ARTICLE

Selection of BGRR® herbaceous cotton lines for the Brazilian semi-arid region

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Abstract: *Cotton farming plays an important socioeconomic role in the Brazilian semi-arid region. The high cost of seeds and risk of crop failure from irregular rainfall limit the use of transgenic cultivars in the region, especially in family farming. Low-cost transgenic cultivars adapted to the semi-arid region would assist in overcoming these limitations. The aim of this study was to select cotton lines grown under rainfed conditions in northeastern Brazil. Nineteen (19) BGRR® cotton lines were evaluated in Alagoinha, PB, over two years under rainfed conditions. Agronomic and fiber quality traits were evaluated. Individual and joint analyses were carried out, followed by use of a selection index. The selected long-fiber lines are CNPA-SA-2018-4226 and CNPA-SA-2018-4231, and selected medium-fiber lines are CNPA-SA-2018-4254, CNPA-SA-2018-4239, and CNPA-SA-2018-4251, as they combine high yield and fiber quality traits that meet market demands. They have potential in development of cultivars for the region.*

Keywords: Gossypium hirsutum *L., plant breeding, transgenic, selection index*

INTRODUCTION

Brazil is the third largest producer of cotton fibers in the world, preceded only by China and India (ICAC 2024). Cotton (*Gossypium hirsutum* L.) growing is of great socioeconomic importance for the Brazilian semi-arid region; the fiber is directed to the textile market and the seed is used to obtain oil and animal feed (Alves et al. 2019, Silva et al. 2020).

The Brazilian Northeast is greatly affected by dry spells, which can cause water stress in crops (Rocha et al. 2020). Water deficit is the most significant environmental stress to which the cotton plant is exposed, with direct impact on agricultural yield (Soares et al. 2020). The cotton plant has high plasticity, which allows it to resist moderate stress. However, severe water stress during the reproductive phase significantly impacts its yield and fiber quality (Singh et al. 2022, Zafar et al. 2023), especially in the semi-arid region of Brazil. Therefore, cotton breeding programs for this region must focus on the development of lines adapted to these rainfed growing conditions.

As transgenic technologies have evolved, they have become an additional strategy in plant breeding, providing new effective instruments for crop management (Raphael 2019). In the Brazilian semi-arid region, there is both conventional and transgenic herbaceous cotton production on a commercial scale, but cotton farming is still predominantly developed by small producers (Coêlho 2019) with a low level of technology (Maia et al. 2016).

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Coutinho et al. (2015) affirm that both conventional and transgenic cultivars evaluated in the semi-arid region of Minas Gerais have fiber traits within industry standards. However, the high risk of crop failure caused by irregular rainfall distribution has discouraged small farmers in the semi-arid region from investing in expensive technologies, including seeds with high technological content.

Transgenic technologies have been stacked to generate multiple traits in a single genotype, as is the case with Bollgard® technology together with Roundup Ready® technology, which gave rise to BGRR® from the Monsanto company, the first transgenic cotton plant approved for commercialization in Brazil, in 2009 (Raphael 2019). This technology is no longer used on a large scale in the Brazilian Cerrado. due to limitations of glyphosate herbicide, which can only be applied on young plants (up to the V4 stage), and due to pest resistance to glyphosate, as it controls few species of caterpillars. However, it is very attractive to small farmers in the semi-arid region, as in their production system, the use of glyphosate in the initial stages of cotton growing and reduction in attacks by the leafworm caterpillar (*Alabama argillacea*) and the pink caterpillar (*Pectinophora gossypiella*) constitute considerable competitive advantages. These advantages include reduced production costs, ease of pest and weed management, and an increase in the profitability and sustainability of this crop, benefiting small cotton farmers in the region.

In this sense, the aim of the present study was to select cotton lines grown under rainfed conditions in the Northeast of Brazil. Selection of these lines derived from crosses between cotton lines and cultivars and DP 555 BGRR® was based on yield and fiber quality standards required by the textile industry.

MATERIAL AND METHODS

Assessments were made of 19 advanced lines ($BC_1F_{3:7}$) originating from crosses of the cultivar BRS 286 and lines from the Embrapa Algodão breeding program (CNPA BA 2010-1366 and CNPA BA 2009-2270 with the cultivar DP 555 BGRR®): CNPA-SA-2018-4212, CNPA-SA-2018-4215, CNPA-SA-2018-4217, CNPA-SA-2018-4220, CNPA-SA-2018-4222, CNPA-SA-2018-4226, CNPA-SA-2018-4230, CNPA-SA-2018-4231, CNPA-SA-2018-4234, CNPA-SA-2018-4236, CNPA-SA-2018-4237, CNPA-SA-2018-4239, CNPA-SA-2018-4242, CNPA-SA-2018-4243, CNPA-SA-2018-4246, CNPA-SA-2018-4251, CNPA-SA-2018-4253, CNPA-SA-2018-4254, and CNPA-SA-2018-4255, along with BRS 286 as a check cultivar.

The DP 555 BGRR® (National Cultivar Registry – NCR no. 26453) genotype is a commercial cultivar from Deltapine-BAYER, with an early to medium cycle, resistance to lodging, and excellent fiber quality; and it was widely cultivated in the Cerrado (Brazilian tropical savanna) (Vilela and Bélot 2020). The BRS 286 (National Cultivar Registry – NCR no. 22664) cultivar has good fiber quality, with high yield (Vasconcelos et al. 2020). It is medium to small in size, is harvested from 140 to 160 days after emergence, and is adapted to both the Cerrado and semi-arid regions, under rainfed or irrigated conditions (Embrapa 2008).

The experiments were carried out at the Experimental Station of Empaer (Empresa Paraibana de Pesquisa, Extensão Rural e Regularização Fundiária – a Paraiba research, rural extension, and land regularization agency) in Alagoinha, PB (lat 6° 57’ S, long 35° 32’42” W, alt 317 m asl), from April to September 2021 and from April to October 2022. The predominant climate is type As’ – tropical hot and humid, according to the Köppen classification, with average annual rainfall of 795.0 mm (Saraiva et al. 2020). The soil in the experimental area is classified as a *Nitossolo* (Embrapa 2013), and plant management followed recommendations described by Beltrão and Araújo (2004). During the experiments, the rainfall volume (recorded daily) in 2021 was 374.9 mm, and 796 mm in 2022, as described in Figure 1.

A randomized block experimental design was adopted, with 4 replications. A plot consisted of two 5-m rows, with a spacing of 0.80 m between rows, 7 plants per linear meter, and a population density of 70 plants plot^{-1}. The following traits were evaluated: seed cotton yield (kg ha^{-1}) – SCY, lint percentage (%) – LP, lint yield (kg ha^{-1}) – LY, boll weight – BW, fiber length (mm) – UHM, short fiber index (%) – SFI, fiber strength (gf tex^{-1}) – STR, fiber breaking elongation (%) – ELG, micronaire index – MIC, and count strength product – CSP. The fiber traits were evaluated by HVI (High Volume Instrument) – Uster HVI from Embrapa Algodão, using a standard 20-boll sample from each plot. The crop was harvested manually and a standard sample was stored in a kraft bag.

The Lilliefors, Bartlett, and Tukey tests were performed to verify compliance with the assumptions of residual normality, homogeneity of variance, and additivity of the model, respectively. For analysis of variance, the effects of genotypes

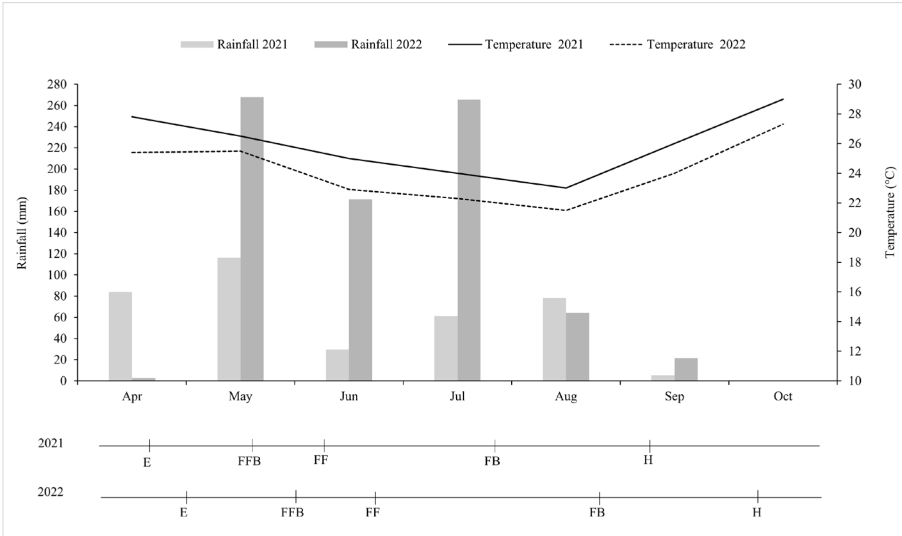

Figure 1. Rainfall and average temperature in Alagoinha, PB, Brazil, in 2021 and 2022 throughout the cotton cycle. The lines below the graph indicate the phenological stages of the cotton plant in each year. E: emergence; FFB: first flower bud; FF: first flower; FB: first boll; H: harvest.

and years were considered fixed. Individual analyses were carried out (data not presented), followed by joint analysis, according to the model cited by Cruz et al. (2012):

$$Y_{ijk} = m + (B/E)_{jk} + G_i + E_j + GE_{ij} + \varepsilon_{ijK}$$

where Y_{ijk}: observation of the i*th* genotype, evaluated in the k*th* block, within the j*th* environment; m: overall average; $(B/E)_{jk}$: effect of block k within environment j; G_i: effect of genotype i; E_j: effect of environment j; GE_{ij}: effect of the interaction between genotype i and environment j; ε_{ijK}: experimental error associated with observation Y_{ijk}. All statistical analyses were performed using the GENES program, version 1990.2022.27 (Cruz 2013).

The following phenotypic and genetic parameters were evaluated, according to Vencovsky and Barriga (1992) and Cruz (2012): genotypic quadratic component (Φ_g), quadratic component of the genotype × environment interaction (Φ_{ge}), genotypic determination coefficient (GDC), genetic coefficient of variation (CV_g), environmental coefficient of variation (CV_e), and relative coefficient of variation (CV_g/CV_e) = *b*. The Scott-Knott (1974) means grouping test was performed ($p \leq 0.05$).

The selection index proposed by Mulamba and Mock (1978) was used to estimate gains from selection and to select the genotypes, with a selection intensity of 25%. A weight of 2 was adopted for the traits SCY, LP, SFI, STR, and MIC, due to their great importance for the cotton grower and the industry. The index corresponds to transformation of phenotypic averages into positions or ranks for each trait. Genotypes are classified in relation to each trait in an order favorable to plant breeding purposes (Ramalho et al. 2012, Cruz et al. 2012, Cruz et al. 2014).

RESULTS AND DISCUSSION

There was a significant effect for genotypes ($p < 0.05$), showing variability among the lines under study (Table 1). The effect of years was significant for most traits, except for LP, BW, and SFI. This significance was due to the difference in rainfall between the years; the year 2021 had notable water restriction. This contributed considerably to the G×E interaction, confirmed by its significance for most of the variables, indicating a different response of the genotypes in the two years, except for ELG and MIC.

As for genetic parameters, the genotypic determination coefficient (GDC), which corresponds to heritability when genotypes are considered fixed, ranged from 60.82% to 87.34%. The traits LP, BW, UHM, STR, and MIC expressed GDC

Table 1. Summary of joint analysis of variance and estimates of genetic and phenotypic parameters for the traits evaluated in cotton lines under rainfed conditions. Alagoinha, PB, Brazil, 2021 and 2022

Sources of variation	Mean Squares									
	SCY	LP	LY	BW	UHM	SFI	STR	ELG	MIC	CSP
Block/Environment	506938.13	9.66	120651.37	0.42	4.08	0.63	2.71	0.90	2.23	167792.87
Genotype (G)	612651.43**	4.98**	112349.61**	0.57**	10.76**	1.38**	13.51**	0.75**	0.34**	209316.50**
Environment (E)	305248017.81**	0.27	47464711.60**	0.24	99.07**	1.76	200.26**	36.10**	19.04**	1378822.57*
G x E interaction	719522.85**	5.48**	137623.06**	0.43**	7.07**	1.01*	6.50**	0.31	0.06	235264.44**
Error	219804.06	1.01	41808.61	0.17	1.49	0.54	2.60	0.27	0.04	67911.93
Mean	3382.33	39.35	1332.06	6.08	30.6	7.02	33.59	5.53	4.16	3133.14
CV_e (%)	13.86	2.55	15.35	6.79	3.99	10.49	4.80	9.47	4.98	8.31
Genetic parameters										
Φ_g	49105.92	0.50	8817.63	0.05	1.16	0.11	1.36	0.06	0.04	17675.57
Φ_{ge}	124929.70	1.12	23953.61	0.07	1.40	0.12	0.96	0.01	0	41838.13
GDC (%)	64.12	79.83	62.79	70.14	86.17	60.82	80.75	63.48	87.34	67.56
CV_g (%)	6.55	1.79	7.05	3.68	3.52	4.62	3.48	4.41	4.63	4.24
CV_g/CV_e	0.47	0.70	0.46	0.54	0.88	0.44	0.72	0.47	0.93	0.51

SCY – seed cotton yield (kg ha^{-1}); LP – lint percentage (%); LY – lint yield (kg ha^{-1}); BW – boll weight; UHM – fiber length (mm); SFI – short fiber index (%); STR – fiber strength (gf.tex-1); ELG – fiber breaking elongation (%); MIC – micronaire index; CSP – count strength product. ** and * – significant at 1% and 5% probability, respectively, by the F test; Genotypic quadratic component (Φ_g); quadratic component of the genotype × environment interaction (Φ_{ge}); genotypic determination coefficient (GDC); genetic coefficient of variation (CV_g); environmental coefficient of variation (CV_e); relative coefficient of variation (CV_g/CV_e).

above 70%. Values above 70% are considered high and contribute to more effective selection with significant and favorable genetic gains. The GDC is a very important indicator, as it shows how much of the existing variability is due to genetic factors (Passos et al. 2007). High GDC values indicate that most of the existing variations are genetic in nature (Carvalho et al. 2019). Thomaz et al. (2024) carried out studies with cotton plants in the same environment as this article and obtained GDC above 73%. Carvalho et al. (2019) evaluated cotton genotypes in the semi-arid Northeast region and found values greater than 80%.

The *b* ratio values (CV_g/CV_e) ranged from 0.44 to 0.93. Values lower than 1.0 for the *b* ratio signal that there is a greater influence of environmental factors on genetic factors. When the ratio is greater than or equal to 1.0, it indicates that the existing variability is more linked to genetic variation between genotypes than to environmental variation (Chaves Neto et al. 2020). In this sense, the values obtained here indicate the need to carry out selection with greater caution.

The means grouping test for agronomic traits and fiber quality considering the average of the two years is found in Table 2. The lines belonging to the control group (group a) had seed cotton yield greater than 3477.35 kg ha^{-1} and lint yield above 1357.22 kg ha^{-1}. This corroborated the results found by Lima et al. (2018), who evaluated the effect of water deficit on yield and fiber quality in different phenological stages of cotton and found an average SCY of 1353.26 kg ha^{-1} for the BRS 286 cultivar. Values similar to those in this study were also obtained by Carvalho et al. (2019). Silva et al. (2020) obtained higher values in a study of adaptability and stability of cotton plants for the semi-arid Northeast region, which can be explained by their evaluation of other populations. Vasconcelos et al. (2018) evaluated cotton hybrid combinations under water suppression and obtained values above 3497.17 kg ha^{-1} for SCY.

As for LP, the lines with the best performance had values higher than 39.43%. According to Jerônimo et al. (2014), this trait is of great importance since the higher the value obtained for this variable, the greater the amount of plume produced per unit area. LP above 40% is desired by cotton farmers due to greater economic yield (Cordão Sobrinho et al. 2015). In this sense, the values obtained for the LP variable are close to those obtained by Cotrim et al. (2020), who obtained averages of 44.12% for the DP 555BGRR genotype and 41.21% for the BRS 286 cultivar used in this study as parents. Lima et al. (2018) found averages between 39.5% and 41.0% for BRS 286, while Vasconcelos et al. (2018) obtained values ranging from 38.01% to 43.0%.

Practically all the lines achieved satisfactory performances that meet the requirements of the textile industry in terms of length, strength, reliability index, and short fiber index. This shows their potential; despite the significant water restriction in 2021, the lines showed plausible performance for most of the traits.

The industry requires values above 30 mm for UHM, 28 gf tex-1 for STR, 6.7 % for ELG, between 3.8 and 4.6 for MIC, 2000 for CSP, and between 6% and 9% for SFI (Freire et. al. 2015, Lima 2018b). For UHM, the lines CNPA-SA-2018-4226, CNPA-SA-2018-4230, and CNPA-SA-2018-4231 differed statistically from the others, exhibiting the highest averages. Similar results were found by Gomes et al. (2022) in their research on selection of cotton lines tolerant to water stress, while Vasconcelos et al. (2020) obtained slightly lower values for cotton genotypes under water stress.

According to Jerônimo et al. (2014), fiber length plays a crucial role in determining the reliability index and the uniformity of fiber distribution in the yarn, with a direct impact on its strength. It should be noted that long fiber is more desirable, and it is a factor of great importance for commercialization of cotton lint (Kazama et al. 2016).

For STR, the best lines had averages ranging from 33.24 gf/tex to 34.84 gf/tex. Albuquerque et al. (2020) evaluated cotton genotypes for semi-arid conditions and found values above 29 gf/tex for most genotypes. Thomaz et al. (2024) found values above 31.45 gf/tex for genotypes evaluated under rainfed conditions. A high resistance value reduces the rate of yarn breakage during manufacturing and thus yields well when spinning is well regulated (Bachelier and Gourlot 2018).

The results obtained for the MIC were very positive. Even though there is a statistical difference between the materials, they are all within the range recommended by the industry, as previously mentioned. Such values exceed those found by Carvalho et al. (2019), which was between 4.21 and 5.26; by Gomes et al. (2022), between 4.19 and 4.91; and by Vasconcelos et al. (2020), between 4.29 and 5.35. The micronaire index indicates the combination of fiber fineness and maturity (Morais et al. 2021). Fiber with greater maturity provides better color fixation and dyeing quality (Santana et al. 2008). Fiber with low micronaire and high maturity, resistance, and elongation values enhance yield and the final product when processed correctly (Lima 2018a).

Short fiber values greater than 10% do not meet the demands of the sector (Mizoguchi 2018), as short fibers in a sample can come together and form imperfections in the yarn. These imperfections reduce the quality of the fabric and the final product (Lima et al. 2007), and they reduce the yield of raw materials (Bellote 2018). All lines had values lower than 7.46% for SFI.

Table 2. Clustering of means by the Scott-Knott test (1974) for agronomic and fiber quality traits of cotton lines evaluated under rainfed conditions

Lines		SCY[1]	LP	LY	BW	UHM	SFI	STR	ELG	MIC	CSP
1	CNPA-SA-2018-4212	3580.86a	38.60b	1383.50a	6.66a	29.31d	7.38a	33.60a	5.35b	4.00b	3078.75c
2	CNPA-SA-2018-4215	3212.89b	39.80a	1280.89b	5.83b	28.88d	7.31a	30.95c	5.55a	3.99b	2923.75c
3	CNPA-SA-2018-4217	3265.24b	38.04c	1246.05b	5.85b	29.62d	7.46a	32.04b	5.40b	3.98b	2955.63c
4	CNPA-SA-2018-4220	3122.27b	40.35a	1258.96b	5.84b	29.70d	7.43a	31.19c	5.91a	3.98b	2929.88c
5	CNPA-SA-2018-4222	3175.78b	38.89b	1226.17b	6.05a	31.55b	6.89a	34.64a	5.88a	4.34a	3224.88b
6	CNPA-SA-2018-4226	3288.67b	40.41a	1320.81b	6.41a	33.00a	6.31b	34.91a	5.31b	3.84b	3487.75a
7	CNPA-SA-2018-4230	2926.56b	38.05c	1099.23b	6.19a	32.70a	6.30b	36.24a	5.44b	4.04b	3494.38a
8	CNPA-SA-2018-4231	3477.35a	39.54a	1357.22a	6.35a	32.74a	6.30b	34.84a	5.71a	4.48a	3278.38b
9	CNPA-SA-2018-4234	3387.11b	39.96a	1331.89b	6.20a	29.58d	7.18a	33.41a	5.70a	4.46a	2976.88c
10	CNPA-SA-2018-4236	3194.14b	39.11b	1244.38b	6.03a	31.10c	6.24b	33.66a	5.41b	4.34a	3237.63b
11	CNPA-SA-2018-4237	2963.28b	39.75a	1173.59b	6.04a	30.19d	7.46a	32.54b	5.18b	3.99b	3040.00c
12	CNPA-SA-2018-4239	3648.83a	39.84a	1463.13a	6.16a	30.79c	7.29a	33.89a	5.11b	3.89b	3220.75b
13	CNPA-SA-2018-4242	3162.11b	38.83b	1228.75b	6.20a	30.18d	6.90a	33.83a	5.68a	4.41a	3160.00c
14	CNPA-SA-2018-4243	3714.45a	37.73c	1403.10a	6.24a	31.00c	7.00a	34.49a	5.94a	4.33a	3152.50c
15	CNPA-SA-2018-4246	3151.56b	39.68a	1270.94b	6.31a	31.09c	7.34a	34.51a	4.69b	4.26a	3085.00c
16	CNPA-SA-2018-4251	3789.45a	40.15a	1530.59a	5.58b	30.61c	7.10a	34.23a	5.80a	4.38a	3102.63c
17	CNPA-SA-2018-4253	3834.77a	38.96b	1501.79a	5.73b	30.00d	6.97a	32.63b	5.55a	4.09b	3101.88c
18	CNPA-SA-2018-4254	3768.36a	40.01a	1521.29a	6.16a	30.06d	7.19a	34.30a	5.59a	4.16b	3155.13c
19	CNPA-SA-2018-4255	3488.67a	39.79a	1406.39a	6.08a	29.94d	7.33a	33.04b	5.70a	4.33a	2949.88c
20	BRS 286 (T)	3494.14a	39.43a	1392.53a	5.71b	30.01d	6.95a	32.94b	5.71a	4.00b	3107.25c

T – check cultivar. [1] See codes in Table 1. Means followed by the same letter in the column belong to the same group according to the Scott-Knott test (1974).

Table 3. Estimates of the mean of the original population ($\bar{X}_o$), mean of the selected population ($\bar{X}_s$), genotypic determination coefficient (GDC), and gain from selection (GS) obtained for the 10 traits (see codes in Table 1) evaluated using the selection index of Mulamba & Mock (1978)

Traits	$\bar{X}_o$	$\bar{X}_s$	GDC (%)	GS	GS (%)
SCY	3382.33	3594.53	64.12	136.0725	4.02
LP	39.35	39.99	79.83	0.52	1.31
LY	1332.06	1438.61	62.79	66.90	5.02
BW	6.08	6.13	70.14	0.04	0.61
UHM	30.60	31.44	86.17	0.72	2.36
SFI	7.02	6.84	60.82	-0.11	-1.54
STR	33.59	34.43	80.75	0.68	2.02
ELG	5.53	5.51	63.48	-0.02	-0.29
MIC	4.16	4.15	87.34	-0.01	-0.31
CSP	3133.14	3248.93	67.56	78.22	2.50
Selected lines: 6, 8, 18, 12, 16					

For CSP, the averages ranged from 2923.75 to 3494.38; CNPA-SA-2018-4226 and CNPA-SA-2018-4230 were the best lines. In studies under semi-arid conditions, Carvalho et al. (2019) found averages from 2465.75 to 3338.13.

Table 3 shows results of the selection index based on the sum of ranks proposed by Mulamba and Mock (1978). The most significant gains from selection were seen for the variables LY (5.02%), SCY (4.02%), CSP (2.50%), UHM (2.36%), STR (2.02%), and LP (1.31%). Gomes et al. (2022) selected cotton lines tolerant to water stress with an emphasis on growing in the Brazilian semi-arid region and found the following gains from selection for the same traits mentioned above: LY (3.19%), SCY (2.96%), CSP (4.69%), UHM (2.26%), STR (2.71%), and LP (-1.06%). In contrast, Ribeiro et al. (2018) evaluated elite cotton lines under rainfed and irrigated systems and obtained the following gains from selection: SCY (5.02%), UHM (3.24%), STR (0.49%), and LP (2.47%). Thomaz et al. (2024) obtained LY (9.81%), LP (6.61%), SCY (3.76%), STR (1.50%), and CSP (1.00%).

An unfavorable gain occurred only for ELG (-0.29%); however, that value is practically insignificant. The variables SFI (-1.54%) and MIC (-0.31%) had negative values for gain from selection, but such values are favorable for cotton breeding, as textile industry standards require low values for such traits. A similar value for ELG was found by Carvalho et al. (2017), which showed a gain of -0.29%. Gomes et al. (2022) found gains similar to those of the present study for the SFI (-2.42%) and MIC (-1.43%) variables. Thomaz et al. (2024) found unfavorable values for MIC (3.69%) and ELG (-3.14%); yet the SFI (-0.48) value was favorable.

For final selection of the lines, analysis was carried out according to the index proposed by Mulamba and Mock (1978), shown in Table 3. The following lines were selected: CNPA-SA-2018-4226, CNPA-SA-2018- 4231, CNPA-SA-2018-4254, CNPA-SA-2018-4239, and CNPA-SA-2018-4251, as they had significant gains from selection when considering all the variables simultaneously, and they revealed satisfactory qualities that meet the demands of cotton farmers and the textile industry.

Among the lines selected, CNPA-SA-2018-4226 (33.00 mm) and CNPA-SA-2018-4231 (32.74 mm) stand out for their long fiber. According to Embrapa (2015), fibers with values between 28 and 31.2 mm are considered medium, values between 31.3 and 34.8 mm are considered long, and values between 34.9 and 41.0 mm are considered extra-long. Long fibers require fewer twists to obtain stronger yarns, which increases industrial yield (Echer et al. 2018). Moreover, the length of the fiber affects the price of the raw material, as the greater the length, the higher the fiber quality. Premium, soft, bulky, flexible, and malleable yarns and fabrics come from long thin fibers (Lima 2018a).

CONCLUSION

The lines CNPA-SA-2018-4226, CNPA-SA-2018-4231, CNPA-SA-2018-4254, CNPA-SA-2018-4239, and CNPA-SA-2018-4251 were selected as superior as they showed satisfactory performance within the standards established by the industry. Given the potential of the selected lines, such genotypes can be recommended for developing cultivars for the semi-arid region. Nevertheless, they require wider studies in different locations in value for cultivation and use (CVU) trials to confirm adaptability and stability in environments with water scarcity.

DATA AVAILABILITY

The datasets generated and/or analyzed in this study are available from the corresponding author upon reasonable request.

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