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EVALUATION OF DIFFERENT GENOTYPES OF COTTON (*GOSSYPIUM HIRSUTUM* L) UNDER MULTI-ENVIRONMENT AND MULTI SOWING TIME FOR STABILITY OF FIBER QUALITY AND PRODUCTION; A COMPREHENSIVE TWO-YEAR STUDY

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Abstract

The production of cotton is delayed by the global differences in environmental conditions. A two-year field study was conducted in 2021 and 2022 at experimental fields in Baluchistan and Sindh investigated the impact of two sowing dates on yield and quality indicators within three cotton genotypes. A split plot within a randomized complete block design was established three replications, with the main plots assigned into two sowing dates (March 30th and April 30th in both years) and three genotypes: CRIS-510, CRIS-543, and CRIS-585 were designated in subplots. The analysis showed that delayed planting led to enhanced vegetative growth but failed to boost lint percentage and overall yield. In contrast, earlier planting facilitated flowering and boll development under lower temperatures. Genotypes CRIS-543 and CRIS-585 exhibited the highest plant height, bolls per plant, boll weight, and cotton seed yield per hectare, along with superior lint percentage (ginning out turn), fiber length, micronaire value, and fiber strength when sown on April 30th compared to March 30th at the experimental site in Baluchistan relative to Sindh. The findings revealed that overall genotype of CRIS-543 significantly performed better than CRIS-510 and CRIS-585 in term of cotton yield and fiber quality in Baluchistan, particularly when sown on April 30th. However, sowing before or after March 30th resulted in lower performance, possible due to a shorter and less favorable growth period. Optimal sowing time around April 30th allowed genotype CRIS-543 to fully utilize the growing season, and resulted in higher yield and better fiber quality. These results emphasize the importance of genotypes selection and accurate sowing time for maximizing the cotton production. This research has broader implication for cotton production in Pakistan, as it provides region specific recommendation that can help farmers in Baluchistan and Sindh to improve yield and fiber quality, contributing to sustainability and profitability of the national cotton sector.

Key words: Genotypes; Sowing times; Cotton yield traits; Fiber quality; Agronomic traits; Growth period; Environmental interaction; Sindh, Baluchistan

Introduction

Cotton (*Gossypium hirsutum* L.) is an important cash crop in Pakistan, substantially impacting the nation's economy via the textile industry (Ishaq *et al*., 2022). Besides fiber, it provided cottonseed cake and oil. Agriculture constitutes the foundation of Pakistan's economy, with cotton representing 0.8% of GDP in the 2019-2020 economic survey. Cotton cultivation rose by roughly 6.5% from 2019 to 2020, escalating from 2.37 to 2.52 million hectares. The cotton yield decreased by 6.9%, from 9.86 million bales to 9.17 million bales, with an average yield of 617 kg per hectare. Climate change, elevated temperatures, pH levels, humidity, salinity, sunshine, heightened insect pest infestations, erratic rainfall during reproductive growth, and availability of water, air, and soil (The Economic Survey of Pakistan 2020). Environmental and organizational factors, including sowing timing, site and genotype selection, planting density, water and nutrient application, and rainfall management, significantly influence optimal economic output. The indeterminate growth habit of cotton adapts to variations in plant population density and sowing dates by morphologically modifying its growing environment and altering canopy structure (Wells & Stewaert, 2010).

Selecting optimal planting dates for cotton genotypes is essential for enhancing crop yield and pest control (Ahmed & Hasanuzzaman, 2020; Iqbal *et al*., 2020). An optimal sowing period enhances cotton yield by postponing flowering prior to the onset of biotic stressors, including bacteria, viruses, fungi, nematodes, and insects, as well as abiotic stressors such as drought, salinity, cold, and heat. This leads to robust plants with enhanced moisture and nutrient absorption, facilitating boll production and maturation (Singh *et al*., 2020; Sekhon & Singh, 2013). Likewise, early planting in May enhanced cotton production by 56% compared to late sowing in June, resulting in superior yield and quality components (Khan *et al*., 2017). Environmental elements and management practices significantly influence cotton growth and

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enhancement. The population of plants and the timing of planting influence maturity (Pauli *et al*., 2016). Consequently, the sowing dates for cotton plants must be optimized to ensure timely completion of their vegetative and reproductive life cycles, while also facilitating the management of pests and cotton diseases (Constable *et al*., 2015).

We evaluate anticipated genotypes for enhanced cotton yield and quality by planting them at different intervals, including early, late, and standard timings. Both late and early sowing adversely affected cotton production and quality. Limited research indicates that early-sown cotton enhances vegetative growth more significantly than cotton output (Usman *et al*., 2016; Baloach *et al*., 2014). Moreover, early-sown cotton attains its reproductive phase during the hottest month, leading to significant output loss challenges (Arshad *et al*., 2021), while late-sown cotton experiences diminished flowering and maturity under elevated temperatures. Consequently, adverse environmental conditions and a reduced growing season impact cotton productivity and quality (Ahmed *et al*., 2020). Consequently, ongoing research is necessary to align genotypes with optimal planting periods in an environment conducive to crop growth and development (Slafer *et al*., 2015). The quality of cotton fiber is assessed on a micro scale, determined by its fineness and maturation. Elevated Micronaire levels signified coarse fiber, which adversely affected the textile sector. If the micronaire number is below 3.8, the fibers are immature, resulting in yarn breakage inside the thread and inadequate pigment absorption during textile processing. The timing of sowing can yield superior-grade lint, which is advantageous in the textile industry. A diverse array of external influences affects fiber quality. Experts have consistently aimed to enhance lint quality, hence ensuring competitive profitability for cotton farmers globally. Regrettably, adverse climatic conditions may exert a detrimental effect, obscuring any genetic alterations in lint quality (Al-khayri *et al*., 2015). Delayed sowing of cotton diminished micronaire and enhanced fiber length. Elevating the temperature reduced fiber length while augmenting fiber microns. Cotton seed necessitates elevated soil temperatures for germination, with robust seedlings to yield healthy plants and superior fabric quality. Research indicates that late-seeding crops enhance fiber length and strength while reducing micronutrient content (Abbas & Ahmed, 2018; Scarpin *et al*., 2023). Keeping these facts in mind, the following objectives were set;

1. The present study was conducted to evaluate the adaptability and performance of three cotton genotypes (CRIS-510, CRIS-543, and CRIS-585) under different sowing dates (March 30th and April 30th) in two distinct environments (Baluchistan and Sindh).
2. To assess the impact of sowing dates on yield traits (plant height, boll number, boll weight, and seed yield) and fiber quality traits (lint percentage, fiber length, micronaire, and fiber strength).
3. To investigate genotype-environment interactions and identify optimal sowing dates for maximizing cotton productivity and fiber quality in Pakistan.

Material and Methods

Site description and experimental design: At Cotton Research Station LUAWMS Lasbela Uthal Baluchistan, Central Cotton Research Institute Sakrand Sindh, Pakistan, a two-year study was carried out to ascertain the impact of various sowing times and genotypes on cotton seed yield and fiber quality under various environmental conditions (Fig. 1).

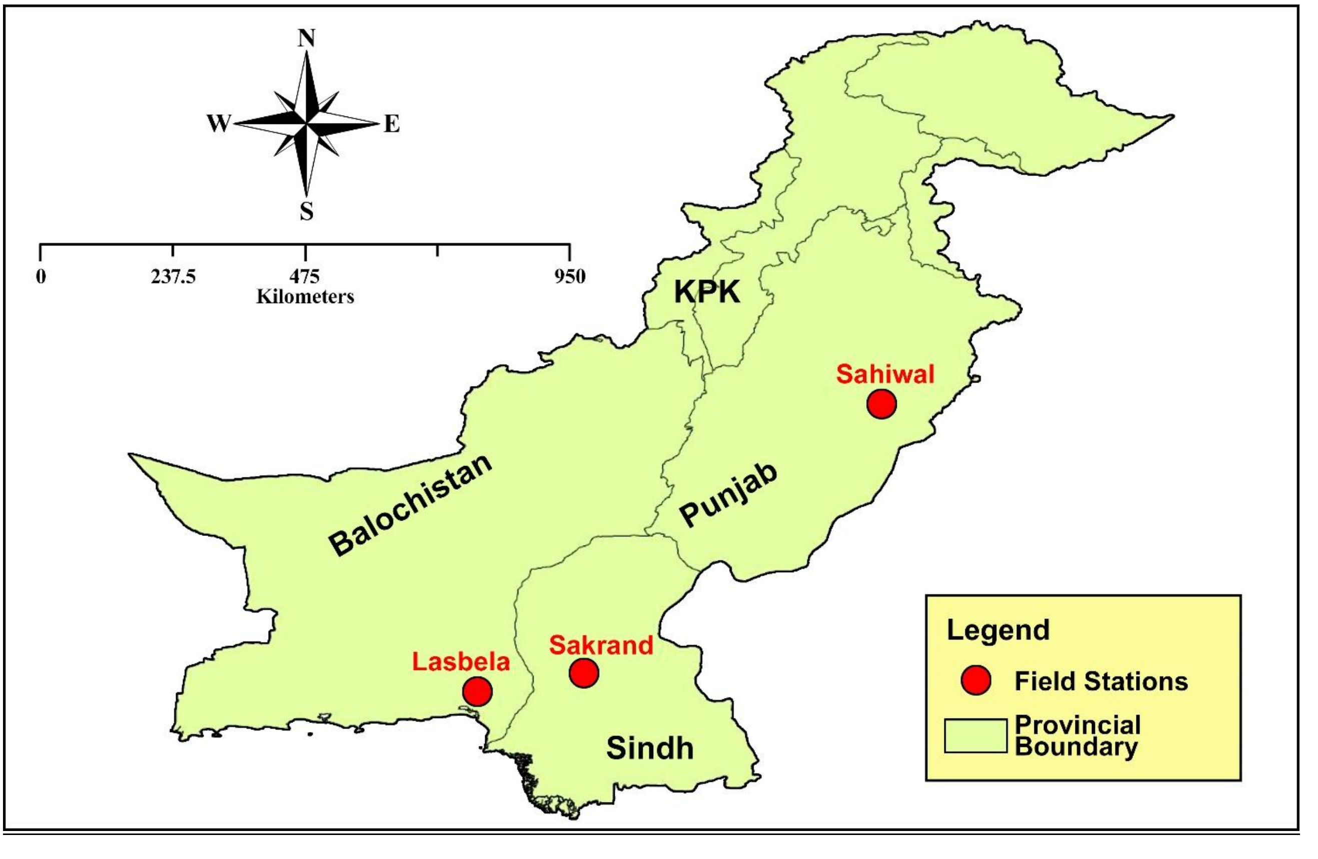

Fig. 1. Baluchistan and Sindh Provinces Study Areas of Cotton Research Institutes of Pakistan.

Description of experiment: the current study was conducted in Sindh and Baluchistan, Pakistan, under three distinct environmental conditions. A split plot in a randomized complete block design with three repeats was used to set up the experiment. Two sowing dates March 30 and April 30-with a 30-day gap between them were part of the primary plot treatments. Three genotypes were included in the subplots: CRIS-510, CRIS-543, and CRIS-585. Five rows of 10 m length and 0.75 m intra-row width made up each subplot.

Environment of Uthal: Located in Uthal, district Lasbela, around 125 kilometres from Karachi, the LUAWMS cotton research station is a coastal area in Baluchistan. With only 169 millimetres of annual precipitation, the summers are scorching (40 to 50 degrees Celsius), while the winters are chilly (25 to 260 degrees Celsius). The most stunning beaches in Lasbela, including as Gadani, Sonmiani, Kund Malir, and Damb, are well-known for their unique hilly topography. The study region experiences hot summers and moderate winters, with an average of 169 mm of rainfall per year shown in (Fig. 2) Baluchistan 2021 and 2022.

Environment of Sakrand (Sindh): Sakarand district Shaheed Benazeer Bhoto Sindh, 377 kilometres from Uthal, is home to the cotton research facility. The region experiences scorching summers (40-51°C) and cool winters (27-26°C), with 170 mm of rain falling there each year shown in (Fig. 2) Sindh 2021 and 2022.

Experimental design: The experiment established a split plot configuration within a randomized complete block design (RCBD) featuring three replicates. The primary plot treatments included two sowing dates: March 30th and April 30th, separated by a 30-day interval, along with tree genotypes identified as CRIS-510, CRIS-543, and CRIS-585.

Treatments: The experimental plots received irrigation every 15 days until crop maturity was reached. Water was applied at a depth of 8 cm during each irrigation event. The final irrigation occurred in September. To control weeds, 1.2 kg ha^{-1} of pendimethaline (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) was applied prior to sowing. Haloxyfopp-ethyl, a post-emergence herbicide (Percept 10.8% EC at 350 ml/acre), was utilized to control grassy weeds during their early growth stages. Novastar 56 EC (bifenthrin + amamectin) was applied to cotton crops twice at a rate of 500 ml per acre using a knapsack hand sprayer, with applications occurring at 15-day intervals. This treatment commenced when the population of sucking insects, including whitefly, jassid, and thrips, reached the economic threshold level. Thinning in the plots was completed within 21 days of sowing. Nitrogen and phosphorus fertilizers, specifically urea and triple superphosphate, were applied at rates of 150 kg ha^{-1} and 90 kg ha^{-1}, respectively. Phosphorus was applied in full at the time of sowing, whereas nitrogen was applied in two equal portions during subsequent irrigations.

Procedure for data recording: Data were collected on plant population, bolls per plant, boll weight (g), seed cotton production (kg ha^{-1}), ginning outturn (Lint %), fiber length (mm), fiber strength (g tex^{-1}), and micronaire. Five sample plants were tagged in each treatment for data collection. The plant population was quantified by counting the number of plants per unit area, typically represented as plants per acre or plants per hectare. Data for bolls per plant were collected by counting the bolls from five randomly selected plants in each treatment at maturity and calculating the average number of bolls per plant. A total of 50 bolls were randomly selected from previously tagged plants in each treatment to measure boll weight (g). The total weight of the bolls was divided by 50 to obtain the mean weight in grams. The middle two rows of each plot were manually harvested to assess seed cotton yield. Seed cotton samples were subjected to sun drying and cleaning to eliminate any foreign matter. The seed cotton samples were weighed and ginned separately using an electric ginning machine following drying and cleaning procedures. GOT represents the ratio of lint weight to the total weight of seed cotton. The lint from each sample was weighed, and the ginning out turn (GOT) was estimated using the formula GOT% = (Lint yield/Seed cotton yield) * 100 (Song *et al.*, 2015). Representative Cotton lint samples were collected from each plot to calculate the mean fiber length in the laboratory using a high-volume instrument (HVI) system. The Cotton Research Institute in Baluchistan, Pakistan assessed micronaire, an indicator of fiber fineness, and fiber strength in a laboratory environment utilizing an HVI system.

Statistical analysis

The statistics presented in this study represent the mean of three replicates. Data were analyzed using ANOVA within a split-randomized complete block design. The significance of each source was assessed using the F-test. Treatments were evaluated according to significant change compared to the least significant difference (LSD $p<0.05$). The Shapiro-Wilk test was employed to assess the normality of variance prior to conducting the ANOVA analysis. Data was calculated using Microsoft Excel 2013, while figures were generated with Origin 8.5. Statistical analyses were performed utilizing SPSS version 19.0 and SAS version 9.3.

Results

Cotton yield and traits: The data presented (Fig. 3) demonstrated that genotypes and sowing dates had a substantial effect on cotton plant height at all experimental sites. For both years, the maximum mean plant height values were 105 and 109 (cm) for genotype CRIS-585 on April 30th at the Baluchistan location. Genotypes strongly influenced cotton plant height at all sites. Plant height for genotype CRIS-585 which was increased 8.18% higher than that for genotypes CRIS-543 increased 5.9%, higher than that for genotype CRIS-510 increased 1.62. The plant heights for genotype CRIS-510 were 90 cm at the experimental site in Sindh on March 30th, which was less than those for genotype CRIS-543 and CRIS-585 at the Baluchistan across all experimental sites, the effect of sowing dates on plant height remained significant. The planting dates of April 30th achieved the highest plant height, which varied from 105 to 109 cm. between April 30th, cotton plant heights in early sown crops ranged from 75 to 87 cm. The effect of years, genotypes, and sowing dates, as well as years and sowing dates, produced non-significant results across all locational locations. In both Baluchistan and Sindh, cotton plant height showed significant outcomes between genotypes and sowing dates. The interaction between genotypes and sowing dates had substantial results for the plant population in Baluchistan and Sindh.

The Bolls plant^{-1} data revealed significant differences between genotypes, planting dates, and their interactions (Tables 2 and 3).The maximum average values for bolls plant^{-1}, reported at genotype CRIS-543 were 46 and 42 respectively, compared to other genotypes under the sowing date of April 30th in Baluchistan as compare to Sindh in both years, as shown in (Fig. 4.) Across all testing sites, genotypes had a significant effect on boll plant^{-1}. On average, genotypes CRIS-510 and CRIS-585 produced the lower bolls per plant at experimental sites in Sindh on March 30th and April 30th of each year. In both years, the lowest bolls on plant^{-1} were 30 and 26 under the CRIS-510 and CRIS-585 genotype at the March 30th sowing date in Baluchistan and Sindh. At all experimental sites, the timing of sowing had a significant effect on boll plant^{-1}, according to the data. At all locations, there were significant interactions between years, genotypes, sowing dates, and experimental sites. Planting cotton on April 30th offers an extended growing season and favorable conditions, resulting in more bolls plant^{-1}. This timing promotes healthy vegetative and reproductive growth, resulting in increased overall yield potential.

The results showed that years had a substantial effect on boll weight (g) at all locations and their interaction presented in (Tables 2 and 3). In both years, the average maximum boll weight (g) was 4.5 and 4.9 at the CRIS-543 genotype at the sowing date of April 30th at the Baluchistan site, respectively. Genotypes had a substantial effect on boll weight (g) at all experimental sites (Fig. 5). Genotypes CRIS-510 and CRIS-585 had the lowest average boll weight (g) of 2.9 and 3.3 at experimental sites in Baluchistan and Sindh on March 30th both years, respectively. At all experimental sites, the timing of planting had a significant effect on boll weight (g), according to the data. In terms of boll weight (g), the interaction between years, genotypes, and sowing dates was significant at all locations. Later planting at the correct time offers a longer growing season and better conditions during important developmental stages. This increases the likelihood of larger and more mature bolls, which eventually leads to greater individual boll weight. However, specific results may differ depending on local factors such as climate, soil conditions, and the cotton genotypes employed.

Data showed that years had a substantial effect on yield kg ha^{-1} at all locations and their interaction presented in (Tables 2 and 3). When comparing genotype CRIS-543 to other genotypes on April 30th the highest mean yields were 4647 and 4427 kg ha^{-1} recorded at the Baluchistan that both year (Fig. 6). Genotypes had a considerable effect on yield kg ha^{-1} across all experimental sites. On average, genotypes CRIS-510 and CRIS-585 produced the lowest yield at experimental sites in Baluchistan and Sindh between March 30th and April 30th of the both year, respectively. At all experimental sites, data showed that the timing of sowing had a significant effect on cotton production. Interactions between years, genotypes, and sowing dates had a significant impact on yield in all locations. Sowing cotton particularly between the 30th typically increased the yield of cotton. Later planting in this time frame gives cotton plants a longer growing season, providing for optimal vegetative and reproductive growth. This can result in more bolls, heavier bolls, and, ultimately, a better overall cotton yield. However, several factors can influence actual output, including local climate conditions, soil quality, and the cotton genotypes planted.

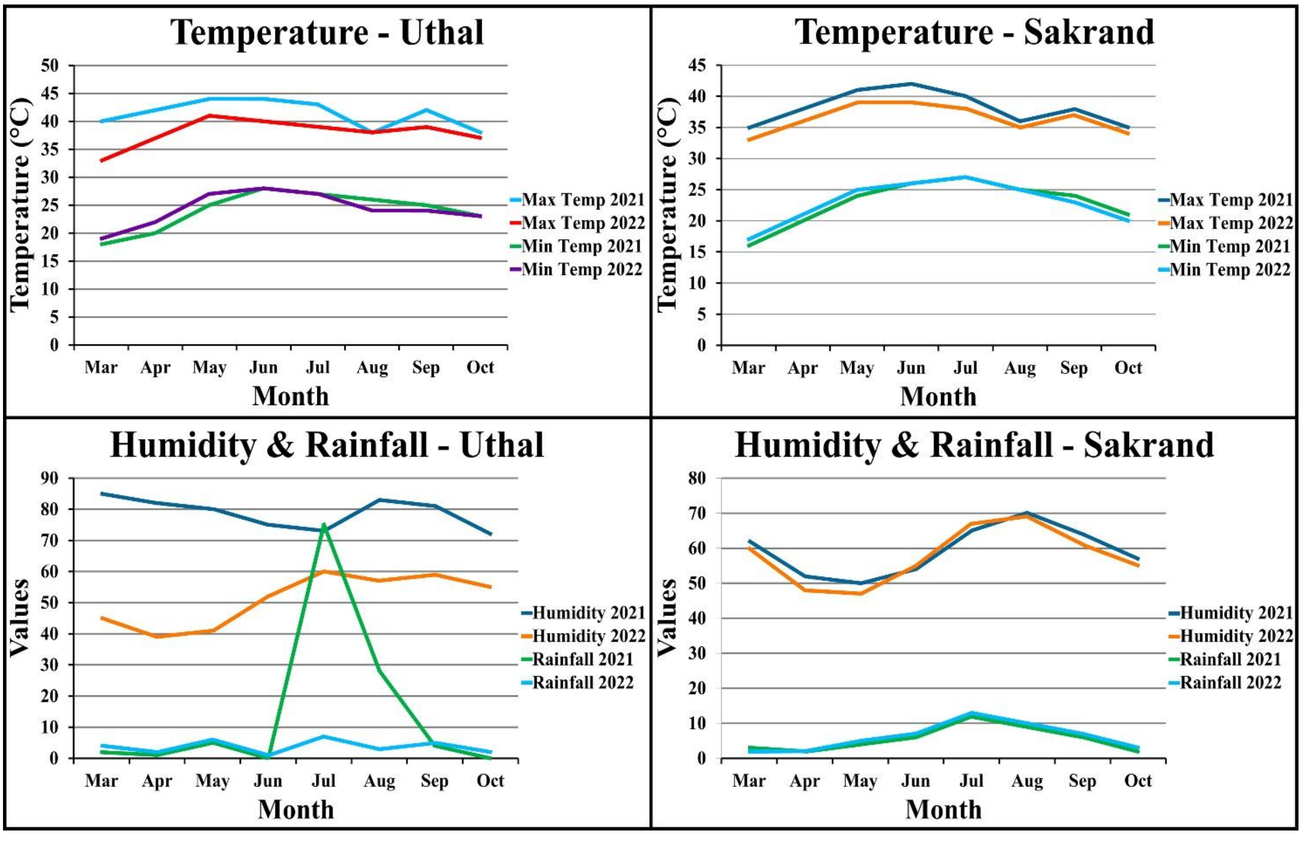

Fig. 2. Climatic conditions of Baluchistan and Sindh during 2021 and 2022.

Table 1. Relationship between cotton seed yield and the other studied parameters.

	Yield	PH	BP	BW	Lint	FL	FS	Micronaire
Plant	0.68**							
BP	0.61**	0.61**						
BW	0.55**	0.55**	0.48*					
Lint	0.53**	0.48*	0.45*	0.07ns				
FL	0.48*	0.15ns	-0.03ns	0.03ns	0.08ns			
FS	0.51**	0.30ns	0.28ns	0.04ns	0.40*	0.19ns		
Micronaire	0.08ns	0.08ns	0.22ns	0.22ns	0.42*	0.42*	0.25ns	0.46*

Note: *, **, and *** represent significance levels at alpha 0.05, 0.01 and 0.001 obtained through honestly significant difference (HSD) test and Ns represent non-significant

Table 2. Significance of F-value from analysis of variance of cotton Traits 2021.

Trait	Source	DF	MS	Error	F-value	Significance
Plant height	G	4	931.04	19.06	48.86	***
	SD	3	2468.87		129.55	***
	G×SD	12	178.34		9.36	***
Yield	G	4	630765	275752	2.29	ns
	SD	3	1509209		5.47	**
	G×SD	12	634080		2.3	*
No. of bolls	G	4	23.29	14.03	1.66	ns
	SD	3	17.72		1.26	ns
	G×SD	12	9.05		0.64	ns
Boll weight	G	4	2.097	0.191	10.96	***
	SD	3	0.505		2.64	ns
	G×SD	12	0.879		4.59	***
Lint %	G	4	0.00158	0.299	0.01	ns
	SD	3	0.00156		0.01	ns
	G×SD	12	0.00167		0.01	ns
Fiber length	G	4	15.919	0.21	75.88	***
	SD	3	4.134		19.7	***
	G×SD	12	0.964		4.59	***
Micronaire	G	4	1.215	0.123	9.87	***
	SD	3	1.295		10.52	***
	G×SD	12	0.823		6.68	***
Fiber strength	G	4	12.361	0.704	17.56	***
	SD	3	8.068		11.46	***
	G×SD	12	6.013		8.54	***

Different Abbreviation Represent: Genotype (G), Sowing date (SD), (PH) Plant height, (BP) Number of bolls per plant, (BW) Bolls weight, (FL) Fiber length, (FS) Fiber strength, Micronaire value (MV). * Significant at 5% level, ** Significant at 1% level of probability. NS; non-significant, respectively

Cotton fiber quality traits: The results showed that genotypes and sowing dates strongly affected the percentage of cotton lint at all sites. The genotype CRIS-585 yielded the highest results for cotton lint, with percentages of 39 and 38%, respectively, compared to other genotypes during the sowing dates of April 30th in both years in Baluchistan (Fig. 7). Genotypes had a significant impact on lint % across all trial sites. The lowest lint % was 29 and 30 obtained at the genotype CRIS-543 under the March 30th planting date in both years at the experimental location in Baluchistan and Sindh. At all experimental sites, data showed that the time of sowing had a significant effect on lint %. The interaction between years, genotypes, and lint sowing dates was significant in all locations. Sowing cotton between months of April 30th increased the lint percentage by providing ideal growing conditions for better fiber quality. However, local factors like climate, soil, and cotton genotypes determine the outcomes.

The results showed that genotypes, sowing dates, and their interactions had a substantial effect on cotton fiber length (staple length mm) at all locations examined (Fig. 8). The highest results were 29 and 28 mm for cotton fiber length under CRIS-543 genotypes at sowing dates of April 30th in both years at the Baluchistan site, as compared to Sindh. Genotypes had a substantial effect on staple length (mm) at all study sites. On March 30th of each year, the lowest staple length (mm) was observed 20 and 21 mm for the genotypes CRIS-510 and CRIS-585 at experimental sites in Sindh and Baluchistan, respectively. At all experimental sites, data revealed that the timing of sowing had a significant effect on staple length (mm). In terms of fiber length, there was no significant interaction between years, genotypes, and sowing dates at any location. Planting cotton later in April increased fiber length due to a longer growing season and ideal weather conditions. Later planting promotes proper fiber growth. The local climate, soil quality, and cotton genotype determine the actual length.

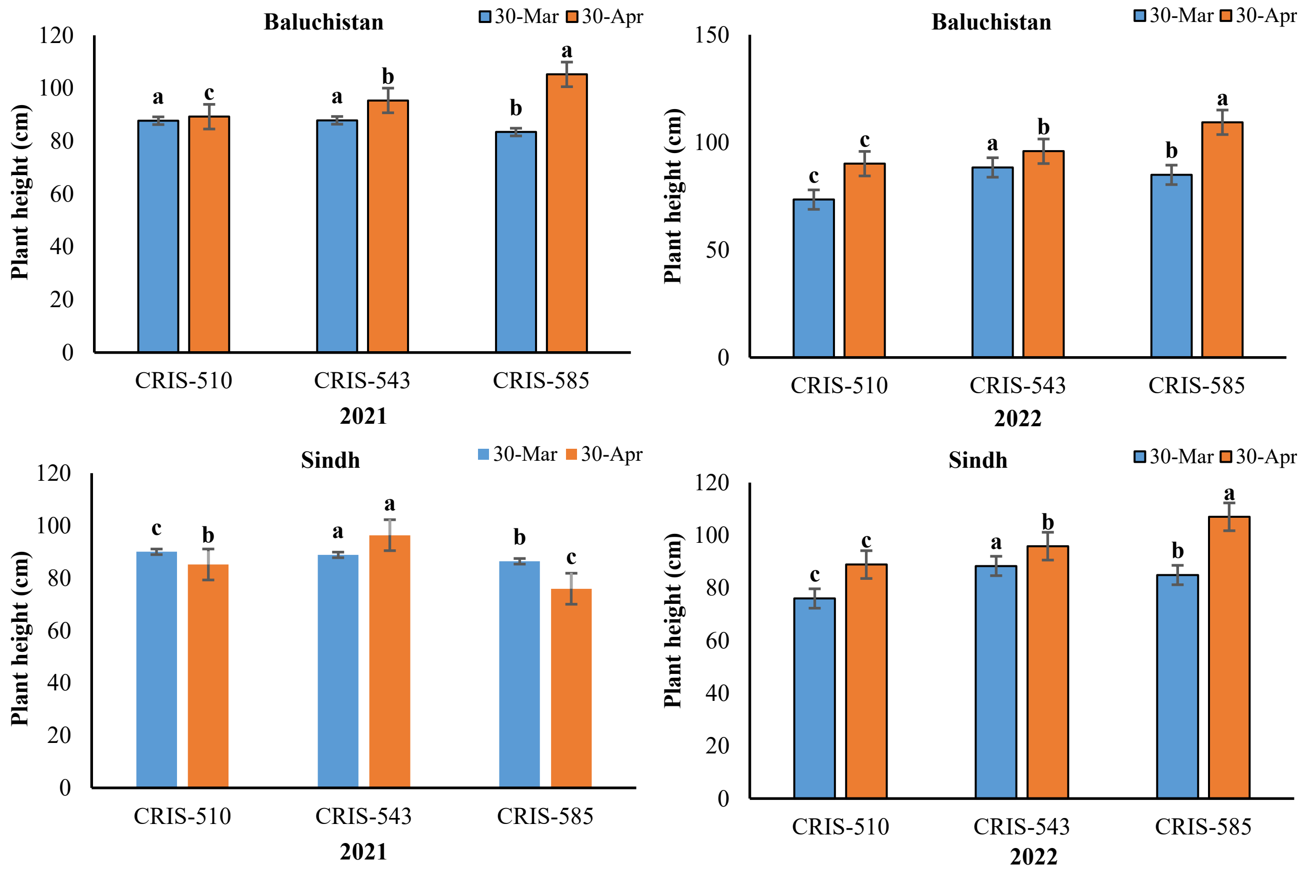

Fig. 3. Interactive effects of sowing dates and genotypes on plant height (cm) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

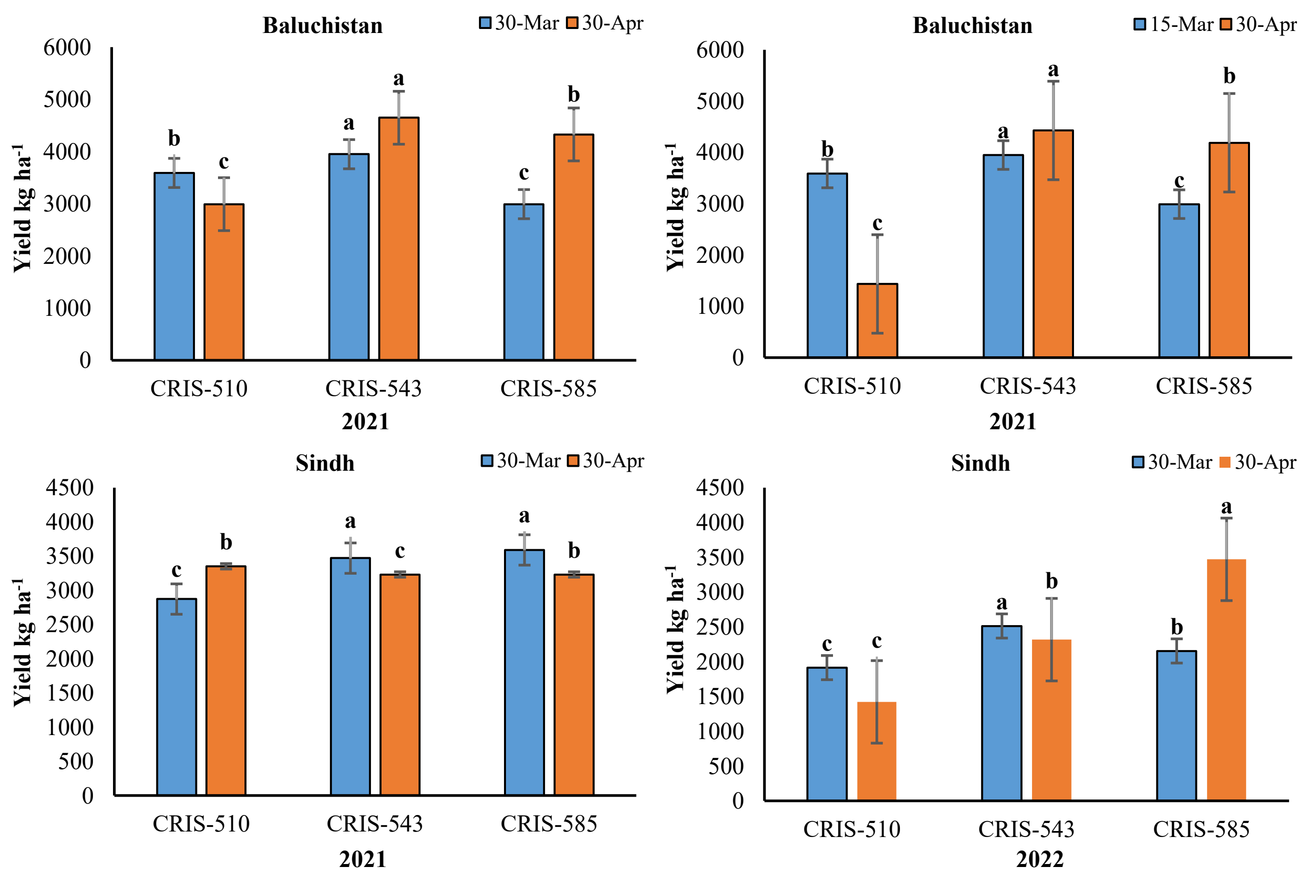

Fig. 4. Interactive effects of sowing dates and genotypes on bolls plant^{-1} under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

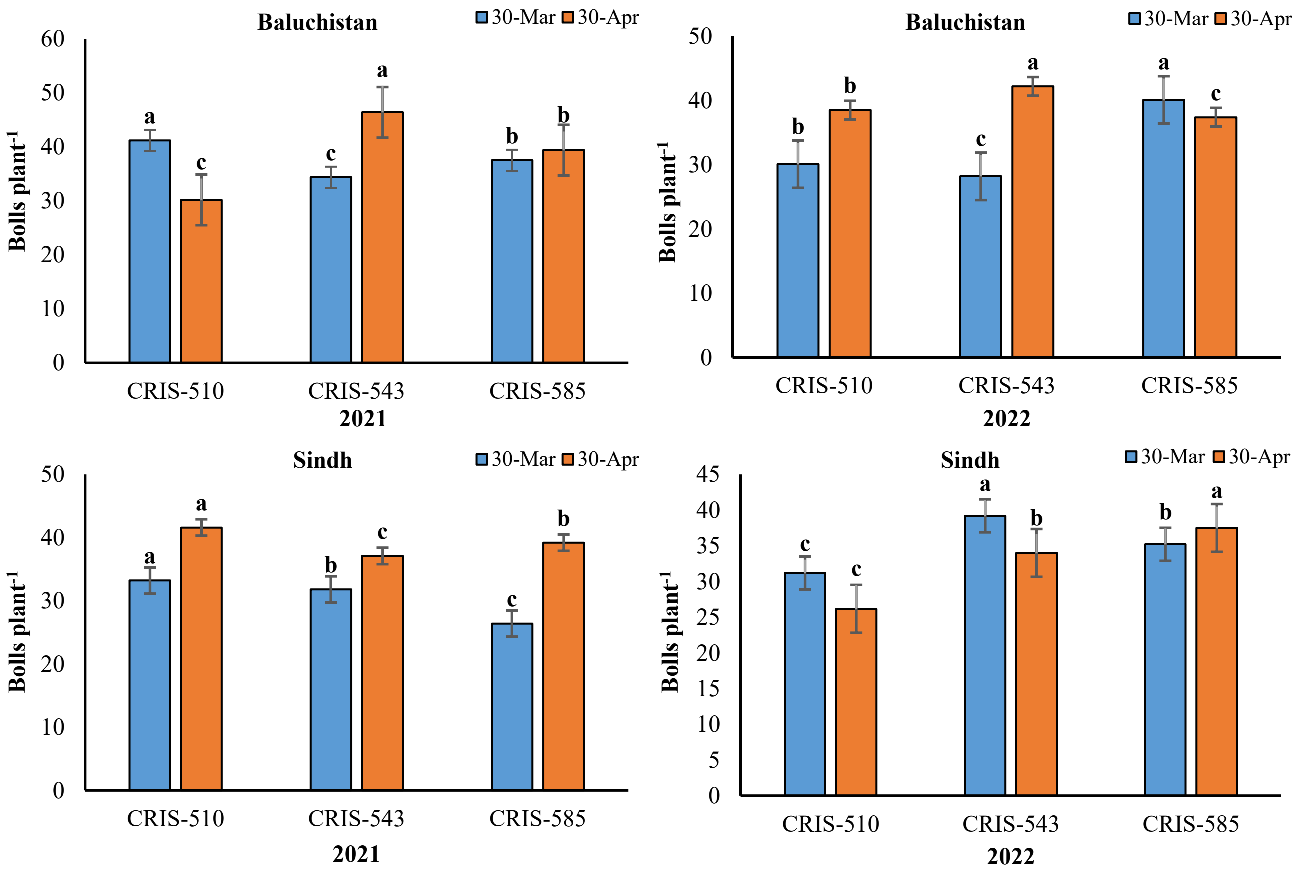

Fig. 5. Interactive effects of sowing dates and genotypes on bolls weight (g) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

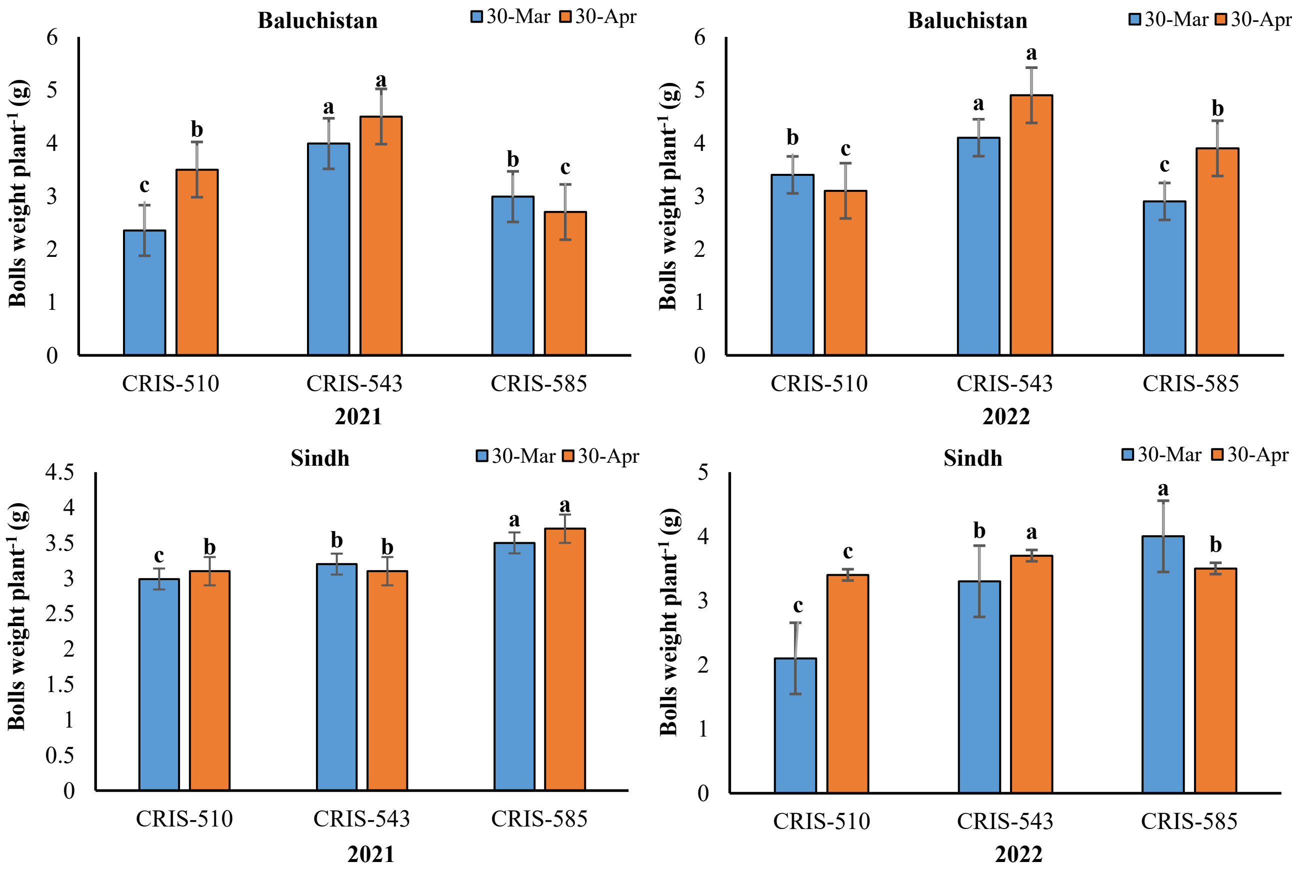

Fig. 6. Interactive effects of sowing dates and genotypes on cotton seed yield (kg ha^{-1}) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

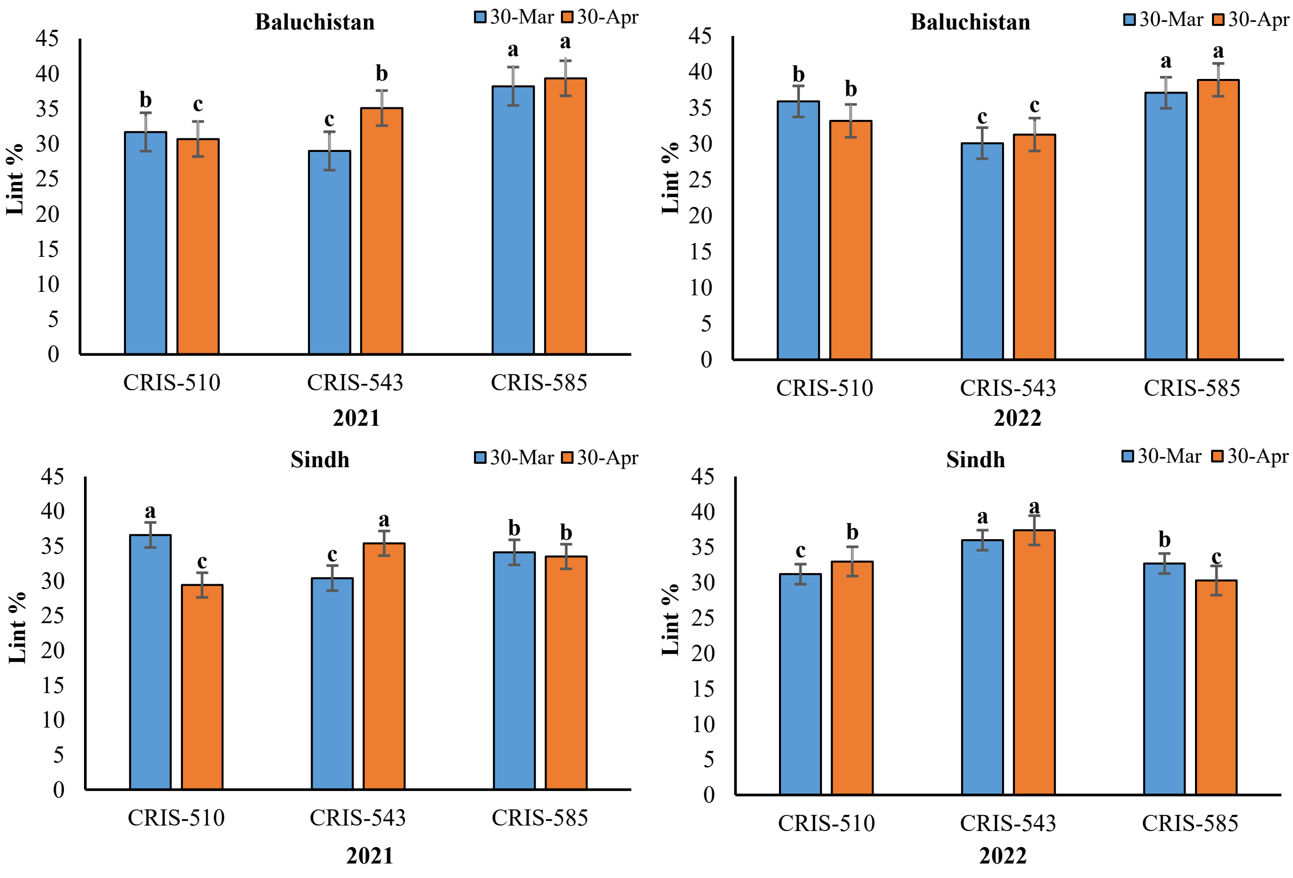

Fig. 7. Interactive effects of sowing dates and genotypes on lint (%) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

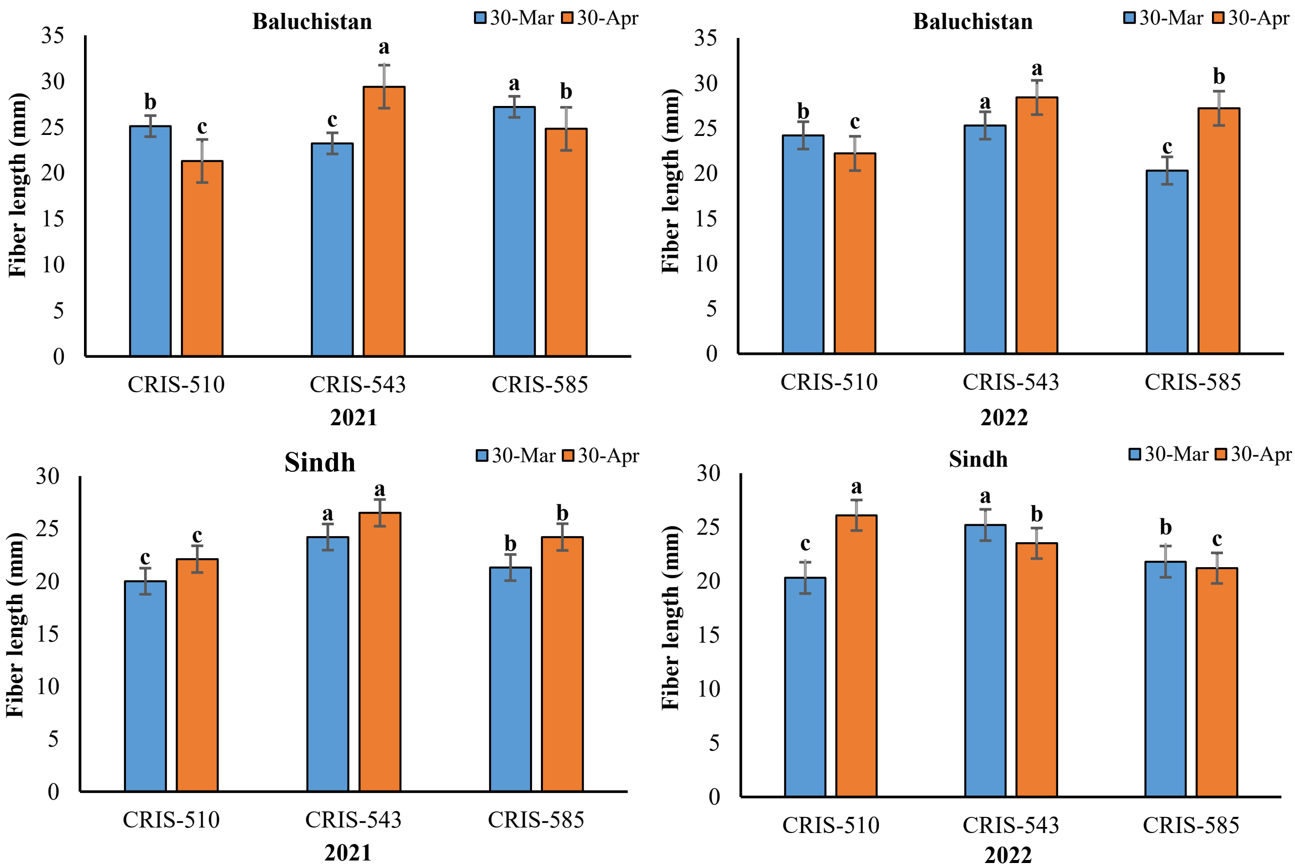

Fig. 8. Interactive effects of sowing dates and genotypes on cotton fiber length (mm) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at $p<0.05$. The values are the mean ± SE.

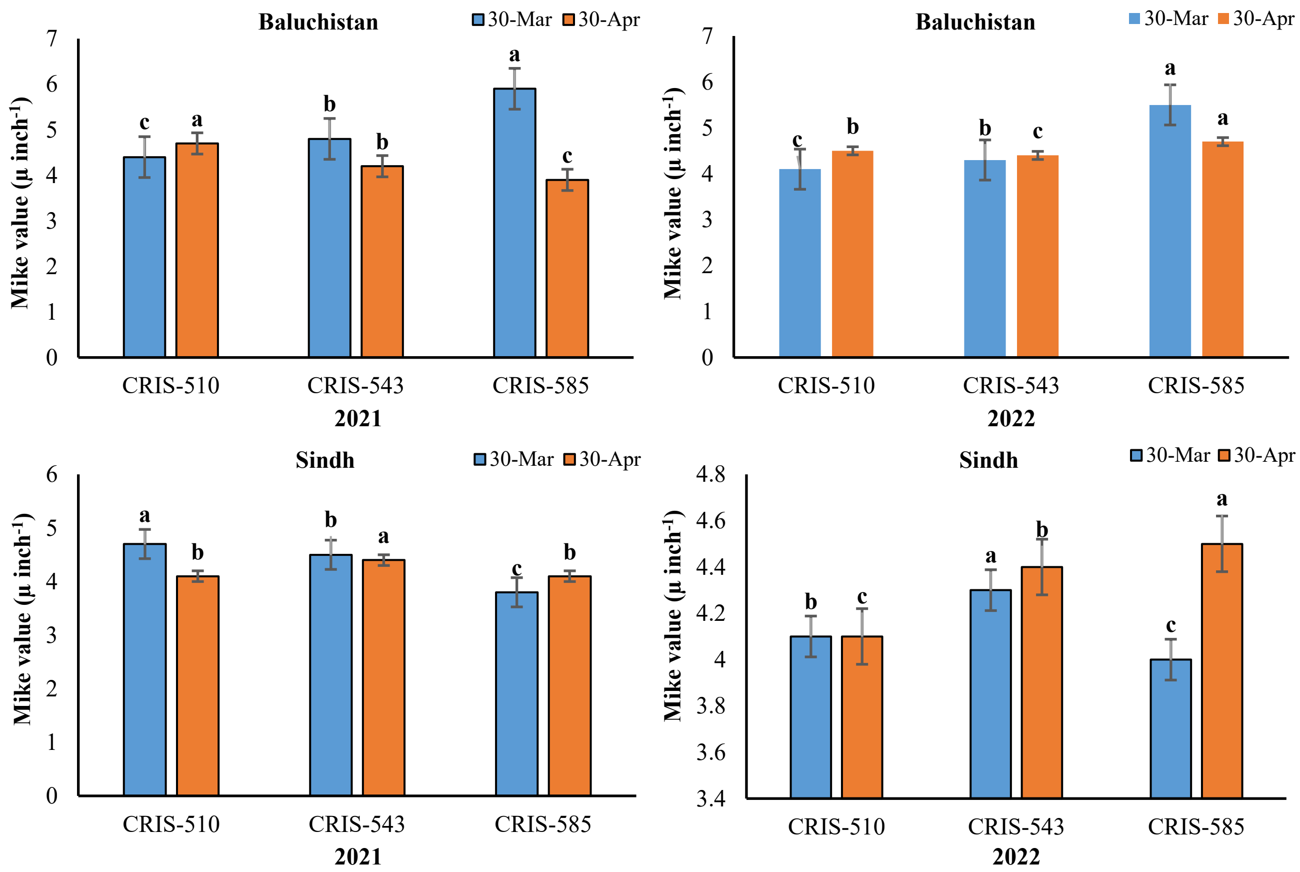

Fig. 9. Interactive effects of sowing dates and genotypes on mike value (μ inch^{-1}) under different locations during 2021 to 2022. Means values in a separate columns followed by the similar letters are not significantly different at p<0.05. The values are the mean ± SE.

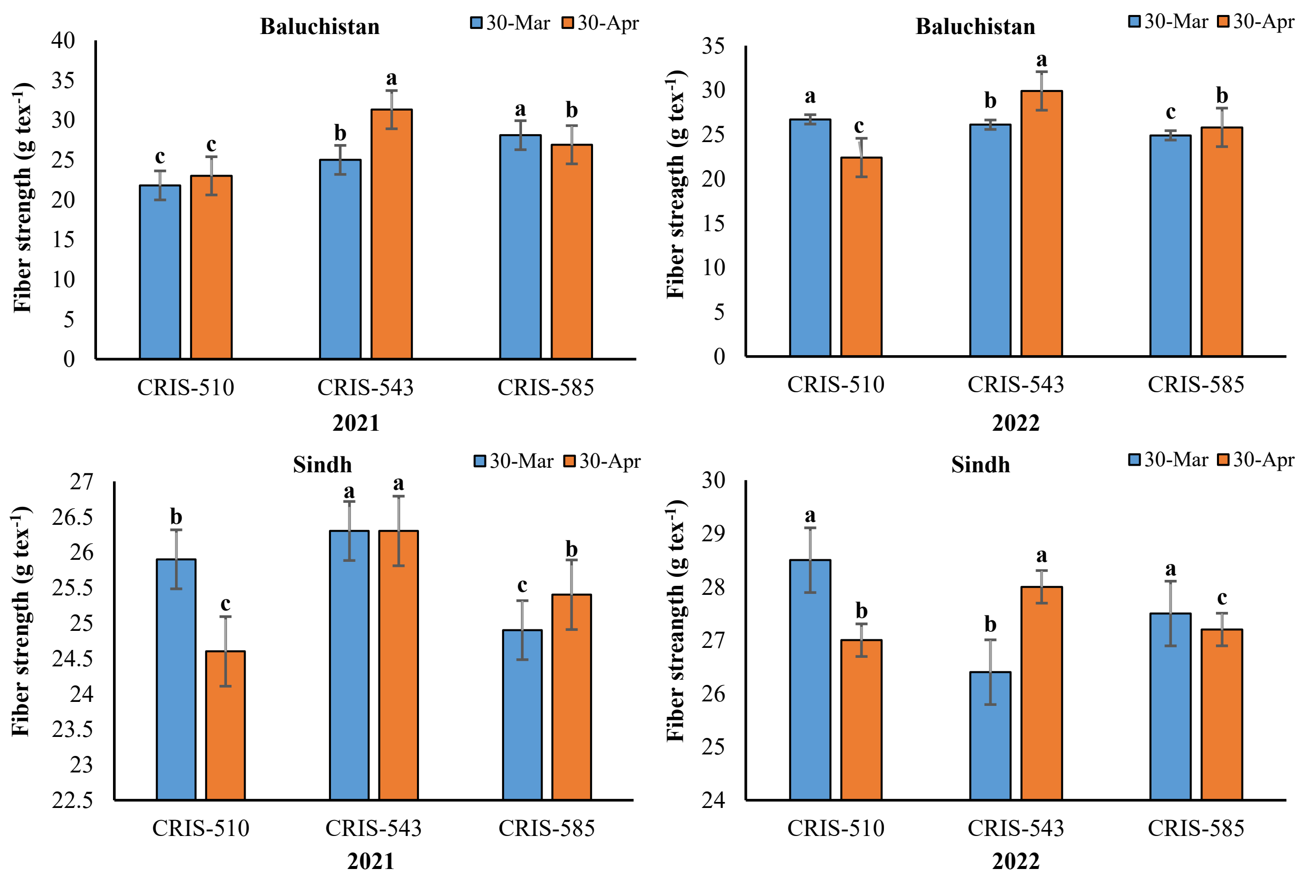

Fig. 10. Interactive effects of sowing dates and genotypes on fiber strength (g tex^{-1}) under different locations during 2021 to 2022. Means values in a separate column followed by the similar letters are not significantly different at p<0.05. The values are the mean ± SE.

Table 3. Significance of F-value from analysis of variance of cotton Traits 2022.

Trait	Source	DF	MS	Error	F-value	Significance
Plant height	G	4	587.39	19.85	29.6	***
	SD	3	2191.1		110.41	***
	G×SD	12	152.58		7.69	***
Yield	G	4	2150862	425988	5.05	**
	SD	3	3804625		8.93	***
	G×SD	12	1745284		4.1	***
No. of bolls	G	4	137.209	7.01	19.58	***
	SD	3	113.898		16.25	***
	G×SD	12	20.665		2.95	**
Boll weight	G	4	1.336	0.105	12.71	***
	SD	3	0.266		2.53	ns
	G×SD	12	0.352		3.35	***
Lint %	G	4	26.545	2.415	10.99	***
	SD	3	11.653		4.83	**
	G×SD	12	5.028		2.08	*
Fiber length	G	4	3.083	0.261	11.84	***
	SD	3	0.396		1.52	ns
	G×SD	12	1.398		5.37	***
Micronaire	G	4	16.567	13.64	1.21	ns
	SD	3	14.5		1.06	ns
	G×SD	12	11.49		0.84	ns
Fiber strength	G	4	88749.9	61441.4	1.44	ns
	SD	3	88920		1.45	ns
	G×SD	12	82200		1.34	Ns

Different Abbreviation Represent: Genotype (G), Sowing date (SD), (PH) Plant height, (BP) Number of bolls per plant, (BW) Bolls weight, (FL) Fiber length, (FS) Fiber strength, Micronaire value (MV). * Significant at 5% level, ** Significant at 1% level of probability. NS; non-significant, respectively

The cotton mike value (µ inch^{-1}) was found to be considerably altered by years in all places (Fig. 9). Cotton mike value (µ inch^{-1}) was highest at 5.9 and 5.5 (µ inch^{-1}) under CRIS-585 genotypes at March 30th sowing dates in both years in Baluchistan as compared to Sindh, respectively. Genotypes had a substantial effect on staple length (mm) at all study sites. It was found that the genotype CRIS-585 had the lowest mike value µ inch^{-1}, measuring 3.9 to 3.8 mm under the sowing time of March 30th at both location Baluchistan and Sindh. Time of sowing had a substantial effect on mike value (µ inch^{-1}) across all study sites. In terms of micronaire, the interaction between years, genotypes, and sowing dates was statistically significant at all locations. Planting cotton on April 30th had a favorable impact on cotton micronaire values, enabling adequate fiber maturity for desired micronaire levels. However, local factors like climate, soil quality, and cotton genotype selection determine the actual outcomes.

Genotypes, sowing dates, and their interaction strongly impacted cotton fiber strength at all studied locations (Fig. 10). The highest results were 31.3 and 29.9 (g tex^{-1}) for cotton fiber strength under the CRIS-543 genotypes at sowing dates of April 30th in both years in Baluchistan, as compared to Sindh. Genotypes had a substantial effect on fiber strength (g tex^{-1}) at all study sites. The CRIS-510 and CRIS-585 genotype reported the lowest fiber strength values of 21 to 24 (g tex^{-1}) at experimental sites in Baluchistan and Sindh under the planting dates of March 30th in the first year. The data revealed that time of sowing had a substantial effect on fiber strength (g tex^{-1}) at all experimental sites. The interaction of years, genotypes, and sowing dates on fiber strength was significant at all locations. Sowing cotton on April 30th increased fiber strength due to favorable growing conditions, resulting in stronger and healthier fibers. However, lack of elements such as climate and soil quality has a specific impact on fiber strength.

Correlation between cotton seed yield and the other examined characteristics. According to Pearson's correlation analysis, there was a strong positive correlation between cotton yield with plant height, bolls per plant, bolls weight, lint percentage, and fiber strength. While cotton yield had a negative relationship with micronaire value, there was positive association between cotton yields with fiber length, as shown in (Table 1).

Discussion

The interaction between genetics and environment regulates crop production. Factors affecting plant growth and development include sunlight, water availability, nutrient levels, and temperature. Operative crop and soil management can mitigate the negative impacts of plant interactions. Genetic factors significantly influenced the response of cultivars to cotton quality attributes. The quality of cotton fiber is influenced by the percentage of maturity. Mature fiber yields superior quality compared to non-mature fiber (Baloach *et al.*, 2010). Our study recorded a maximum plant height of 105 and 109 cm for the genotype CRIS-585, observed under the sowing date of April 30th in both years at Baluchistan, in contrast to the Sindh experimental sites. This led to an increased allocation of photosynthesis to newly opening bolls, resulting in early maturity. Our findings align with those of Cafaro *et al.*, (2023) who demonstrated that genotypes and showing dates positively influenced early sowing dates during the initial growth stage. A separate study found that plant height is predominantly influenced by prevailing environmental conditions. Early-sown genotypes exhibit greater plant height compared to late-sown genotypes due to an extended growth period. The results of Lamichhane *et al*., (2023), and Khan *et al*., (2017) indicate that sowing dates are essential for achieving optimal plant height, thereby corroborating the previously mentioned findings. Deviations in plant height from the optimal range adversely affect yield, quality, and quantity. The optimal height of plants can lower input costs and enhance their success in the existing environment by improving temperature, air, and water conditions. Fahad *et al*., (2022supported these findings.

In our study, Baluchistan recorded the highest number of bolls, with 46 and 42 observed under CRIS-543 on the sowing date of April 30th, in comparison to Sindh. The results align with those of Jamro *et al*., (2017), who indicated that successive delays in sowing dates led to a reduction in the number of bolls, with a notable decline observed when sowing was postponed until May 30th. Soomro *et al*., (2014) demonstrated that delayed seeding produced effects on crop yield that were similarly detrimental to those observed with early sowing. Later sowing dates in the field resulted in decreased productivity in cotton yield and bolls per plant, likely attributed to adverse weather conditions that primarily impacted the reproductive stage due to declining temperatures (Kuar *et al*., 2019). Adombilla *et al*., (2023) determined that the temperature and growth conditions were optimal on April 30th relative to all other sowing dates. This facilitated the processes of photosynthetic translocation and mobilization, resulting in an increased number of bolls. Genotypes, sowing dates, and their interactions significantly affected the results regarding cotton boll weight. The optimal sowing date for CRIS-543 was April 30th, resulting in the highest boll weights of 4.5 g and 4.9 g across both years in Baluchistan, in contrast to the Sindh experimental sites. Compared to previous sowings, cotton bolls exhibited reduced weight, likely attributable to heightened insect pest infestations. Planting a genotype prior to the optimal date can adversely affect germination and growth outcomes. Delaying planting dates past April 30th led to a reduction in boll weight. The minimum boll weight recorded was 2.9 g and 3.3 g, observed from the sowing dates of March 30 under the CRIS-510 and CRIS-585 genotypes in Baluchistan and Sindh during the first year. Cold night temperatures likely contributed to reduced development in May-June sowing, adversely affecting boll growth and development. Yeates *et al*., (2013) indicate that night temperatures falling below 12 degrees Celsius can adversely affect boll maintenance and growth. Conversely, early seeding leading to flowering was associated with elevated temperatures, adversely affecting boll growth and development. The elevated summer temperature constitutes a distinctive physical characteristic of the research area. Consequently, sterility and boll retention present significant challenges in cotton cultivation at 40 degrees Celsius for four or twelve hours per day, leading to a 0% boll yield. The studies conducted by Usman *et al*., (2016) further corroborated these findings.

Our study recorded the highest cotton yields of 4647 and 4427 kg ha^{-1} for the CRIS-543 genotype, sown on April 30th, in both years in Baluchistan. The data indicate that the optimal sowing date fluctuates around April 30th, with both early and late sowing resulting in minimal cotton yield. The reproductive cycle of the crop commenced in the hottest month of the year, leading to enhanced vegetative growth and diminished cotton production (Arshad *et al*., 2021). The findings indicate a significant disparity in cotton yield among genotypes, as reported by Amein *et al*., (2020). Baloach *et al*., (2014) found that April sowing dates produced blooms more rapidly compared to both earlier and later sowing dates. An increased number of blossoms led to an improved cotton yield (Xu *et al*., 2018). Environmental factors predominantly affect lint yield percentage (ginning outturn), which is a trait governed by compound polygenic inheritance. Lint weight directly influences cotton yield. Selection for a higher lint percentage often leads to increased production per plant and per unit area. The results indicate a significant difference among the genotypes, with CRIS-585 exhibiting the highest lint percentage at 39% and a notable growth of 38%. This was followed by CRIS-510, which recorded a lint percentage of 33% at the planting date of April 30th. Genotype CRIS-543 exhibited the lowest lint percentage at 29%. Baloach *et al*., (2014) evaluated cotton genotypes exhibiting contrasting growth patterns in relation to yield and lint percentage characteristics, alongside plant growth traits, and found that the earlier crop produced lower cotton yield and lint percentage. Khan *et al*., (2013) observed differing lint percentage values among highland cotton genotypes, noting that the lowest cotton yield occurred in early developmental growing genotypes and their progeny. A separate study indicated that sowing in April resulted in higher yield and lint percentage compared to sowing in May or June (Usman *et al*., 2016). Delayed seeding led to a reduced lint yield percentage, likely attributable to a shortened fruiting period and later maturity relative to April sowing (Khan *et al*., 2017). Late sowing leads to delayed flowering in the season, coinciding with lower temperatures, potentially resulting in decreased radiation use efficiency and incomplete growth of cotton. In the case of April sowing, favorable temperature and water supply facilitated boll growth and dropping, potentially leading to an increased lint yield percentage, as noted by Mauget *et al*., (2019).

The timely sowing of cotton enhances productivity and fiber quality by mitigating the impacts of drought and elevated temperatures. Following the initial week of anthesis, the fiber and external integuments exhibited the highest levels of photosynthetic activity. Fiber length initiation occurs three days post-anthesis and continues for a duration of three to four weeks. Cellulose secondary wall accumulation commences 20 days post-anthesis, leading to complete fiber maturity (Usman *et al*., 2016). Our investigation yielded maximum fiber lengths of 29 mm and 28 mm for the genotype CRIS-543 during the sowing dates of April 30th in both years at the experimental site in Baluchistan. Ahmed *et al*., (2020) indicated that the CRIS-

543 and CRIS-585 genotypes achieve optimal staple length when sown in late April, corroborating our results. The results indicated that both early and late sowing adversely affect staple length. In the scenarios of earlier and later seeding, harvesting will commence at the initial and final stages of the process, respectively. Both early and late harvesting lead to reduced staple lengths and inferior quality, yielding substandard textiles and immature fibers in bolls that deteriorate rapidly. The findings align with the studies conducted by and Bradow & Davidonis (2010).

Genotypes exhibited a notable sensitivity to cotton quality traits as a result of their genetic composition. As nighttime temperatures dropped below 25°C, there was a corresponding decrease in Mike value (micronaire) readings. Mike's value is directly proportional to the photosynthetic rate; low-sunlight conditions result in the production of low-quality fiber. Mike's values increased at an average temperature of 30.3°C and subsequently decreased. Lint and mike values showed improvement with early sowing, whereas fiber strength, leaf litter, and lint yellowness were superior with late sowing compared to early sowing. These findings align with the studies conducted by Kaur *et al*., (2023) and Virk (2022) (2015). The values of 5.9 and 5.5 (µ inch-1) recorded by Mike were the highest in our study conducted under the CRISS-585 on April 30, coinciding with the planting date at the experimental site in Baluchistan. Both years are included. Our findings align with Deho *et al*., (2012), who indicated that the Mike value was lower (indicating more fine fiber) in April sowing compared to May sowing, which exhibited a higher value. In the context of advertising, a study conducted by Holladay (2023) identified three categories of Mike values: a premium range (3.7 to 4.2) compared to the typical prices (3.5, 3.6, and 4.9), and a price discount range (3.4 and below, as well as 5.0 or above, considered to have a lower value).

The timing of sowing influenced cotton production and the superiority of yarn wool, yet the findings remained inconsistent. Delayed planting led to a reduction in boll weight and fiber strength, presumably attributable to the lower temperatures experienced during the boll development phase. In postponed planting, the sucrose and cellulose contents increased, resulting in a higher sucrose transformation rate, whereas the cellulose content decreased. Deteriorating environmental conditions during postponed planting resulted in cellulose formation. The results align with the studies conducted by Abbas & Farooq (2018) and Abdalla (2015). Previous research indicated that reduced cellulose accumulation in fiber cells controlled to reduced staple strength. The conversion of cellulose and sucrose, along with their collection parameters, may lead to variations in ultimate fiber strength and quality. Researchers concluded that the genetic characteristics of fiber growth, including cellulose, callose, and sucrose, as well as sowing time and cotton characteristics related to cellulose, callose, and sucrose, significantly influence the response of fiber quality to environmental factors (Zhao *et al*., 2013; Ahmed *et al*., 2020).

Analysis of person's correlation established a strong positive association of seed cotton yield with plant height, boll count per plant, boll weight, lint percentage, and fiber strength, alongside a negative correlation with micronaire and a modest positive correlation to fiber length. Side *et al*., 2025 reported that correlations were found between seed cotton yield and plant height (0.68), bolls per plant (0.93), and boll weight, while micronaire exhibited a consistent negative correlation suggesting that denser, coarser fiber often corresponds with lower yield structure integrity and informed a notable negative correlation (0.36, 0.51) among micronaire and also for fiber length and fiber strength, confirming concerns about thicker fiber compromising yield components (Begum *et al*, 2025; Abdelghany *et al*., 2024). Similarly, Virk *et al* (2024) also underlined that boll weight and lint % utilize the direct significant impact on cotton. Cooperatively, these researcher's underlined that improving cotton characteristics such as plant height and boll development is dynamic for increasing the cotton seed yield, however, fiber fineness and length demand careful management to preserve quality without decline productivity.

Conclusion

The findings of this study exhibit significant difference among the three cotton genotypes (CRIS-510, CRIS-543, and CRIS-585) and between the two sowing times (March 30th and April 30th). Among these, genotypes CRIS-543, when sown on April 30th, consistently exhibited superior performance in term of cotton yield and fiber quality, particularly in the both region Sindh and Baluchistan. Early sowing on March 30th led to suboptimal outcomes due to lower temperatures during flowering and boll development, negatively affecting the yield and quality traits. Based on these results, it is recommended that cotton sowing in Baluchistan be carried out between April 15th and 30th to support crop growth with favorable climatic conditions. Genotypes CRIS-543 are especially suitable for this sowing time and it is recommended for achieving higher yield and fiber quality. For future research, it is suggested to explore genotype-environment interaction across additional climate zones, planting times, and to assess their economic viability under farmers filed condition. These findings provide practical guidance for improving cotton production and fiber quality, supporting sustainable cotton cultivation in Pakistan's arid regions.

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