

Fiber quality stability across canopy positions in upland cotton genotypes

Gabriel Gonçalves Athos

Universidade Federal de Uberlândia

Fabício Oliveira Fernandes

fabriciof9@gmail.com

Universidade Estadual Paulista (Unesp)

Elvécio Gomes da Silva Júnior

Universidade Federal de Uberlândia

Larissa Barbosa Sousa

Universidade Federal de Uberlândia

Research Article

Keywords: High Volume Instrument (HVI), Micronaire, Fiber technological traits, Intraplant variability, Canopy stability, Heritability, Cotton breeding

Posted Date: August 11th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10501475/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Fiber quality is a major target of upland cotton (*Gossypium hirsutum* L.) breeding because it directly affects textile processing and commercial value. However, most studies evaluate fiber quality using composite samples from entire plants, overlooking variation among canopy positions. This study evaluated the effects of genotype and canopy position on fiber technological traits and identified genotypes combining superior fiber quality with greater intraplant stability. The experiment was conducted in a randomized complete block design with four replications using a nested arrangement involving 12 cotton genotypes and three canopy positions. Twenty bolls were collected from each canopy position per plot and analyzed by High Volume Instrument (HVI) for micronaire (MIC), fiber maturity (MAT), upper half mean length (UHML), uniformity index (UI), short fiber index (SF), fiber strength (STR), and elongation (ELG). Genotype significantly affected all evaluated traits, whereas canopy position influenced MIC, MAT, and UHML. DP 1552 B2RF exhibited the most favorable fiber quality profile, combining high UI and ELG, low SF, and stable performance across canopy positions. BRS 372 showed superior UHML and STR, whereas IMA 5675 B2RF displayed the greatest reduction in MIC. These findings demonstrate that evaluating fiber quality together with canopy stability provides an additional criterion for selecting cotton genotypes with more uniform and predictable fiber quality.

Introduction

Upland cotton (*Gossypium hirsutum* L.) is the most widely cultivated cotton species worldwide and accounts for the largest share of natural fibers used by the textile industry (Liz et al., 2025). Fiber technological traits result from the interaction between the genetic potential of cultivars and environmental conditions during boll development (May, 1999). In this context, attributes such as fiber length, strength, uniformity, micronaire, elongation, and short fiber index are widely used to characterize fiber quality through High Volume Instrument (HVI) systems (Davidonis et al., 2005; Stetina et al., 2014).

Several studies have demonstrated that the genetic variability present in cotton germplasm represents an important resource for the development of superior cultivars (Klueva et al., 2000; Bolek, 2010; Mangi et al., 2024). In addition, morphological and physiological traits simultaneously influence lint yield and fiber quality, making their integrated evaluation essential for breeding programs (Reddy and Hodges, 2006; Bechere, Zeng, and Boykin, 2014).

Despite advances in the genetic and agronomic characterization of cotton, most studies have focused on comparisons among genotypes using composite fiber samples collected from the entire plant (Davidonis et al., 2005; Stetina et al., 2014; Bechere, Zeng, and Boykin, 2014). Few studies have investigated how boll position within the plant canopy influences fiber technological traits or whether this response differs among genotypes (Manivannan, 2024). This limitation restricts the understanding of intraplant variation and its effects on final fiber quality (Reddy and Hodges, 2006).

Therefore, simultaneously evaluating the effects of genotype and boll position on fiber technological traits is of considerable interest. Such information can support cotton breeding programs and crop management strategies aimed at improving fiber quality (Liu et al., 2023). We hypothesized that significant genetic variability exists among cotton genotypes and that different canopy positions exhibit distinct fiber quality patterns, with possible interactions between these factors.

Accordingly, the objective of this study was to evaluate the influence of cotton genotype and boll position within the plant canopy on fiber technological traits determined by High Volume Instrument (HVI), providing information to support breeding programs and the production of high-quality cotton fiber.

Materials e Methods

The experiment was conducted during the 2017/2018 growing season at the experimental field of the Federal University of Uberlândia (UFU), Uberlândia, Minas Gerais, Brazil (18°52' S, 48°20' W; 805 m above sea level). The experimental area covered approximately 500 m².

Soil preparation and sowing

The experiment was conducted on a clayey dystrophic Dark Red Latosol, classified according to the Brazilian Soil Classification System (Santos et al., 2018). Soil chemical analysis was performed before trial establishment to guide liming and fertilization recommendations. Conventional tillage consisted of one plowing operation followed by two harrowings. At sowing, NPK fertilizer (20–80–10) was applied manually. Seeds were treated with fipronil and carboxin + thiram at a rate of 450 mL of commercial product per 100 kg of seed. Sowing was carried out in December at a density of 16 seeds m⁻² and a depth of 2 cm. At 30 days after emergence, plants were thinned to eight plants m⁻², and 80 kg N ha⁻¹ was applied as topdressing.

Crop management

Throughout the growing season, crop management practices followed standard recommendations for cotton production. Weed control consisted of pre-emergence application of S-metolachlor and post-emergence applications of glyphosate and paraquat, supplemented by manual hoeing when necessary. Pest and disease management was carried out according to crop requirements. Vegetative growth was regulated with mepiquat chloride. Foliar boron fertilization was performed using boric acid at a total rate of 2 kg ha⁻¹, split into three applications.

Boll sampling

At the end of the growing season, 20 bolls were manually harvested from each canopy position in each experimental plot and separated according to their location within the plant canopy. The lower canopy comprised the first four fruiting branches, whereas the upper canopy comprised the last four fruiting branches; the intermediate branches were considered the middle canopy. Thus, a total of 60 bolls were sampled per plot, with 20 bolls collected from each canopy position (Fig. 1).

Samples were identified according to genotype and canopy position and ginned using a laboratory cotton gin at the Cotton Laboratory of Capim Branco Experimental Farm. After ginning, lint and seeds were separated and weighed.

Fiber technological traits

Fiber samples obtained after ginning with a laboratory saw gin were analyzed using a High Volume Instrument (HVI) at the Fiber Analysis Laboratory of MinasCotton, affiliated with the Minas Gerais Cotton Producers Association (AMIPA), Uberlândia, Minas Gerais, Brazil. The following fiber technological traits were determined: micronaire (MIC), fiber maturity (MAT), upper half mean length (UHML, mm), uniformity index (UI, %), short fiber index (SF, %), fiber strength (STR, gf tex⁻¹), and fiber elongation (ELG, %) (Table 1).

Table 1
Classification criteria and reference ranges for the technological fiber traits of upland cotton.

Classification	MIC	MAT	UHML		UI		SF		STR		ELG		
		(%)	(mm)	(%)	(%)	(gf tex ⁻¹)	(%)						
Very low	< 3.0	Inadequate	< 0.70	Short	25.5	Very irregular	< 77	Very low	< 6.0	Low	21.0–23.0	Low	< 5.0
Low	3.0–3.9	Immature	0.70–0.80	Medium	25.6–27.94	Irregular	77–79	Low	6.0–9.0	Medium	24.0–27.0	Low	5.0–5.9
Regular	4.0–4.9	Inferior to mature	0.80–0.85	Long	27.94–33.0	Medium	80–82	Medium	10.0–13.0	High	27.0–29.0	Medium	5.9–6.7
Coarse	5.0–5.9	Mature	0.85–0.95			Uniform	83–85	High	14.0–17.0	Very high	> 30.0	High	6.8–7.6
Very coarse	> 6.0	Superior to mature	> 0.95			Very uniform	> 85	Very high	> 17.0			Very high	> 7.6
Notes: MIC, micronaire index; MAT, fiber maturity; UHML, upper half mean length; UI, uniformity index; SF, short fiber index; STR, fiber strength; ELG, fiber elongation.													

Experimental design and statistical analysis

Twelve upland cotton genotypes were evaluated, including ten commercial cultivars and two breeding lines developed by the Cotton Breeding Program (PROMALG) of the Federal University of Uberlândia (UFU): BRS 368RF, BRS 372, DP 1228 B2RF, DP 1552 B2RF, FM 975 WS, FM 982, IMA 5675 B2RF, IMA 8405 GLT, TMG 45 B2RF, TMG 82 WS, UFU-H, and UFU-P.

The experiment was conducted in a randomized complete block design with four replications using a nested arrangement, in which three canopy positions (lower, middle, and upper) were nested within the 12 genotypes. Each experimental plot consisted of four 5-m-long rows spaced 1.0 m apart. The harvest area comprised the two central rows, excluding 0.5 m from each end.

Before the analysis of variance, the assumptions of residual normality and homogeneity of variances were verified using the Shapiro–Wilk and Bartlett tests, respectively. Data were subjected to analysis of variance (ANOVA) using the F-test, considering the hierarchical structure of the experimental design. When significant differences were detected, means were grouped using the Scott–Knott test at the 5% probability level. All statistical analyses were performed using R software (R Core Team, 2026).

Results

Genotype significantly affected all fiber technological traits ($P \leq 0.01$), indicating substantial variability among the 12 cotton genotypes evaluated. Canopy position significantly influenced micronaire (MIC) and fiber maturity (MAT) ($P \leq 0.01$), as well as upper half mean length (UHML) ($P \leq 0.05$). In contrast, uniformity index (UI), short fiber index (SF), fiber strength (STR), and fiber elongation (ELG) were not significantly affected by canopy position ($P > 0.05$). Coefficients of variation ranged from 1.03% for MAT to 8.75% for MIC. Overall means were 3.53 for MIC, 0.83 for MAT, 28.83 mm for UHML, 82.83% for UI, 8.34% for SF, 30.25 gf tex⁻¹ for STR, and 7.83% for ELG. The highest broad-sense heritability estimates were observed for MIC (95.06%), UHML (93.45%), MAT (93.07%), SF (90.76%), and UI (89.21%), whereas STR and ELG showed lower heritability estimates of 70.27% and 68.86%, respectively (Table 2).

Table 2
Summary of the analysis of variance for seven fiber technological traits evaluated in 12 upland cotton genotypes.

FV	GL	MIC	MAT	UHML	UI	SF	STR	ELG
Genotype	11	0.87**	> 0.01**	4.05**	7.61**	5.99**	21.43**	2.48**
Canopy position	24	0.88**	> 0.01**	0.83*	1.32 ns	0.70 ns	2.,90 ns	0.13 ns
Residual	69	0.09	> 0.01	0.40	1.09	0.41	2.07	0.17
CV (%)	-	8.75	1.03	2.2	1.26	8.19	4.76	4.75
Means	-	3.53	0.83	28.83	82.83	8.34	30.25	7.83
H ² (%)	-	95.06	93.07	93.45	89.21	90.76	70.27	68.86
ns, not significant; ** and * significant at the 1% and 5% probability levels, respectively, according to the F-test. SV, source of variation; DF, degrees of freedom; MIC, micronaire index; MAT, fiber maturity (%); UHML, upper half mean length (mm); UI, uniformity index (%); SF, short fiber index (%); STR, fiber strength (gf tex ⁻¹); ELG, fiber elongation (%); CV, coefficient of variation; H ² , broad-sense heritability.								

Genotypes differed significantly in all fiber technological traits (Table 3). DP 1552 B2RF exhibited the most favorable fiber quality profile, showing the highest values for micronaire (MIC; 4.14), uniformity index (UI; 84.93%), and fiber elongation (ELG; 9.04%), as well as the lowest short fiber index (SF; 6.74%). BRS 372 showed the highest fiber strength (STR; 33.02 gf tex⁻¹) and, together with FM 982 and UFU-H, the greatest upper half mean length (UHML). In contrast, IMA 5675 B2RF exhibited the lowest MIC (3.04) and STR (28.08 gf tex⁻¹), whereas TMG 45 B2RF showed the shortest UHML (27.47 mm).

Table 3
Mean values of fiber technological traits measured at three canopy positions in 12 upland cotton genotypes.

Genotypes	Plant third	MIC		MAT		UHML		UI		SF		STR		ELG	
		XTer	XGen	XTer	XGen	XTer	XGen	XTer	XGen	XTer	XGen	XTer	XGen	XTer	XGen
BRS 368RF	Lower	3.59a	3.26C	0.84a	0.82B	27.83a	28.30C	82.65a	82.47C	8.95a	8.92C	29.70a	29.62C	7.85a	7.82C
	Middle	3.53a		0.83b		28.58a		83.10a		8.26a		29.70a		8.20a	
	Upper	2.77b		0.81b		28.33a		81.73a		9.56a		29.50a		7.93a	
BRS 372	Lower	4.19a	3.76B	0.85a	0.84A	29.65a	29.67A	83.93a	82.94C	7.70a	8.27B	31.76a	33.02A	7.43a	7.40A
	Middle	3.60ab		0.84b		29.87a		82.63a		8.43a		33.60a		7.33a	
	Upper	3.30b		0.83b		29.49a		82.26a		8.70a		34.00a		7.60a	
DP 1228 B2RF	Lower	3.79a	3.79B	0.84a	0.84A	28.58a	28.39C	82.90a	83.23C	8.23a	8.05B	31.26a	31.93B	7.36ab	7.34B
	Middle	3.93a		0.85a		28.70a		84.00a		7.58a		33.65a		7.14b	
	Upper	3.64a		0.83a		27.91a		82.80a		8.33a		30.86a		7.90a	
DP 1552 B2RF	Lower	4.06a	4.14A	0.83a	0.83B	29.43a	29.12B	84.86a	84.93A	7.06a	6.74A	30.80a	31.31B	9.03a	9.04A
	Middle	4.37a		0.84a		29.44a		85.36a		6.23a		30.73a		8.80a	
	Upper	4.00a		0.83a		28.51a		84.56a		6.93a		32.40a		9.30a	
FM 975 WS	Lower	0.83a	3.46C	0.83a	0.83B	29.29a	29.15B	83.26a	82.77C	8.53a	8.68C	30.40a	31.43B	7.43a	7.40B
	Middle	3.66a		0.83a		29.43a		83.20a		8.46a		31.23a		7.36a	
	Upper	3.13a		0.82a		28.72a		81.26a		9.06a		32.66a		7.46a	
FM 982	Lower	3.79a	3.71B	0.84a	0.84A	29.71ab	29.57A	82.86a	82.78C	8.50a	8.22B	31.03a	31.25B	7.40ab	7.38B
	Middle	3.79a		0.84a		30.27a		83.26a		7.70a		32.40a		7.06b	
	Upper	3.56a		0.83a		28.73b		82.23a		8.46a		30.33a		7.76a	
Notes. Means followed by the same lowercase letter within a genotype do not differ among canopy positions according to the Scott–Knott test ($P \leq 0.05$). Uppercase letters compare genotype means for each trait. MIC, micronaire index; MAT, fiber maturity; UHML, upper half mean length; UI, uniformity index; SF, short fiber index; STR, fiber strength; ELG, fiber elongation.															
Continue...															

The response to canopy position depended on both genotype and fiber trait. Micronaire exhibited the most consistent intraplant variation, decreasing from the lower to the upper canopy in six genotypes. The greatest reduction was observed in IMA 5675 B2RF, in which MIC decreased by 29.8%, from 3.52 to 2.47. Differences in fiber maturity (MAT) among canopy positions were detected only in BRS 368RF, BRS 372, IMA 5675 B2RF, and UFU-H.

Upper half mean length (UHML) differed among canopy positions only in FM 982, IMA 8405 GLT, and TMG 82 WS, with lower values in the upper canopy. In contrast, uniformity index (UI), short fiber index (SF), and fiber strength (STR) remained stable across canopy positions. Overall, intraplant variation was

mainly associated with micronaire, whereas the other fiber technological traits showed high stability.

The heatmap revealed substantial variation in fiber technological traits among the evaluated genotypes (Fig. 2). DP 1552 B2RF exhibited the most favorable profile, with above-average values for micronaire (MIC), uniformity index (UI), and fiber elongation (ELG), as well as the lowest short fiber index (SF) among all genotypes.

BRS 372 was characterized by high upper half mean length (UHML) and fiber strength (STR). FM 982 also exhibited above-average UHML, combined with high fiber maturity (MAT). In contrast, IMA 8405 GLT showed the highest relative SF values, whereas IMA 5675 B2RF exhibited below-average values for MIC, MAT, and STR.

TMG 45 B2RF showed the lowest relative UHML values and low STR but stood out for its above-average ELG. UFU-H exhibited above-average UHML and UI, whereas UFU-P showed the highest relative ELG. Overall, DP 1552 B2RF and BRS 372 displayed the most favorable fiber technological profiles, although for different sets of fiber traits (Fig. 2).

Discussion

The differences observed among genotypes confirm the existence of genetic variability for fiber technological quality. The diversity observed is likely associated with the genetic background and selection history of the evaluated materials (Zeng and Pettigrew, 2015). Continuous breeding efforts modify allele frequencies and may reduce the genetic diversity available in modern cultivars (Mangi et al., 2024; Wedegaertner et al., 2022). In this context, DP 1552 B2RF exhibited the most favorable technological profile, combining higher fiber uniformity and elongation with the lowest short fiber index. The high heritability estimates obtained for the evaluated traits reinforce the potential for selecting superior phenotypes and increase the predictability of genetic gains. Similar patterns have been reported for micronaire, fiber length, and fiber strength in cotton germplasm (Gurmessa and Balcha, 2026).

Beyond differences among genotypes, this study highlights canopy stability of fiber technological traits as a complementary selection criterion in cotton breeding programs. Although breeding has traditionally focused on improving mean fiber quality, the consistency of these traits across canopy positions has received comparatively less attention. Fiber properties naturally vary according to boll position within the plant canopy, influencing the homogeneity of the harvested lint (Bauer et al., 2009). Genotypes capable of maintaining stable fiber quality despite differences in boll position are expected to produce more uniform raw material, thereby increasing the predictability of fiber performance during industrial processing. Thus, evaluating both fiber quality and its stability within the plant provides additional information that can improve the identification and selection of superior cotton genotypes.

However, the genetic expression of fiber quality traits is not necessarily controlled by the same mechanisms. Differences in the genetic basis of fiber quality components have been demonstrated through genomic analyses. Distinct loci and candidate genes associated with fiber maturity, structural integrity, and mechanical strength highlight the complex genetic architecture underlying these traits (Amarasinghe et al., 2026).

This complex genetic architecture helps explain why the magnitude of genetic variability and heritability differs among fiber traits (Lakshmanan et al., 2025). Fiber quality is governed by quantitative traits and genetic relationships that may either facilitate or constrain simultaneous genetic improvement. Genotypic correlations among fiber quality traits and differences in additive and non-additive genetic effects further support the complexity of these characteristics (Zeng and Pettigrew, 2015).

The evaluated materials also exhibited complementary technological profiles. BRS 372, FM 982, and UFU-H were distinguished by superior fiber length, whereas BRS 372 showed the highest fiber strength. TMG 45 B2RF and UFU-H exhibited greater fiber elongation and the lowest short fiber index, respectively. This distribution of desirable traits among different genotypes demonstrates that the available genetic variability is not concentrated in a single technological profile, thereby expanding the opportunities for selecting materials according to specific fiber quality objectives (Bao et al., 2025; Gurmessa and Balcha, 2026).

The existence of distinct genetic bases controlling individual fiber quality components reinforces the importance of conserving genetic diversity within cotton breeding programs. Genetically structured populations enable the identification of genomic regions associated with specific traits and facilitate the incorporation of favorable alleles into elite breeding lines (Amarasinghe et al., 2026).

Therefore, the evaluated genotypes represent a genetically contrasting set for fiber technological traits. The distribution of desirable attributes among commercial cultivars and UFU breeding lines revealed distinct fiber quality profiles. This heterogeneity broadens the genetic base available for selection and indicates that the evaluated materials may contribute differently to cotton fiber quality improvement.

Boll position within the plant canopy primarily affected micronaire and fiber maturity. This effect is associated with boll formation at different stages of the growing season. The indeterminate growth habit of cotton exposes reproductive structures to distinct environmental and physiological conditions throughout their development (Kuai et al., 2015; Zhang et al., 2026; Zhao et al., 2026).

A reduction in micronaire in the upper canopy was observed for BRS 368RF, BRS 372, IMA 5675 B2RF, TMG 82 WS, UFU-H, and UFU-P. In IMA 5675 B2RF, MIC decreased from 3.52 to 2.47. This pattern suggests reduced secondary cell wall deposition in fibers from bolls formed later in the growing season. Changes in developmental conditions may reduce micronaire and impair fiber maturation (Zeng and Pettigrew, 2015).

Fiber maturity partially followed the same trend. IMA 5675 B2RF and UFU-H exhibited lower MAT values in the upper canopy. In contrast, uniformity index (UI), short fiber index (SF), and fiber strength (STR) remained relatively stable across canopy positions. These results indicate that the developmental

environment of the boll does not affect all fiber technological traits to the same extent. Differential responses among fiber quality traits have also been reported under changes in plant architecture (Sawan, Mahmoud, and Fahmy, 2008).

Fiber length showed a genotype-specific response to canopy position. FM 982, IMA 8405 GLT, and TMG 82 WS exhibited lower upper half mean length (UHML) in the upper canopy. In IMA 8405 GLT, UHML decreased from 29.50 to 27.76 mm. These differences may be associated with photoassimilate availability during boll development. The subtending leaf supplies approximately 60% to 87% of the sucrose required by the developing boll, making the source–sink relationship a key determinant of fiber development (Wang et al., 2026).

The combination of superior fiber quality and canopy stability was most evident in DP 1552 B2RF. This genotype exhibited high uniformity index (84.93%) and fiber elongation (9.04%), together with the lowest short fiber index (6.74%). Moreover, its fiber technological traits remained stable across the three canopy positions.

This profile is particularly relevant because fiber quality depends on the combined expression of multiple traits. Superiority in a single characteristic does not necessarily define a high-quality genotype. Fiber length, micronaire, uniformity, and strength should be considered jointly in breeding programs (Bourland et al., 2010). BRS 372 exhibited a complementary profile, combining high UHML (29.67 mm) with the greatest fiber strength (33.02 gf tex⁻¹). These traits remained stable across canopy positions; however, MIC and MAT varied within the canopy. Consequently, the stability of BRS 372 was primarily associated with fiber length and strength.

The stability of fiber technological traits is essential for maintaining consistent fiber quality. Stable cultivars exhibit smaller performance fluctuations under variable production environments, an important characteristic for ensuring predictable fiber quality (Bradov et al., 1997; Snider et al., 2013).

FM 975 WS also exhibited stable performance across canopy positions; however, its overall fiber technological profile was less favorable. This contrast demonstrates that stability and performance should be evaluated simultaneously. Multi-trait selection enables the identification of genotypes that combine desirable fiber attributes with high stability (Manivannan, 2024; Supriha et al., 2024).

Among the evaluated genotypes, DP 1552 B2RF exhibited the best combination of fiber technological quality and canopy stability. In contrast, BRS 372 was distinguished by its superior fiber length and strength. Therefore, DP 1552 B2RF displayed the most balanced multi-trait profile among the evaluated genotypes.

Canopy stability also has important implications for the uniformity of fiber produced by the plant. At harvest, fibers originating from bolls formed at different canopy positions and developmental stages are combined into a single seed-cotton mass. Consequently, favorable genotype means may mask intraplant variation that affects the consistency of the final product (Ge et al., 2011). Reducing the variability of fiber length, strength, and micronaire may be as important for textile processing as improving the average values of these traits (Bauer et al., 2009). In this context, the stability observed in DP 1552 B2RF suggests greater homogeneity of the raw material throughout the canopy, adding an important technological dimension to its agronomic superiority.

These findings demonstrate that evaluating fiber quality solely on the basis of genotype means may overlook important differences in fiber consistency within the plant (Supriha et al., 2024). Identifying genotypes that combine superior technological traits with stability across canopy positions improves the precision of cultivar selection. This approach addresses the increasing demand for cotton fibers with uniform and predictable quality, an essential requirement for textile processing (Bourland et al., 2010; Snider et al., 2013). Therefore, the integrated evaluation of fiber technological quality and canopy stability provides a more comprehensive understanding of genotype performance and can support the selection of cotton genotypes with more consistent fiber quality.

Conclusion

This study evaluated the intraplant stability of fiber quality and identified cotton genotypes capable of combining superior technological performance with consistency across canopy positions. The results demonstrated that boll position selectively affects fiber technological traits and that the magnitude of this response varies among genotypes.

DP 1552 B2RF exhibited the most balanced fiber quality profile, combining high fiber uniformity and elongation, a low short fiber index, and stable performance throughout the canopy. BRS 372 was distinguished by superior fiber length and strength, although variation in micronaire and fiber maturity was observed among canopy positions.

These findings demonstrate that evaluating fiber quality solely on the basis of genotype means may overlook important intraplant variation and reinforce canopy stability of fiber quality as a complementary criterion for genotype selection. This study was conducted under a single environmental condition using a set of 12 genotypes, which limits the extrapolation of the results. Further evaluations across multiple environments and growing seasons are needed to confirm the consistency of the observed patterns. Future studies should also integrate multi-trait selection indices with intraplant stability to improve the identification of cotton genotypes combining superior, uniform, and predictable fiber quality.

Declarations

Competing interests

The authors declare no competing interests.

Generative AI use

Generative AI tools (SciSpace, ChatGPT, and Napkin) were used to support language revision, text organization, and figure preparation. All content, interpretations, and final decisions regarding the manuscript and figures were reviewed and approved by the authors, who assume full responsibility for the work.

Funding

Coordination for the Improvement of Higher Education Personnel (CAPES) - Finance Code 001.

Author Contribution

AGGN conducted the experiment, collected the data, analyzed it, and wrote the text. EGSJ and LBS assisted in setting up the experiment, designing it, and proofreading the text. FOF assisted with the statistics, interpretation of the results, and writing the text. All authors read, edited, and approved the final manuscript.

Acknowledgement

The authors acknowledge the Federal University of Uberlândia, National Council for Scientific and Technological Development (CNPq), the Minas Gerais State Research Support Foundation (FAPEMIG), and the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support.

Data Availability

The data that support the findings of this study are available from the corresponding author, FOF, upon reasonable request.

References

1. Amarasinghe, P., G. Pinnika, G. N. Thyssen, M. Naoumkina, D. D. Fang, C. B. Florane, P. Li, J. N. Jenkins, J. C. McCarty, L. Zeng, B. T. Campbell, C. D. Delhom, D. C. Jones, and H. J. Kim. 2026. "Genome-wide association studies of single-fiber phenotypes uncover distinct genetic bases for fiber and seed coat neps that lower cotton quality and value." *Industrial Crops and Products* 249:123766. <https://doi.org/10.1016/j.indcrop.2026.123766>.
2. Bao, B., X. Yu, E. Wang, D. Chu, W. Gao, Y. Ouyang, C. Zhang, W. Chen, C. Wang, H. Jin, and S. Zhang. 2025. "Mechanical specimen preparation method for next-generation cotton quality testing using HVIs." *Industrial Crops and Products* 233:121455. <https://doi.org/10.1016/j.indcrop.2025.121455>.
3. Bauer, P. J., J. A. Foulk, G. R. Gamble, and E. J. Sadler. 2009. "A comparison of two cotton cultivars differing in maturity for within-canopy fiber property variation." *Crop Science* 49:651–657. <https://doi.org/10.2135/cropsci2008.06.0350>.
4. Bechere, E., L. Zeng, and D. Boykin. 2014. "Correlation and path-coefficient analyses of lint yield and other traits in upland cotton (*Gossypium hirsutum* L.)." *Journal of Crop Improvement* 28:852–870. <https://doi.org/10.1080/15427528.2014.955621>.
5. Bolek, Y. 2010. "Genetic variability among cotton genotypes for cold tolerance." *Field Crops Research* 119:59–67. <https://doi.org/10.1016/j.fcr.2010.06.015>.
6. Bourland, F. M., R. Hogan, D. C. Jones, and E. Barnes. 2010. "Development and utility of Q-score for characterizing cotton fiber quality." *Journal of Cotton Science* 14:53–63. <https://www.cotton.org/journal/2010-14/2/53.cfm>
7. Bradow, J. M., L. H. Wartelle, P. J. Bauer, and G. F. Sassenrath-Cole. 1997. "Small-sample cotton fiber quality quantitation." *Journal of Cotton Science* 1:48–60. <https://journal.cotton.org/article/1-1-048/>.
8. Davidonis, G. H., et al. 2005. "The influence of cotton seed weight on fibers per seed and fiber property uniformity." *Journal of New Seeds* 7:1–13. https://doi.org/10.1300/J153v07n03_01.
9. Ge, Y., J. A. Thomasson, C. L. S. Morgan, S. M. Stanislav, and R. Sui. 2011. "Cotton revenue apportioned between lint yield and fiber quality: a precision agriculture perspective." *Journal of Cotton Science* 15:274–281. <https://www.cotton.org/journal/2011-15/3/274.cfm>.
10. Gurmessa, D., and M. Balcha. 2026. "Genetic potential and limitations of Ethiopian cotton (*Gossypium* spp.) germplasm for improving important fiber quality attributes." *Industrial Crops and Products* 242:122999. <https://doi.org/10.1016/j.indcrop.2026.122999>.
11. Klueva, N. Y., R. C. Joshi, C. P. Joshi, D. B. Wester, R. E. Zartman, R. G. Cantrell, and H. T. Nguyen. 2000. "Genetic variability and molecular responses of root penetration in cotton." *Plant Science* 155:41–47. [https://doi.org/10.1016/S0168-9452\(00\)00205-3](https://doi.org/10.1016/S0168-9452(00)00205-3).
12. Kuai, J., Z. Zhou, Y. Wang, Y. Meng, B. Chen, and W. Zhao. 2015. "The effects of short-term waterlogging on the lint yield and yield components of cotton with respect to boll position." *European Journal of Agronomy* 67:61–74. <https://doi.org/10.1016/j.eja.2015.03.005>.
13. Lakshmanan, S., S. Selvaraj, S. R. Silambiah, P. Anantharaju, D. Vijayalakshmi, T. Ragavan, and P. Dhamodharan. 2025. "Managing cotton canopy architecture for machine picking cotton via high plant density and plant growth retardants." *Journal of Cotton Research* 8:2. <https://doi.org/10.1186/s42397-024-00202-0>.
14. Li, Z., Z. Lei, M. Jia, Ü. Niinemets, W. Zhang, F. Liu, and Y. Zhang. 2025. "Patterns of domestication in upland cotton (*Gossypium hirsutum*)." *BMC Plant Biology* 25:1093. <https://doi.org/10.1186/s12870-025-07154-w>.

15. Liu, S., D. Zuo, H. Cheng, M. He, Q. Wang, L. Lv, Y. Zhang, J. Ashraf, J. Liu, and G. Song. 2023. "Cotton pedigree genome reveals restriction of cultivar-driven strategy in cotton breeding." *Genome Biology* 24:282. <https://doi.org/10.1186/s13059-023-03124-3>.
16. Mangi, N., M. S. Iqbal, F. Shuli, M. T. Iqbal, B. Alharthi, G. H. Jatui, Z. Sarfraz, Q. Ma, and X. Sun. 2024. "Empowering cotton breeding programs through the strategic exploration and exploitation of phenotypic diversity of genetic resources under climate change conditions." *Plant Stress* 13:100548. <https://doi.org/10.1016/j.stress.2024.100548>.
17. Manivannan, A. 2024. "Combining ability studies in desi cotton (*Gossypium arboreum* L.) genotypes." *Journal of Cotton Research* 7:37. <https://doi.org/10.1186/s42397-024-00200-2>.
18. May, O. L. 1999. "Producing quality cotton by conventional breeding, marker assisted selection, and transgenic methods." *Journal of New Seeds* 1:65–82. https://doi.org/10.1300/J153v01n02_05.
19. R Core Team. 2026. *R: A language and environment for statistical computing*. Version 4.5.0. Vienna: R Foundation for Statistical Computing. <https://www.R-project.org/>.
20. Reddy, K. R., and H. F. Hodges. 2006. "Exploring the limitations for cotton growth and yield." *Journal of New Seeds* 8:1–22. https://doi.org/10.1300/J153v08n02_01.
21. Santos, H. G., P. K. T. Jacomine, L. H. C. Anjos, V. A. Oliveira, J. F. Lumbreras, M. R. Coelho, J. A. Almeida, J. C. Araujo Filho, J. B. Oliveira, and T. J. F. Cunha. 2018. *Sistema Brasileiro de Classificação de Solos*. 5th ed. Brasília: Embrapa. <https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1094003>.
22. Sawan, Z. M., M. H. Mahmoud, and A. H. Fahmy. 2008. "Cotton (*Gossypium barbadense* L.) yield and fiber properties as affected by plant growth retardants and plant density." *Journal of Crop Improvement* 21:171–189. <https://doi.org/10.1080/15427520701885683>.
23. Snider, J. L., G. D. Collins, J. Whitaker, and J. W. Davis. 2013. "Quantifying genotypic and environmental contributions to yield and fiber quality in Georgia: data from seven commercial cultivars and 33 yield environments." *Journal of Cotton Science* 17:285–292. <https://www.cotton.org/journal/2013-17/4/285.cfm>.
24. Stetina, S. R., R. B. Turley, N. Bellaloui, and J. C. Boykin. 2014. "Yield and fiber quality of five pairs of near-isogenic cotton (*Gossypium hirsutum* L.) lines expressing fuzzless/linted and fuzzy/linted seed phenotypes." *Journal of Crop Improvement* 28:680–699. <https://doi.org/10.1080/15427528.2014.931901>.
25. Supritha, D. S. R., R. S. Patil, B. R. Patil, S. N. Nayak, and K. N. Pawar. 2024. "Characterization of early maturing elite genotypes based on MTSI and MGIDI indexes: an illustration in upland cotton (*Gossypium hirsutum* L.)." *Journal of Cotton Research* 7:25. <https://doi.org/10.1186/s42397-024-00187-w>.
26. Wang, C., S. Wang, Y. Zhang, W. Hu, W. Zhao, B. Chen, and Z. Zhou. 2026. "Optimizing photoassimilate synthesis, metabolism, and loading in cotton's 'source-sink-flow' system by boron fertilizer management to increase boll weight." *The Crop Journal* 14:1028–1038. <https://doi.org/10.1016/j.cj.2025.12.011>.
27. Wedegaertner, K., A. Shekoofa, K. Sheldon, J. Simón, and T. B. Raper. 2022. "Screening cotton cultivars under induced water-deficit stress in controlled environments and field settings: expression of drought tolerance traits." *Journal of Crop Improvement*. <https://doi.org/10.1080/15427528.2022.2098217>.
28. Zeng, L., and W. T. Pettigrew. 2015. "Combining ability, heritability, and genotypic correlations for lint yield and fiber quality of upland cotton in delayed planting." *Field Crops Research* 171:176–183. <https://doi.org/10.1016/j.fcr.2014.10.004>.
29. Zhang, Z., K. Li, J. Zhang, Q. Liao, Y. Wang, X. Yuan, K. Yu, M. Yang, G. Chen, S. Wan, S. Lou, F. Li, M. Du, X. Tian, and Z. Li. 2026. "Regulating sink-source ratio optimizes cotton defoliation efficiency during the early-to-mid flowering and boll stages." *Industrial Crops and Products* 243:123056. <https://doi.org/10.1016/j.indcrop.2026.123056>.

Figures

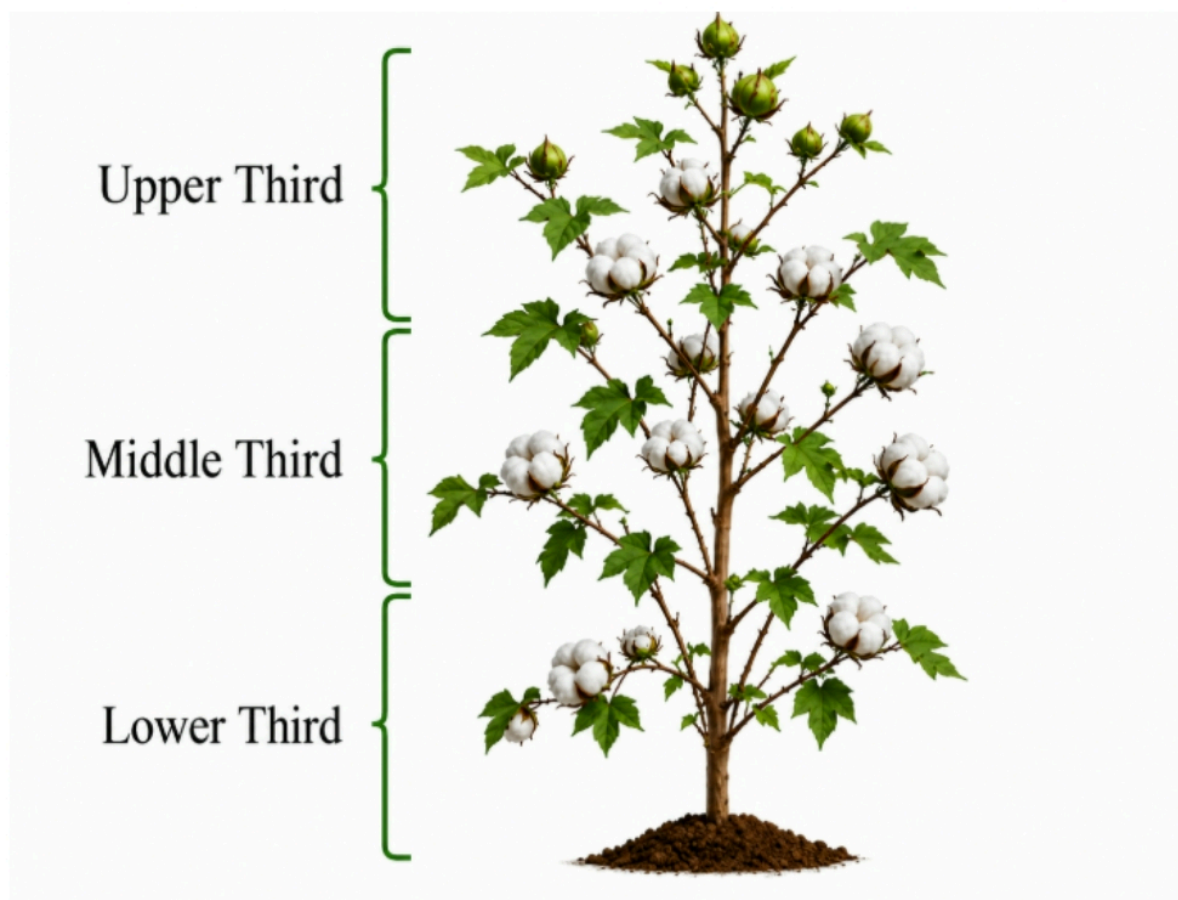


Figure 1

Schematic representation of a cotton plant showing the boll positions used for fiber sampling.

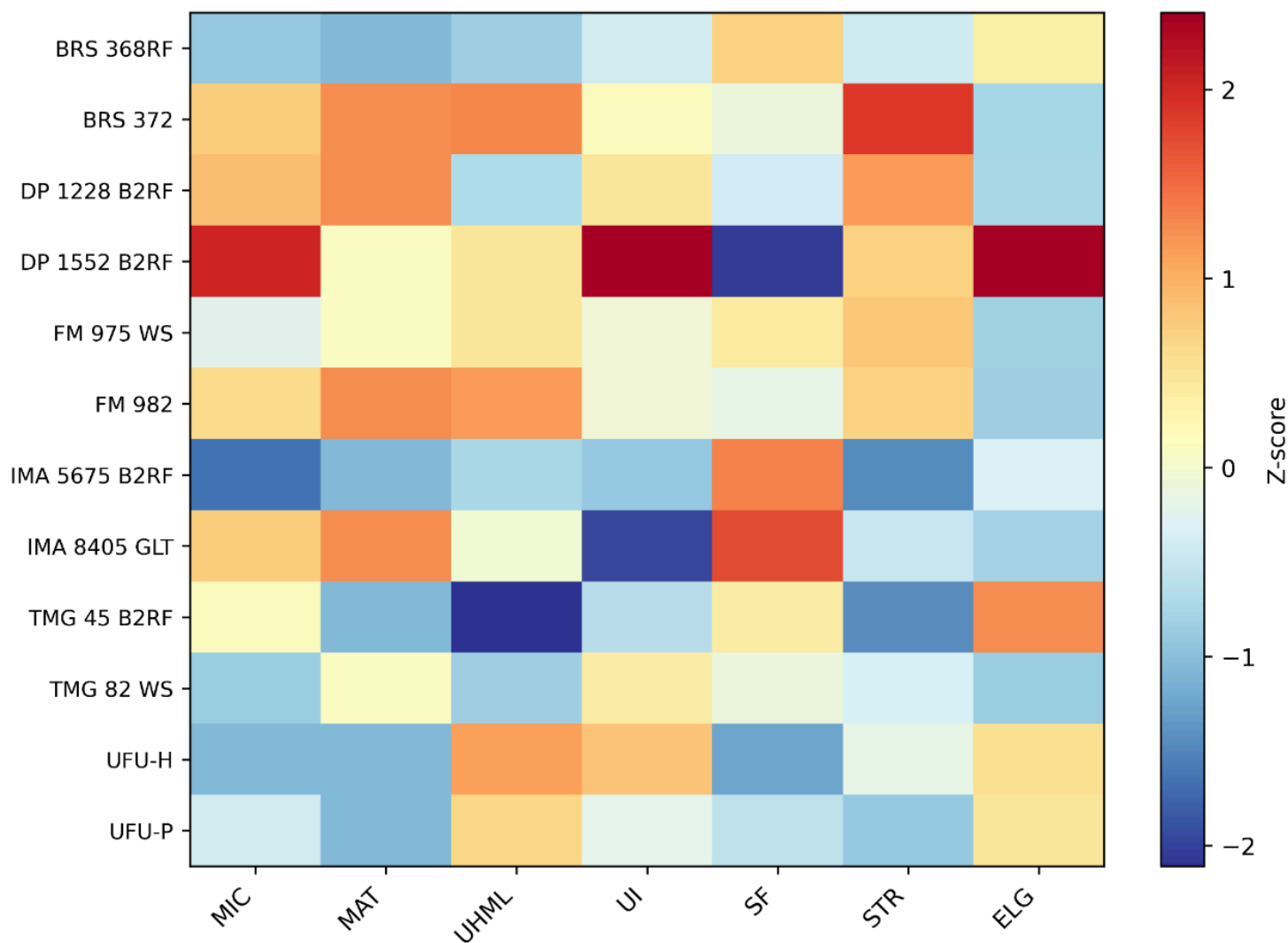


Figure 2

Heatmap of standardized mean values (z-scores) for fiber technological traits of 12 cotton genotypes. Red values indicate means above the overall mean for each trait, whereas blue values indicate means below the overall mean. MIC: micronaire index; MAT: fiber maturity; UHML: upper half mean length; UI: uniformity index; SF: short fiber index; STR: fiber strength; ELG: fiber elongation.