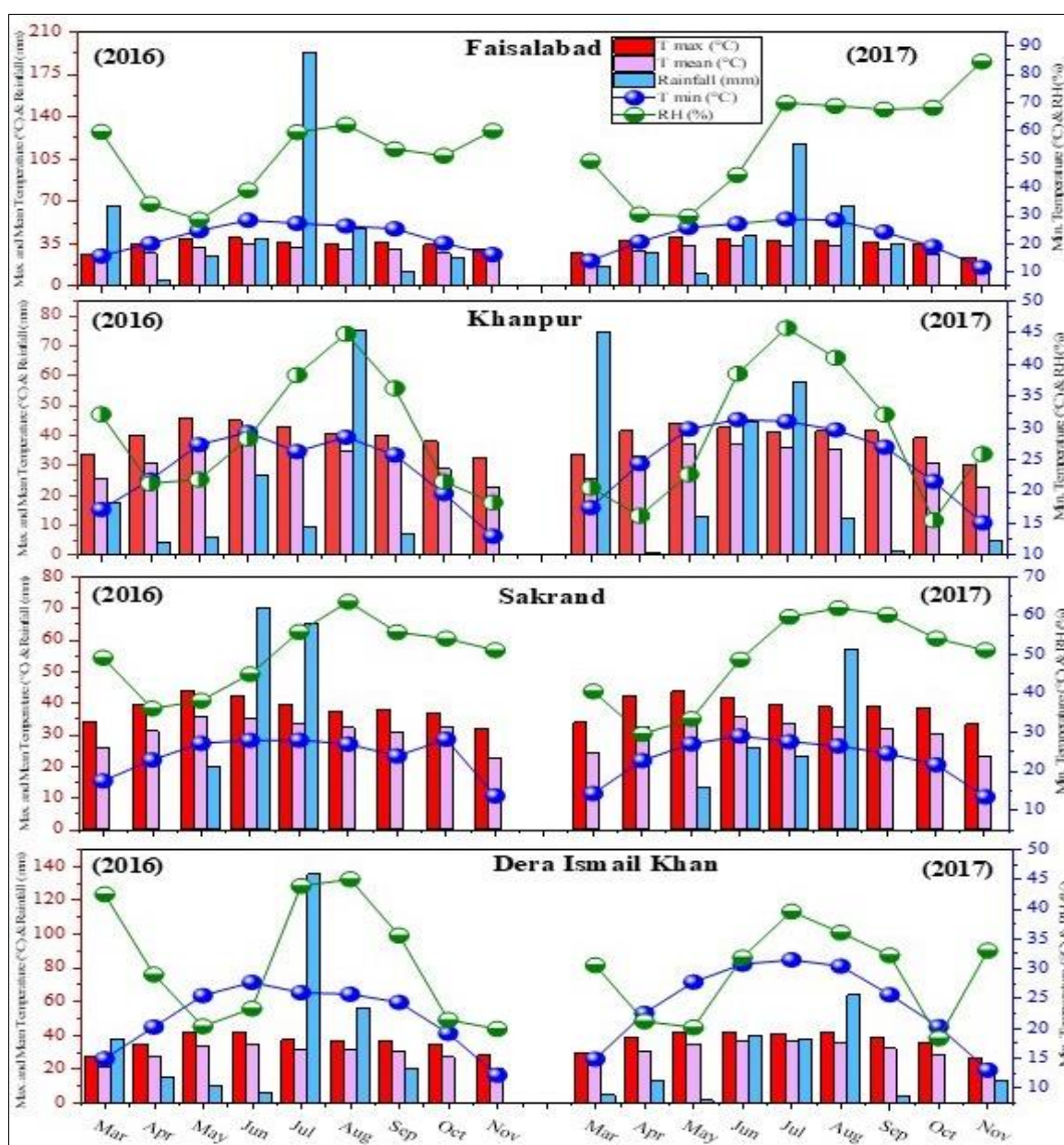


Figure 1. Weather conditions at different experiments sites during 2016 and 2017

Crop husbandry

A fine seed bed was prepared by alternate ploughing and planking after getting laser levelled field. Beds of recommended geometry were prepared with the help of tractor mounted bedder at all the locations throughout both years of investigations. Seed was sown on beds on recommended geometry, manually, keeping seed rate of 20 kg delinted seed per hectare keeping beds (75 cm apart) and plant to plant distance of 30 cm. Nitrogen (N) in the form of Urea (46% N₂O) was applied at the rate of 125 kg ha⁻¹ in 3 equal splits. 1/3rd of N and 100 % of Phosphorus and potash (75 kg PK per hectare) in the form of TSP (46 % P₂O₅) and SOP (50% K₂O) were broadcasted at the time of sowing while remaining N splits were side dressed at squaring and peak flowering stages of the crop. For effective weed control, pre-emergence herbicide spray (Pandimethalin) was carried out on 2nd day of sowing @ 2.5 L ha⁻¹. Plant population of 55,000 plants ha⁻¹ was maintained by thinning and gap filling practices where applicable. Good agricultural practices were adopted for better pest control, weeds and insect pest management. The management practices was standardized in terms of sowing date, number of irrigation, fertilizer application and weed management.

Crop growth and yield indicators

From each plot, three plants were harvested randomly from the ground level at 30 days interval after the crop establishment keeping an appropriate border during both years of experimentation. Fresh weight of all plant parts including leaves, stem, squares, flowers and bolls was measured by using an electronic balance. Sample of 10 g from stem and 5 g from leaves was first sundried for 48 hrs and then oven dried weight was estimated after keeping in an oven at 65°C till the constant weight. Crop growth rate was determined from the gain in dry weight (W₂-W₁) over time between two sampling dates (T₁ and T₂) as suggested by Hunt (1982). Leaf sub ample of 5 g leaf lamina was also used for the measurement of leaf area by portable leaf area meter (model CI-202, CID, inc. USA). Leaf area index (LAI) was

determined from this leaf area as the ratio between leaf area and land area. The capacity of the plant leaf to be useful for photosynthesis process was denoted by leaf area duration (LAD) which was calculated by

$$(LAI_1 + LAI_2) \times (T_2 - T_1) / 2$$

where LAI₂ and LAI₁ were leaf area indices at time T₂ and T₁, respectively (Hunt, 1978). Individual LADs were added to get cumulative LAD during the whole crop growing season. Net assimilation rate (NAR) is the efficiency of plant photosynthesis structure to produce plant biomass per unit leaf area index in a unit time. It was calculated as the ratio of total dry matter accumulation to cumulative LAD (Brown, 1984).

Fifteen randomly selected plant's height was measured with the help of a meter rod from basal node to the plant tip and averaged. Similarly, count the total number of bolls, number of monopodial branches plant⁻¹ and number of sympodial branches plant⁻¹ and then the averaged. The picked bolls were ginned out and 100 seeds were counted from each plot. The weight of 100 seeds was estimated by using weighing balance.

Fiber quality Parameters

A micronaire is a measure of lint's surface area, which is an indirect indicator of maturity and fineness (i.e., thickness or development of the cell wall). Mike is the average weight, measured in micrograms per inch of fibre, per unit length. Fibre strength, fineness, and spinning efficiency are all described by fibre length. The measurement of fibre strength is expressed in terms of grammes of breaking load per tex, or breaking tenacity.

Statistical analysis

The data on phenology, growth parameters, biomass production, and final cotton yield were analysed using Fisher's analysis of variance technique, and the significance of treatment means was tested using the Tukey's honest significant difference (HSD) test at a 5% probability level.

RESULTS AND DISCUSSION

Crop growth indices

LAI increased gradually until the reproductive stage, reached a maximum, and declined toward crop maturity. The maximum leaf area index varied significantly among locations and sowing dates. It was noted that LAI max was gradually increasing till 15th April at all locations except Khanpur, where it reached its peak in 1st April sowing and then there was reduction in attaining maximum LAI value during both cropping

seasons (Table 1). However, the trend of maximum LAI was different with respect to sowing date at all locations during course of study. Two years mean values also confirmed the already described pattern of LAI at all locations and there was 12.77% increase in LAI at Sakrand in comparison with LAI at D.I. Khan. It was also shown that 15th April sowing attained 14.96 and 17.33% higher LAI than 1st March and 15th May sowing, respectively, which showed significant impact in increasing total crop biomass and seed cotton yield from this sowing date.

Table 1. Influence of sowing date at different locations on leaf area index, leaf area duration, crop growth rate, and net assimilation rate

Treatment	Leaf area index			Leaf area duration			Crop growth rate			Net assimilation rate		
A) Locations	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Faisalabad	3.78 c	3.67 b	3.72 C	341.67 b	337.95 c	339.81 C	10.33 b	8.70 b	9.51 B	4.46 a	4.07 a	4.27 A
Khanpur	4.03 b	3.93 a	3.98 B	380.99 a	377.45 b	378.97 B	8.53 c	8.30 c	8.41 C	3.29 d	3.43 c	3.36 D
Sakrand	4.15 a	3.99 a	4.07 A	378.79 a	390.88 a	384.81 A	10.87 a	9.60 a	10.24 A	4.18 b	3.78 b	3.98 B
D I Khan	3.71 c	3.39 c	3.55 D	321.22 c	314.08 d	317.65 D	8.22 c	7.95 c	8.09 D	3.76 c	3.93 ab	3.84 C
HSD (5%)	0.121	0.115	0.072	6.640	4.973	3.557	0.247	0.361	0.129	0.109	0.169	0.070
Significance	**	**	**	**	**	**	**	**	**	**	**	**
B) Sowing Time												
1 st March	3.70 de	3.46 c	3.58 C	356.85 d	347.76 c	352.31 C	9.30 cd	9.76 a	9.53 A	3.92	4.24 a	4.08 A
15 th March	3.92 c	3.74 ab	3.83 B	376.11 c	370.24 b	373.17 B	9.66 c	9.42 ab	9.54 A	3.87	3.86 b	3.86 B
1 st April	4.15 b	4.04 a	4.09 A	395.33 b	384.94 a	390.13 A	10.13 b	9.08 bc	9.60 A	3.88	3.59 c	3.73 C
15 th April	4.36 a	4.06 a	4.21 A	403.10 a	385.24 a	394.17 A	10.53 a	8.69 cd	9.61 A	3.93	3.50 c	3.72 C
1 st May	3.84 cd	3.74 b	3.79 B	341.88 e	348.67 c	345.28 D	9.02 d	8.26 d	8.64 B	4.03	3.71 bc	3.87 BC
15 th May	3.53 e	3.44 c	3.48 C	259.98 f	259.30 d	276.83 E	8.27 e	6.63 e	7.45 C	3.91	3.92 b	3.92 B
HSD (5%)	0.179	0.160	0.118	6.731	9.304	5.970	0.368	0.469	0.314	-	0.235	0.153
Significance	**	**	**	**	**	**	**	**	**	NS	**	**
Interactions (A×B)	**	**	**	**	**	**	**	NS	**	**	NS	**
Year Mean	3.92 A	3.75 B		355.54	355.09		9.48 A	8.64 B		3.92	3.80	

During 1st year of experimentation, the highest LAD was achieved at Khanpur site in 1st April sowing date which was closely followed by 15th April sowing at Khanpur as well as Sakrand site. It was noted that LAD was gradually increased up to 15th April sowing date at all locations except Khanpur, where it was found in 1st April sowing date and there was sharp decline during last two sowing dates and the lowest LAD was found in 15th May sowing date. The LAD behavior during 2nd year of study was different from 1st year and there was incremental attitude from first sowing date towards 3rd sowing date (1st April) at Faisalabad and D.I. Khan site whereas this attitude was prolonged up to 4th sowing date (15th April) at Khanpur and Sakrand location. The highest LAD was also

in 15th April sowing date at Sakrand which was also closely followed by the same sowing date at Khanpur along with 2nd and 3rd sowing dates at Sakrand site, respectively.

The mean CGR varied between the crop growing seasons and 1st year gave higher (4.95%) crop growth rate than 2nd year of study. The interactive effect of sowing dates at varied locations was noted significant during 1st year of the study while it was found non-significant during 2nd year of the experiment (Table 1). The variation among crop growth rate at different sowing dates was prominent in Sakrand site where the maximum crop growth rate was observed in 15th April sowing while at other locations the sowing dates showed narrow differences. The increasing trend of CGR was observed at

Faisalabad, Sakrand and D.I. Khan locations till mid of the April while this was restricted to 1st April sowing at Khanpur location.

Two year mean data depicted that sowing date and locations had significant effect on NAR individually as well as interactively. The data revealed that the assimilation rate was higher in early sowings at all locations and there was gentle decrease while moving towards normal sowing window and even in May sowings at Sakrand, while there was again upright in NAR in these sowings at other three locations under study. The maximum NAR was noted in 15th May sowing in Faisalabad location which was closely followed by 1st March sowing date at the same station. The lowest NAR was noted on 15th April sowing at Khanpur location which was also similar with 15 days earlier and later sowing date at the same location.

Plant height was significantly affected by different sowing dates at all locations, but it was non significantly different during the two crop years ($P > 0.05$). Two-year mean data depicted that the maximum plant height (185.53 cm) was attained at Sakrand location which was significantly higher (19.83, 31.64 and 35.22%) than Khanpur, Faisalabad and D I Khan location. The highest plants at Sakrand confirmed the favorable environment for cotton plant at this site

(Table 1). The plant height was also significantly different among sowing dates and the maximum plant height (161.29 cm) was found in 1st March sowing which was 3.69 and 6.83% higher than subsequent sowing dates (15th March and 1st April), respectively but it was statistically similar with these sowing dates. The taller plants in 1st March sowing were due to longer plant growing season and more solar radiation accrual during plant life.

Fiber indices

Total bolls were significantly more (2.72%) during 2016 than 2017 crop season. The change in boll setting behavior of different sowing dates during both years was due to climatic variability between the two seasons as the 1st year was cooler than 2nd year and there was more rainfall during March and April 2016 than 2017, which was dryer than the earlier one. The maximum bolls (70.67) were produced at Sakrand which was significantly higher (31.45 and 16.36 %) than Khanpur and Faisalabad, respectively during 2016, while the minimum bolls per plant (46.39) were given at D.I. Khan location which were 34.35% lower bolls than Sakrand. The similar trend among the locations was observed during 2nd year of experiment (2017).

Table 2. Influence of sowing date at different locations on plant height, total bolls plant⁻¹, sympodial branches plant⁻¹, and monopodial branches plant⁻¹

Treatment	Plant height (cm)			Total Bolls plant ⁻¹			Sympodial branches plant ⁻¹			Monopodial branches plant ⁻¹		
A) Locations	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Faisalabad	114.67 c	139.00 b	126.83 C	48.44 bc	54.78 b	51.61 C	29.94 b	16.78 c	23.36 C	1.89 b	1.55 b	1.72 B
Khanpur	151.22 b	146.83 b	149.03 B	59.11 b	60.05 ab	59.58 B	30.89 b	14.23 c	22.56 C	1.78 b	2.28 b	2.03 B
Sakrand	188.24 a	182.82 a	185.53 A	70.67 a	63.67 a	67.17 A	37.64 a	39.98 a	38.81 A	1.16 b	3.78 a	2.47 B
D I Khan	98.83 c	141.50 b	120.17 C	46.39 c	40.00 c	43.19 D	31.44 b	23.22 b	27.33 B	4.89 a	2.56 b	3.72 A
HSD (5%)	17.849	26.103	13.557	11.272	6.339	5.544	5.141	4.639	2.969	1.551	1.219	0.846
Significance	**	**	**	**	**	**	**	**	**	**	**	**
B) Sowing Time												
1 st March	158.31 a	164.27 a	161.29 A	55.92 ab	60.08 a	58.00 A	40.19 a	27.19 a	33.69 A	3.48 a	3.92 a	3.70 A
15 th March	151.87 ab	158.79 a	155.33 AB	57.92 ab	62.81 a	60.37 A	36.31 b	26.05 a	31.18 B	3.04 ab	3.33 ab	3.18 AB
1 st April	147.00 ab	153.51 a	150.26 AB	60.57 a	56.31 ab	58.44 A	34.42 bc	25.20 a	29.81 B	2.62 a-c	2.67 bc	2.64 BC
15 th April	137.07 c	158.65 a	147.86 B	63.43 a	57.02 ab	60.23 A	32.10 c	22.44 b	27.27 C	2.26 b-d	2.17 cd	2.21 CD
1 st May	123.09 cd	146.76 ab	135.42 C	52.97 bc	49.73 bc	51.35 B	28.22 d	21.53 b	24.87 D	1.76 cd	1.75 de	1.76 DE
15 th May	112.10 d	132.26 b	122.18 D	46.08 c	41.80 c	43.94 C	23.63 e	18.89 c	21.27 E	1.42 d	1.42 e	1.42 E
HSD (5%)	15.721	17.228	11.381	7.519	8.675	5.602	3.247	2.124	1.893	0.891	0.693	0.551
Significance	**	**	**	**	**	**	**	**	**	**	**	**
Interactions (A×B)	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Year Mean	138.24	152.54		56.15 A	54.62 B		32.48 A	23.58 B		2.43	2.54	

The number of sympodial branches per plant were 27.49% higher in 2016 than the 2nd year of study (Table 2). The maximum sympodial branches (37.64 and 39.98) per plant were produced at Sakrand site during 2016 and 2017, respectively. The lower fruit bearing branches were produced at D.I. Khan, Faisalabad and Khanpur during 2016 (16.47 to 20.45%) than Sakrand while during 2017, the overall reduction at these locations was more prominent (41.92, 58.02 and 64.41%).

The higher reduction during 2nd year may be due to more heat stress during the season at these sites as compared with Sakrand site. Sowing dates also gave varied number of direct fruit bearing branches and the maximum sympodial branches (40.19 and 27.19) were shown in early season planting (1st March) and a linear decreasing trend of these branches was observed with each 15 day delay in sowing till the last sowing date (15th May) during both years of study.

Table 3. Influence of sowing date at different locations on 100 grain weight and seed cotton yield (kg ha⁻¹)

Treatment	100 grain weight			Seed cotton yield (kg ha ⁻¹)		
A) Locations	2016	2017	Mean	2016	2017	Mean
Faisalabad	6.62 b	6.14 b	6.38 BC	2468.07 c	2357.59 c	2412.83 C
Khanpur	6.76 b	6.26 b	6.51 B	2712.37 b	2601.00 b	2656.68 B
Sakrand	7.66 a	3.13 a	7.39 A	3168.09 a	2748.22 a	2958.16 A
D I Khan	6.41 b	5.67 b	6.04 C	2267.23 d	1519.49 d	1893.36 D
HSD (5%)	0.664	0.709	0.417	97.94	133.40	64.05
Significance	**	**	**	**	**	**
B) Sowing Time						
1 st March	7.27 a	6.75 a	7.01 A	2452.02 d	1923.47 d	2187.75 C
15 th March	7.24 a	6.59 ab	6.92 A	2679.39 c	2458.24 b	2568.82 B
1 st April	6.99 ab	6.26 bc	6.62 B	2964.33 b	2699.18 a	2831.76 A
15 th April	6.80 bc	6.00 c	6.40 BC	3193.17 a	2641.89 a	2917.53 A
1 st May	6.60 cd	6.13 c	6.36 BC	2554.05 cd	2223.76 c	2388.90 C
15 th May	6.26 d	6.07 c	6.16 C	2080.68 e	1892.91 d	1986.79 D
HSD (5%)	0.389	0.445	0.288	198.36	158.21	128.31
Significance	**	**	**	**	**	**
Interactions (A× B)	NS	NS	NS	**	**	**
Year Mean	6.86	6.30		2653.94 A	2306.58 B	

Means within column sharing unlike letters are dissimilar from each other at 5% probability.

Two year mean data disclosed that the maximum monopodial branches (3.72) were produced in D I Khan location which showed significantly higher (33.60 to 53.76 %) vegetative growth than other experimental sites. The over vegetative growth may retard crop yield potential in D.I. Khan conditions. The early sowing dates also enhanced crop vegetative growth prominently and the maximum number of monopodial branches (3.70) were observed in 1st March sowing which was also closely followed by 15th March sowing mainly due to prolonged growing season available to these sowing dates.

The overall decreasing trend was observed with each two-week delay in sowing date, reaching to the minimum (1.42) in last sowing date (15th May).

Yield parameters

The two year mean data explained that the maximum 100 seed weight (7.39 g) was given at Sakrand location showing an increase of 11.9 and 13.66% over Khanpur and Faisalabad sites, respectively while in D I Khan, 100 seed weight was remained 18.27 % lower than Sakrand conditions that may be due to more vegetative growth and comparatively unfavorable crop growing conditions over there (Table 3). Sowing date being the controlling factor of crop life span, the seed index was hence, varied among the sowing dates. The early sowing gave the maximum seed weight (7.01 g) due to longest crop growing season available to this sowing date. Seed weight was linearly decreased with each subsequent sowing date reaching to the minimum (6.16 g) in last sowing date which was 12.12% lower than the 1st one.

The final seed cotton yield was also significantly different among the locations, sowing dates and between the two comparative seasons. During 2016, overall crop yield ($2653.94 \text{ kg ha}^{-1}$) was more than the 2nd year of study (13.08%) mainly due to less heat stress and prolonged crop growing season (Table 3). The interactive effect of sowing dates on all four locations showed that the maximum crop yield was observed in 15th April sowing in Sakrand conditions during 1st year which was closely followed by 15 days earlier (1st April) and 15 days later sowing date in the same location during 2016. While during 2017, 15th April sowing date also proved best cotton producer but it was closely followed by crop sown on 1st April at same station, 1st April sowing at Faisalabad along with 1st April to 1st May sown crop in Khanpur conditions.

It was also shown that the cotton yield was increased till 15th April at Faisalabad, Sakrand and D.I. Khan condition but it attained its peak in 1st April sowing at Khanpur location during 2016 crop season while 1st April gave higher yields at Faisalabad and D.I. Khan conditions during 2nd year (2017).

Quality parameters

During 2016, the highest uniformity index was shown by 15th April sowing date in Khanpur conditions which was followed by 1st April sowing at the same station and 15th April sowing under Sakrand conditions (Table 4). The overall lower values were noted in DI Khan conditions. During 2017, the similar trend was observed in all sowing dates at all four locations. The results showed that during 2016, higher micronaire values were noted in Khanpur conditions while the lowest micronaire were observed in Faisalabad conditions which was also similar to Sakrand location where the values remained below 4 means good quality cotton was produced at these sites in comparison to other two locations. During 2nd year, once again Khanpur produced average quality cotton fiber while other sites gave fine thread quality of the cotton fiber. This may be due to frequent temporal fluctuations at Khanpur which reduced the fiber quality. The results also indicated that sowing dates showed significant effect on this important quality parameter and the finest fibers were collected at 15th April sowing date, whereas, early or late sowing gave lower quality fiber during both years of study.

Table 4. Influence of sowing date at different locations on uniformity index, micronaire value, staple length, and staple strength

Treatment	Uniformity Index (%)			Micronaire ($\mu\text{g inch}^{-1}$)			Staple length (mm)			Staple strength (g tex^{-1})		
A) Locations	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
Faisalabad	82.09 c	82.33 b	82.21 C	3.92 c	3.81 b	3.86 C	27.37	27.84 ab	27.60 AB	28.13 a	29.46 a	28.80 A
Khanpur	82.51 a	82.73 a	82.62 A	4.52 a	4.48 a	4.50 A	28.00	28.28 a	28.14 A	27.75 a	27.59 b	27.67 B
Sakrand	82.22 b	82.42 b	82.32 B	3.99 bc	3.91 b	3.95 BC	27.69	27.92 ab	27.80 AB	28.52 a	29.34 a	28.93 A
D I Khan	82.01 c	82.22 c	82.11 D	4.12 b	3.94 b	4.03 B	26.83	27.44 b	27.14 B	26.91 b	27.95 b	27.43 B
HSD (5%)	0.124	0.094	0.067	0.165	0.167	0.101	NS	0.751	0.645	0.783	0.835	0.491
Significance	**	**	**	**	**	**	**	**	**	**	**	**
B) Sowing Time												
1 st March	81.64 d	81.79 e	81.72 E	4.49 a	4.37 a	4.43 A	26.00 e	26.63 d	26.32 D	26.60 c	27.32 c	26.96 D
15 th March	81.97 c	82.13 d	82.05 D	4.29 b	4.20 b	4.24 B	26.96 cd	27.48 cd	27.22 C	27.47 bc	28.12 bc	27.80 C
1 st April	82.38 b	82.59 b	82.48 B	4.04 d	3.98 d	4.01 D	28.27 bc	28.65 b	28.46 B	28.09 b	28.83 b	28.46 B
15 th April	82.79 a	83.11 a	82.95 A	3.84 e	3.69 f	3.77 F	29.19 a	29.88 a	29.54 A	29.17 a	29.89 a	29.53 A
1 st May	82.40 b	82.59 b	82.50 B	3.99 d	3.90 e	3.95 E	27.29 c	28.02 bc	27.66 C	28.22 b	28.92 ab	28.57 B
15 th May	82.06 c	82.33 c	82.19 C	4.17 c	4.07 c	4.12 C	26.58 de	26.55 d	26.57 D	27.42 bc	28.42 b	27.92 BC
HSD (5%)	0.092	0.140	0.082	0.087	0.411	0.056	0.623	1.108	0.374	0.911	0.992	0.657
Significance	**	**	**	**	**	**	**	**	**	**	**	**
Interactions (A × B)	**	**	**	NS	NS	NS	NS	**	NS	**	**	**
Year Mean	82.21 B	82.42 A		4.14 A	4.04 B		27.47	27.87		27.83 B	28.57 A	

Staple length

Fiber length was mainly affected by sowing dates at all locations during 2016 crop season while their interactive effect was

found significant during 2017 (Table 4). During 2016, fiber length showed sigmoid behavior, lower values were observed during early season (1st and 15th March) sowing

dates which was linearly increased to maximum on 15th April sowing date, after which, it was once again lowered down towards last sowing date (15th May). During 2017, the longest fibers were obtained from 15th April sowing date in Khanpur conditions which was statistically like all mid-season sowing dates at all other locations under study, while the lowest fiber length was noted in 15th May sowing in D.I. Khan conditions which was similar to early sowing (1st March) at the same location. The non-significant results during 1st year at all locations was mainly due to cool temperatures due to more and scattered rainfall at all sites during crop growth period specially boll maturation period whereas during 2nd year, rainfall was less, and temperatures were warm and variable among the locations.

Staple strength

The overall data showed sigmoid behavior of fiber strength at all locations with changing sowing dates from 1st March to 15th May (Table 4). The data also depicted that the interactive effect of locations and sowing dates was significant during both years. During 2016, the strongest fibers were obtained in 15th April sowing in Sakrand conditions which was similar with the same sowing date at all other locations while the lowest values were observed in early as well as late sowing dates. During 2017, the maximum staple strength was obtained in mid-season sowing date (15th April) at Faisalabad location which was also similar with the same sowing date at other locations. The lowest staple strength was noted at Khanpur and D.I. Khan location in early sowing date (1st March).

The semiarid and subtropical origin is best for the cultivation of cotton but it is recurring to arid situation and high temperature (Jabran et al., 2019). However, the planting time is a major concern which plays a key role in high production and good quality of cotton and other crops (Mathangadeera et al., 2020). Planting period has a direct impact on the cotton growth parameters (LAI, LAD, CGR,

and NAR), which are very susceptible to temperature fluctuations (Ali et al., 2021). Our trial outcomes confirmed the results of Khan et al. (2017) who found that optimum sowing dates had significantly and positively improves plant growth. Likewise, a cotton crop's ability to grow is positively impacted by optimal sowing, while growth tends to decline with delayed sowing (Huang, 2016). Timely planting, thus, maximizes growth time, LAI, and LAD, which enhances radiation interception and yields maximum production of total dry matter (Kaur et al., 2023). Ullah et al. (2016) noted that cotton sown on 15th April and 1st May gave highest total dry matter, LAI and LAD whereas too late or early sown demonstrated lowest growth indicators as they receive less units of heat. Under late sown, the crop needs more water and nutrients in such conditions, the higher soil temperature has a detrimental effect on crop growth and development from emergence to maturity (Xu et al., 2022).

Numerous researchers worldwide have identified sowing time as a critical component of cotton cultivars (Salih, 2019). Growers should choose the right sowing time for a crop of cotton in order to maximize production and quality, as there are noticeable environmental influences on cotton growth, yield, and lint quality. It can be challenging to determine when the optimum time is to sow in a certain area since one must weigh the risks of planting too late and losing potential yield or planting too early and suffering from issues related to cold weather (Liu, 2013). The maximum plant height was found in 1st March sowing on Sakrand. However, maximum height when the crop was sown 15th of March. Similar outcomes were noted that the highest bolls plant⁻¹, boll⁻¹, and seed cotton yield, on April 15th sowing (Ullah et al., 2019). Many researchers have concluded that sowing dates has profound effect on plant height and more bolls, sympodial and monopodial branches of the cotton crop and longer growing season mostly gave taller plants (Arshad et al., 2017; Bilal et al., 2019). Cotton cultivars planted late in the growing season have an impact on

the bolls shedding that reduced the cotton yield (Deho et al., 2021). The maximum total bolls, and 100-seed weight and seed cotton yield were obtained on April 30th sowing (Mehboob et al., 2020). The cotton crop that was sown early showed the high cotton yield (Bilal et al., 2019). In our current study, the maximum 100 seed weight was recorded at Sakrand location followed by Khanpur and Faisalabad sites. The early sowing gave the maximum seed weight due to the longest crop growing season available to this sowing date. Seed weight was linearly decreased with each subsequent sowing date. The highest seed yield was obtained at Sakrand site followed by Khanpur, Faisalabad, and DI Khan sites. Cotton yield was increased till 15th April, but it attained its peak in 1st April sowing (Table 3). These results confirm the findings already reported by Mohamed et al. (2016), Bilal et al. (2019) and Mehboob et al. (2020), they reported significant differences among the sowing dates regarding cotton yield and seed weight.

The higher micronaire values, fiber length, and uniformity index were noted in Khanpur conditions while strongest fibers were obtained at Sakrand conditions. Similarly, Abbas and Ahmad (2018) noted the change in micronaire, fiber length, fiber strength, and uniformity index values confirmed the significant impacts of either high temperature stress during boll formation in early sowing dates or colder nights during this phase of the crop in late sowing dates. Zhao et al. (2012) late sowing of cotton, decreased micronaire, fiber length, and fiber strength decreased. However, Pettigrew (2008) reported that higher temperature lessens the fiber length and enhanced the fiber maturity. Previous studies also exhibited that the early and late cultivation of cotton decreases micronaire, fiber length, fiber strength, and uniformity index (Usman and Ayatullah, 2016; Çopur et al., 2019).

CONCLUSIONS

The results demonstrated that sowing on 15 April consistently produced the highest seed cotton yield across the evaluated environments. Among the evaluated

environments, Sakrand produced the highest seed cotton yield and superior fiber quality, likely because its warm and relatively dry climate provided favorable conditions during reproductive growth. Consequently, under the climatic conditions evaluated in this study, warm and relatively dry environments combined with optimum sowing time favored cotton productivity and fiber quality. In addition, for the purpose of advising farmers on the growth, yield, and quality of cotton plants, these findings provide useful information for developing location-specific sowing recommendations for cotton production. However, cotton genetic regulation under these treatments required further knowledge to extend.

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