PHENOTYPIC ADAPTABILITY AND STABILITY OF COTTON CULTIVARS IN MATO GROSSO STATE, BRAZIL[1]

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RESUMO

ADAPTABILIDADE E ESTABILIDADE FENOTÍPICA DE CULTIVARES DE ALGODOEIRO NO ESTADO DO MATO GROSSO, BRASIL

O objetivo deste trabalho foi o de avaliar a adaptabilidade e a estabilidade de cultivares de algodão (*Gossypium hirsutum* L.), utilizando a metodologia proposta por Eberhart & Russell (1966). Para tanto, onze variedades de algodão foram avaliadas em sete locais do Estado do Mato Grosso, Brasil, em dois anos agrícolas (2002/2003 e 2003/2004). O delineamento experimental empregado foi o de blocos casualizados com quatro repetições e as características avaliadas foram a produtividade de algodão em caroço e a porcentagem de fibra. Com relação à produção de algodão em caroço, as cultivares BRS Aroeira, BRS Ipê, BRS Cedro, BRS Jatobá e Delta Opal demonstraram ampla adaptabilidade e estabilidade para as regiões produtoras do Estado. Entretanto, considerando a porcentagem de fibra, não foram encontradas cultivares de algodão com ampla adaptabilidade e estabilidade nos ambientes estudados.

PALAVRAS-CHAVE: *Gossypium hirsutum*, fibra, estabilidade de rendimento, interação genótipo-ambiente.

ABSTRACT

The objective of this work was to evaluate the stability and adaptability of cotton (*Gossypium hirsutum* L.) cultivars using the method of Eberhart & Russell (1966). Eleven varieties of cotton were tested at seven locations in Mato Grosso State, Brazil, in two growing seasons (2002/2003 and 2003/2004). The experimental design was the randomized complete blocks with four replications and the evaluated traits were lint percentage and seed cotton yield. For seed cotton yield, BRS Aroeira, BRS Ipê, BRS Cedro, BRS Jatobá and Delta Opal showed broad adaptability and stability in Mato Grosso State. However, for lint percentage there were not found cotton cultivars with both broad adaptability and stability for the studied environments.

KEY WORDS: *Gossypium hirsutum*, lint, yield stability, genotype-environment interaction.

INTRODUCTION

The interaction of genotypes by environments (weather, soil, management, etc.) is one of the major challenges in plant breeding, either in the selection procedure or cultivar recommendation. The choice of a cultivar with high adaptability and predictable performance is an option to deal with this fact (Cruz & Carneiro 2003). Breeders usually seek highly stable and productive genotypes to select. According to Gonçalves *et al.* (2003), a genotype is considered stable when its performance under a particular environment (years and/or locations) does not diverge from an average performance of this genotype in a group of environments.

In cotton breeding, two major traits are responsible for lint production: seed cotton yield and lint percentage (Carvalho *et al.* 1995). However, superior genotypes of cotton should not be recommended based only on their average performance, because this practice tends to show that the best genotypes are adapted only to suitable environments (Murakami *et al.* 2004). But, this recommendation should also consider their stability

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and adaptability for seed cotton yield and lint percentage.

In order to select adapted genotypes, an important tool that assists the breeder is the study of the genotype by environment interaction (Scapim *et al.* 2000). Several methods have been proposed to analyze this effect and these techniques are based on univariate or multivariate analysis (Cruz & Regazzi 1997, Gonçalves *et al.* 2003, Lin *et al.* 1986). The most popular method is that proposed by Eberhart & Russell (1966), because it is easy to use and its results are simple to understand (Benin *et al.* 2005).

Studies of genotype by environment interactions in cotton are scarce in Brazil and most of them were carried out in the Northeast region (Moreira *et al.* 1983, Santana *et al.* 1983, Moreira *et al.* 1990, Carvalho *et al.* 1995, Farias *et al.* 1997) and just a few were made on central west environmental conditions (Sobreira *et al.* 2003, Hoorgerheide 2004, Morello *et al.* 2005). However, this region had its importance on cotton production decreased because of the boll weevil (*Anthonomus grandis*) introduction in 1983 (Vieira & Lima 1999). At the moment, the majority of lint cotton production in Brazil is from the Midwest region (Suinaga 2003). Taking into account these facts, information on stability and adaptability parameters will contribute to better recommending cotton cultivars for this region and selecting appropriate genotypes in the cotton breeding program.

The objective of this study was to determine phenotypic adaptability and stability of eleven cotton cultivars for seed cotton yield and lint percentage, using the model proposed by Eberhart & Russell (1966).

MATERIAL AND METHODS

This research was carried out in seven locations in Mato Grosso State, Brazil, as follows: Itiquira (522 m; 17º12'32"; 54º09'01"), Lucas do Rio Verde (330 m; 13º04'16"; 55º55'36"), Novo São Joaquim (400 m; 14º54'21"; 53º01'06"), Primavera do Leste (636 m; 15º17'45"; 54º17'46"), Rondonópolis (450 m; 16º50'23"; 54º02'39"), Sapezal (545 m; 13º32'53"; 58º48'54"), and Pedra Preta (740 m; 16º42' 16"; 54º41'05"). The eleven genotypes were: BRS Aroeira; BRS Ipê; BRS Cedro; BRS Jatobá; FM 966; SG 821; Delta Opal; IAC 24; Makina; Fabrika; and ST 474. All evaluations were made in the growing seasons of 2002/2003 and 2003/2004. According to Lopes *et al.* (2001), each combination of location and year was considered as anone environment, since the trials were carried out under variable conditions of soil, plant management and weather.

The experimental design used in each trial was the complete randomized blocks with four replications. Each plot comprised four rows (spaced by 0.90 m) with 5.0 m long and 4.0 m wide. The central rows represented the harvested plot, in which all the evaluations were performed. The evaluated traits were lint percentage (%) and total seed cotton yield (kg.ha^{-1}).

Initially, the analysis of variance for the assessed traits was carried out considering each particular environment. Since the ratio between the maximum and minimum mean square of the errors from the individual analyses of variance was not greater than seven (Gomes 1987), it was possible to perform a joint analysis of variance including all environments.

In the method proposed by Eberhart & Russell (1966), the linear regression coefficient of genotype yield on an environmental index, plus a function of the squared deviations from this regression would provide estimates of adaptability and stability parameters. These parameters are defined by the model: $Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij} + \varepsilon_{ij}$; where Y_{ij} is the mean response the ith variety at the jth environment (i = 1, 2,…, v and j = 1, 2,…, n), μ_i is the mean of the ith variety over all environments; β_i is the regression coefficient of the ith variety through location indexes, which measures the response of this variety to varying environments; I_j is the environmental index which is defined as the mean deviation of all varieties at a given location from the overall mean; δ_{ij} is the deviation from regression of the ith variety in the jth location; ε_{ij} is the mean experimental error, assumed i.i.d. N(0, σ^2).

The authors also emphasized the need of considering both linear (β_i) and non-linear (σ^2_{di}) components of genotype x environment interactions in judging the stability of a genotype. A genotype with broad adaptation was defined as one with β_i = 1.0, and high stability as one with σ^2_{di} = 0. All statistical analyses of this research were performed using the software Genes (Cruz 2001).

RESULTS AND DISCUSSION

The results of joint analyses of variance for yield and lint percentage of eleven cotton cultivars are presented in Table 1. Regarding seed cotton yield

Table 1. Analysis of variance for seed cotton yield (kg.ha^{-1}) and lint percentage (%) of eleven cotton cultivars in fourteen environments of Mato Grosso State, Brazil (2002/2003 and 2003/2004). The nested interaction environments/cultivars was partitioned using the method of Eberhart and Russell (1966).

Source of variation	Degrees of freedom	Mean square	
		Yield	Lint percentage
Blocks/environments	42	-	-
Cultivars	10	173703,00**	156.75**
Environments	13	5590392,30**	49.14**
Cultivars x Environments	130	43256,10**	3.69**
Environments/Cultivars	143	547541,10**	7.82**
Environments (linear)	1	72675099,60**	638.79**
Cultivars x Environments (linear)	10	81317,40**	5.94**
Pooled deviations	132	36440,25**	3.18**
BRS Aroeira	12	24886,05 ns	3.96*
BRS Ipê	12	31783,65 ns	1.53ns
BRS Cedro	12	31828,80 ns	6.13**
BRS Jatobá	12	32611,35 ns	4.81*
FM 966	12	30021,45 ns	2.98 ns
SG 821	12	65985,15**	1.39 ns
Delta Opal	12	26722,80 ns	1.25 ns
IAC 24	12	14681,70 ns	4.53*
Makina	12	35333,25*	3.54 ns
Fabrika	12	35031,00*	1.84 ns
ST 474	12	71957,55**	3.04 ns
Error	420	19308,45	2.17

ns, * and **: indicate non significant, and significance at 5% and 1% level (F test), respectively.

and lint percentage, it was observed highly significant effects ($p < 0.01$) for environments (linear) and linear interaction cultivars x environments sources of variation. For both traits, the first effect means that differences on environments (soil and weather) will generate disparities on cultivar responses, while the latter effect indicates that there are genetic divergences among cultivars taking into account their responses to variation of environmental conditions. Similar results were found by Ribeiro *et al.* (2004a) in common beans, Lopes *et al.* (2001) in maize, Gonçalves *et al.* (2003) in rubber, and Gualberto *et al.* (2002) in tomato.

The comparisons among eleven cotton varieties cultivated under fourteen environments (combinations involving years and locations) for seed cotton yield are described in Table 2. Pedra Preta (2003-2004) was the most favorable environment for all cultivars evaluated in this study (60% greater than the overall average yield). This fact is explained by the adoption of high input techniques (high doses of fertilizers and massive application of pesticides) for crop management. These observations – differential responses of the genotypes under varying environments – support a deep investigation on the cultivar by environmental interactions as reported by Gualberto *et al.* (2002), Lopes *et al.* (2001) and Ribeiro *et al.* (2004b).

The data of lint percentage from assessed cotton cultivars under the environments (seven locations x two growing seasons) are showed in Table 3. Either varieties or environments did not present a trend as observed for yield data (Pedra Preta, 2003-2004), which means that it was not possible to distinguish one environment or environments where the cultivars are able to produce high lint percentages. Again, the existence of differential responses of varieties in a particular environment, as observed for this trait, validates the study of cultivar by environment interactions (Murakami *et al.* 2004, Peixoto *et al.* 2002).

The adaptability and stability estimates of Eberhart & Russell's parameters for seed cotton yield

Table 2. Average seed cotton yield (kg.ha^{-1}) of eleven cotton cultivars based on seven environments in two growing seasons, in Mato Grosso State, Brazil (2002/2003 and 2003/2004).

Years	Locations[1]	Cultivars[2]											Means
		1	2	3	4	5	6	7	8	9	10	11	
2002/2003	ITQ	4557 Ad	4269 Ad	4368 Ac	4346 Ad	3777 Ae	3915 Ae	4086 Ae	4194 Ac	3945 Ad	3986 Ae	4220 Ad	4151
	LRV	4242 Ad	4886 Ac	4482 Ac	4509 Ad	4151 Ad	3887 Be	4241 Ae	4377 Ac	3902 Bd	4683 Ad	3513 Be	4260
	NSJ	6512 Ab	6102 Ab	5984 Ab	6717 Ab	6621 Ab	6663 Ab	6743 Ab	6143 Aa	6209 Ab	6389 Ab	6557 Ab	6422
	PVA	4047 Ad	4071 Ad	3752 Ad	4505 Ad	3993 Ad	3045 Bf	3773 Ae	4170 Ac	2970 Be	3810 Ae	3225 Be	3761
	ROO	2465 Af	2856 Ae	2612 Ae	2325 Af	2145 Af	2250 Ag	2765 Af	2771 Ae	2433 Ae	2208 Ag	2834 Ae	2514
	SAP	3888 Ad	3588 Ad	3560 Ad	3348 Ae	3678 Ae	3206 Af	3732 Ae	3590 Ad	3252 Ae	3356 Af	3405 Ae	3509
	PP	4673 Ad	5000 Ac	4836 Ac	4812 Ad	3267 Be	2999 Bf	4386 Ae	4520 Ac	2892 Be	4055 Ae	2666 Be	4010
2003/2004	ITQ	5504 Ac	5312 Ac	5543 Ab	5453 Ac	5501 Ac	4649 Ad	5792 Ac	5243 Ab	5459 Ac	5735 Ac	5844 Ac	5457
	LRV	5777 Ac	4859 Bc	5502 Ab	5295 Ac	4295 Bd	5306 Ac	5196 Ad	4544 Bc	4380 Bd	4784 Bd	4877 Bd	4982
	NSJ	3494 Ae	3738 Ad	3347 Ad	3555 Ae	3815 Ae	3825 Ae	3660 Ae	3462 Ad	3711 Ad	3767 Ae	3941 Ad	3665
	PVA	4487 Ad	4791 Ac	4785 Ac	4760 Ad	4598 Ad	3492 Be	5169 Ad	4167 Bc	3894 Bd	3885 Be	4319 Bd	4395
	ROO	6234 Ab	6405 Ab	5862 Bb	6785 Ab	5817 Bc	5141 Bc	6569 Ab	5411 Bb	5262 Bc	4929 Bd	6399 Ab	5892
	SAP	5726 Ac	5196 Bc	5966 Ab	6029 Ab	5225 Bc	5424 Bc	5111 Bd	5045 Bb	5198 Bc	5294 Bc	5405 Bc	5420
	PP	7647 Ba	7865 Aa	7862 Aa	8151 Aa	8049 Aa	8708 Aa	7700 Ba	6863 Ba	8136 Aa	8088 Aa	7461 Ba	7866
Means		4946	4925	4889	5042	4638	4464	4923	4607	4403	4640	4619	---

[1-] ITQ: Itiquira, LRV: Lucas do Rio Verde, NSJ: Novo São Joaquim, PVA: Primavera do Leste, ROO: Rondonópolis, SAP: Sapezal and PP: Pedra Preta.

[2]-Cultivars: 1) BRS Aroeira; 2) BRS Ipê; 3) BRS Cedro; 4) BRS Jatobá; 5) FM 966; 6) SG 821; 7) Delta Opal; 8) IAC 24; 9) Makina; 10) Fabrika; 11) ST 474.

* Means within each row followed by the same uppercase letter or whithin each column followed by the same lowercase letter are not significantly different at the 5% level as judged by Scott & Knott's statistical method.

Table 3. Average lint percentage (%) of eleven cotton cultivars based on seven environments in two growing seasons, in Mato Grosso State, Brazil (2002/2003 and 2003/2004).

Years	Locations[1]	Cultivars[2]											Means
		1	2	3	4	5	6	7	8	9	10	11	
2002/2003	ITQ	37.6Ca	39.3Cb	43.7Ab	38.8Cc	40.7Bb	41.4Bb	40.3Cb	41.4Ba	41.8Bb	41.6Bb	44.0Ab	41.0
	LRV	39.7Ca	41.7Ca	45.2Aa	41.2Ca	41.9Cb	43.4Ba	43.3Ba	40.8Ca	43.4Ba	43.3Ba	45.8Aa	42.7
	NSJ	37.7Ca	39.3Cb	43.1Ab	37.9Cc	42.6Aa	41.5Bb	40.3Bb	38.1Cb	41.4Bb	41.0Bb	43.7Ab	40.6
	PVA	38.2Ca	38.4Cb	43.6Ab	41.8Ba	42.1Bb	42.0Bb	41.3Bb	39.4Cb	43.9Aa	41.0Bb	44.2Ab	41.5
	ROO	39.6Ba	39.8Bb	44.6Aa	40.4Bb	40.5Bb	40.2Bb	41.4Bb	39.2Bb	39.6Bb	38.8Bc	43.9Ab	40.7
	SAP	39.2Da	41.4Ca	46.5Aa	42.5Ca	41.8Cb	43.9Ba	42.5Ca	39.7Db	43.6Ba	42.9Ca	46.3Aa	42.7
	PP	40.3Ca	43.0Ba	46.2Aa	44.0Ba	43.4Ba	43.5Ba	44.5Aa	41.9Ca	43.0Ba	43.1Ba	46.3Aa	43.6
2003/2004	ITQ	38.9Ca	41.0Ca	44.2Ab	40.7Cb	43.2Ba	42.9Ba	42.5Ba	39.7Cb	43.9Aa	42.4Ba	45.6Aa	42.2
	LRV	38.9Da	40.9Ca	44.9Aa	41.4Ca	41.4Cb	41.3Cb	42.3Ba	38.5Db	42.9Ba	41.2Cb	44.3Ab	41.6
	NSJ	41.5Aa	40.7Aa	40.6Ac	41.3Aa	42.8Aa	41.2Ab	42.8Aa	41.9Aa	41.6Ab	41.0Ab	42.6Ac	41.6
	PVA	39.3Ca	37.2Cb	42.8Ab	40.0Bb	40.9Bb	39.4Cb	40.3Bb	38.4Cb	40.8Bb	39.4Cc	40.1Bd	39.9
	ROO	38.6Ca	41.8Ca	46.2Aa	40.0Cb	43.7Ba	42.8Ba	42.7Ba	40.4Ca	43.2Ba	43.1Ba	45.7Aa	42.6
	SAP	39.9Ca	41.8Ba	45.9Aa	42.1Ba	43.2Ba	42.7Ba	42.5Ba	40.8Ca	43.0Ba	43.0Ba	46.1Aa	42.8
	PP	39.1Ca	41.5Ba	45.4Aa	41.8Ba	43.8Aa	43.8Aa	43.4Aa	39.9Cb	42.4Ba	43.2Aa	44.9Ab	42.7
Means		39.2	40.5	44.5	41.0	42.3	42.2	42.1	40.0	42.5	41.8	44.5	---

[1]- ITQ: Itiquira, LRV: Lucas do Rio Verde, NSJ: Novo São Joaquim, PVA: Primavera do Leste, ROO: Rondonópolis, SAP: Sapezal and PP: Pedra Preta.
[2]-Cultivars: 1) BRS Aroeira; 2) BRS Ipê; 3) BRS Cedro; 4) BRS Jatobá; 5) FM 966; 6) SG 821; 7) Delta Opal; 8) IAC 24; 9) Makina; 10) Fabrika; 11) ST 474.
* Means within each row followed by the same uppercase letter or whithin each column followed by the same lowercase letter are not significantly different at the 5% level as judged by Scott & Knott's statistical method.

and lint percentage are in Table 4. For seed cotton yield, the varieties BRS Ipê ($\hat{\beta}_i$ = 0.89) and IAC 24 ($\hat{\beta}_i$ = 0.76) presented regression coefficients significantly less than 1.0 (p<0.05 and p<0.01, respectively), which indicates that they could exceed average performances only under very unfavorable conditions. Meanwhile, a dissimilar trend was observed with SG 821 ($\hat{\beta}_i$ = 1.18), which presented a regression coefficient greater than 1.0 (p < 0.01). Hence, this variety may perform better than the others in favorable environments. Regarding the eight remaining cultivars, all of them presented regression coefficients not differing of unit ($\hat{\beta}_i \cong 1.0$). Among of them, BRS Aroeira, BRS Cedro, BRS Jatobá and Delta Opal can be considered of broad adaptability due to their unitary regression coefficients plus high average yields. Moreover, these varieties showed deviation variance from regression ($\hat{\sigma}^2_{di}$) statistically equal to zero (p>0.05), and high determination coefficients (r^2 = 95.36%; 94.04%; 95.17%; 95.21%, respectively). Therefore they might exhibit not only broad adaptability to all environments but also highly predictable yields.

Table 4. Adaptability and stability estimates for seed cotton yield ($kg.ha^{-1}$) and lint percentage by the Eberhart and Russell (1966) analysis for eleven cotton cultivars assessed in fourteen environments at Mato Grosso State, Brazil (2002/2003 and 2003/2004).

Cultivars	Total yield			
	Mean[1]			r^2 (%)
BRS Aroeira	329.7A	0.96^{ns}	92.96^{ns}	95.36
BRS Ipê	328.3A	0.89^{*}	207.92^{ns}	93.22
BRS Cedro	325.9A	0.96^{ns}	208.67^{ns}	94.04
BRS Jatobá	336.1A	1.08^{ns}	221.72^{ns}	95.17
FM 966	309.2B	1.06^{ns}	178.55^{ns}	95.38
SG 821	297.6C	1.18^{**}	777.95^{**}	92.10
Delta Opal	328.2A	0.98^{ns}	123.57^{ns}	95.21
IAC 24	307.1B	0.76^{**}	-77.11^{ns}	95.60
Makina	293.5C	1.07^{ns}	267.08^{*}	94.77
Fabrika	309.3B	1.01^{ns}	262.04^{*}	94.17
ST 474	307.9B	1.03^{ns}	877.48^{**}	89.04
Cultivars	Lint percentage			
	Mean[1]			r^2(%)
BRS Aroeira	39.2E	0.35^{**}	0.45^{*}	43.31
BRS Ipê	40.5C	1.38^{*}	-0.16^{ns}	85.78
BRS Cedro	44.5A	1.04^{ns}	0.99^{**}	46.04
BRS Jatobá	41.0C	1.06^{ns}	0.66^{*}	52.86
FM 966	42.3B	0.72^{ns}	0.20^{ns}	45.89
SG 821	42.2B	1.19^{ns}	-0.20^{ns}	83.03
Delta Opal	42.1B	1.09^{ns}	-0.23^{ns}	82.13
IAC 24	40.0D	0.68^{ns}	0.59^{*}	33.27
Makina	42.5B	0.85^{ns}	0.34^{ns}	49.90
Fabrika	41.8B	1.24^{ns}	-0.08^{ns}	80.14
ST 474	44.5A	1.40^{*}	0.22^{ns}	75.67

[1]- Means within each column followed by the same uppercase letter are not significantly different as judged by Scott & Knott's test at 5% of probability.
ns, * and **: indicate non significant, and significance at 5% and 1% leval, respectively, by t-Student test, for the following null hypotesis: H0: $\beta_i = 1$, and H0: $\sigma^2_{di} = 0$.

For lint percentage, BRS Ipê and ST 474 can be considered as adapted to favorable environments due to their $\hat{\beta}_i$ values. In addition, just the latter cultivar produced high values of lint percentage (44.5%) and deviation from regression equal to zero. This results in highly stable rates of this trait when cultivated in environments with high technology level. This statement, however, should be carefully analyzed in order to recommend this cultivar, due to its low determination coefficient (r^2 = 75.67%). Another cultivar that expressed a high value for lint percentage was BRS Cedro (44.5%). This genotype might have broad adaptability ($\hat{\beta}_i \cong 1.0$), but analyzing its deviation from regression ($\hat{\sigma}^2_{di} > 0$; $p < 0.05$) and r^2 (46.04%), some restrictions for a broad recommendation might be considered.

Regarding the parameters of adaptability and stability and their average values for seed cotton yield, the cultivars BRS Aroeira, BRS Ipê, BRS Cedro, BRS Jatobá and Delta Opal might be recommended for their general adaptability and good performance.

CONCLUSIONS

1. For seed cotton yield, BRS Aroeira, BRS Ipê, BRS Cedro, BRS Jatobá and Delta Opal may be recommended as broadly adapted and stable to the Mato Grosso State environmental conditions.

2. For lint percentage, it was not found any cultivar with both broad adaptability and stability for the environments considered in this study.

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