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General and specific combining ability of cotton germplasm in Mozambique using circulant dialells

Leonel Domingos Moiana[1*], Pedro Soares Vidigal Filho[2], Manuel Pedro Maleia[1], Sudanailly Mufambira[1], Joaquim João[1], Jaime Omar Teca[1], Celestino Manuel Domingos[1], Constantino Rico Raimundo Artur[1]

[1]Instituto de Investigação Agrária de Moçambique, Av. das FPLM, 2698. C.P. 2698, Maputo, Mozambique
[2]Universidade Estadual de Maringá, Pós-Graduação em Genética e Melhoramento, Av. Colombo, 5.790, Bloco J45, CEP 87.020-900, Maringá-PR-Brasil

***Corresponding author: leonel.moiana@gmail.com**

Abstract

The genetic diversity of species is an important way to maintain the natural capacity to respond to climate change and all stresses. This study aimed to estimate the general combining ability (GCA) and the specific combining ability (SCA) of the characteristics among 41 cotton cultivars and 9 inbred lines using circulant diallel. In 2016, 41 cultivars and 9 inbred lines and 75 hybrid combinations were evaluated at the Namialo Cotton Research and Seed and Multiplication Centre in the Meconta District, Nampula province. The experimental design was Federer's augmented blocks with four repetitions. The evaluated characteristics were: days for 50% of flowering (DAFlw), days for 50% of fruiting (DAFrut), plant height, average number of bolls (AnB), seed cotton yield in kilograms per hectare (Yield) and the mass of one hundred seeds (M100). The algorithm for establishing diallel crosses was based on Kempthorne and Curnow, where S was equal to 3. There was a predominance of non-additive effects for all characteristics analysed. The genotypes ALBAR FQ 902, IRMA 12-43 and MARICO showed greater additive effects for DAFlw, DAFrut, AnB, Yield and, M100.

Keywords: Circulant diallel; combining ability; yield of seed cotton; *Gossypium hirsutum* L.; non-additive effects.
Abbreviation: GCA_General combining ability, SCA_Specific combining ability, ΦGCA_Quadratic component associated with GCA, ΦSCA_Quadratic component associated with SCA, ANOVA_Analysis of variance.

Introduction

Cotton (*Gossypium spp*.) belongs to Malvaceae family, Genus *Gossypium*, which includes 45 diploid species (2n=2x=26) and six allotetraploids (2n=4x=52) between wild and cultivated (Brubaker et al., 1999; Ulloa et al., 2013). The species of genus Gossypium are divided into genomic groups, being eight diploids (A, B, C, D, E, F, G and K) and tetraploid (AD), based on chromosome sizes and homologous chromosome pairing of interspecific hybrids (Freire 2000; Ulloa et al., 2007).
The global cotton production in 2018/19 growing season was 29.11 million tons of fiber, with the largest producers being to India, China, United States of America, Brazil, Pakistan and Australia (Johnson et al., 2020).
Cotton production in Africa is about 1.5 million tons of fiber and represents about 6% of global production (Johnson et al., 2020). The same authors reported that the largest production is West Africa responsible for about 60% of the production of the whole continent, followed by the Southern and Eastern region with about 31% and finally, North Africa region that is responsible for about 9% of the production of the continent (Amanet et al., 2020).
In Mozambique, cotton is one of the cash crops that contributes to the increase in family income (IAM, 2011; ICAC, 2014). This crop represents 20% of agricultural sales by farmers, while in cotton producing areas, it represents between 50 and 85% of the population's income and is predominantly made in the North and Center regions of the country, areas where edaphoclimatic conditions are more favourable compared to the South region (IAM, 2011).
According to Maleia et al. (2017), the average cotton productivity in Mozambique is characterized by low yield (500 kg ha^{-1}) compared to the world average (800 kg ha^{-1}) according FAOSTAT (2019), and even when compared to the average of some neighbouring African countries such as Malawi (800 kg ha^{-1}), Tanzania (750 kg ha^{-1}) and Zambia (800 kg ha^{-1}).
The low productivity obtained by Mozambican cotton growers is associated with inappropriate agronomic practices such as: inadequate crop management; absence of liming and soil fertilization; lack of adequate pest control and disease; lack of supportive scientific research and use of cultivars bred from other countries (Moiana et al., 2014; Maleia et al. 2017).
The Cotton Breeding Program developed by IIAM (Instituto de Investigação Agrária de Moçambique- Mozambique Agriculture Research Institute) started in the 1990s. At that time, high-potential cotton cultivars and strains productive and

tolerant to biotic and abiotic factors from the United States of America and Zimbabwe were introduced (Moiana et al., 2014; Maleia et al., 2017). Subsequently, studies on adaptability and stability were carried out that enabled the identification of those that proved to be more stable and more adaptable to the agro-ecological conditions of Mozambique (Maleia et al., 2017).

Plant breeders are looking for desirable genes and gene complexes. Identification of promising individuals is very important in any breeding program (Cruz and Carneiro, 2006). Meanwhile, diallel mating design is one of the tools which help the breeder to identify the potential genotypes and the promising recombinants produced by combining the parental individuals through GCA and SCA (Khan et al., 2011).

The general combining ability (GCA) is the genetic parameter responsible for designating the average behaviour of a parent in all crosses, in which it participates and associated with additive genetic effects (Borem and Miranda, 2007). The authors tried to identify the variety that best related to the others, estimating frequency of favourable alleles in the genitor (Cruz et al., 2004). On the other hand, the specific combining ability (SCA) is the deviation of the hybrid behaviour in relation to the expected based on the GCA of the genitors (Borem and Miranda, 2007), providing information related to concentration of predominantly non-additive genes (Cruz and Carneiro, 2006).

Batool et al. (2010) reported the importance of non-additive type of gene action for different cotton traits. However, Khan et al. (2011) observed that mean squares due to GCA and SCA were highly significant. However, the genetic variances due to SCA were greater than GCA for the yield related traits, showing the predominance of non-additive gene action.

As mentioned above, the diallel analysis of germplasm has not been applied in cotton breeding program of IIAM, Mozambique. In this research, we estimated a general and specific combining ability of cotton germplasm using circulant dialells. This research will benefit the cotton breeders as we will identify the potential parents in order to release new cultivars.

Results and Discussion

Analysis of Variance

The coefficient of variations for plants height, average number of bolls (AnB), seed cotton yield (Table 1), differed from those obtained by Mendez et al. (2012). The general and specific capacity of combination of cotton in highlands showed coefficients of variation of 14 to 28 for plant height, average number of bolls and cotton yield characteristics.

Significance GCA was found for all characteristics, except AnB and M100, demonstrating that there are effects of dominance and non-additive epistasis for the latter characteristics. Raza et al. (2013) studied the existence of variability and genetic inheritance among five cotton cultivars. They detected non-significant GCA, indicating additive effects for plant height, cotton yield, percentage of fibres and weight of boll, which were different from this study.

Similar results of the present study were found by Khan et al. (2011) studying the general and specific combine abilities in a diallel scheme of 12 herbaceous cotton cultivars. They found a significant difference between all hybrids for productivity, boll weight and boll number, and both the general and the specific combine ability were highly significant, showing greater genetic variances of SCA compared to GCA, showing predominance of non-additive gene action. These results are different from those obtained by Basal and Turgut (2003), when they studied the production components and six parameters for cottonseed yield and fibre quality in cotton genotypes, where they observed GCA significance for all the studied characteristics, suggesting additive effects genes in the control of characteristics for fiber yield and quality.

For SCA (Table 1), we verified significance for all studied variables indicating genes with additive effects for these evaluated characteristics. Basal and Turgut (2003) identified that the SCA was significant for the characteristics of productivity, precocity, length and fineness, indicating non-additive effects genes for these characteristics. Table 1, showed ($\Phi GCA < \Phi SCA$) indicating that the material under study must have undergone breeding in other environments. These results are in agreement with the results obtained by Ashokkumar et al. (2013), who state that the performance of relatives and crosses can vary widely with the genotypes and the conditions where they were tested.

Agronomic Characteristics Comparison of Means Test

The Tukey's tests adjusted mean test at 5% significance level showed a significant differences between the genotypes on the DAFlw; DAFrut; plant height, cotton yield and M100 suggesting that that the genotypes showed variability (Supplementary Table S1). The days to 50% flowering (DAFlw) characteristic ranged from 42 to 46 days. The genotypes Tam-94WE-37s, Tam-94L-25, Tamcot Luxor, NT66/122, KENIA, IMACD 26, FLASH, NT66/88, IRMA 1239, C118, SICALA, BRS-335, C118, and the hybrid combination (ALBAR SZ9314 x IS96/122) presented 42 days for 50% flowering. Queiroz et al. (2017) obtained similar results, in which the genotype TAMCOT-CAMD-E was the one that presented a smaller number of days for the appearance 50% of the first flower (39 days), followed by the combinations: CNPA 04 -2080 x TAMCOT-CAMD-E (40.00 days), FM 993 x TAMCOT-CAMD-E (40.98 days) and TAM B139-17 x TAMCOTCAMD-E (41.33 days).

On the other hand, the genotypes that presented the greatest number of days for 50% flowering (about 46 days) were: ALBAR SZ9314, ALBAR FQ 902, ALBAR BC 853, STAM-42, CA-222, CA-324, IRMA12-34, Tamcot-22, Tam-96WD-69S, Tam-98D-102, Tam-96W-18, Tam-98G-104, Tamcot Sphinix, Tam-98D-99ne, Tamcot Pyramid as well as some hybrid combinations (Supplementary Table S1).

Results of Queiroz (2017), indicated that the genotype IAC 26 was the one that presented a greater number of days (46.33 days) for the appearance of 50% the first flower (APF), followed by the combinations: PSC 355 x IAC 26 (45, 66 days), TAM B 139-17 x IAC 26 (45.33 days) and FM 993 x IAC 26 (45.33 days).

The variation for the days needed for 50 % fruiting ranged from 44.5 to 57.5 days, in which the genotypes with the lowest days were: ISA-205 and REMU-40 (Table 2). On the other hand, the genotypes with the greatest number of days for 50 % fruiting were: ALBAR SZ9314, ALBAR FQ902, ALBAR BC 853, STAM-42, CA-22, CA-324, IRMA 12-34, Tamcot-22, Tam-96WD-69s, Tamcot Pyramid, Tam-98D-102, Tam-98G-104, Tamcot Sphinix, Tam-98D-99ne (Supplementary Table S1).

According to Carvalho et al. (2015), the height of the plant is the characteristic that has the greatest effect on the cotton harvest, whereas plants with height above 1.20 m can suffer damage by the harvester, reducing the quality and the amount of fiber during harvest.

We observed that the variation for plant height was from 0.19 m to 1.41 m, while the lowest plant height was found in the hybrid combination (NORSENKO x IRMA139) and the highest height for ALBACALA-72B genotype (Supplementary Table S1). The average number of bolls per plant was between 2 to 188 bolls. Regarding the cotton yield and weight of one hundred seeds, the values ranged from 32 to 2,439 kg ha^{-1} and 8 to 12 seeds, respectively. According to Snider and Oosterhuis (2012), reproductive development is possibly the most sensitive phase to stress. Small increases in temperature can result in reduced productivity due to limitations in the number of seeds produced, where the thermal stress affects the productivity of two main components of cotton production: number and weight of bolls, and the number of seeds per boll.

Estimate of General Combining Capacity effects (ĝi))

In the circulant diallel, the number of crosses of each parent (s) affects the estimates of the GCA and SCA. However, with a minimum value, it is possible to obtain a good agreement in the estimates compared to the complete diallel. The GCA estimates showed fluctuations in the diallel circulant, being more pronounced in S=5 and S = 3, particularly for characters of low heritability (Cruz and Regazzi, 1994).

In the Supplementary Table S2, we observed that the estimates of the effects of GCA (ĝi) for the parents CA-324, Tam-94J-3, BA – 320, and BULK41 presented high positive values, while parents ALBAR BC 853, IRMA12-43 and IMACD 26 presented high negative values for DAFlw, indicating that these parents can contribute to the breeding of this characteristic. The parents STAM-42 and IS 96/122 presented high positive values, while the parents ALBAR BC 853, MARICO, ALBACALA-72B presented high negative values for DAFrut, (Supplementary Table S2), indicating that these parents can contribute to the breeding of this trait.

The parents ALBAR FQ 902 and ISA-205 showed high positive values, while the parents Tamcot-22, Tam-96WD-69s and BULK41 presented high negative values for height, indicating that these parents can contribute to the breeding of this trait (Supplementary Table S2). However, the parents ISA-205, REMU-40, and BA – 919 showed high positive values, while the parents FLASH, IRMA12-43 and ALBACALA-72B presented high negative values for cotton yield, indicating that these genotypes can contribute to breeding this trait (Supplementary Table 2). Silva (2007) emphasized that depending on the objectives of the breeding program, low values for plant height are more important. Aguiar et al. (2007) evaluated GCA and SCA in eight cotton cultivars (ITA-90, ITA96, Antares, Alva, CD-403, Delta Opal, CS-50 and IAC 22), based on agronomic characters and verified significant effects for plant height and cotton yield results similar to those of this study.

Estimate of Specific Combining Ability effects (ŝij)

According to Cruz et al. (2012), the effect of specific combining ability (ŝij) can be explained as the deviation of a hybrid combination from what would be expected based on the general combining ability (ĝi) of its parents. Absolute low values indicate that the hybrid combinations F_1's, among the studied parents, behaved as what was expected based on that of the parents. However, high absolute values indicate that the behaviour of a particular cross is better or worse than expected based on the parents. The estimate of ŝij indicates the importance of genes that exhibit non-additive effects (Cruz et al., 2004). The most significant combinations for DAFlw were Tamcot Luxor x BRS-336 with 19.6 days and Tam-96W-18 x Flash with 19.4 days (Supplementary Table S3).

The combination of Tam-96WD-69s x BA - 525 followed by the combination CA-324 x FK-37, showed the lowest ŝij estimates in relation to plant height (Supplementary Table S3). Similar results were obtained by Queiroz et al. (2017), where the lowest SCA was obtained in the combination of FM 993 x PSC 355, demonstrating that low values for plant height are more important, depending on the objectives of the breeding program. For the DAFrut characteristic (Supplementary Table 4), the hybrid combinations of STAM-42 x ALBACA-72B and STAM-42 x MARICO had 23,699 and 23,798 days. These results highlight the STAM-42 that is present in both combinations is an ideal parent for future breeding programs for days to fruiting. Also, we verified that the parents MARICO and ALBACA presented negative values for GCA (Supplementary Table S2). As for the variation in yield, the hybrid combination Tam-98G-104 x IMACD26, and the hybrid combination IRMA1234x FK-37 were the ones that had the highest and lowest cottonseed yield, respectively (Supplementary Table S3). Vasconcelos et al. (2018), studied the diallel analysis in cotton for drought tolerance and reported that the combinations BRS 286 X CNPA 5M, FMT 705 X CNPA 7MH, BRS RUBI X CNPA 5M, FM 966 X CNPA 7MH and BRS 701 X CNPA 7MH would be the most recommended, all contributing to reduce plant height and increase productivity by 749.10, 362.93, 281.26, 214.45 and 188.85 Kg ha^{-1}, respectively.

Parents with high and positive GCA estimates should be selected, as they are the ones that most contribute to increasing the expression of the studied characteristics. Therefore, the REMU-40 and BA-919 parents showed high positive values for Yield (kg ha^{-1}) being more favourable in the breeding programs (Supplementary Table S2). On the other hand, high negative values contribute to the reduction of its manifestation (Cruz et al., 2012). The parents who contribute to obtaining low yield are NORSENKO, ALBAR QM-301 and Tam98G-104 (Supplementary Table S2).

Table 1. Analysis of variance for the genotypes, GCA and SCA for the characteristics evaluated by the model of Kempthorne and Curnow (1961), involving parents and hybrids.

Source	GL	DAFlw	DAFrut	Height	AnB	Yield (kg/ha)	M100
Genotypes	124	1954.33**	3074.82 **	7723.99**	7403.08^{ns}	846731.19**	95.48**
GCA	49	4.16**	10.99**	1029.35**	3377.70^{ns}	431251.21*	1.01^{ns}
SCA	75	3228.45**	5076.52**	12097.83**	10033.00*	1118178.10**	157.21*
Erro	69	0.18	0.62	494.21	4037.55	303455.67	2.21
ΦGCA		0.31	0.81	42.02	-51.82	10035.23	0.09
ΦSCA		807.07	1268.97	2900.90	1498.86	203680.61	38.73
Mean		45.035	56.44	88.79	89.801	921.13	9.93
CV (%)		1.00	1.40	25.04	30.76	21.66	14.97

**, * level of significance at 1 and 5% probability by the F test; GCA-General combining ability, SCA-specific combining ability, ΦGCA-Quadratic component associated with GCA, ΦSCA-Quadratic component associated with SCA, AnOva-Analysis of variance. CV - coefficient of variation; GL – degrees of freedom; DAFlw –Days for 50% of flowering; DAFrut –Days for 50% of fruiting; Yield-Yield of cotton wool; M100- Mass of one hundred seeds.

Table 2. List of cotton 41 cultivars and 9 inbred lines, origin, tolerance to *E. fascilis** and vegetative cycle.

Order	Cultivar	Origin	Tolerance toa *E. fascilis*	Vegetative cycle
1	ALBAR SZ9314	African	Medium	Medium
3	ALBAR FQ 902	African	Medium	Medium
3	ALBAR BC 853	African	Little tolerant	Medium
4	STAM-42	African	Little tolerant	Medium
5	CA-222	African	Little tolerant e	Medium
6	CA-324	African	Medium	Long
7	IRMA 12-43	African	Little tolerant	Medium
8	ISA-205	African	Little tolerant	Medium
9	REMU-40	African	Little tolerant	Medium
10	Tamcot-22	American	Little tolerant	Medium
11	Tam-96WD-69s	American	Little tolerant	Medium
12	Tamcot Pyramid	American	Little tolerant	Medium
13	Tam-98D-102	American	Little tolerant	Medium
14	Tam-96W-18	American	Little tolerant	Medium
15	Tam-94J-3	American	Little tolerant	Medium
16	Tam-98G-104	American	Little tolerant	Medium
17	Tamcot Sphinx	American	Little tolerant	Medium
18	Tam-98D-99ne	American	Little tolerant	Medium
19	Tam-94WE-37s	American	Little tolerant	Medium
20	Tam-94L-25	American	Little tolerant	Medium
21	Tamcot Luxor	American	Little tolerant	Medium
22	SICALA	American	Little tolerant	Long
23	OR-3	American	Little tolerant	Median
24	DELTAPINE ACALA 90	American	Little tolerant	Long
25	ACALA 1517/88	American	Medium	Medium

Source: Moiana et al., 2014; Maleia et al., 2017; * *Empoasca fascilis*.

Materials and methods

Description of the study site

The experiments were installed in the village of Namialo, located in the Northern Region of Mozambique, 39º 59 'east longitude and 14º55' east latitude, at an altitude of 157 m. The average rainfall varies between 800 to 1,000 mm, with an average temperature of 26^{o}C (Koppën, 1928). The studies were developed in places located between the Agroecological Regions 7 and 8 (INIA, 2000), in the agricultural years 2015/16 to 2016/2017. Cotton production in Mozambique is more concentrated in Agro-ecological regions 6, 7 and 8, with almost half of production in Region 7 (Rohrbach et al. (2001), these regions, for the most part, represent the North Region of the country. The Agro-ecological Region 7 (R7) located in the provinces of Zambézia, Nampula, Tete, Niassa and Cabo-Delgado, has an average altitude of 500 to 1000 m, and the texture of the soils is variable (INIA, 2000). In almost all of these regions there is great potential for the production of cotton that has been practiced for several decades. In contrast, the Agro-ecological Region 8 (R8) is represented by the Coastal Region of the Provinces of Zambézia, Nampula and Cabo-Delgado, where the soils are generally sandy, with low fertility being the most limiting factor (INIA, 2000).

Table 2. List of cotton 41 cultivars and 9 inbred line, origin, tolerance to *E. Fascilis** and vegetative cycle (Continued.)

Order	Cultivar	Origin	Tolerance a *E. fascilis*	Vegetative cycle
26	NORSENKO	African	Little tolerant	Long
27	IS 96/122	African	Little tolerant	Long
28	MARICO	African	Little tolerant	Long
29	ALBACALA 72B	African	Little tolerant	Long
30	NT 66/88	African	Little tolerant	Medium
31	KOMATI	African	Little tolerant	Long
32	FK-37	African	Little tolerant	Medium
33	ALBAR QM-301	African	Little tolerant	Intermediate
34	BA–320	Turkey	Little tolerant	Medium
35	BA –525	Turkey	Little tolerant	Medium
36	BA–919	Turkey	Medium	Medium
37	BA –2018	Turkey	Little tolerant	Medium
38	FLASH	Turkey	Little tolerant	Medium
39	CHUREDZA	African	Little tolerant	Medium
40	BRS –293	Brazil	Medium	Intermediate
41	KËNIA	Kenya	Medium	Intermediate
56	IMAIC 26	Brazil/IMANT	Little tolerant	Short
59	IMACD 07-6372	Brazil/IMANT	Little tolerant	Intermediate
62	IMACD 8276	Brazil/IMANT	Little tolerant	Long
45	BRS –286	Brazil/Embrapa	Little tolerant	Intermediate
46	BRS –335	Brazil/Embrapa	Little tolerant	Intermediate
47	BRS –336	Brazil/Embrapa	Little tolerant	Intermediate
48	C118	France	Little tolerant	Medium
49	BULK41	France	Medium	Intermediate
50	IRMA A1239	France	Little tolerant	Medium

Source: Moiana et al., 2014; Maleia et al., 2017. * *Empoasca fascilis.*

Soil and climate

The Namialo Region is characterized by an Aw type climate according to the Köppen classification (Köppen, 1928), with a dry to sub-humid season, where annual rainfall varies from 800 to 1,000 mm, and the average annual temperature is around 26°C. The classification of soils varies from sand Ferralics with sand Texture to clay and sand a Claysoils Sandy that alternatively occur with sandy soils Hydromorphic (MAE, 2005).

In the 2015/2016's growing season, crosses involving 50 cultivars were performed in the field (Table 2), with three crosses each (S = 3), totalizing 75 hybrids. Each experimental unit consisted of a row of male plants and three rows of female plants of 5.0 m in length, spaced at 1.0 m between the rows and 0.10 m between the plants in the row, having been harvested all the bolls from the crosses.

Experimental design

In the 2016/2017 growing season, for estimation of general combining capacity (GCA) and the specific combining capacity (SCA) of field characteristics among 50 cotton cultivars by means of circulating diallels, an experiment was carried out in the field conditions. The experiment was in the experimental design of incomplete blocks - Federer's augmented blocks, with four repetitions.

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$$

where:

Y_{ij}: characteristic value for the i-th genotype in the j-th block (or repetition). To better express the value of a genotype, for the same trait considered, it can be given by:

Z_{ij}: characteristic value for the i-th genotype in the j-th block;

μ: constant associated with the model;

τ_i: effect of the i-th treatment, which can be broken down into:

Ti: effect of the i-th witness, with i = 1,2 …… t; and

G_{ij}: effect of the i-th genotype, with i = 1,2 …… gi;

The total genotypes evaluated are:

$$g = \sum_{j=1}^{b} gj$$

where :

gj : total number of genotypes in the j-th block

β_j : effect of the j-th block, with j = 1,2… b; and

ε_{ij} : random error.

Experiment installation and conduction

The experiments were carried out in the field, under rainfed conditions, during the beginning of the rainy season, usually in the first half of December to June of 2017. Each experimental unit consisted of 2 rows of plants with 5.0 m in length, spaced 1.0 m between rows and 0.20 m between plants in the row. Sowing was carried out manually in pits, placing 25 plants in a 5.0 m line, approximately 0.04 m deep. Fifteen days after seedling emergence, the first thinning was carried out, leaving two plants per hole. Subsequently, at twenty-one days after emergence, a second thinning was carried out, leaving only one plant per hole to obtain a population density of 50,000 plants.ha^{-1}. No fertilization was carried out, either at sowing or covering to allow the experiments to simulate conditions similar to those prevailing in the fields of rural producers in local regions of Mozambique. The control of weeds was carried out by means of five to six manual weeding, with the aid of a hoe to avoid weeds competing with the crop. In the pest control, two sprays of insecticide Endosulfan (475 g.L^{-1}) were made, followed by three applications of Lambda-cihalothrin (50 g.L^{-1}), once in two weeks, starting from the sixth week after emergence (Moiana et al., 2014). The application of insecticides was carried out with a micro ulva of the ULV type (Ultra Low Volume).

Evaluated characteristics

The characteristics evaluated were: days to complete 50% of flowering (DAFlw), days to complete 50% of fruit set (DAFrut), plant height (m), average number of Bolls (AnB), seed cotton yield in kilograms/ha (Yield) and the mass of one hundred seeds (M100).

Statistical analysis

The data obtained were subjected to analysis of variance and the adjusted means were compared by the Tukey test (Dias and Barros, 2009). The algorithm for establishing diallel crosses was based on the one proposed by Kempthorne and Curnow (1961), having adopted the unequal value at 3, in which the effects of general combining ability (GCA) for parents and children were estimated. Effects for specific combining ability (SCA) based on the statistical model:

$Yij = \mu + g_i + g_j + s_{ij} + \varepsilon_{ij}$,

where:

Y_{ij} is the mean of the observation associated with the hybrid combination ij ($i \neq j$) or the i-th parent ($i = j$); μ is the general average; gi and gj are the fixed effects of the general combining ability; sij is the fixed effect of the specific combining ability; and ε_{ij} is the average experimental error.
The estimators of the mean squares of the effects for GCA and SCA were considered fixed. Statistical analysis for the data obtained in the experiment was performed using the statistical software GENES version 2014.6.1 (Cruz, 2013).

Conclusion

The genotypes ALBAR BC 853, IRMA 12-43 and ALBACALA -72B, ISA-205, IS 92/122 and BULCK 41 showed greater additive effects for more than three variables studied DAFlw, DAFrut, AnB, Yield and M100. The parents ISA-205, REMU-40, and BA – 919 presented high positive values, while the parents FLASH, IRMA12-43 and ALBACALA-72B and presented high negative values for yield. Parental CA-324, Tam-94J-3, BA - 320, and BULK41 had high positive values, while parental ALBAR BC 853, IRMA12-43 and IMACD 26 had high negative values for DAFlw. The genotypes ALBAR FQ 902, IRMA 12-43 and MARICO showed the greatest additive effects for more than three variables studied DAFlw, DAFrut, Yield and M100.

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