



Correlations and selection of parents to technological traits of upland cotton

Luiz Paulo de Carvalho¹ Francisco José Correia Farias¹ Josiane Isabela Silva Rodrigues¹
Katiane Secco Castro² Alan Mario Zuffo^{2*}  Paulo Eduardo Teodoro²

¹Empresa Brasileira de Pesquisa Agropecuária, Embrapa Algodão, Campina Grande, Paraíba, Brasil.

²Universidade Federal de Mato Grosso do Sul (UFMS), Rodovia MS-306, 75560-000, Chapadão do Sul, Mato Grosso do Sul, Brasil. E-mail: alan_zuffo@hotmail.com. *Corresponding author.

ABSTRACT: *Technological traits improvement of cotton fiber is a constant demand by textile industry. This research aimed to identify the potential of improved materials with high lint percentage to contribute with alleles that increase the lint percentage in Extra long staple fiber (ELS) upland cotton. Two contrasting materials for lint percentage (LP) and fiber length (FL) were used, one with long fiber and a low lint percentage (parent A) and another with high lint percentage and medium length (parent B). The following variables were evaluated: lint percentage (LP), upper half mean length (UHML), fiber uniformity (FU), fiber strength (FS), and elongation (EL). Diallel analysis was performed using the Griffing's Method 4 adapted to partial diallel. Additive effects were predominant over non-additive effects. The mean LP was higher when using parent B. The opposite occurred for UHML. A negative correlation was detected between LP and UHML, showing the difficulty of obtaining genetic gain for both traits at the same time.*

Key words: diallel analysis, extra long staple fiber, genotypic correlations.

Correlações e seleção de genitores para caracteres tecnológicos em algodoeiro herbáceo

RESUMO: *O aprimoramento das características tecnológicas da fibra de algodão é uma demanda constante da indústria têxtil. Este trabalho teve como objetivo identificar o potencial de materiais melhorados com alta porcentagem de plumas para contribuir com alelos que aumentam a porcentagem de plumas com fibra extra longa (ELS) no algodão de terras altas. Dois materiais contrastantes para porcentagem de fibra (LP) e comprimento de fibra (FL) foram usados, um com fibra longa e uma baixa porcentagem de fibra (pai A) e outro com alta porcentagem de fibra e comprimento médio (pai B). As seguintes variáveis foram avaliadas: porcentagem de fibra (LP), comprimento médio da metade superior (UHML), uniformidade da fibra (FU), resistência da fibra (FS) e alongamento (EL). A análise dialélica foi realizada utilizando o Método 4 de Griffing adaptado para diallelo parcial. Os efeitos aditivos foram predominantes em relação aos efeitos não aditivos. O LP médio foi maior quando se usou o pai B. O oposto ocorreu para o UHML. Uma correlação negativa foi detectada entre LP e UHML, mostrando a dificuldade de obter ganho genético para ambas as características ao mesmo tempo.*

Palavras-chave: análise dialélica, fibra extra longa, correlação genotípica.

INTRODUCTION

The improvement of the technological traits of cotton fiber is a constant demand by the textile industry. One of the primary objectives of cotton breeding programs worldwide is to select genotypes that present the quality required by the textile industries and maintain the productive potential (HOOGERHEIDE et al., 2007).

The cotton breeding programs in Brazil have developed *Gossypium hirsutum* L. (Malvaceae) cultivars with longer upper half mean length (UHML), as in SMITH (2008) research, to meet the demand for this fiber. Some cultivars have reached 32 mm or longer. Besides increasing the international standard

for UHML, industries have also required greater fiber bundle strength, lower short fiber content, greater fiber uniformity, and mature fibers. Extra long staple fiber (ELS) of upland cotton in the United States present a UHML value ≥ 32 mm, according to Cotton Incorporated (SMITH et al., 1999).

The *G. hirsutum* fiber commercialized in Brazil presents a UHML value of 28 mm. However, in the past few years, cultivars have presented UHML between 32-35 mm, which classifies them as ELS upland. Low fiber content of ESL upland cotton hinders the development of cultivars (SMITH et al., 2008). Breeders have long sought to develop upland cultivars that contain the elite quality traits of pima cotton by crossing both materials (SMITH et al.,

2008). Little success has been reported due to the low yield and low lint percentage of the materials obtained. The preferred germplasm source for UHML improvement is the use of the natural variability present in upland cotton, which avoids reproductive obstacles and undesirable agronomic traits with interspecific hybridization (BEYER et al., 2014).

The partial diallel can be used to enable the study of the combining ability of a relatively large group of parents (CRUZ et al., 2012). This diallel involves the evaluation of parents arranged in two groups, being the inference made for the group. The diallel allows identifying lines with high lint percentage to donate alleles that could increase the UHML value and that could later be crossed to obtain genotypes with high UHML and high lint percentage. This research aimed to identify the potential of improved materials with high lint percentage to contribute with alleles that increase the lint percentage in ELS upland materials.

MATERIALS AND METHODS

Two contrasting materials for lint percentage (LP) and fiber length (FL) were chosen for this research, the genotype PI 651 440 with long fiber and low lint percentage (denominated parent A) selected by SMITH (2008) and the genotype BRS 335 with high lint percentage and medium fiber length of 28 mm (denominated parent B), constituting group II (Table 1). Nine lines with high lint percentage (higher than 40%) from the Embrapa

breeding program were selected to be crossed with the material from Group II, in a partial diallel scheme, constituting group I (Table 1).

Nine parents of group I and the two of group II were planted in 2016 in a greenhouse, in Campina Grande-PB, Brazil. During flowering stage, each parent of group I was crossed with two parents of group II. In 2017, the F₁ generation was planted in the municipality of Barbalha-CE, Brazil, in a randomized block design with two replications. The plot consisted of two 5-m rows, with ten plants per linear meter after thinning. Cultural practices were standard for this area, including irrigation and insect control.

During the harvest, 20 bolls per plot were taken in the medium third of the plant whose fiber properties were determined in HVI (high volume instrument), in Campina Grande - PB. Seed cotton of each F₁ was ginned on a roller gin. This research evaluated the following fiber properties (determined by HVI): upper half mean length (UHML) defined by mean of the longest 50% of the fibers in mm of a sample of cotton; fiber strength (FS) defined by fiber bundle strength in gf/tex; fiber length uniformity (FU, %); and elongation of fibers at break (EL, %). The FU is referred to as uniformity index and is calculated as: (mean fiber length/UHML) x 100. Elongation at break during the measure of strength is the percentage of stretch at the point of complete breakage of the fibers. The lint percent (LP) was also determined as (sample lint weight/sample seed cotton weight) x 100.

For the diallel analysis, the Griffing's Method 4 (1956) adapted to partial diallel was used,

Table 1 - Mean values of lint percentage (LP) and upper half mean length (UHML) of the parents used in the diallel evaluated in different environments in the Brazilian Cerrado.

Parent	LP(%)*	UHML(mm)*	Number of Locations
-----Group I-----			
1-BA 07-3601	43.9	29.7	2
2-BA 2009-2247	41.2	32.1	3
3-BA 2008-115	40.9	32.3	4
4-BA 2009 666	43.8	30.8	4
5-BA 2009 1366	43.5	32.4	1
6-BA 2009-1174	43.8	32.3	2
7-BA 2009-2334	41.4	33.3	4
8-BA 2009 692	41.0	31.5	1
9-BA 2009 2270	40.3	32.2	4
-----Group II-----			
A-PI (631 440)	42.51	29.8	
B-BRS 335	-	29.0**	

*Estimated based on regional variety and lines test data in the Cerrado region of Brazil, between 2008 and 2011. ** Smith (2008).

which estimates the effects of the general combining ability (GCA) of each parent and the effects of specific combining ability (SCA), using only the F_1 hybrids, according to the model described in Equation 1:

$$Y_{ij} = \mu + g_i + g'_j + s_{ij} + \varepsilon_{ij} \quad (1)$$

where: Y_{ij} is the mean of the cross between the i -th line of Group I and the j -th line of Group II; μ is the overall mean of the diallel; g_i is the general combining ability of the i -th line of Group I; g'_j is the general combining ability of the j -th line of Group II; s_{ij} is the specific combining ability of lines of Groups I and II; and ε_{ij} is the mean experimental error.

The genotypic correlations (r_g) between the pairs of traits were estimated according to Equation 2:

$$r_g = \frac{COV_{G(x,y)}}{\sqrt{\hat{\sigma}_{Gx}^2 \times \hat{\sigma}_{Gy}^2}} \quad (2)$$

Where: $COV_{G(x,y)}$ is the estimate of the genotypic covariance between traits x and y ; $\hat{\sigma}_{Gx}^2$ is the estimate of the genotypic variance of trait x ; and $\hat{\sigma}_{Gy}^2$ is the estimate of the phenotypic variance of trait y . The correlation network was used to graphically express the functional relationship between the estimates of the correlation coefficients between the environments, in which the proximity between the nodes (traces) is proportional to the absolute value of the correlation between them. The thickness of the edges was controlled by applying a cut-off value of 0.60, meaning that only $|r_{ij}| \geq 0.60$ have their edges highlighted. Finally, positive correlations were highlighted by solid lines, while negative correlations were represented in dashed lines. This analysis was performed with the Rbio software (BHERING, 2017).

RESULTS AND DISCUSSION

To serve as a reference, mean data of LP (%) and UHML of the parents were taken in assays of

lines and cultivars conducted in different environments in the Brazilian Cerrado region (Table 1). This strategy was applied because only the F_1 hybrids were used among the parents of groups I and II, and parents are not included in the diallel. Results revealed high lint percentage ($\geq 40.3\%$) and UHML between 29.7 and 33.3 mm.

Table 2 shows a difference between the F_1 hybrids for all traits, except for UHML, which evidences the variability among F_1 hybrids. The additive variability expressed by the GCA mean squares is higher than the non-additive variability for the traits in the two groups, except for fiber uniformity (FU) in group II (Table 2). These results indicate the existence of additive genetic effects involved in the control of all traits evaluated and the presence of non-additive genetic effects for lint percentage and fiber strength, regardless of the generation.

Several studies have shown the predominance of additive genetic effects in the control of most agronomic and fiber quality traits of cotton plants (BALOCH et al., 1999; HASSAN et al., 2000; CHINCHANE et al., 2002; YUAN et al., 2002; TUTEJA et al., 2003; KHAN et al., 2007; AGUIAR et al., 2007; HAGUE et al., 2008; KHAN et al., 2009; BECHERE et al., 2016). These results indicated that breeders should use genotypes with higher GCA to generate the segregating populations for selection. This strategy is justified by the fact that the additive genetic effect is only directly fixable. However, a few studies in China and India have explored hybrid vigor in cotton to improve fiber yield and quality (KHAN et al., 2007).

The coefficient of experimental variation ranged from 1.28% (fiber uniformity) to 7.81% (elongation), which, based on PIMENTEL-GOMES (2009), means high experimental precision. Other

Table 2 - Mean squares estimates for the general combining ability (GCA) and specific combining ability (SCA) for the variables lint percentage (LP), upper half mean length (UHML), fiber uniformity (FU), fiber strength (FS), and elongation (EL) evaluated in 18 cotton F_1 hybrids.

Source of variation	DF	LP	UHML	FU	FS	EL
Crosses	17	3.55*	1.88 ^{ns}	2.57*	6.99*	0.28*
GCA – Group I	8	4.11*	2.70*	3.91*	9.41*	0.24 ^{ns}
GCA – Group II	1	10.80*	6.12*	0.57 ^{ns}	27.21*	2.27*
SCA	8	2.06 ^{ns}	0.54 ^{ns}	1.49 ^{ns}	2.04*	0.09 ^{ns}
Residue	17	1.16	0.94	1.15	2.53	0.12
Coefficient of variation (%)		2.88	3.03	1.28	5.20	7.81

^{ns} and * : not significant and significant at 5% probability by the F test, respectively.

studies have reported similar results in magnitude when using the diallel cross in cotton crops (AGUIAR et al., 2007; KHAN et al., 2007; HAGUE et al., 2008; KHAN et al., 2009).

Parents BA 2008-115 and BA 2009-1174 (group I) have high combining ability for lint percentage and fiber length, proving to be an excellent combinatory to increase these two traits simultaneously (Table 3). Parents BA 07-3601, BA 2009-2247, and BA 2008-115 are good donors of favorable alleles to increase fiber uniformity. In turn, fiber strength may have breeding populations with use in crosses of parents BA 2008-115 and BA 2009-2334. These results indicated that complex crosses may be a strategy to generate a population with segregating individuals for the traits evaluated.

In general, when the nine parents of group I combined with the two parents of group II, the lint percentage of all F_1 hybrids (Table 4) decreased when compared with the means of the parents (Table 1). When using parent B in the peer crosses, a tendency to maintain the lint percentage higher than when using parent A (odd crosses) was detected, which decreased the lint percentage in the hybrids. The opposite occurred for UHML, *i.e.*, the fiber length was higher when using parent A than when using parent B (Table 3).

Some parents of group I that presented high lint percentage were efficient in increasing the length when used as parent PI 631 440 (1xA), (2xA), (3xA),

and (4xA) (Table 4). Some combinations resulted in high fiber strength, highlighting 3xB, 7xA, 7xB, and 9xB (Table 2). Figure 1 showed that the mean lint percentage of F_1 is higher when using parent B with high lint percentage than when using parent A. However, the opposite occurred for fiber length, *i.e.*, when using parent A to generate the F_1 , the fiber length was higher than when using parent B (Figure 1).

Figure 1 present the genotypic correlations between the evaluated traits. Negative correlation between lint percentage and fiber length should be highlighted since it reveals the difficulty of obtaining genetic gain for both traits at the same time. The correlations (positive between lint percentage x elongation and negative between fiber length x elongation) should also be highlighted. Table 4 shows that the combination of each of the nine parents of group I with the two parents of group II (A and B) tended to maintain high lint percentage when using parent B and to decrease fiber length when using the same parent of group II. Even when the UHML values in hybrids are higher than 33 mm, if the parent of group II is the low-fiber A parent, the F_1 hybrids will exhibit lower lint percentage values. However, some combinations presented good UHML and lint percentage, such as (2 x B), (3xB), (7 x A), and (8 x B) (Table 4).

Several studies involving technological traits have been developed (NG et al., 2015). However, UHML is a fiber quality trait that still

Table 3 - General combining ability estimates for groups I and II for the variables lint percentage (LP), upper half mean length (UHML), fiber uniformity (FU), fiber strength (FS), and elongation (EL), evaluated in 18 cotton F_1 hybrids.

Parent	LP	UHML	FU	FS	EL
-----Group I-----					
1-BA 07-3601	-0.28	-1.49*	1.57*	-1.13*	-
2-BA 2009-2247	0.07	0.99*	1.33*	0.54	-
3-BA 2008-115	0.52	0.26	1.65*	1.89*	-
4-BA 2009 666	0.52	-0.51	-0.02	-0.08	-
5-BA 2009 1366	-1.65*	0.99*	-0.02	-0.58	-
6-BA 2009-1174	0.85*	0.44	0.35	-1.00*	-
7-BA 2009-2334	-1.33*	0.31	0.05	2.62*	-
8-BA 2009 692	1.53*	-0.74	-0.24	-2.33*	-
9-BA 2009 2270	-0.25	-0.24	-0.82*	0.09	-
$\hat{\sigma}_{G_i}^2$	0.26	0.21	0.25	0.56	-
A-PI (631 440)	-0.55	0.41	-	-0.87*	-0.25
B-BRS 335	0.55	-0.41	-	0.87*	0.25
$\hat{\sigma}_{G_i}^2$	0.03	0.03	-	0,09	0.01

*: differs statistically from zero by the t-test at 5% probability; $\hat{\sigma}_{G_i}^2$: variance of general combining ability.

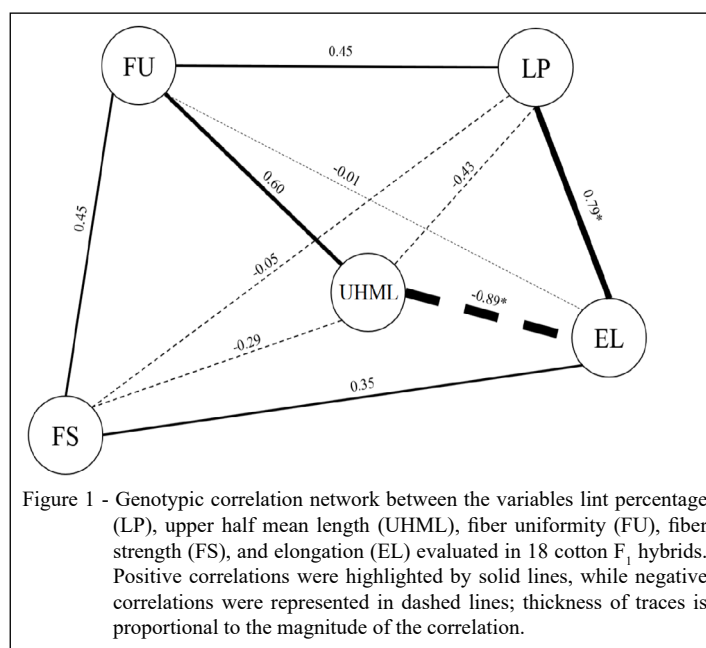
Table 4 - Mean clustering for lint percentage (LP), upper half mean length (UHML), fiber uniformity (FU), fiber strength (FS), and elongation (EL), evaluated in 18 cotton F₁ hybrids.

F ₁	LP(%)	UHML(mm)	FU(%)	FS(gf/tex)	EL(%)
1- (1 x A)	37.05 b	32.35 a	85.25 a	29.45 b	4.45 a
2- (1 x B)	39.65 a	30.75 a	84.70 a	31.3 b	5.25 a
3- (2 x A)	37.70 b	34.93 a	88.15 a	30.55 b	4.05 a
4- (2 x B)	39.70 a	33.10 a	87.60 a	33.55 a	4.60 a
5- (3 x A)	38.30 b	33.75 a	88.05 a	32.70a	4.15 a
6- (3 x B)	40.00 a	32.85 a	88.35 a	34.10 a	4.55 a
7- (4 x A)	38.90 a	33.10 a	86.70 a	31.35 b	4.70 a
8- (4 x B)	39.40 a	31.95 a	86.35 a	31.50 b	5.10 a
9- (5 x A)	36.40 b	33.80 a	85.75 a	30.45 b	4.35 a
10-(5 x B)	37.55 b	34.25 a	87.30 a	31.40 b	4.50 a
11- (6 x A)	39.60 a	33.80 a	86.05 a	29.15 b	4.15 a
12- (6x B)	39.35 a	33.15 a	86.35 a	31.89b	4.70 a
13- (7 x A)	38.05 b	33.90 a	87.45 a	34.15 a	4.20 a
14- (7x B)	36.55 b	32.80 a	85.75 a	34.10 a	4.25 a
15- (8 x A)	39.85 a	32.65 a	85.15 a	28.55 b	4.25 a
16- (8x B)	40.46 a	31.92 a	87.47 a	29.79 b	5.21 a
17- (9x A)	36.85 b	32.75 a	85.25 a	29.4 b	4.35 a
18- (9x B)	39.90 a	32.85 a	86.20 a	33.8 a	5.00 a

Means followed by the same letter in each column do not differ at 5% by the Scott-Knot's test.

requires further research. Therefore, understanding the correlations between agronomic and technological traits in breeding programs is fundamental. This fact is justified by the changes that occur in other traits of agronomic interest, and which are correlated with

each other when the selection is based on one trait. Results for genotypic correlations reported in this study evidenced the difficulty of selection based on important fiber quality traits, mainly UHML, since selection based on this trait could; consequently,



lead to the selection of undesirable traits, such as lower FP and EL.

Other breeders have stated the existence of negative correlations between agronomic and technological traits in cotton (HOOGERHEIDE et al., 2007; CARVALHO et al., 2015; ZENG & PETTIGREW, 2015; FARIAS et al., 2016; REDDY et al., 2017), indicating that the direct selection of one trait will result in unwanted gains to others. To overcome this problem, breeders have used selection indices, which allow aggregating the information of the experimental unit, aiming selection based on a set of variables that involved different traits of economic interest.

However, it is important to note that; although, there is a negative genetic correlation among the evaluated technological traits, hybrid 11 (6 x A) was the genotype that collected the best values for these traits. This revealed that transgressive individuals can be selected in future generations from this cross.

CONCLUSION

Additive effects were predominant over non-additive effects in the traits evaluated in cotton. The mean lint percentage was higher when using the genotype BRS 335 (parent B). The opposite occurred for upper half mean length. A negative correlation was detected between these traits, showing the difficulty of obtaining genetic gain for both traits at the same time.

Hybrid 11 (BA 2009-1174x PI (631 440)) was the genotype that collected the best values for these traits. This revealed that transgressive individuals can be selected in future generations from this cross.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 and Universidade Federal de Mato Grosso do Sul (Edital PROPP/UFMS N° 033, de 21 de março de 2019).

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

REFERENCES

- AGUIAR, P. A. D. et al. Diallel analysis of upland cotton cultivars. **Crop Breeding and Applied Biotechnology**, v.7, n.4, p.353-359, 2007. Available from: <<http://dx.doi.org/10.12702/1984-7033.v07n04a04>>. Accessed: Aug. 10, 2018. doi: 10.12702/1984-7033.v07n04a04.
- BALOGH, M. J. et al. Line-tester analysis for estimating genetic components of some quantitative traits in *G. hirsutum*. **Sindh Journal of Plant Science**, v.1, p.28-34, 1999.
- BECHERE, E. et al. Combining ability of ginning rate and net ginning energy requirement in upland cotton. **Crop Science**, v.56, n.2, p.499-504, 2016. Available from: <<https://doi.org/10.2135/cropsci2015.05.0297>>. Accessed: Aug. 10, 2018. doi: 10.2135/cropsci2015.05.0297.
- BEYER, B. M. et al. Test cross evaluation of upland cotton accessions for selected fiber properties. **Crop Science**, v.54, n.1, p.60-67, 2014. Available from: <<https://doi.org/10.2135/cropsci2013.06.0374>>. Accessed: Aug. 8, 2018. doi: 10.2135/cropsci2013.06.0374.
- BHERING, L. L. Rbfo: a tool for biometric and statistical analysis using the R platform. **Crop Breeding and Applied Biotechnology**, v.17, n.2, p.187-190, 2017. Available from: <<http://dx.doi.org/10.1590/1984-70332017v17n2s29>>. Accessed: Aug. 8, 2018. doi: 10.1590/1984-70332017v17n2s29.
- CARVALHO, L. P. et al. Selection for increased fiber length in cotton progenies from Acala and Non-Acala types. **Crop Science**, v.55, n.3, p.1-7, 2015. Available from: <<https://doi.org/10.2135/cropsci2014.08.0547>>. Accessed: Aug. 8, 2018. doi: 10.2135/cropsci2014.08.0547.
- CHINCHANE, V. N. et al. Studies on combining ability in cotton (*G. hirsutum*). **Annual Review of Plant Physiology**, v.16, p.160-165, 2002.
- CRUZ, C. D. et al. **Modelos biométricos aplicados ao melhoramento genético**. Viçosa: Editora UFV, 2012. 508p.
- FARIAS, F. J. C. et al. Correlations and path analysis among agronomic and technological traits of upland cotton. **Genetics and Molecular Research**, v.15, n.3, 2016. Available from: <<https://doi.org/10.4238/gmr.15038239>>. Accessed: Aug. 8, 2018. doi: 10.4238/gmr.15038239.
- GRIFFING, B. Concept of general and specific combining ability in relation to diallel crossing systems. **Australian journal of biological sciences**, v.9, n.4, p.463-493, 1956.
- HAGUE, S. S. et al. Combining ability of upland cotton, *Gossypium hirsutum* L., with traits associated with sticky fiber. **Euphytica**, v.164, n.75-79, 2008. Available from: <<https://doi.org/10.1007/s10681-008-9644-2>>. Accessed: Aug. 10, 2018. doi: 10.1007/s10681-008-9644-2.
- HASSAN, G. et al. Combining ability in inter-varietal crosses of Upland cotton. **Sarhad Journal of Agriculture**, v.16, p.407-410, 2000.
- HOOGERHEIDE, E. S. S. et al. Correlações e análise de trilha de caracteres tecnológicos e a produtividade de fibra de algodão. **Pesquisa Agropecuária Brasileira**, v.42, n.10, p.1401-

- 1405, 2007. Available from: <[https://doi.org/10.1590-s0100-204x2007001000005](https://doi.org/10.1590/s0100-204x2007001000005)>. Accessed: Aug. 8, 2018. doi: 10.1590/s0100-204x2007001000005.
- KHAN, N. U. et al. Heterosis and inbreeding depression and mean performance in segregating generations in upland cotton. **European Journal of Scientific Research**, v.17, p.531–546, 2007.
- KHAN, N. U. et al. Combining ability analysis to identify suitable parents for heterosis in seed cotton yield, its components and lint % in upland cotton. **Industrial Crops and Products**, v.29, n.1, p.108-115, 2009. Available from: <<https://doi.org/10.1016/j.indcrop.2008.04.009>>. Accessed: Aug. 8, 2018. doi: 10.1016/j.indcrop.2008.04.009.
- NG, E. H. et al. Generation mean analysis for fiber elongation in upland cotton. **Crop Science**, v.54, n.4, p.1347-1353. 2015. Available from: <<https://doi.org/10.2135/cropsci2013.07.0490>>. Accessed: Aug. 10, 2018. doi: 10.2135/cropsci2013.07.0490.
- PIMENTEL-GOMES, F. **Curso de Estatística Experimental**. 15 ed., Fealq, São Paulo, 2009.451 p.
- REDDY, K. B. et al. Character association and path coefficient analysis for yield and component traits in upland cotton (*Gossypium hirsutum* L.). **Journal of Cotton Research and Development**, v.31, n.1, p.29-33, 2017. Available from: <<https://www.cabdirect.org/cabdirect/FullTextPDF/2017/20173143993.pdf>>. Accessed: Aug. 10, 2018.
- SMITH, C. W. et al. **History of cultivar development in the United States**. In: SMITH, C. W.; COTHREN J. T. (eds). Cotton: Origin, history, technology and production. John Wiley and Sons, New York. p. 99–171, 1999.
- SMITH, C. W. et al. Development of extra-long staple upland cotton. **Crop Science**, v.48, n.5, p.1823–1831, 2008. Available from: <<https://doi.org/10.2135/cropsci2008.01.0052>>. Accessed: Aug. 7, 2018. doi: 10.2135/cropsci2008.01.0052.
- TUTEJA, O. P. et al. Combining ability analysis in upland cotton (*Gossypium hirsutum*) for yield and its components. **Indian Journal of Agricultural Sciences**, v.73, n.12, p.671–675, 2003.
- YUAN, Y. et al. Heterosis and gene action of boll weight and lint percentage in high quality fiber property varieties in upland cotton. **Acta Agronomica Sinica**, v.28, n.2, p.196–202, 2002. Available from: <<http://europemc.org/abstract/cba/384181>>. Accessed: Aug. 7, 2018.
- ZENG, L.; PETTIGREW, W. T. Combining ability, heritability, and genotypic correlations for lint yield and fiber quality of Upland cotton in delayed planting. **Field Crops Research**, v.171, p.176-183, 2015. Available from: <<https://doi.org/10.1016/j.fcr.2014.10.004>>. Accessed: Aug. 10, 2018. doi: 10.1016/j.fcr.2014.10.004