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Diallel analysis for agronomic traits in upland cotton in semi-arid zones in Brazil

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Genet. Mol. Res. 16 (3): gmr16039677
Received March 20, 2017
Accepted April 25, 2017
Published July 28, 2017
DOI http://dx.doi.org/10.4238/gmr16039677

ABSTRACT. This study aimed to estimate the general- (GCA) and specific-combining ability (SCA) and obtain information on the genetic control of agronomic traits among six upland cotton genotypes and their hybrid combinations. In 2015, six cotton genotypes (FM 993, CNPA 04-2080, PSC 355, TAM B 139-17, IAC 26, and TAMCOT-CAMD-E), and fifteen hybrid combinations were evaluated at the Experimental Station of Embrapa Algodão. The experiment consisted of a randomized block design with three replications. The characteristics evaluated were: the appearance of the first flower (AFF); the appearance of the first boll (AFB); plant height (PH); the weight of one boll (BW); lint percentage (LP); cotton seed yield (CSY); and cotton fiber yield (LY). Significant genetic variability was observed for all the traits studied, which is fundamental for the formation of populations that maximize genetic gains. Additive effects were predominant for AFF, AFB, PH, and LP. Non-additive effects were predominant for CSY, LY, and BW. Genotypes FM 993 and CNPA 04-2080 presented the highest GCA estimates for CSY, LP, and LY, as well as the highest means, being indicated for breeding programs that aim at the improvement of these traits. The best hybrid combinations were FM 993 x PSC 355, FM 993 x TAMCOT-CAMD-E, CNPA 04-2080 x TAM B 139-17, PSC 355 x IAC 26, and TAM B 139-17 x IAC 26, since they presented means associated with positive and high SCA estimates for CSY, LP, LY, and at least one of their parents presented high GCA.

Key words: *Gossypium hirsutum*; General-combining ability; Specific-combining ability; Fiber; Earliness

INTRODUCTION

Upland cotton (*Gossypium hirsutum* L.), denominated annual or herbaceous cotton, is one of the four species cultivated worldwide for fiber production. The species is exploited in large areas in tropical and subtropical regions and is of great importance in Brazil. Also, it is responsible for providing 90% of the world textile fiber.

The efficient choice of the parents to be used in crosses and the selection of the best hybrid combinations increases the chances of obtaining a successful breeding program and promising segregating populations. In this context, information on the general - (GCA) and specific-combining abilities (SCA) and on the heterotic expression between the crosses are useful (Carvalho, 1993; Aguiar et al., 2007). Diallel cross systems have been widely used in plant breeding programs to obtain information on the behavior of a group of parents *per se* and their hybrid combinations (Cruz and Vencovsky, 1989; Cruz et al., 2004).

There are several methodologies used to estimate GCA and SCA. The methodology proposed by Griffing (1956) is applied to a group of parents with any level of endogamy (Cruz and Vencovsky, 1989). The estimates of the effects of GCA provide information on the concentration of genes of predominant additive effect and are useful in the indication of parents to be employed in intrapopulation breeding programs. The significance of the SCA reflects the non-additive genetic effects, which indicates relevant non-allelic interactions. In this case, the breeder is interested in hybrid combinations with more favorable SCA estimates, with at least one parent with favorable effects of GCA (Sprague and Tatum, 1942; Cruz et al., 2004).

Several works have used diallel crosses to estimate the GCA and SCA in various traits of upland cotton. Aguiar et al. (2007) estimated GCA and SCA and the heterosis to study the genetic control of the agronomic and technological fiber traits in hybrid combinations of upland cotton. Studies on combining ability and heterosis have been carried out in cotton germplasm to estimate combining abilities and heterotic effects (Khan et al., 2009; Basal et al., 2011).

Berger et al. (2012) evaluated the fiber quality in eight upland cotton genotypes using diallel analysis and observed significant effects of GCA and SCA values for most of the fiber traits evaluated, including lint percentage. Simon et al. (2013) studied the effects of combining abilities on eight cotton genotypes in northeastern Nigeria and observed both additive and non-additive effects on the genetic control of the traits under study. Bechere et al. (2016) studied the effects of SCA and GCA estimates for the ginning rate and the net ginning energy requirement on a set of upland cotton germplasm (*Gossypium hirsutum* L.), and found both additive and non-additive effects, with a predominance of additive effects in the control of the traits under study.

This study aimed to estimate the GCA and SCA and to obtain information on the genetic control of agronomic traits among six upland cotton genotypes and their hybrid combinations.

MATERIAL AND METHODS

In 2015, six cotton genotypes (FM 993, CNPA 04-2080, PSC 355, TAM B 139-17, IAC 26, and TAMCOT-CAMD-E) and 15 hybrid combinations were evaluated at the Experimental Station of Embrapa Algodão, located in Patos - PB (latitude 7°0'40.55"S; longitude 37°16'14.80"W, at 243.28 m asl). The average rainfall recorded in the year of 2015 was of 495.7 mm (AESA - Agência Executiva de Gestão das Águas do Estado da Paraíba, 2017). The experiment was carried out under irrigation regime. The experimental plot consisted of two 5 m rows, spaced 1.0 m between rows and 0.20 m between plants, with a useful area of 10 m^2, and a population density of 50 plants/row. The experiment consisted of randomized block design with three replications.

Planting was carried out manually, with 25 plants in each 5.0 m row. Thinning was performed 30 days after planting. Cultural treatments were carried out according to the culture's need throughout the experiment. The following traits were evaluated: characteristic appearance of the first flower (AFF, days), appearance of the first boll (AFB, days), plant height (PH, cm), cotton seed yield (CSY, kg/ha), lint percentage (LP, %), cotton fiber yield (LY, kg/ha), and weight of one boll (BW, g).

Statistical genetic analyses for the data obtained in the experiment were carried out using the GENES software (Cruz, 2013). The F-test at 1 and 5% probability was used for analysis of variance. Means between treatments were compared using the Scott and Knott (1974) test at 5% probability. Diallel analyses and estimates of combining abilities were carried out according to method 2, model 1 of Griffing (1956), which estimates the effects of the GCA ($\hat{g}_i$) of each parent, as well as the effects of the SCA ($\hat{s}_{ij}$). The model was considered fixed for genotype effects. The statistical genetic model is given by Equation 1:

$$Y_{ij} = m + g_i + g_j + s_{ij} + \bar{e}_{ij} \quad \text{(Equation 1)}$$

where Y_{ij}: mean value of hybrid combination (i ≠ j) or of the parent combination (i = j); *m*: general mean; g_i, g_j: effects of the GCA of the i-th and the j-th parent, respectively; s_{ij}: effects of the SCA for crosses between the parents i and j; $\bar{e}_{ij}$: mean experimental error.

RESULTS AND DISCUSSION

Combining abilities

Table 1 shows the diallel analyses for the traits under study. All traits were significant for GCA, indicating that at least one parent was superior to the others concerning the mean performance in their hybrid combinations. The means of all traits evaluated are demonstrated in **Table S1**. AFF, AFB, and PH, showed no significance for SCA. Except for yield, GCA was predominant in all traits related to SCA, indicating greater importance of additive effects in the control of the traits under study. These results are in agreement with those obtained by Aguiar et al. (2007) who estimated the GCA and SCA in 28 hybrid combinations of upland cotton.

Table 1. Analysis of variance for genotypes and for general-combining ability (GCA) and specific-combining ability (SCA) of the characteristics: appearance of the first flower (AFF, days), appearance of the first boll (AFB, days), plant height (PH, cm), cotton seed yield (CSY, kg/ha), lint percentage (LP, %), cotton fiber yield (LY, kg/ha), and weight of one boll (BW, g) according to the Griffing model (1956) involving parents and F_1 hybrids.

Sources of variation	d.f.	AFF	AFB	PH	CSY	LP	LY	BW
Genotypes	20	10.46**	19.14**	153.26**	3718996.27**	4.84**	668444.84**	0.96**
GCA	5	36.14**	71.11**	536.22**	3300854.79*	13.75**	721222.06**	1.88**
SCA	15	1.90^{ns}	1.81^{ns}	25.61^{ns}	3858376.76**	1.87**	650852.43**	0.65**
Residual	40	2.43	2.35	59.39	942289.69	0.71	170856.76	0.07
ΦGCA		1.40	2.86	19.86	98273.54	0.54	22931.88	0.07
ΦSCA		-0.17	-0.17	-11.25	972029.02	0.38	159998.55	0.19
Mean		43.07	85.44	69.00	4518.46	41.57	1881.51	6.21
CV (%)		3.62	1.79	11.16	21.48	2.03	21.96	4.35

**,*Significant at 1 and 5% probability by the F-test, respectively; ΦGCA = quadratic component associated with GCA; ΦSCA = quadratic component associated with SCA; d.f. = degrees of freedom; CV = coefficient of variation.

Quadratic effects associated with GCA were predominant for AFF, AFB, PH, and LP, which indicates a predominance of the additive genetic effects. For AFF, these results were in agreement with those obtained by Khan et al. (2011), Alkuddsi et al. (2013), and Khan (2013). Variance associated with SCA concerning GCA was predominant for flowering, which evidences the predominance of the non-additive effects for this trait; this fact does not agree with the present results. Conversely, for SCA, quadratic effects were more important for CSY, LY, and BW.

According to Usharani et al. (2014), additive effects were predominant in a study on combining abilities for AFB. On the other hand, non-additive effects were predominant in the study of Pusphpam et al. (2015). For PH, the present results were similar to those observed by Méndez-Natera et al. (2012), Patel et al. (2014), Usharani et al. (2014), Kumar et al. (2014), and Waqar et al. (2015).

For CSY, Rauf et al. (2006) observed similar results when studying cotton yield components, i.e., both additive and dominance effects controlled yield. Conversely, Aguiar et al. (2007), Khan et al. (2011), Hinze et al. (2011), Khan (2013), Srinivas et al. (2014), and Patel et al. (2014) observed predominant GCA variance over SCA variance. Other authors have observed predominant SCA (Kumar et al., 2014; Ekinci and Basbag, 2015; Kannan and Saravanan, 2015; Çoban and Ünay, 2015; Pusphpam et al., 2015).

For LP, similar results were found by Hinze et al. (2011), Khan et al. (2011), Khan (2013), and Zeng and Pettigrew (2015). Other authors, such as Basal et al. (2011) and Imran et al. (2012), found non-additive genetic effects in the control of this trait. For LY, in the study of Ashokkumar et al. (2010) on GCA and SCA in yield components, non-additive effects were predominant for most of the traits.

GCA effects

Table 2 shows the estimates of the effects of the GCA ($\hat{g}_i$) of the parents under study.

Regarding AFF and AFB, the genotype TAMCOT-CAMD-E obtained the highest negative estimate and the lowest mean estimate for both traits. It should be noticed that the fewer the days for the AFF and AFB, the higher is earliness. In this case, the genotype with the lowest ($\hat{g}_i$) estimate is recommended.

Table 2. Estimates of the effects of the general-combination ability ($\hat{g}_i$) of six cotton parents for the characteristics: appearance of the first flower (AFF, days), appearance of the first boll (AFB, days), plant height (PH, cm), cotton seed yield (CSY, kg/ha), lint percentage (LP, %), cotton fiber yield (LY, kg/ha), and weight of one boll (BW, g).

Parents	AFF	AFB	PH	CSY	LP	LY	BW
FM 993	0.11	1.78**	3.49*	372.93*	0.87**	190.51*	-0.09
CNPA 04-2080	-0.29	-0.14	-0.80	197.72	0.68**	112.24	0.00
PSC 355	0.13	-0.42	-0.87	103.06	-0.25	32.29	-0.42**
TAM B 139-17	0.39	0.85**	-4.49**	-227.66	-1.24	-147.73	0.43**
IAC 26	1.72**	1.02**	7.43**	193.83	0.03	80.90	0.12*
TAMCOT-CAMD-E	-2.06**	-3.10**	-4.76**	-639.90**	-0.08**	-268.22**	-0.05
SD (g_i)	0.29	0.28	1.43	180.88	0.15	77.02	0.05
SD (g_i - g_j)	0.45	0.44	2.22	280.22	0.24	119.32	0.07

**,*Significant at 1 and 5% probability by the *t*-test; SD (g_i) = standard deviation; SD (g_i - g_j) = standard deviation of the difference of the effects of two parents.

For PH, the highest positive estimate was observed for the genotype IAC 26 that also obtained the highest mean. The genotype TAMCOT-CAMD-E and TAM B 139-17 obtained the highest negative ($\hat{g}_i$) estimates and lower mean values, respectively (Table 2). Depending on the breeding program, lower height may be desired. In this study, genotypes TAMCOT-CAMD-E and TAM B 139-17 presented the highest ($\hat{g}_i$) negative estimates, contributing to a reduction in plant height.

In relation to CSY, only two genotypes presented negative estimates. The genotype FM 993 presented the highest positive estimate; however, it did not have the highest mean among the genotypes. Genotype CNPA 04-2080 presented the highest mean with positive estimates, followed by IAC 26. Regarding LP, genotype FM 993 presented the highest positive estimate and the highest mean estimate among genotypes. This trait is influenced by the environment. The position of the boll in the plant, in function of the height of the fruiting branch, and the position of this branch related to the stem significantly influence the level of lint percentage. The bolls of the upper and lower third of the plant showed lower lint percentage. Currently, breeding programs have selected genotypes with 40% or greater LP (Farias et al., 2008).

Regarding LY, except for TAMCOT-CAMD-E and TAM B 139-17, all genotypes presented positive ($\hat{g}_i$) estimates. Genotype FM 993 stood out with the highest positive estimate; however, it did not present the highest mean among the genotypes. The genotypes CNPA 04-2080 and IAC 26 obtained the highest means ($\hat{g}_i$) and positive estimates, meaning that they genetically contributed to increasing fiber yield. For BW, the genotype TAM B 139-17 showed the highest positive estimates and the highest mean among the genotypes, meaning that this parent may genetically contribute to increasing the weight of one boll.

SCA effects

Table 3 shows the estimates of SCA effects ($\hat{s}_{ij}$). Considering AFF, the hybrid CNPA 04-2080 x TAMCOT-CAMD-E presented the highest negative estimate, followed by the parents with a low ($\hat{g}_i$) estimate. For AFB, the combination FM 993 x CNPA 04-2080 presented high and negative estimates and parents with negative ($\hat{g}_i$) estimates, which is important for the obtainment of earliness. For PH, the combination CNPA 04-2080 x PSC 355 presented the highest positive estimates; however, both parents showed negative ($\hat{g}_i$) estimates. The combination FM 993 x PSC 355 obtained the lowest estimate, and the parents presented low ($\hat{g}_i$) estimates.

Table 3. Estimates of the effects of the specific-combining ability ($\hat{s}_{ij}$) among six genotypes of cotton for the characteristics: appearance of the first flower (AFF, days), appearance of the first boll (AFB, days), plant height (PH, cm), cotton seed yield (CSY, kg/ha), lint percentage (LP, %), cotton fiber yield (LY, kg/ha), and weight of one boll (BW, g).

Genotypes	AFF	AFB	PH	CSY	LP	LY	BW
FM 993 x FM 993	0.02	0.30	3.71	-1040.34*	0.62	-404.22*	-0.42
CNPA 04-2080 x CNPA 04-2080	-0.47	-0.15	-4.90	701.08	-0.59	277.31	-0.57**
PSC 355 x PSC 355	-1.68*	0.05	-0.29	-278.26	-0.96**	-162.07	-0.60**
TAM B 139-17 x TAM B 139-17	-0.19	-0.83	-1.78	298.18	-0.47	99.60	-0.84**
IAC 26 x IAC 26	-0.19	-1.16	0.06	372.51	-0.58	127.15	-0.60**
TAMCOT-CAMD-E x TAMCOT-CAMD-E	0.06	-0.57	-0.90	-493.33	0.09	-204.85	-0.10
FM 993 x CNPA 04-2080	0.43	-1.09	-0.12	-1009.13*	-0.09	-431.07*	0.00
FM 993 x PSC 355	0.15	-0.34	-4.29	3188.25**	-0.63	1302.13**	0.00
FM 993 x TAM B 139-17	-0.91	0.23	-0.87	-274.41	0.36	-94.16	0.41**
FM 993 x IAC 26	0.41	0.73	-2.39	-1001.24	-0.28	-428.57*	0.28*
FM 993 x TAMCOT-CAMD-E	-0.14	-0.16	0.25	1177.22*	-0.60	460.13*	0.13
CNPA 04-2080 x PSC 355	0.56	-0.91	4.65	-869.52	1.10*	-321.59	0.40**
CNPA 04-2080 x TAM B 139-17	0.83	0.17	4.65	223.46	0.52	111.12	0.36**
CNPA 04-2080 x IAC 26	-0.16	0.67	1.42	-402.03	-1.03*	-211.52	0.48**
CNPA 04-2080 x TAMCOT-CAMD-E	-0.70	1.46	-0.80	655.04	0.69	298.44	-0.10
PSC 355 x TAM B 139-17	0.39	0.78	-0.70	-627.20	0.26	-244.60	0.61**
PSC 355 x IAC 26	0.72	0.28	-1.69	96.62	1.27**	100.54	0.21
PSC 355 x TAMCOT-CAMD-E	1.52	0.07	2.63	-1231.63*	-0.08	-512.32*	-0.03
TAM B 139-17 x IAC 26	0.14	0.66	1.65	128.68	0.60	75.11	0.15
TAM B 139-17 x TAMCOT-CAMD-E	-0.06	-0.20	-1.14	-46.90	-0.80	-46.66	0.14
IAC 26 x TAMCOT-CAMD-E	-0.73	-0.03	0.89	432.92	0.60	210.13	0.07
SD (S_{ii})	0.65	0.64	3.25	410.20	0.35	174.67	0.11
SD (S_{ij})	0.79	0.78	3.94	496.77	0.43	211.53	0.13
SD (S_{ii} - S_{jj})	0.90	0.88	4.44	560.44	0.48	238.64	0.15
SD (S_{ij}- S_{ik})	1.19	1.17	5.88	741.39	0.64	315.69	0.20
SD (S_{ij} - S_{kl})	1.10	1.08	5.44	686.39	0.59	292.28	0.19

**,*Significant at 1 and 5% probability by *t*-test, respectively. SD = standard deviation.

For CSY and LY, the combination FM 993 x PSC 355 showed the best positive estimate, followed by parents with high and positive ($\hat{g}_i$) estimates, and with high mean values, being indicated for yield improvement. For LP, the best combinations were PSC 355 x IAC 26 and CNPA 04-2080 x PSC 355; moreover, one of the parents presented positive ($\hat{g}_i$) estimates and high mean values. Concerning BW, the combination PSC 355 x TAM B 139-17 presented the highest positive estimate, and parents presented positive ($\hat{g}_i$) values, being indicated for the improvement of this trait.

ACKNOWLEDGMENTS

We thank Empresa Brasileira de Pesquisa Agropecuária - Embrapa Algodão.

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Supplementary material

Table S1. Means of the parents and their hybrid combinations for the characteristics: appearance of the first flower (AFF, days), appearance of the first boll (AFB, days), plant height (PH, cm), cotton seed yield (CSY, kg/ha), lint percentage (LP, %), cotton fiber yield (LY, kg/ha), and weight of one boll (BW, g) evaluated in 21 cotton genotypes.