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PLANT BREEDING - Article

Comparison of testers in the selection of S_3 families obtained from the UENF-14 variety of popcorn

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ABSTRACT: The use of topcross has proven to be an interesting option for the maize crop; however, for the popcorn, there is little information about the choice of the appropriate tester. In this context, this study aimed to analyze four testers including two open pollinated varieties(BRS Angela and UENF-14), one topcross hybrid (IAC125) and a line (P_2), to evaluate the combining ability of 50 S3 families of popcorn, obtained from the UENF-14 variety. Popcorn families were evaluated for grain yield (GY) and popping expansion (PE). The estimates of general and specific combining abilities were obtained and the discrimination of each tester through differentiation index was carried out. The testers BRS Angela (for GY) and IAC 125 (for PE) were the most adequate, when combined with the best S_3 families derived from UENF-14, for the production of popcorn hybrids for the Northern and Northwestern Fluminense Regions.

Key words: *Zea mays* var. *everta*, topcross, yield, popping expansion.

INTRODUCTION

Any breeding program focusing on successful hybrid combinations must concentrate its efforts to identify superior lines and their ability to transmit these desirable traits to the hybrids (Hallauer et al. 2010). In this context, diallel analysis is considered an important statistical tool for estimating parameters useful in selecting parents (Seifert et al. 2006; Barreto et al. 2012; Souza Neto et al. 2015).

However, a limiting factor of diallel analysis is the number of assessed parents, usually not exceeding ten, because of the effort to obtain the hybrids. In this case, the topcross technique, proposed by Davis (1927) and Jenkins and Brunson (1932), has proven to be a more appropriate option, aiming at overcoming the impossible assessment of progenitor lines in works with hybrids, involving a large number of lines.

The term "*topcross*" is used to denote crosses of lines with a tester. The tester can be a variety, a hybrid or even a line and receives this name for playing a role in evaluating the combining ability of the lines. Testers can be classified according to their genetic base (broad *versus* narrow), the degree of relatedness with the material evaluated (related *versus* unrelated) and their intrinsic genetic value (high pattern *versus* regular or inferior pattern) (Miranda Filho and Gorgulho 2001; Hallauer et al. 2010).

Despite the wide acceptance of the topcross method, the ideal tester selection process still remains a goal to be achieved by hybrid development programs, since issues of choice, type, number and efficiency of testers are perpetuated amidst theoretical and experimental studies (Ferreira et al. 2009). According to Hallauer et al. (2010), the choice of the tester should be on simplicity in use and generation of information that correctly classifies →

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the relative potential of lines in cross, thus maximizing the genetic gain. According to Rodovalho et al. (2012), it is more important to use testers with broad genetic base (synthetic and open pollinated varieties) during the initial phase of breeding, since they test for general combining ability or additivity.

Compared to the common maize, there are few studies regarding the definition of testers for popcorn (Pinto et al. 2004; Viana et al. 2007; Scapim et al. 2008; Arnhold et al. 2009). An important detail that possibly hampers to choose the most suitable tester is the fact that the two main traits of the crop, popping expansion and grain yield, which should be evaluated together, have different mechanisms of inheritance (Pereira and Amaral Júnior 2001). Popping expansion is controlled by a small number of genes and there is predominance of additive gene action (Yongbin et al. 2012; Rodovalho et al. 2014). On the other hand, grain yield is genetically controlled by a large number of genes with predominance of non-additive gene effects.

Given these considerations, this study analyzed and compared four testers (BRS Angela, UENF-14, IAC 125 and P_2) in the assessment of 50 partially inbred families (S_3), obtained from the UENF-14 variety of popcorn.

MATERIAL AND METHODS

For this study, 50 S_3 families of popcorn were obtained from the variety UENF-14 of Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF) (Amaral Júnior et al. 2013). Four materials were evaluated as testers: BRS Angela (open pollinated variety), IAC 125 (topcross hybrid), P_2 Line (S_7 generation coming from the CMS-42 composite of the Embrapa Maize and Sorghum) and UENF-14 (open pollinated variety). Hybrids were evaluated in the Experimental Station of PESAGRO-RIO, Itaocara, State of Rio de Janeiro, Northwestern Fluminense region (21°39'S latitude and 42°04'W longitude), in the growing season of 2013/2014.

Five trials were implemented in blocks with two replications, four for assessing the hybrids derived from crosses of families with each tester and the fifth for testing the performance of S_3 families. Each experimental unit consisted of a row of 3 m, with spacing of 0.90 m between rows and five plants per meter. In the trials, the cultural practices, such as fertilization at planting and topdressing, irrigation, pest and weed control, among others, were made as required by the popcorn crop.

The traits evaluated were grain yield (GY) and popping expansion (PE). GY was assessed by measurement of the grain mass produced in each plot after discarding the cob and is expressed in kg·ha^{-1}. In order to adapt the measurement of the yield, it was carried out the stand correction method, by analysis of covariance between the number of plants per plot and GY, according to the covariance of ideal stand methodology, proposed by Vencovsky and Barriga (1992). PE was determined by means of a seed sample, taken from the basal center of the ears (Granate et al. 2002) in each plot. All samples were sent to cold dry chamber to reach the equilibrium moisture content of 12 to 13%. PE was determined in laboratory with the use of a microwave Panasonic NN-S65B, placing a sample of 30 g seed in a plastic container obtained in the USA, at the power of 1,000 W for 2 minutes and 30 seconds, in two replications per treatment. PE was expressed by the ratio between the volume of the popped popcorn, measured in a 2,000-mL measuring cylinder, and the initial weight of grains (30 g), being the final unit expressed in mL·g^{-1}.

Statistical analysis of data followed the model of randomized blocks. The mean squares of treatment and the residue were used for the F test. The analysis of general and specific combining ability, based only on topcross crosses, was performed according to the scheme of analysis of variance in partial diallel at the level of average of treatments using the model proposed by Griffing (1956), adapted by Geraldi and Miranda Filho (1988). The efficiency of testers was evaluated by statistical indices of performance (P) and differentiation (D) proposed by Fasoulas (1983). The P index gives the percentage, in relation to the number of means, that a particular cultivar statistically outperforms the others based on the minimum significant difference (MSD), determined by test of means. The T index gives the percentage of pairwise comparisons between cultivars that showed significant differences. Analyses were run using the software GENES (Cruz 2013).

RESULTS AND DISCUSSION

The mean squares of treatments (*topcrosses*) were significant at 5% probability for the four testers and families *per se*, indicating genetic variability for GY and PE (Table 1). The coefficients of variation (CVe) for GY and PE were within acceptable limits for agricultural experimentation, except for the experiment assessing the lines *per se* that showed CVe values of 24.62 and 26.00, respectively, considered high (Scapim et al. 1995; Arnhold and Milani 2011; Fritsche Neto et al. 2012).

In the case of estimates of genetic parameters, the largest genetic variances were observed for the crossing BRS Angela × S_3 (22,830.61) and with the S_3 families *per se* (0.93) for GY and PE, respectively (Table 1). The greatest increase in variability in topcross hybrids from the tester BRS Angela, for GY, can be explained because it is a broad base and unrelated tester, or because it presents many heterozygous loci. It is noteworthy that the high variability observed in S_3 families *per se*, for PE, is possibly related to the intrapopulation genetic variance, as they are individuals from the same population (UENF-14) (Amaral Júnior et al. 2013).

Considering the estimates of heritability, in general, their magnitudes remained very close independently of the tester. The exception applies to hybrids from the tester BRS Angela, specifically for PE, noting that this tester was not able to express the genetic variability among S_3 families (Table 1).

There was a significant effect of general and specific combining abilities, estimated by diallel analysis of Griffing (1956), adapted by Geraldi and Miranda Filho (1988). The general and specific combining abilities of S_3 families and testers have statistical significance, revealing differences for both traits between the values of the estimates of general ($\hat{G}_i$) and specific ($\hat{S}_{ij}$) combining abilities (Table 2). Regarding the general combining ability, the tester with the best estimate of $\hat{G}_i$ for GY was the P_2

Table 1. Analysis of variance and estimates of genetic and phenotypic parameters for grain yield (in kg·ha^{-1}) and popping expansion (PE, in mL·g^{-1}) of topcross hybrids and S_3 families *per se*.

		Mean squares				
SV	**DF**	**BRS Angela**	**IAC 125**	**P_2**	**UENF14**	**S_3 *per se***
		Grain yield				
Repetitions	1	2183900.99	593525.18	343761.99	370365.60	76517.79
Treatments	49	1219809.45**	1178969.05**	1056164.30*	1127949.90**	398531.47**
Residual	49	489229.97	573285.61	540400.29	544026.16	122655.83
Mean		4638.79	4531.62	5264.58	4353.59	1346.69
$\hat{\sigma}^2_G$		22830.61	18927.61	16117.62	18247.62	8621.11
σ^2_F		38119.04	36842.78	33005.13	35248.43	12454.11
$\hat{h}^2$		0.59	0.51	0.49	0.51	0.69
CV_e		15.07	16.71	13.96	16.94	26.00
CV_g		3.25	3.03	2.41	3.10	6.89
I_v(%)		21.61	18.17	17.27	18.31	26.52
		Popping expansion				
Repetitions	1	0.24	1.62	14.31	3.05	32.12
Treatments	49	23.21**	25.04**	27.60**	18.35**	67.87*
Residual	49	19.46	10.89	13.58	7.85	38.11
Mean		30.99	32.13	25.44	30.13	25.06
σ^2_G		0.11	0.44	0.44	0.33	0.93
σ^2_F		0.72	0.78	0.86	0.57	2.12
h^2		0.16	0.56	0.51	0.57	0.44
CV_e		14.23	14.22	14.48	9.3	24.62
CV_g		1.10	2.07	2.60	1.90	3.85
I_v(%)		7.76	14.55	17.97	20.44	15.63

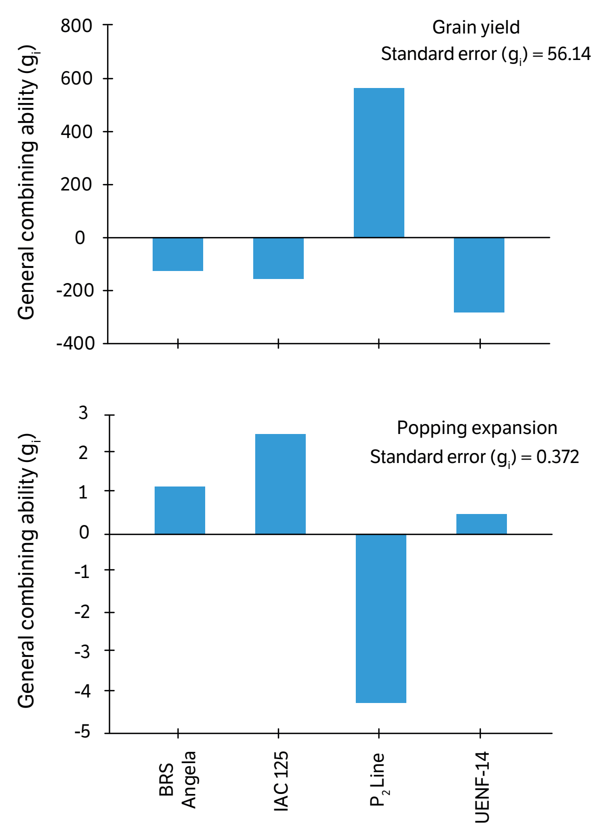
*,**Significant at 5 and 1% probability, respectively; SV = Sources of variation; DF = Degrees of freedom; $\hat{\sigma}^2_G$= Genotypic variance; $\hat{\sigma}^2_F$= Fenotypic variance; $\hat{h}^2$ = Heritability; CV_e = Experimental variance coefficient; CV_g = Genetic variance coefficient; I_v(%) = Variation index

Line, while, for the PE, testers IAC 125 and BRS Angela achieved the best estimates, reflecting the greater allelic complementarity of these testers with S_3 families (Figure 1). Barreto et al. (2012) evaluated the combining ability of S_2 families of popcorn and also obtained a similar result for the tester IAC 125, indicating it as the tester with the best general combining ability (GCA) indices for PE.

S_3 families with higher estimates of GCA were 9, 33, 4, 20 and 16 for GY, and 18, 23, 42, 11, and 25 for PE (Figure 2). Among the 50 S_3 families, only 9, 16 and 23 stood out for concomitantly presenting significantly positive estimates of GCA for GY and PE and should be evaluated more carefully in the breeding program conducted in the Northern and Northwestern Fluminense Regions by UENF.

As for the specific combining ability of S_3 families, for crosses with the tester BRS Angela, families 21, 4, 13, 50, 22 and 45 demonstrated the highest values of specific combining ability (SCA); for the tester IAC 125, the families 9, 20, 11, 35, 3 and 45 stood out. For tester P_2, families 49, 43, 24, 41, 18 and 50 showed the highest SCA indices and, in relation to the tester UENF-14, families 19, 2, 4, 45, 48 and 47 were those with higher estimates of $\hat{S}_{ij}$ (Table 3). The two hybrids showing better estimates of the effects of SCA were derived from crosses between tester P_2 and family 49 and between the tester IAC 125 and family 9. These hybrids, respectively, had $\hat{S}_{ij}$ effects of 2,359 and 1,960, besides having values around 7,400 kg·ha^{-1}. These two materials are very interesting because they express high genetic non-additive effects in their genotypes, derived from allelic complementation of their parents, and will certainly comprise hybrids with high average GY, which may be useful in interpopulation breeding programs in popcorn.

According to the SCA estimates for PE, families with better performance in relation to the tester BRS Angela were the genotypes 19, 44, 39, 30, 31 and 50. As for the



g_i = Effect of general combining ability associated with the progenitor i.

Figure 1. Estimates of the effects of general combining ability ($\hat{G}_i$) associated with testers for grain yield (kg·ha^{-1}) and popping expansion (mL·g^{-1}) according to Griffing (1956).

Table 2. Partial diallel analysis of means of treatments for grain yield and popping expansion in the study of general and specific combining abilities.

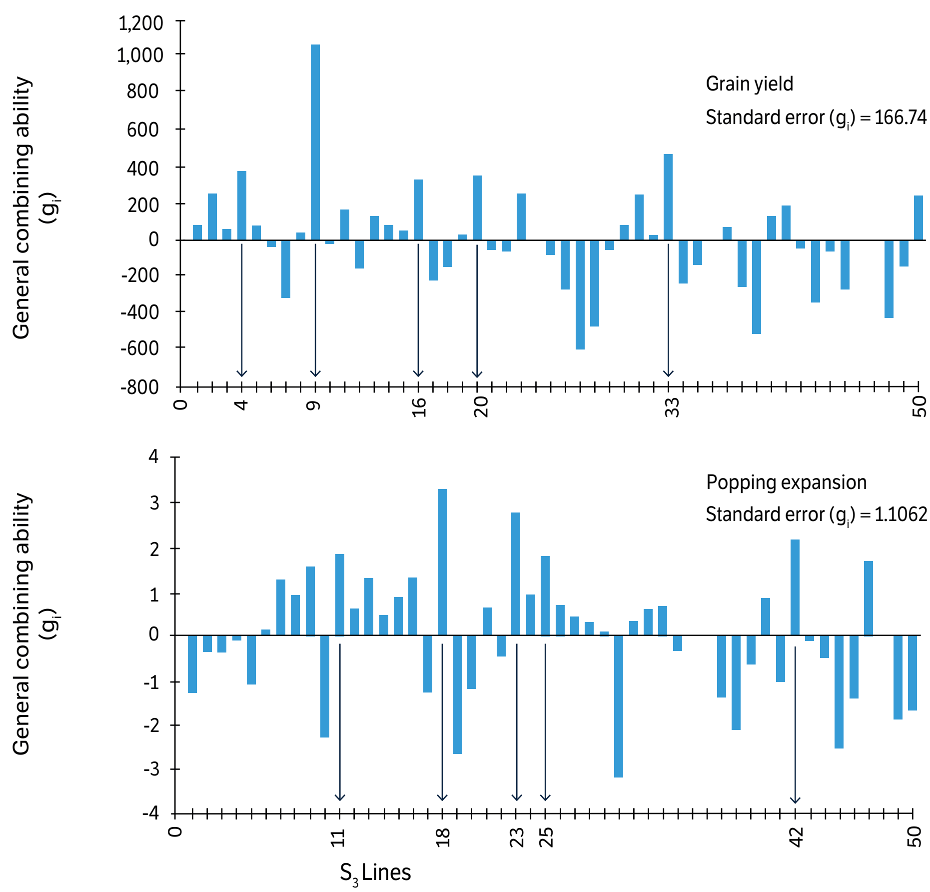
SV	DF	MS	
		GY	PE
Crossings	199	1635761.22**	35.25**
GCA S_3 Families (I)	49	1938796.04**	25.25**
GCA Testers (II)	3	19506622.89**	883.32**
SCA	147	1170038.15**	21.28**
Residual	196	536735.51	12.94

**Significant 1% probability; MS = Mean squares; SV = Sources of variation; DF = Degrees of freedom; GY = Grain yield; PE = Popping expansion; GCA = General combining ability; SCA = Specific combining ability.

tester IAC 125, families with higher indices were 2, 49, 17, 46, 44 and 39. For P_2 tester, families with greater SCA effects were 2, 30, 1, 39, 45 and 46 and, for the tester UENF-14, families 26, 22, 1, 20, 40 and 37 stood out with the highest indices of $\hat{S}_{ij}$ (Table 4). Among the better crosses in relation to SCA, with high GCA values and relevant estimates of PE, for the tester BRS Angela, it can be highlighted family 18 with PE of 35 mL·g^{-1}; for the tester IAC 125, family 23, with PE of 36.67 mL·g^{-1}; and, for the tester UENF-14, family 11, with 33 mL·g^{-1} (Table 4). By different mechanisms of genetic action of PE (additive and non-additive) which determine respectively the GCA and SCA, it can be inferred that these crossings are interesting and also deserve attention from the popcorn breeding program of UENF.

Higher values for differentiation index (D) of Fasoulas (1983), for GY, were obtained by tester UENF-14 (D = 28.98) and BRS Angela (D = 28.24), indicating these testers as having greater efficiency in discriminating S_3 families (Table 3). Rodovalho et al. (2012) examined different testers in the discrimination of 64 S_2 families of popcorn, for GY, and also indicated the tester BRS Angela using this differentiation index. Considering the trait PE, the highest differentiation indices, 25.22 and 19.92%, were obtained, respectively, for the testers UENF-14 and IAC 125, indicating that these parents discriminated better the trait PE of S_3 families.

Among the testers used, the P_2 Line exhibited only one hybrid of high GY by combining with one of the seven S_3 families of greater values of GCA, the family 2. The BRS Angela was the tester that concomitantly classified most high-yield hybrids with S_3 families of high GCA. Of the seven S_3 families with the highest GCA indices, five that comprised the topcross hybrids of higher yields, →



g_i = Effect of general combining ability associated with the progenitor i.

Figure 2. Estimates of the effects of general combining ability ($\hat{G}_i$) associated with S_3 families for grain yield (kg·ha^{-1}) and popping expansion (mL·g^{-1}) according to Griffing (1956).

Table 3. Means, estimates of specific combining ability ($\hat{S}_{ij}$) and discrimination ability of testers, according to the D index and P performance index (Fasoulas 1983), for grain yield (kg·ha^{-1}) of topcross hybrids, based on the Student's t-test (0.05) for means comparisons.

Order	BRS Angela			IAC 125			P_2			UENF-14		
	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$
1°	4	5113.81	**1463.8**	9	7444.44	**1960.3**	49	7349.70	**2359**	2	6803.70	**1223.7**
2°	9	5112.79	771.9	20	6481.48	**1712.5**	41	6768.82	**1445**	19	6039.06	**1719.6**
3°	13	4790.06	**1387.6**	11	5577.78	**996.7**	24	6589.84	**1460**	4	5837.04	**1169.4**
4°	50	4751.87	**1235.2**	33	5574.07	689.1	43	6580.71	**1785**	20	5352.94	709.6
5°	16	4583.67	981.8	3	5451.85	**976**	50	6454.00	**1074**	47	5296.88	**957**
6°	22	4359.79	**1149.8**	14	5374.07	875.5	18	6370.02	**1375**	46	5251.93	-1032
7°	15	4195.29	871.0	31	5346.30	681	2	6235.66	846.5	16	5238.64	619.1
8°	23	4160.94	634.1	35	5274.07	**993.5**	30	6120.85	903	44	5238.64	-563.6
9°	33	4150.85	409.2	37	5222.22	736.8	36	6102.33	965.5	23	5174.58	630.1
10°	30	4128.63	774.0	45	5088.89	**943.0**	13	6012.06	746.3	21	5076.77	842.2
11°	31	4111.77	589.7	25	5081.48	747.9	1	5846.00	628.6	30	5072.98	700.7
12°	45	4108.45	**1106**	5	5000.00	504.6	10	5830.41	715.2	24	4976.69	294.2
13°	41	4002.19	-459.7	23	4970.37	300.3	15	5823.77	636.2	3	4954.97	604.7
14°	7	3964.13	1007.4	41	4855.56	251.9	31	5783.81	398.5	9	4932.24	-426.2
15°	6	3930.67	695.7	4	4851.85	58.6	29	5734.88	653.4	31	4883.51	-1104
16°	17	3874.61	819.4	42	4840.74	470.9	11	5719.29	418.2	15	4875.67	533.7
17°	8	3811.64	499.3	1	4829.63	332.2	33	5608.96	4.0	8	4832.24	502.2
18°	3	3807.43	-603.9	18	4829.63	555.3	17	5583.98	665.5	32	4775.59	459.2
19°	19	3775.24	-604.8	19	4662.96	217.8	8	5537.81	362.2	10	4725.85	456.2
20°	40	3749.51	344.7	50	4655.56	-4.4	9	5511.11	-5.7	11	4712.71	257.3
21°	2	3722.37	196.5	46	4625.93	205.2	44	5504.05	430.7	6	4648.65	396
22°	46	3637.06	359.6	8	4618.52	162.9	40	5500.78	232.7	33	4628.03	-131.2
23°	1	3627.61	273.5	6	4607.41	229.1	14	5464.69	246.1	34	4591.50	539
24°	20	3549.32	-76.3	16	4511.11	-234	35	5418.52	418	1	4493.86	122.1
25°	14	3539.23	184.0	36	4496.30	79.4	23	5377.78	-12.2	50	4453.96	38.7
26°	32	3515.47	216.7	30	4492.59	-5.3	4	5352.80	-160	22	4409.94	182.3
27°	21	3488.01	**1517.1**	15	4488.89	21.3	19	5331.96	166.8	13	4373.49	-46.5
28°	37	3406.41	64.3	32	4474.07	32.06	42	5317.92	228.1	37	4368.27	8.5
29°	5	3378.44	26.3	47	4429.63	3.06	25	5208.96	155.4	40	4362.96	317
30°	42	3369.24	142.7	2	4400.00	-269.1	5	5207.41	-7.9	49	4183.59	-415
31°	36	3356.21	82.6	49	4385.19	114.6	34	5168.99	271	29	4118.52	-117.3
32°	11	3329.14	-1094	26	4377.78	232.4	47	5061.01	-85.5	28	4107.41	286.3
33°	38	3270.52	254.2	44	4225.93	-127.3	3	4991.22	-204	39	4093.10	6
34°	34	3260.94	-590.7	39	4137.04	235.3	38	4977.18	97.6	26	4058.67	38.9
35°	43	3252.00	-1023	12	4051.85	-207.3	16	4963.14	-502	12	3942.34	-191.2
36°	35	3251.36	114.2	24	4033.33	-376.8	37	4807.58	-398	7	3805.22	-169.1
37°	39	3181.63	-740.6	10	4000.00	-395.2	28	4754.18	87.5	14	3799.92	-573
38°	10	3164.13	-87.8	34	3970.37	-207.7	20	4719.89	-769	25	3760.86	-447.0
39°	26	2980.99	-21.06	48	3951.85	-36.9	12	4664.51	-314	41	3747.06	-59.4
40°	18	2849.70	-281.3	38	3940.74	-218.8	32	4583.03	-580	36	3730.64	-560.5
41°	25	2846.64	-343.5	13	3770.37	-775.3	45	4562.19	-303	18	3495.20	-653.4
42°	49	2842.42	-1315	40	3729.63	-818.4	6	4436.44	-662	48	3448.15	**996**
43°	47	2780.35	-502.9	29	3585.19	-776.2	7	4434.88	-385	38	3423.23	-610
44°	27	2630.67	-42.8	43	3540.74	-534.2	27	4426.53	-110	5	3416.92	-952.8
45°	48	2622.24	-223.2	22	3496.30	-856.9	48	4401.55	-307	35	3407.91	-747
46°	12	2529.27	-586.6	21	3340.74	-1019	26	4284.58	-581	43	3385.69	-1084
47°	24	2231.31	-1035	28	3255.56	-691.1	46	4283.21	-857	27	3306.82	-384.3
48°	28	2121.22	-682.2	27	3122.22	-694.6	21	4095.09	-985	42	3159.77	-731
49°	44	2113.30	-1096	7	2966.67	-233.3	22	3883.98	-120	17	3150.17	-922.7
50°	29	1125.56	-2092	17	2651.85	-880	39	3829.80	-792	45	2988.30	**1011**
	D = 28,24			D = 26.53			D = 27.18			D = 28.98		

Table 4. Means, estimates of specific combining ability ($\hat{S}_{ij}$) and discrimination ability of testers, according to the D index and P performance index (Fasoulas 1983), for popping expansion (mL·g^{-1}) of topcross hybrids, based on the Student's t-test (0.05) for means comparisons.

Order	BRS Angela			IAC 125			P_2			UENF-14		
	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$	S_3	Mean	$\hat{S}_{ij}$
1°	44	37.33	**7.08**	21	41.33	-4	2	34.17	**9.22**	40	34.83	**3.93**
2°	39	36.67	**6.56**	2	40.67	**8.96**	1	31.92	**7.88**	25	34.58	2.74
3°	7	36.25	4.2	45	40.00	3.04	7	30.58	4.01	4	33.83	3.88
4°	31	35.83	**4.76**	23	36.67	1.83	30	30.50	**8.37**	47	33.58	1.85
5°	19	35.42	**7.3**	48	36.25	0.39	39	30.42	**5.75**	1	33.33	**4.55**
6°	18	35.00	0.95	44	35.42	**3.84**	18	29.33	0.73	11	33.00	1.11
7°	48	34.67	3.88	9	35.00	1.37	8	29.25	3.03	20	32.92	**4.05**
8°	13	34.58	2.54	39	35.00	**3.57**	46	29.00	**5.09**	27	32.83	2.35
9°	16	34.25	2.19	25	34.58	0.72	45	28.25	**5.47**	14	32.58	2.07
10°	34	34.00	2.49	14	34.58	2.05	23	28.08	0.01	37	32.58	**3.91**
11°	33	33.92	3.6	46	34.58	**3.92**	12	27.75	1.83	15	32.42	1.49
12°	2	33.83	3.4	33	34.50	1.76	27	27.58	1.84	22	32.33	**5.41**
13°	21	33.75	2.3	35	34.50	2.39	49	27.58	4.15	23	32.33	-0.5
14°	26	33.67	2.22	49	34.50	**4.31**	9	27.42	0.55	31	32.33	1.95
15°	14	33.42	2.2	41	34.33	3.30	16	27.33	-6.8	8	32.25	1.29
16°	23	33.33	-0.2	47	34.17	0.42	40	27.25	1.09	34	32.00	2.3
17°	50	33.33	**4.25**	37	33.42	2.73	21	27.17	1.23	48	31.92	1.83
18°	30	33.08	**5.52**	6	33.33	1.12	48	27.00	1.66	45	31.42	3.89
19°	47	32.92	0.48	24	33.33	0.34	33	26.92	0.94	50	31.33	2.95
20°	5	32.67	3.01	34	33.33	1.60	5	26.50	2.28	49	31.17	3
21°	9	32.42	0.11	40	33.33	0.41	28	26.50	0.88	16	31.00	-0.3
22°	43	32.33	-5.2	42	33.17	-1.1	36	26.25	0.96	39	30.92	1.50
23°	46	32.08	2.73	4	33.17	1.19	4	26.08	0.87	26	30.75	**5.92**
24°	35	32.00	-8.4	8	33.00	0.02	14	25.92	0.15	35	30.67	0.58
25°	45	32.00	-3.9	15	32.92	-0.1	42	25.58	-1.9	44	30.33	0.77
26°	11	31.92	-0.6	20	32.83	1.95	15	25.42	-0.7	7	30.00	-1.3
27°	32	31.67	0.32	31	32.83	0.43	22	25.08	0.24	24	29.83	-1.1
28°	25	30.92	-1.6	36	32.67	-9.1	13	24.92	-1.7	19	29.50	2.10
29°	20	30.50	0.94	30	32.42	3.53	31	24.92	-0.7	17	29.17	0.38
30°	40	30.17	-1.4	13	32.42	-0.9	10	24.75	1.72	42	29.17	-3.0
31°	42	30.17	-2.7	43	32.42	0.46	26	24.58	-1.4	5	29.08	0.12
32°	15	30.00	-1.6	10	32.17	2.37	6	24.50	-0.9	13	28.92	-2.4
33°	27	29.92	-1.2	18	31.92	-3.4	43	24.25	-0.9	29	28.83	-1.3
34°	24	29.92	-1.7	3	31.58	-0.1	35	24.17	-1.2	2	28.75	-0.9
35°	49	29.83	0.96	5	31.50	0.52	37	24.00	0.1	18	28.75	-4.6
36°	1	29.50	0.03	17	31.42	**4.19**	20	23.50	-0.6	6	28.42	-1.7
37°	10	29.50	1.03	11	31.33	-2.6	32	23.50	-2.4	28	28.33	-2.0
38°	12	29.33	-2.0	27	31.25	-1.2	44	23.50	-13	38	28.25	0.31
39°	29	29.17	-1.6	1	31.00	0.21	34	23.42	-1.5	9	28.08	-3.5
40°	22	28.67	-1.6	29	31.00	-1.1	11	23.25	-2.3	3	27.83	-1.8
41°	3	28.50	-1.8	50	30.58	0.19	29	23.08	-3.9	41	27.75	-1.2
42°	41	28.50	-1.2	7	30.25	-3.1	25	22.92	-4.2	30	27.67	0.79
43°	4	28.25	-2.4	26	30.08	-2.7	41	22.92	-1.3	43	27.33	-2.6
44°	8	27.75	-3.9	16	30.00	-3.4	19	22.33	-0.3	32	27.17	-3.5
45°	38	27.67	-0.9	28	29.75	-2.6	50	22.17	-1.5	10	26.50	-1.3
46°	17	27.58	-1.9	38	29.33	-0.6	24	21.92	-4.3	12	26.25	-4.4
47°	36	27.25	-3.5	19	28.17	-1.2	47	21.42	-5.5	36	24.42	1.96
48°	28	26.33	-4.7	12	27.33	-5.3	3	20.92	-4.0	33	24.08	-0.2
49°	6	25.83	-5.0	22	26.50	-5.1	38	20.83	-2.3	46	22.25	-6.4
50°	37	25.25	-4.1	32	25.25	-7.4	17	17.25	0.72	21	18.92	-12
		D = 7.51			D = 19.92			D = 16.08			D = 25.22	

among the 50 produced with this tester, in descending order of yield, were the families 4, 9, 16, 23 and 33. Of the nine topcross hybrids from the IAC 125 that showed better average of GY, three were formed with families (9, 20 and 33) which obtained high indices of GCA. In the tester UENF-14, three topcross hybrids with high average GY stood out, combined with families of high GCA effect, namely, families 2, 4 and 20 (Table 5). Thus, it can be said that the tester BRS Angela discriminated more consistently S_3 families, according to their genetic merit for GY.

Among the nine hybrids showing better values of PE, obtained with the tester BRS Angela, only one (sixth most expansive) was formed with a family of high index of GCA; the best family for such effect was the family 18. For the tester IAC 125, three hybrids (fourth, seventh and ninth) of greater PE were formed by families that presented high GCA indices, the families 23, 25 and 9. The tester P_2, as well as the tester BRS Angela, classified only one hybrid with high PE (sixth best hybrid) with the family 18, which had the best GCA index for the trait. Among the hybrids from the UENF-14 tester with the highest values of PE, three were formed by families with significantly high GCA effects, the families 11, 25 and 47 (Table 5). The testers IAC 125 and UENF-14 stood out for having three topcross hybrids, classified with high PE indices within each group (tester), obtained from crossing with S_3 families that held high indices of GCA. However, the hybrids from the tester IAC 125 provided a higher general average for the trait PE in relation to hybrids produced by crossings with the tester UENF-14. Therefore, the best tester for PE is the IAC 125.

Table 5. Classification order of S_3 families with respect to general combining ability and nine topcross hybrids with the highest indices with testers, for grain yield and popping expansion

Grain yield							Popping expansion						
S_3	RG	T1	T2	T3	T4	CGC	S_3	CE	T1	T2	T3	T4	CGC
2	1106			7°	1°	7°	1	16.6			2°	5°	
4	1087	1°			3°	3°	2	21.5		2°	1°		
5	1972		5°				4	23.5				3°	
9	2585	2°	1°			1°	7	26.1	3°		3°		
11	1640		3°				8	27.1			7°		
13	1202	3°					9	29.3		7°			7°
14	1397		6°				11	32.2				6°	4°
15	670	7°					13	29.3	8°				
16	1824	5°			7°	5°	14	23.2				9°	
18	817			6°			16	28.5	9°				
19	907				2°		18	35.2	6°		6°		1°
20	1516		2°		4°	4°	19	28.6	5°				
22	1830	6°					20	19.9				7°	
23	1330	8°			9°	6°	21	32.7		1°			
24	1416			3°			23	30.4		4°			2°
30	576			8°			25	30.2		9°		2°	5°
31	1814		7°				27	25.5				8°	
33	2051	9°	4°			2°	30	11.6			4°		
35	938		8°				31	22.9	4°				
36	1316			9°			39	15.5	2°	8°	5°		
37	1531		9°				40	25.2				1°	
41	1720			2°			42	34.2					3°
43	1084			4°			44	25.2	1°	6°			
44	1364				8°		45	16.2		3°	9°		

Tabela 5. Continuation...

Grain yield							Popping expansion						
S_3	RG	T1	T2	T3	T4	CGC	S_3	CE	T1	T2	T3	T4	CGC
46	1276				6°		46	20.0			8°		
47	1414				5°		47	30.2				4°	6°
49	709			1°			48	21.7	7°	5°			
50	974	4°		5°									

CONCLUSION

The testers BRS Angela (for GY) and IAC 125 (for PE) were the most appropriate, when combined with S_3 families derived from UENF-14 for the production of popcorn hybrids for the Northern and Northwestern Fluminense Regions.

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