ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.8, p.610-617, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n8p610-617

Selection of cotton genotypes for yield and fiber quality under water stress[1]

Seleção de genótipos de algodoeiro sob estresse hídrico para produtividade e qualidade de fibra

Itallo H. R. A. Gomes[2*], José J. V. Cavalcanti[2], Francisco J. C. Farias[2],
Francisco J. R. da Paixão[3], João L. da Silva Filho[2] & Nelson D. Suassuna[2]

[1] Research developed at Quixeramobim, CE, Brazil
[2] Embrapa Algodão, Campina Grande, PB, Brazil
[3] Instituto Centec/Fatec Sertão Central, Quixeramobim, CE, Brazil

HIGHLIGHTS:
The environment used is quite significant for the stress conditions.
The ratio CVg/CVe was higher than 1, indicating the possibility of gains in the genetic selection process.
All genotypes tested showed cottonseed yield higher than 2.000 kg ha^{-1}.

ABSTRACT: The objective of this work was to select a cotton line tolerant to water stress, based on yield and fiber quality characteristics. A total of nine cotton genotypes were evaluated (six breeding lines and three commercial cultivars) in two field experiments conducted in Quixeramobim - CE without water supplementation in 2018 and 2019, respectively. Traits related to cotton lint yield and intrinsic fiber quality were measured. Data were submitted to individual and joint analysis of variance, and selection by the selection index. The genetic variability among the materials demonstrates the possibility of significant gains in the cotton selection process. The genotypes CNPA 2013 - 2235 RF FL, CNPA 2013 - 2064 RF FL and CNPA 2012 - 160 RF FL, as well as the cultivar FM 944 GL, had higher production and better fiber quality under rainfed conditions.

Key words: *Gossypium hirsutum* L., semi-arid, genetic improvement

RESUMO: O objetivo deste estudo foi selecionar linhagens de algodoeiro tolerantes ao estresse hídrico, com base em caracteres de produtividade e qualidade de fibra. O experimento foi conduzido em dois experimentos de campo em Quixeramobim - CE sem suplementação hídrica, nos anos: 2018 e 2019. Foram avaliados nove genótipos de algodoeiro, sendo seis linhagens e três cultivares comerciais. Foram mensuradas variáveis relacionadas com produtividade de algodão em pluma e qualidade intrínseca de fibra. Os dados foram submetidos à análise de variância individual e conjunta, e a seleção pelo índice de seleção. A variabilidade genética encontrada entre os materiais demonstra a possibilidade de ganhos significativos no processo de seleção do algodoeiro. Os genótipos CNPA 2013 - 2235 RF FL, CNPA 2013 - 2064 RF FL e CNPA 2012 - 160 RF FL e a cultivar FM 944 GL tiveram maior produção e melhor qualidade de fibra em condições de sequeiro.

Palavras-chave: *Gossypium hirsutum* L., semiárido, melhoramento genético

---

• Ref. 256110 – Received 26 Sept, 2021
* Corresponding author - E-mail: italloharlan@gmail.com
• Accepted 13 Apr, 2022 • Published 03 May, 2022
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most important natural fiber crop in the world and a source of oil and food products (ABRAPA, 2018). Cotton-growing areas have been re-established in the semi-arid region (Caatinga biome) of Northeast Brazil, based on the use of modern technologies and high-quality fiber cultivars. However, in the northeastern semi-arid region, the rainy season is not very predictable, with frequent dry periods.

Several studies have shown that prolonged water deficit in cotton crops affects growth, productivity and fiber quality (Carvalho et al., 2019; Vasconcelos et al., 2018; Zonta et al., 2015a; Zonta et al., 2015b).

The selection of lines that best adapt to the conditions of the semi-arid region of the Brazilian northeast is fundamental to subsidizing the cotton productivity of the region, with conditions of competitiveness in relation to other cotton-producing regions, and also essential for regional development and job creation (Silva et al., 2020). Therefore, improving cotton for the semi-arid region can substantially contribute to offering producers more stable genotypes that are more adapted to the regional rainfall pattern (Vasconcelos et al., 2018).

Cotton can resist water stress during the pre-quad period. During this initial period of vegetative growth, the roots expand rapidly while the leaf area expands slowly (Freire, 2015). However, during flowering and fruiting periods, cotton is more sensitive, requiring 5 to 8 mm of water per day to achieve high yields and fiber quality (Freire, 2015). There is genetic variation in cotton for abiotic stresses such as water deficit, salinity, and high temperatures; in addition, some cotton cultivars are more tolerant to water deficit (Vasconcelos et al., 2018). In Brazil, most cotton cultivars were developed with a focus on cultivation in the Brazilian semi-arid environment (Barroso et al., 2017; Suassuna et al., 2020).

The objective of this work was to select cotton lines tolerant to water stress, based on the characteristics of yield and fiber quality.

MATERIAL AND METHODS

The experiment was conducted in the experimental field of the CENTEC (Institute of the Center for Educational Technology) in Quixeramobim, CE (5° 10' 28.97" S, 39° 17' 13.56" O, and 191 m of altitude), in April to September, in 2018 and 2019. During the period of conducting the experiment, the total amount of rain was 174.4 mm in 2018 and 279.0 mm in 2019 (FUNCEME, 2019). The minimum average amount of water during cotton planting is around 300 mm, and this medium is considered adequate for obtaining a reasonable fiber yield (Carvalho et al., 2019).

With an average annual temperature of 27.3°C, this region is classified as 'Tropical savanna climate with dry-winter characteristics' (Aw), following the Köppen climate classification. Aw climates have a pronounced dry season, with the driest month having less than 60 mm precipitation.

The plant material used involved cotton breeding lines provided by EMBRAPA's Cotton Breeding Program. All lines were previously selected based on agronomic and fiber traits. They were derived from an initial backcross-breeding program to incorporate the event MON 88913 using the conventional preliminary lines as recurrent parents, followed by the pedigree selection method. The initial biparental cross was performed involving the recurrent parents and the transgenic trait donor, Sure Grow 125R, followed by three backcrosses. From the BC_3F_2 generation, only homozygous plants for the Roundup Ready Flex® gene were advanced to progeny rows tests and subsequent advance as breeding lines. The event MON 88913 (Roundup Ready Flex - RF) confers resistance to the herbicide Glyphosate in all stages of cotton plant development.

The experiments were carried out without additional water supply. Crop management was carried out following agronomic recommendations, and fertilization was based on technical recommendations for the crop (EMBRAPA, 2004).

A total of nine transgenic genotypes (treatments) were tested, including six cotton lines and three commercial cotton cultivars used as controls. The commercial cultivars were BRS 368 RF, BRS 371 RF, FM 944 GL, and the lines used were CNPA 2012 - 120 RF, CNPA 2013 - 81 RF, CNPA 2013 - 535 RF, CNPA 2012 - 160 RF FL, CNPA 2013 - 2064 RF FL and CNPA 2013 - 2235 RF FL.

The experimental design it was randomized blocks, with four replicates. The experimental plot consisted of two lines of 5 m and a spacing of 0.90 m. A population density of seven plants per meter was used, with a final stand of 70 plants per plot.

Pest and weed management were carried out using chemical insecticides or herbicides in accordance with integrated pest management as recommended (Carvalho et al., 2019).

The harvest was carried out after 128 days and samples were collected in each plot (20 bolls) to be analyzed according to Vasconcelos et al. (2020). The following agronomic and fiber characteristics were measured: boll weight (g) - PC, cottonseed production (kg ha^{-1}) - CY, fiber percentage (%) - LP, fiber production (kg ha^{-1}) - LY, fiber length (mm) - UHM, uniformity index (%) - UNF, hardwood index (%) - SFI, fiber strength (gf tex^{-1}) - STR, fiber elongation (%) - ELG, micronaire index - MIC and spinning consistency index - CSP.

Statistical analyses were carried out using the software GENES version 6.1 (Cruz, 2012). For the analysis of variance (ANOVA), the effects of environment (years) and genotype were considered fixed. The means were grouped by the Scott-Knott hierarchical clustering algorithm (Scott & Knott, 1974), at $p \leq 0.05$. The data were submitted to individual analysis of variance and selection of genotypes through the selection index proposed by Mulamba & Mock (1978) and by the direct and indirect selection index, through the GENES software. Data were pooled as the hypothesis of equal variances was not rejected, and joint analysis was performed according to Cruz et al. (2012).

$$Y_{ijk} = \mu + \left(\frac{B}{A}\right)_{kj} + G_i + A_j + \left(GA\right)_{ij} + \varepsilon_{ijk} \qquad (1)$$

where:

Y_{ijk} - observation of the i-th genotype evaluated in the k-th block, and in the j-th environment;

μ - general average;

$(B/A)_{kj}$ - effect of block k within environment j;

G_i - effect of genotype i;

A_j - effect of the environment j;

$(GA)_{ij}$ - effect of the interaction between genotype i and environment j; and,

ε_{ijk} - experimental error associated with the Y_{ijk} observation.

In order to detect possible patterns of interaction Genotypes x Environments (G x E) and to facilitate a visual data inspection as well, graphic dispersions were performed for the traits CY, LP, LY, BW, UHM, UNF, SFI, STR, ELG, MIC, and CSP, considering as abscissa the values of the phenotypic performances of the genotypes in year 1 (2018) and as ordinate those observed in year 2 (2019). The graphics were created using R software, using the 'ggplot2' package. The position of each genotype in the quadrants on the scatter plot was then used as an interpretation criterion.

Results and Discussion

The water conditions during the experiment period were quite severe, considering the rainfed planting and that there was no water complementation during planting. The water precipitation during planting was 174.4 mm in 2018 and 279.0 mm in 2019 (FUNCEME, 2019) far below the ideal for this crop (600 mm) and below the values found by Carvalho et al. (2019) and Vasconcelos et al. (2020).

Significant differences among genotypes (G) were found for all traits analyzed, demonstrating variability among the cotton genotypes used (Table 1). Environment (E) had no effect on LP, UHM, STR, MIC and CSP. On the other hand, G x E interaction did not show any significant effect, indicating that genotypes had similar responses to tested traits in the two years (2018 and 2019).

The values of the coefficients of variation ranged from 1.04 (UNF) to 26.33% (LY). Higher CV values for LY are expected due to the influence of environment on this trait, which was also verified in other works (Vasconcelos et al., 2018; Carvalho et al., 2019).

Broad-sense heritability, that is the proportion of phenotypic variation due to genetic values, represents the safety of phenotypic values as estimates of genotypic values, in which higher heritability means the greater the genetic gain obtained in the selection process (Carvalho et al., 2015). However, this approach is only valid when the effects of the genotypes are taken as random, and are assumed to represent a reference population, allowing the breeder to produce and/or simulate selection.

When genotype effects are assumed to be fixed, as in the present case, this fraction of the variance is called the genotypic determination coefficient (GDC). The GDC found was over 80% for most of the variables evaluated (Table 2), with the exception of CY and LY, showing that variation in yield and fiber quality must be of a genetic nature, which allows for a more effective selection for superior genotypes with a greater probability of success and selection gain, mainly as a

Table 1. Summary of the combined ANOVA with mean square values of the agronomic traits and fiber quality of cotton genotypes, evaluated at Quixeramobim - CE (2018 and 2019)

Variable	Genotype (G)	Environment (E)	G x E	Residual	CV (%)
CY	831855.09*	7046539.55 **	592558.93	349116.24	24.31
LP	51.19*	1.87	1.90791	1.12	2.74
LY	229191.58**	1165192.71**	92177.38	61773.65	26.33
BW	2.17**	2.96**	0.28	0.17	7.20
UHM	20.32**	2.01	2.09	1.96	4.18
UNF	4.09**	19.17**	1.66	0.79	1.04
SFI	1.26**	2.39*	0.47	0.39	9.07
STR	25.81**	1.22	2.57	2.55	4.83
ELG	2.19**	5.29**	0.18	0.16	7.77
MIC	0.45**	0.08	0.11	0.05	5.25
CSP	625907.06**	277282.83	46108.77	51951.26	7.69

** and * - Significant at $p \leq 0.01$ and 0.05 by the F test; CV - coefficient of variation; CY - cotton seed yield; LP - lint percentage; LY - lint yield; BW - boll weight; UHM - fiber length; UNF - uniformity index; SFI - short fiber index; STR - fiber strength; ELG - fiber elongation at break; MIC - micronaire index; CSP - spinning consistence index

Table 2. Estimates of genetic parameters of agronomic and fibers quality traits of cotton genotypes based on average of the two years used (2018 and 2019). Quixeramobim - CE

Variable	CQG	GDC (%)	VR	CVg (%)	CVg/CVe
CY	60342.35	58.03	349116.24	10.10	0.41
LP	6.26	97.80	1.12	6.47	2.36
LY	20927.24	73.04	61773.65	15.32	0.58
BW	0.25	92.07	0.17	8.67	1.20
UHM	2.29	90.32	1.96	5.19	1.08
UNF	0.41	80.57	0.79	0.75	0.72
SFI	0.10	68.58	0.39	4.74	0.52
STR	2.90	90.11	2.55	5.16	1.06
ELG	0.25	92.54	0.16	9.68	1.24
MIC	0.05	87.78	0.05	4.98	0.94
CSP	71744.47	91.69	51951.26	9.03	1.17

QGC - quadratic genotypic component, GDC - genotypic determination coefficient; VR - residual variance; CVg - coefficient of genotypic variation; CY - cottonseed yield); LP - lint percentage; LY - lint yield; BW - boll weight; UHM - fiber length; UNF - uniformity index; SFI - short fiber index; STR - fiber strength; ELG - fiber elongation at break; MIC - micronaire index; CSP - spinning consistence index preliminary group of genitors for this region. However, the use of the GDC has direct implications for the interpretation of results, being restricted to this data set, since in this study a fixed model was used, although estimators and estimates are similar when compared to heritability.

In the present study, either due to the limited number of evaluated genotypes, in which there is less saturation of the sample space of the variable considered, or due to the genotypes' origin (some of which are of long fiber, others of medium fiber, for example), which would increase the estimate of the variability, the best alternative is to accept the genotype effects as fixed, restricting discussion to this studied set.

In a trial with 22 cotton genotypes conducted in a tropical environment, GDC values higher than 80% were found for most of the fiber traits, with a maximum value for UHM (92.90%) and STR (98.65%) (Bonifácio et al., 2015).

In this work it was verified that the variability of the fiber traits was high, giving greater flexibility in the selection process, thus optimizing the genetic gain in the selection of new breeding lines. Through the genetic variation coefficient (CVg) there is a perception on the proportion of the gain in relation to the average, corroborated by the coefficient of relative variation (CVg/CVe), estimated at ≥ 1, which indicates the possibility of successful selection from the perspective of genetic gain (Vencovsky, 1987).

The ratio between the CVg and the coefficient of environmental variation (CVe) indicates the obtaining of higher genetic gains in the selection of a certain trait (Cruz et al., 2012). In this study, the ratios for CVg/CVe were ≥ 1, as they were for most of the traits, except for CY, LY, UNF, and the MIC, again indicating the possibility of higher gains in the selection process.

Carvalho et al. (2019), evaluating the performance of the cotton in the semi-arid region underneath the supplementation of the water, found the values of the ratio CVg/CVe to be 0.80 (CY), 1.07 (LP), and 2.07 (LY). Ribeiro et al. (2018) evaluated 36 cotton breeding lines in a semi-arid region using the supplementation of water and in a rainfed condition in a Brazilian semi-arid area, obtaining significant values of the ratio CVg/CVe of 0.73 (CY), 0.60 (LP), and 1.23 (BW).

Given that the genotypes x environments (years) interaction was not significant, it was decided to perform the Scott-Knott cluster tests considering the means of the genotypes across the years (Table 3).

All genotypes tested showed cottonseed yield higher than 2.000 kg ha^{-1}, and had an average mass of one open boll higher than 5.1 g, with adequate agronomic performance, considering the condition for rainfed planting.

In Brazil, the fiber quality pattern of cotton cultivars in use has an average fiber length (UHM) between 28 mm and 32 mm (Vidal Neto & Freire, 2013). Cotton lines CNPA 2013 - 2235 RF LF, CNPA 2012 - 160 RF LF, and CNPA 2013 - 2064 RF FL, obtained the highest fiber length averages, at 32.29, 30.23 and 30.16 mm, respectively, and the first line can be classified as long-fiber cotton (Vidal Neto & Freire, 2013). These results are similar to those found by Carvalho et al. (2019), with values ranging from 27.66 to 34.04 in semi-arid conditions with water supplementation.

Carvalho et al. (2017) evaluated the performance of 22 cotton lines in semi-arid conditions in terms of their oil content and the traits related to the quality and fiber yield in cotton lines and obtained average values of UHM varying between 28.0 and 30.0 mm. Zonta et al. (2015a) assessed cotton lines under different irrigation levels, resulting in average UHM values between 27.9 to 31.5 mm and higher than those found by Campbell et al. (2016), who discovered mean values of 28.79 mm in research estimating the genetic variation for agronomic and fiber quality characteristics, through diallel analysis, finding significant additive effects on strength, length and micronaire.

Fiber resistance (STR) of all cotton genotypes examined exceeded 30 gf tex^{-1} with the higher values for the lines CNPA 2013 - 2235 RF FL (36.08) and CNPA 2012 - 160 RF FL (35.11). Carvalho et al. (2019) obtained values between 26.59 and 34.95 (gf tex^{-1}) when evaluating 18 cotton lines in a semi-arid region with water supplementation, while Zonta et al. (2015b), assessing the performance of four lines in a semi-arid environment under supplementary irrigation with 40, 70, 100 and 130% of the crop evapotranspiration, found STR values varying between 30.30 and 35.30 (gf tex^{-1}).

The micronaire index averages ranged from 4.19 to 4.91. These values are above the values considered desirable, which are between 3.6 to 4.2 (Farias, 2015). However, the textile industry considers the fibers to be very thick when they have indexes greater than 5.0 and immature when they have values below 3.5, which for the textile industry causes defects in the threads and decreases the affinity with the use of paints during the finishing process (Lima et al., 2019; Vidal Neto & Freire, 2013).

Table 3. Overall mean of the productivity and fiber quality for cotton lines grown in based on average of the two years used (2018 and 2019). Quixeramobim - CE

Genotypes	CY (kg ha^{-1})	LP (%)	LY (kg ha^{-1})	BW (g)	UHM (mm)	UNF (%)	SFI (%)	STR (gf tex^{-1})	ELG (%)	MIC	CSP
1- BRS 368 RF (T)	2478.47 c	40.42 b	1000.67 c	5.92 a	27.40 c	84.56 a	7.22 a	31.72 b	6.01 a	4.19 a	2804.54 f
2- BRS 371 RF (T)	2449.86 d	39.90 b	980.54 d	5.96 a	27.60 c	84.52 a	7.30 a	30.64 b	5.25 a	4.91 a	2585.50 i
3- FM 944 GL (T)	2943.33 a	42.18 a	1246.83 a	5.15 a	29.21 c	84.84 a	6.96 a	32.96 b	5.14 a	4.59 a	2914.72 e
4- CNPA 2012 - 120 RF	2190.83 g	38.90 b	851.35 f	5.68 a	28.37 c	84.54 a	7.22 a	31.90 b	5.54 a	4.58 a	2780.26 g
5- CNPA 2013 - 81 RF	2370.13 f	39.17 b	930.21 e	5.30 a	27.66 c	85.12 a	7.28 a	31.55 b	4.96 a	4.62 a	2769.27 h
6- CNPA 2013 - 535 RF	2089.86 h	38.72 b	807.35 h	5.22 a	29.22 c	84.49 a	7.23 a	33.02 b	5.70 a	4.22 a	2962.71 d
7- CNPA 2012 - 160 RF FL	2024.44 i	35.37 c	716.03 i	6.51 a	30.23 b	85.69 a	6.63 a	35.11 a	4.78 a	4.41 a	3220.79 b
8- CNPA 2013 - 2064 RF FL	2903.88 b	39.25 b	1140.49 b	5.56 a	30.16 b	85.91 a	6.41 a	34.18 a	5.18 a	4.63 a	3137.67 c
9- CNPA 2013 - 2235 RF FL	2421.11 e	33.90 c	821.87 g	6.55 a	32.29 a	86.41 a	6.31 a	36.08 a	4.24 a	4.26 a	3499.73 a

Control cultivars (T); the means followed by the same letter in the column did not differ statistically from each other by the Scott-Knott test at $p \leq 0.05$. Y: CY - cottonseed yield; LP - lint percentage; LY - lint yield; BW - boll weight; UHM - fiber length; UNF - uniformity index; SFI - short fiber index; STR - fiber strength; ELG - fiber elongation at break; MIC - micronaire index; CSP - spinning consistence index

The lines CNPA 2013 - 2064 RF FL, CNPA 2013 - 81 RF and CNPA 2012 - 120 RF had higher micronaire values with averages of 4.63, 4.62 and 4.59 respectively. Cordão Sobrinho et al. (2015) obtained results above five and Zonta et al. (2015b) with average values of 4.88 for this character when submitted to the irrigation regime recommended for cotton.

Albrecht et al. (2018) obtained values between 4.2 and 4.8, while Carvalho et al. (2019) obtained values between 4.16 and 5.33 for the micronaire index in a study with water supplementation. These results demonstrate that the tested genotypes adapt better than the others and are more tolerant to environmental conditions with water stress.

In general, the performance of the strains was quite satisfactory, since they were sowing under rained conditions, obtaining results similar to those of the controls that already have characteristics or affinity for semi-arid regions. From the results of the joint analysis (Table 1), the G x E interaction was not significant for all characteristics, indicating that selection in the average performance of the evaluated years is possible. The graphic dispersion of the genotypes for the traits CY, LY, LP and BW is shown in Figure 1. The dashed lines indicate the average values of the traits in each year. In this graph, the more profiled the points plotted on a 45° line (tg = 1), the greater the consistency of the behavior of the genotypes in the two years of evaluation, by analogy to the 'father - son' covariance, since the errors of the two years are independent.

Genotypes in the first quadrant performed above average in the two years of evaluation; those in the third quadrant below average; the genotypes in the second quadrant were above average in the first year and below in the second; finally, cotton genotypes in the fourth quadrant were below average in the first year and above average in the second. The genotypes g3 (FM 944 GL) and g8 (CNPA 2013 - 2064 RF FL) performed above average, in the two years, for CY and LY (Figures 1A and B) and LP. On the other hand, genotypes g7 (CNPA 2012 - 160 RF FL) and g6 (CNPA 2013 - 535 RF) were allocated to the third quadrant, with the lowest averages of CY and LY in the two years. Other genotypes showed yield inconsistency across the years. The g1 (BRS 368 RF) and g2 (BRS 371 RF) genotypes were below average in the first year and above average in the second. Both genotypes are full-season cultivars adapted to Brazilian semi-arid conditions (Barroso et al., 2017) and the better performance in 2019 must be due the greater availability of water in that year.

Genotype g3 showed a high LP (Figure 1 D) and lower BW (Figure 1C). Similarly, g8 was allocated to the first quadrant for LP and the third quadrant for BW. Thus, the largest number of bolls per plant should be the production component that

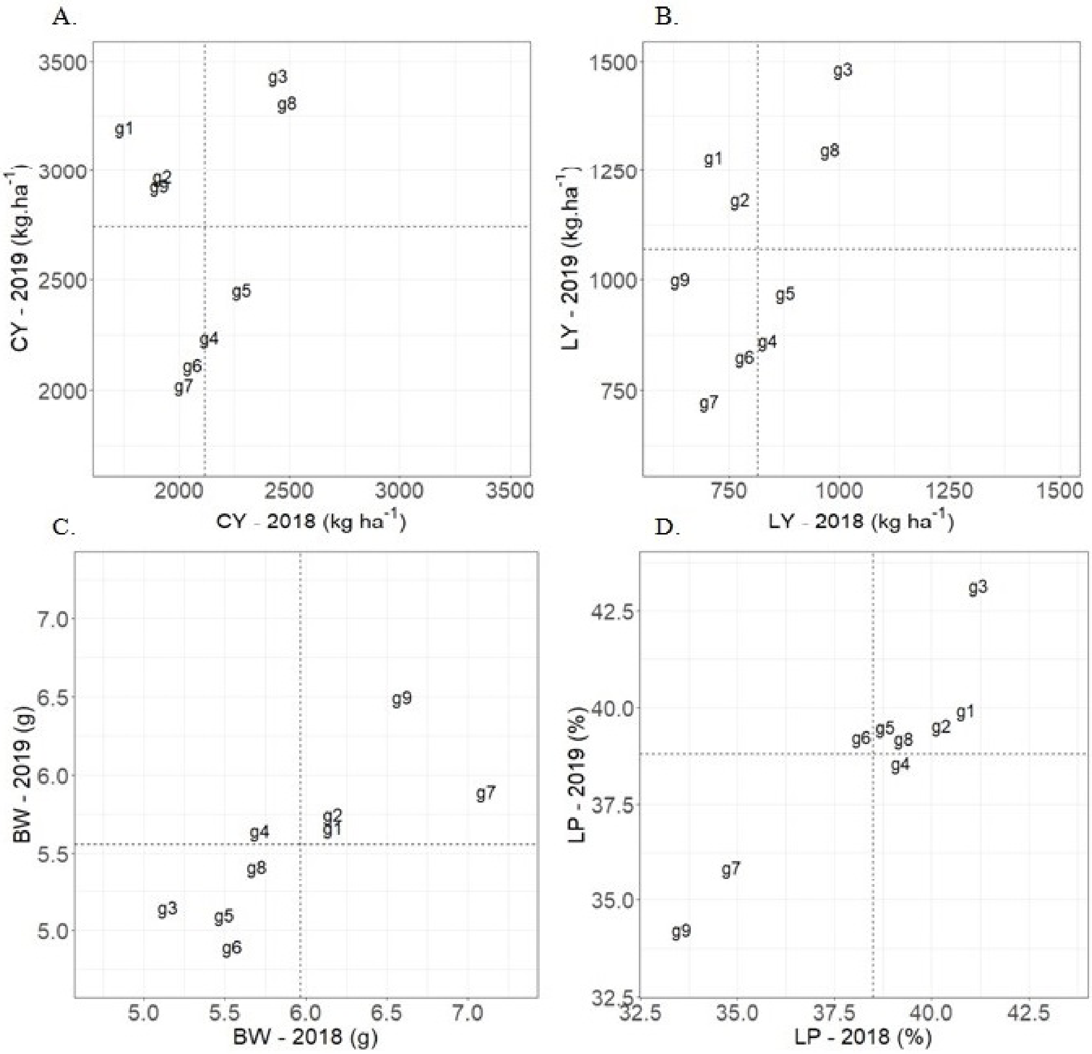

Figure 1. Dispersion of the genotypic values observed in 2018 and 2019 of the traits cottonseed yield (CY), lint yield (LY), lint percentage (LP) and boll weight (BW) of cotton genotypes, evaluated in Quixeramobim - CE

should be contributing the most to the better performance of these genotypes in CY and LY.

Genotypes allocated to the second and fourth quadrants had averages above and below the average from one year to the next; if far removed from the origin, they are inconsistent genotypes, with a marked environmental effect on the phenotype. The LP trait (Figure 1D) was very consistent across the years, with little interaction intensity between genotypes and environments for this trait.

The graphic dispersion of the characteristics related to fiber quality for the two years is shown in Figure 2A for compliance (UHM), Figure 2B for strength (STR), Figure 2C for micronaire (MIC), Figure 2D for the reliability index (CSP), Figure 2E for fiber uniformity (UNF) and Figure 2F for elongation at break (ELG).

For UHM, STR, UNF, and CSP, a consistent group was formed with the genotypes g7 (CNPA 2012 - 160 RF FL), g8 (CNPA 2013 - 2064 RF FL), and g9 (CNPA 2013 - 2235 RF FL). Cultivar FM 944 GL (g3) is a commercial grow crops widely planted in Brazil due to its good fiber quality required by the textile industry. Compared with FM 944 GL, genotypes g7, g8 and g9 represent a genetic gain in terms of fiber quality produced in semi-arid conditions.

The results obtained for the index of Mulamba & Mock (1978), and the grouping of the means of the genotypes with the estimates of the genotypic determination coefficient and the selection gains (GS %) for all the traits evaluated, are shown in Table 4.

Positive selection gains in CY (2.96%), LY (3.19%), and BW (2.81%) were recorded. According to Carvalho et al. (1997), in

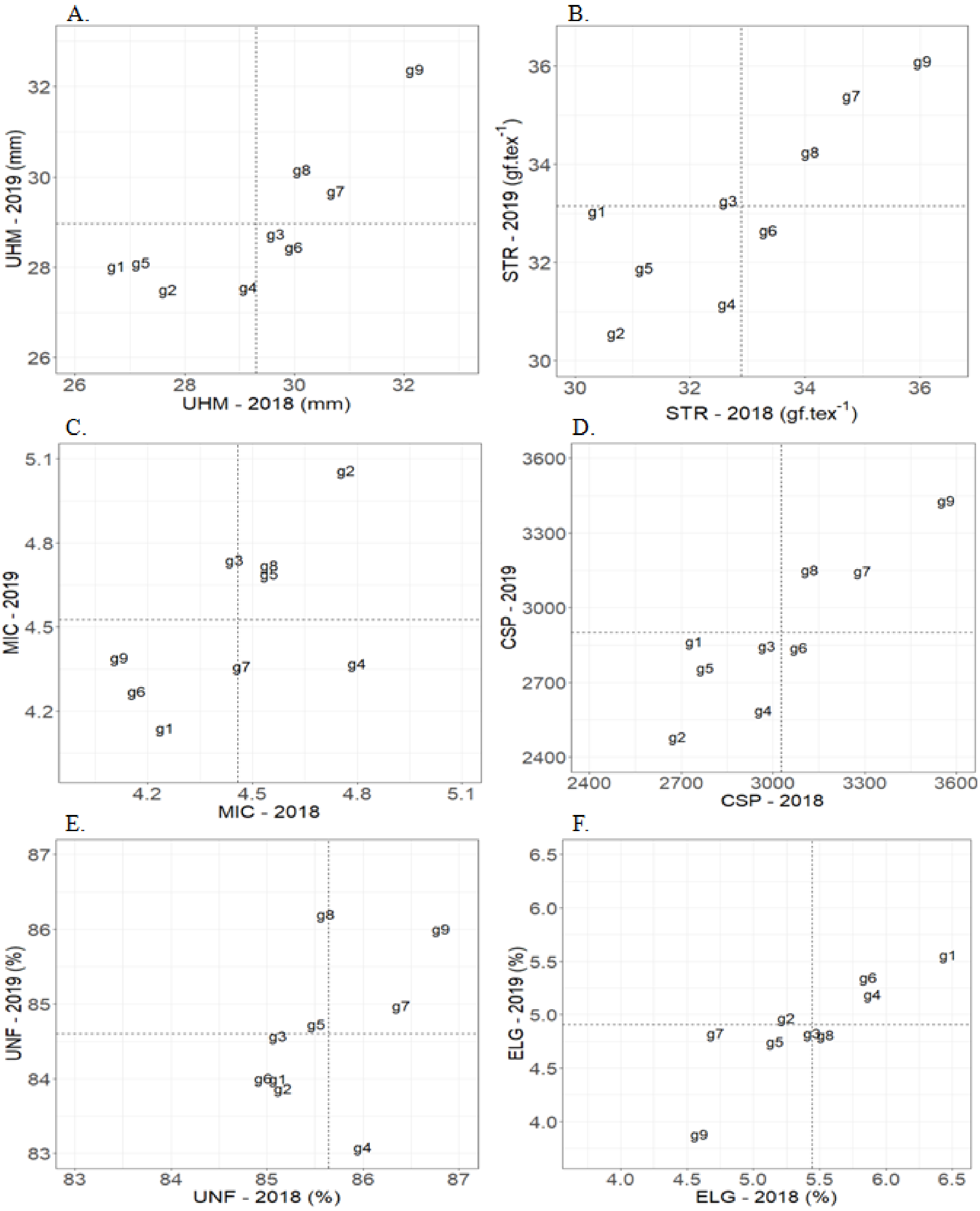

Figure 2. Dispersion of the genotypic values observed in fiber quality data in 2018 and 2019: fiber length (UHM), fiber resistance of the fiber (STR), micronaire index (MIC), spinning consistence index (CSP), uniformity index (UNF), and fiber elongation (ELG) of cotton genotypes, evaluated in Quixeramobim - CE

Table 4. Estimates of selection gains (GS), initial population (Xo), selected population (M), and (genotypic determination coefficient (GDC) obtained for 11 traits by the sum index of the ranks of Mulamba & Mock (1978), for the nine cotton genotypes tested based on average of the two years used (2018 and 2019). Quixeramobim - CE

Variable	Xo	Xs	GDC %	GS	GS%
CY	2430.21	2554.25	58.03	71.96	2.96
LP	38.65	38.23	97.80	-0.41	-1.06
LY	943.93	985.18	73.04	30.13	3.19
BW	5.76	5.94	92.07	0.16	2.81
UHM	29.13	29.85	90.32	0.65	2.26
UNF	85.12	85.48	80.57	0.29	0.34
SFI	6.95	6.71	68.58	-0.16	-2.42
STR	33.02	34.01	90.11	0.89	2.71
ELG	5.20	5.07	92.54	-0.12	-2.33
M1C	4.49	4.42	87.78	-0.06	-1.43
CSP	2963.91	3115.49	91.69	138.99	4.69

Xo - average of the original population; Xs - average of the selected population; GDG - coefficient of genotypic determination; GS - total selection gain

the selection of cotton genotypes, gains of more than 1% per year are very significant in environments with reduced water, as in the case of the semi-arid region of Brazil.

Carvalho et al. (2019) obtained selection gains of 5.64% for CY and of 4.95% for BW in a study with cotton genotypes under controlled conditions in the field in a semi-arid region with under-watering. Ribeiro et al. (2018) reported values of selection gains of 5.02% for CY and of 6.02% for BW in a study of 36 genotypes in two different regions of Brazil.

In terms of fiber quality traits, selection gains in UHM (2.26%), STR (2.71%), and CSP (4.69%) were observed, with an undesirable negative gain in ELG (-2.33%) and LP (-1.06%). Negative selection gains in cotton fiber traits also were detected in other studies. Carvalho et al. (2019) found negative gains for UHM (-0.37%) and ELG (-0.73%). Positive values of UHM (3.24%), CSP (0.49%), and ELG (6.28%) were reported by Ribeiro et al. (2018). Carvalho et al. (2017) obtained much lower values for UHM (0.26%), STR (1.87%) and CSP (1.3%) and negative values for ELG (-0.29%) in an irrigated field trial conducted in the northeastern semi-arid region..

Currently, the Brazilian cultivars with the highest fiber quality are BRS 336 and BRS 433 FL B2RF (Morello et al., 2020), conventional and transgenic, respectively, with values of UHM over of 32.5 mm, resistance greater than 33.0 gf tex^{-1}, and a micronaire index between 4 and 4.5.

Despite the negative values of selection gains obtained for SFI (-2.42%), and MIC (-1.43%), the values recorded for these two traits are suitable for the textile industry. The SFI and MIC values found result in a better performance of the fiber in yarn processing (Cordão Sobrinho et al., 2015; Santos et al., 2017). Negative selection gains results for MIC were obtained by Carvalho et al. (2019), -0.66%, Ribeiro et al. (2018), -7.48%, and Carvalho et al. (2017), -1.52%.

Cotton genotypes with the best fiber quality also had the lowest fiber percentage and lower fiber yields, being less productive than medium fiber lines. However, high quality fiber cotton lines had lower SFI, favoring the yarn process (Cordão Sobrinho et al., 2015; Vasconcelos et al., 2020).

Cotton breeding programs aim to obtain cotton genotypes that combine high CY, LY, and BW with good fiber quality, with an emphasis on higher values of UHM, STR, UNIF, and ELG, and smaller values of SFI, and MIC values between 3.8 and 4.6.

CONCLUSIONS

1. There is genetic variability from the perspective of genetic gain in breeding programs, according to the estimates of the genetic parameters.

2. The most promising lines are CNPA 2013 - 2235 RF LF, CNPA 2013 - 2064 RF LF and CNPA 2012 - 160 RF LF, which are indicated for use in breeding programs aimed at cultivating the semi-arid region of Brazil.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), the Serviço Nacional de Aprendizagem Rural (FAEC/SENARCE) System, and Antônia Sâmia Lima for technical support during the experiments.

LITERATURE CITED

ABRAPA - Associação Brasileira dos Produtores de Algodão. 2018. Available on: <http://www.abrapa.com.br/estatisticas/paginas/algodao-no-brasil.aspx>. Accessed on: Jul. 2020.

Albrecht, L. P.; Braccini, A. de L.; Ávila, M. R.; Barbosa, M. C.; Ricci, T. T.; Albrecht, A.J. P.; Aplicação de biorreguladores na produtividade do algodoeiro e qualidade de fibra. Scientia Agraria, v.10, p.191-198, 2018.

Barroso, P. A. V.; Suassuna, N. D.; Pedrosa, M. B.; Morello, C. de L.; Silva Filho, J. L. da; Lamas, F. M.; Bogiani, J. C. BRS 368RF: A glyphosate tolerant, midseason upland cotton cultivar for Northeast and North Brazilian savanna. Crop Breeding and Applied Biotechnology, v.17, p.388-402, 2017. https://doi.org/10.1590/1984-70332017v17n4c59

Bonifácio, D. O. C.; Mundim, F. M.; Souza, L. B. Variabilidade genética e coeficiente de determinação em genótipos de algodoeiro quanto a qualidade da fibra. Revista Verde, v.10, p.66-71, 2015. https://doi.org/10.18378/rvads.v10i3.3618

Campbell, B. T.; Greene, J.; Wu, J.; Jones, D. C. Genetic variation for agronomic and fiber quality traits in population derived from high quality cotton germplasm. Crop Science, v.56, p.1689-1697, 2016. https://doi.org/10.2135/cropsci2015.10.0657

Carvalho, J. F. de; Cavalcanti, J. J. V.; Farias, F. J. C.; Ramos J. P. C.; Queiroz, D. R.; Santos, R. C. dos. Selection of upland cotton for the Brazilian semi-arid region under supplementary irrigation. Crop Breeding and Applied Biotechnology, v.19, p.185-192, 2019. https://doi.org/10.1590/1984-70332019v19n2a26

Carvalho, L. P. de; Barbosa, M. H. P.; Costa, J. N. da; Farias, F. J. C.; Santana, J. C. F. de; Andrade, F. P. de. Progresso genético do algodoeiro herbáceo no Nordeste. Pesquisa Agropecuária Brasileira, v.32, p.283-291, 1997.

Carvalho, L. P. de; Rodrigues, J. I. da S.; Farias, F. J. C. Selection of cotton lines for high oil content. Pesquisa Agropecuária Brasileira, v.52, p.530-538, 2017. https://doi.org/10.1590/S0100-204X2017000700007

Carvalho, L. P. de; Salgado, C. C.; Farias, F. J. C.; Carneiro, V. Q. Estabilidade e adaptabilidade de genótipos de algodão de fibra colorida quanto aos caracteres de fibra. Ciência Rural, v.45, p.598-605, 2015. https://doi.org/10.1590/0103-8478cr2013023

Cordão Sobrinho, F. P.; Guerra, H. O.; Araújo, W. P.; Pereira, J. R.; Zonta, J. H.; Bezerra, J. R. Fiber quality of upland cotton under different irrigation depths. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.1057-1063, 2015. https://doi.org/10.1590/1807-1929/agriambi.v19n11p1057-1063

Cruz, C. D.; Regazzi, A. J.; Carneiro, P. C. S. Análise dialélica. In: Cruz, C. D. Modelos biométricos aplicados ao melhoramento genético. Viçosa, p.236-367, 2012.

Cruz, C. D. GENES: A software package for analysis in experimental statistic and quantitative genetics. Acta Scientiarum, v.35, p.271-276, 2012.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Algodão: O produtor pergunta, a Embrapa responde. Brasília: Embrapa Informação Tecnológica, 2004. 265p.

Farias, F. J. C.; Silva Filho, J. L. da; Morello, C. de L.; Suassuna, N. D.; Pedrosa, M. B.; Lamas, F. M.; Ribeiro, J. L. Resultados do ensaio nacional de cultivares de algodoeiro herbáceo nas condições do cerrado - safra 2013/2014. Campina Grande: Embrapa Algodão, 2015. 51p.

Freire, E. C. Fatores que afetam a qualidade das fibras. In: Freire, E. C. (ed.) Algodão no cerrado do Brasil. Brasília, 2015. p.751-766.

FUNCEME - Fundação Cearense de Meteorologia e Recursos Hídricos. Prognósticos Climáticos para o Ceará. Fortaleza: Funceme, 2019. 2p.

Lima, A. S.; Costa, M. E. da; Cavalcanti, J. J. V.; Rodrigues, A. P. M. dos S.; Mendonça Júnior, A. F. de. Fibra de cultivares de algodoeiro sob condições de sequeiro. Revista Verde, v.14, p.166-169, 2019.

Morello, C. de L.; Suassuna, N. D.; Pedrosa, M. B.; Barroso, P. A. V.; Silva Filho, J. L. da; Suassuna, T. de M. F.; Perina, F. J.; Sofiat, V.; Magalhães, F. O. da C.; Lamas, F. M. Cultivars BRS 433FL B2RF: upland cotton with high-quality fiber, insect resistance and glyphosate tolerance for the Brazilian Savanna. Crop Breeding and Applied Biotechnology, v.20, p.1-6, 2020. https://doi.org/10.1590/1984-70332020v20n3c43

Mulamba, N. N.; Mock, J. J. Melhoria do potencial produtivo da população de milho Eto Blanco (*Zea mays* L.) por melhoramento genético de plantas. Egypt Journal of Genetics and Cytology, v.7, p.40-51, 1978.

Ribeiro, L. P.; Carvalho, L. P. de; Farias, F. J. C.; Rodrigues, J. I. da S.; Teodoro, P. E.; Bhering, L. L. Genetic gains in agronomic and technological traits of elite cotton genotypes. Revista Bragantia, v.77, p.466-475, 2018. https://doi.org/10.1590/1678-4499.2017329

Santos, I. G.; Teodoro, P. E.; Farias, F. C.; Farias, F. J. C.; Carvalho, L. P.; Rodrigues, J. L. S.; Cruz, C. D. Genetic diversity among cotton cultivars in two environments in the State of Mato Grosso. Genetics and Molecular Research, v.16, p.1-8, 2017. http://dx.doi.org/10.4238/gmr16029628

Scott, A. J.; Knott, M. A cluster analysis method for grouping means in the analysis of variance. Biometrics, v.30, p.507-512, 1974.

Silva, R. dos S.; Farias, F. J. C.; Teodoro, P. E.; Cavalcanti, J. J. V.; Carvalho, L. P. de.; Queiroz, D. R. Phenotypic adaptability and stability of herbaceous cotton genotypes in the Semiarid region of the Northeast of Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.800-805, 2020. http://dx.doi.org/10.1590/1807-1929/agriambi.v24n12p800-805

Suassuna, N. D.; Morello, C. de L.; Silva Filho, J. L. da; Pedrosa, M. B.; Perina, F. J.; Magalhães, F. O. da C.; Sofiatti, V.; Lamas, F. M. BRS 372 and BRS 416: High-yielding cotton cultivars with multiple disease resistance. Crop Breeding and Applied Biotechnology, v.20, p.1-6, 2020.

Vasconcelos, U. A. A.; Cavalcanti, J. J. V.; Farias, F. J. C.; Vasconcelos, W. S.; Santos, R. C. dos. Diallel analysis in cotton (*Gossypium hirsutum* L.) for water stress tolerance. Crop Breding and Applied Biotechonology, v.18, p.24-30, 2018. https://doi.org/10.1590/1984-70332018v18n1a4

Vasconcelos, W. S.; Santos, R. C. dos; Vasconcelos, U. A. A.; Cavalcanti, J. J. V.; Farias, F. J. C. Estimates of genetic parameters in diallelic populations of cotton subjected to water stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.541-546, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n8p541-546

Vencovsky, R. Herança quantitativa. In: Paterniani, E. (Coord.). Melhoramento e a produção de milho no Brasil. Piracicaba, p.137-214, 1987.

Vidal Neto, F. C.; Freire, E. C. Melhoramento genético do algodão. In: Vidal Neto, F. C.; Cavalcanti, J. J. V. (eds.) Melhoramento genético de plantas no Nordeste. Brasília: Embrapa, 2013. p.49-83.

Zonta, J. H.; Bezerra, J. R. C.; Sofiatti, V.; Brandão, Z. N. Yield of cotton cultivars under different irrigation depths in the Brazilian semi-arid region. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.748-754, 2015a. https://doi.org/10.1590/1807-1929/agriambi.v19n8p748-754

Zonta, J. H.; Bezerra, J. R. C.; Sofiatti, V.; Farias, F. J. C.; Carvalho, L. P. de. Efeito da irrigação no rendimento e qualidade de fibras em cultivares de algodoeiro herbáceo. Revista Caatinga, v.28, p.43-52, 2015b. https://doi.org/10.1590/1983-21252015v28n405rc