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COMBINING ABILITY AND GENE ACTION IN THE EXPRESSION TRAITS IN MAXIXE[1]

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ABSTRACT - The gherkin (*Cucumis anguria* L.) is a species of African origin, belonging to the family of cucurbits, widely cultivated in Brazil, but with little information on the genetic control of the characteristics. Additive gene effects, reflected in estimates of variety or performance effects “per se,” are important in the expression of traits in maxixe genotypes. The objective of this study was to estimate the combinatorial capacity and the gene effect in gherkin genotypes. Two experiments were conducted in 2 years in a randomized block design with three replications. The treatments were nine parents of gherkin and their hybrid combinations obtained in a diallel cross. Varietal heterotic expression as the greatest in the characteristics of fruit diameter, average weight, and firmness of the fruit pulp. In gherkin genotypes, the largest deviations due to non-additive gene effects were in the characteristics of fruit diameter, length, and yield. In general, the crosses that had commercial genotypes as parents, presented high average estimates, associated in some cases with favorable estimates of non-additive gene effects.

Keywords: *Cucumis anguria L*. Heterosis. Crossing.

CAPACIDADE DE COMBINATÓRIA E AÇÃO GENICA NA EXPRESSÃO DE CARACTERÍSTICAS EM MAXIXE

RESUMO - O maxixe (*Cucumis anguria* L.) é uma espécie de origem africana, pertencente à família das cucurbitáceas, muito cultivado no Brasil, porém com pouca informação sobre o controle gênico das características. Efeitos gênicos aditivos, refletidos nas estimativas dos efeitos de variedade ou desempenho “per se” é importante na expressão das características em genótipos de maxixe. O objetivo do trabalho foi estimar a capacidade combinatória e o efeito gênico em genótipos de maxixe. Dois experimentos foram conduzidos em dois anos, em delineamento de blocos casualizados com três repetições. Os tratamentos foram nove progenitores de maxixe e suas combinações híbridas obtidas em cruzamento dialélico. Nas características diâmetro, peso médio e firmeza da polpa dos frutos a heterose varietal teve expressividade maior. Em maxixe, os maiores desvios devido aos efeitos gênicos não-aditivos, foram maiores nas características diâmetro, comprimento e produtividade de frutos. Em geral, os cruzamentos que tiveram genótipos comerciais como parentais, apresentaram maiores estimativas de médias, associado em alguns casos, a estimativas favoráveis dos efeitos gênicos não-aditivos.

Palavras-chave: *Cucumis anguria L*. Heteroses. Cruzamento.

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INTRODUCTION

Cucumis anguria L., commonly known as maxixe or the West Indian gherkin, among other names, is a species belonging to the Cucurbitaceae family that is indigenous to Africa. Its ancestor is the *Cucumis longipes* species, which gave rise to the *Cucumis anguria* L. species through natural mutations (MEDEIROS, et al., 2014; SOUSA; LIMA; LIMA, 2015; MATSUMOTO; WATANABE; KUBOYAMA, 2012). Most cucurbit species are monoecious (both sexes in the same plant) or dioecious (all flowers on the same plant have one sex), with one known androdioecious species (AKIMOTO; FUKUHARA; KIKUZAWA, 1999) and several andromonoecious species (BOUALEM et al., 2008). Most melon cultivars (*C. melo*) are andromonoecious, whereas cucumber (*C. sativus*) and maxixe (*C. anguria*) are usually monoecious (LI et al., 2019).

Maxixe reproduces sexually through self-pollination, but cross-pollination (allogamy) by bees is predominant, and fertilization occurs within 24 h. Male flowers appear first, followed by female flowers, opening at sunrise and remaining functional until around noon (SEPASAL, 2016).

In Brazil, the cultivation of maxixe occupies a prominent position in the Northeastern and Northern regions of the country and in Northern Minas Gerais, Rio de Janeiro, and São Paulo. In the Northeast, maxixe is part of the culinary tradition, and it is grown mainly spontaneously along with subsistence crops (NASCIMENTO; NUNES; NUNES., 2011). It is one of the most popular vegetables aside from sweet potatoes, yams, okra, and pumpkin (OLIVEIRA et al., 2012). Generally, small farmers do not adopt many cultural practices in these regions (ALVES et al., 2014; GOMES et al., 2015).

There is little information regarding the development and genetic variability of populations of maxixe and of the genotypes that are cultivated. This species multiplies by true seeds, but there are few studies relative to their genetic selection and characterization and controlling traits of interest.

The genetic basis for Brazil's germplasm collection for maxixe is quite narrow, which means that the genotypes maintained by the farmers of a region should be used for its expansion. Therefore, the parameters that are useful in identifying the parents should be determined. When crossed, the parameters would facilitate the estimation of the favorable heterotic effects that can be applied to generate variability so as to select superior families and increase the probability of recovering superior genotypes in advanced generations (BAHARI et al., 2012; SOUZA et al., 2013).

Depending on the methodology, diallel crosses can help determine which parents to select, and the heterotic effects, the per se performance effect, and the specific combining ability effect can be estimated. The magnitude of the expression of these parameters depends on the predominant type of genetic action (BAHARI et al., 2012; SOUZA et al., 2013; SAPOVADIYA et al., 2014).

When the magnitude of the presence of heterosis is significant and favorable for the expression of a trait, it evidences the presence of dominance and or overdominance and indicates the possibility of exploring variability through hybrids or by generating segregating populations for future selection. To identify heterotic pairs, it is necessary to apply specific methodologies that can predict this behavior.

The methodology of Gardner and Eberhart (1966) for diallel crosses is one of the most preferred for allogamous plants because it allows for a detailed examination of the components of heterosis (NASCIMENTO et al., 2010; TAVARES et al., 2019) and of the types of effects involved in controlling the trait(s) of interest.

To breed maxixe, superior genotypes can be selected based on the genetic complementation capacity of the alleles that control the traits. This study aimed to estimate heterosis, combining ability, and the predominant genetic effect for traits of agronomic interest in genotypes of maxixe.

MATERIALS AND METHODS

The experiments were conducted in the municipality of Gurupi in Tocantins (TO), Brazil, located at the following geographic coordinates: 11° 43′45″ S, 49°04′07″ W, 280 m above sea level. The Köppen (1948) climate classification for the region is type B1wA“a,” humid with a moderate water deficit. The average annual temperature is 29.5°C. The average annual precipitation is 1.804 mm. The soil is characterized as Dystrophic Red-yellow Latosol (EMBRAPA, 2011), the physicochemical characteristics of which are presented in Table 1.

Table 1. Physicochemical characteristics of the soil in the experimental area at a depth of 0 to 20 cm.

Year	pH	K	Ca	Mg	B	Cu	Fe	Mn	Zn	O.M.	O.C.	Clay	Silt	Total Sand
	$CaCl_2$	-----$cmol_c/dm^{-3}$ ------			---------------mg/dm^{-3}---------------					-----dag/kg^{-1}-----		--------------g/kg^{-1}------------		
2016	5.1	0.16	1.9	1.2	0.2	0.5	22	1.5	2.1	2.1	1.2	272	50	678
2017	5.3	0.14	2.1	0.7	0.1	0.8	36	1.7	8.7	1.8	1.0	300	50	650

Maxixe genotypes were obtained from seeds collected from fruits provided by local farmers, which had been self-fertilized for five generations, and those from commercial cultivars, as described in Table 2.

The experimental genotypes and commercial cultivars were seeded in 128-cell polyethylene trays containing the Multiplant® commercial substrate. After germination, one seedling was left in each cell. At the 4-5 leaf stage, the seedlings were transplanted to beds for crossing and self-fertilization based on the methodology adapted from Juhász et al. (2010).

Table 2. Identification and origin of the maxixe genotypes.

Genotypes	Type	Origin
1 - MAXGU#01	Common “spines”	Farmer (Vale Verde, Gurupi)
2 – MAXGU#02	São Paulo type	Farmer (Near Parque Mutuca, Gurupi)
3 – MAXGU#03	Common “spines”	Farmer (Vale Verde, Gurupi)
4 – MAXGU#04	Common “spines”	Farmer (Vale Verde, Gurupi)
5 – MAXGU#05	Common “spines”	Farmer (Vale Verde, Gurupi)
6 – MAXGU#06	Common “spines”	Farmer (Vale Verde, Gurupi)
7 – Feltrin® Nordeste	Northeast “spines”	Commercial (Feltrin)
8 – Feltrin® Calcutá	Liso Calcutta	Commercial (Feltrin)
9 – Topseed® Norte	North with spines	Commercial (Topseed)

The ripe fruits were then collected and identified for the subsequent extraction of the seeds, which were washed in running water and dried at room temperature.

The crosses were performed manually by identifying the parents (by identifying the father with a thread of a specific color). Once the fruits were ripe, they were taken to the laboratory for seed extraction.

Seeds were obtained from ripe fruits. The genotypes and crosses were evaluated in the field in a randomized block design with four replications in two consecutive years, according to the methodology proposed by Gardner and Eberhart (1966), model IV:

$$Y_{ij} = m + \frac{V_i + V_j}{2} + \theta\left(\bar{h} + h_i + h_j + s_{ij}\right) + \bar{\varepsilon}_{ij}$$

where

Y_{ij}: Mean value observed in a parent (i = j) or in a hybrid combination (i ≠ j);

m : mean effect;

V_i and V_j : Effects of the i and j parental varieties, respectively;

θ : Conditional coefficient of heterosis: $\theta = 0$ when i = j, $\theta = 1$ when i ≠ j;

$\bar{h}$: mean heterosis effect;

h_i and h_j Heterosis effects of the i and j parental varieties, respectively;

s_{ij} Specific heterosis effect of the cross between the ith and jth parental varieties;

$\bar{\varepsilon}_{ij}$: mean experimental error.

A total of 45 genotypes were obtained: 36 hybrids (from crosses) and 9 parents. The field evaluation was conducted in plots in which 10 plants were transplanted to beds with a row spacing of 0.80 m × 0.80 m between plants. The plants were fertilized with 3 kg m^2 of cattle manure compost and 150 g m^2 of NPK (04-14-08), based on the results of the soil analysis.

Top dressing was performed weekly with the application of 250 gm^2 of AP (monoammonium phosphate) and 85 gm^2 ^{of} K_2O. Regarding micronutrients, sources of boron, copper, iron, manganese, and zinc were applied. Cultural treatments were performed as necessary, such as a drip irrigation system with a daily watering schedule during dry periods. Weeding was performed for weed control. Owing to the absence of pests and diseases, no insecticides or fungicides were applied.

The fruits were harvested between 65 and 110 days after seedling transplantation, when the fruits were underripe with an intense green color and has attained the commercial size. The following traits were evaluated: fruit diameter (FD in mm) and length (FL in mm), mean weight of the fruit (MW in g), pulp firmness (PF in N), and yield (Y in t ha^{-1}).

Individual analyses of variance were conducted, followed by a joint analysis of the data. The Scott–Knott test was applied to compare the means ($p \leq 0.05$). The diallel analysis and its decompositions were performed using each treatment mean. The statistical software GENES was utilized for all the analyses (CRUZ, 2016).

RESULTS AND DISCUSSION

Results of the analysis of variance indicated significant values for the sources of genotypic variation, varieties, genotype × year interaction, heterosis, and development of the types of heterosis (mean, variety, and specific) relative to all the traits evaluated. Only the mean heterosis effect for fruit yield was not significant.

Regarding the varietal effect (V_j), the commercial Feltrin® Calcutá genotype stood out, given all the traits evaluated, and demonstrated the greatest per se performance potential: varietal effect was 15.40; FL was 7.51 mm; MW was 7.84 g; PF was 6.22 N, and Y was 21.72 t ha^{-1}. The MAXGU#05 genotype was also notable with respect to FD (7.65 mm), MW (7.57 g), and PF (3.65 N), and the MAXGU#03 genotype presented noteworthy results relative to FL (3.64 mm) and Y (15.25 t ha^{-1}) (Table 3).

Table 3. Estimates of the varietal (V_j) and heterotic (H_j) effects for five traits in maxixe genotypes obtained from diallel crosses during 2 years of evaluation.

Genotype	FD		FL		MW		PF		Y	
	V_j	H_j	V_j	H_j	V_j	H_j	V_j	H_j	V_j	H_j
1	-4.08	3.30	-0.10	0.75	3.04	-1.83	0.54	0.45	2.43	4.36
2	-17.74	-7.13	-14.56	-7.26	-23.30	-10.90	-13.41	-6.29	-19.85	-5.16
3	2.95	-0.10	3.64	0.44	3.24	1.01	2.77	0.43	15.25	-10.18
4	6.02	0.29	1.31	2.60	4.59	1.93	2.51	1.92	10.70	-3.35
5	7.65	-4.64	3.12	-1.79	7.57	-3.74	3.65	-2.56	-2.58	3.66
6	-7.11	5.20	-0.34	1.23	-4.22	4.89	-1.31	2.09	-15.68	11.71
7	-1.28	2.46	-1.25	2.21	-1.33	4.13	-0.42	1.88	-12.41	4.95
8	15.40	-3.16	7.51	-0.12	7.84	1.94	6.22	-0.15	21.72	-6.16
9	-1.81	3.77	0.67	1.93	2.58	2.57	-0.54	2.22	0.42	0.17

FD, Fruit diameter in mm; FL, Fruit length in mm; MW, Mean fruit weight in g; PF, Pulp firmness in N; and Y, Yield in t ha^{-1}; 1 – MAXGU#01; 2 – MAXGU#02; 3 – MAXGU#03; 4 – MAXGU#04; 5 – MAXGU#05; 6 – MAXGU#06; 7 – Feltrin® Nordeste; 8 – Feltrin® Calcutá; 9 – Topseed®.

The highest values with respect to reducing the expression of traits by varietal effects were observed in the MAXGU#02 genotype for FD (-17.74 mm), FL (-14.56 mm), MW (-23.30 g), PF (-13.41 N), and Y (-19.85 t ha^{-1}). Reduced FD (-7.11 mm), MW (4.22 g), PF (-1.31 N), and Y (-15.68 t ha^{-1}) was observed in the MAXGU#06 genotype. The most negative contribution was that of the Feltrin® Nordeste genotype to the FL in the evaluated crosses (Table 3).

For heterosis (H_j), the MAXGU#06 genotype presented the highest favorable values for the traits, particularly for FD (5.20 mm), MW (4.89 g), and Y (1.71 t ha^{-1}). The MAXGU#04 genotype presented a favorable value for FL (2.60 mm), and the Topseed® genotype had a favorable value for PF (2.22 N) (Table 3).

The greatest heterotic effects that were unfavorable for FD (-7.13 mm), FL (-7.26 mm), MW (-10.90 g), and PF (-6.29 N) were found in the MAXGU#02 genotype. The MAXGU#03 genotype had the highest unfavorable value for Y (-10.18 t ha^{-1}) (Table 3).

The Feltrin® Calcutá cultivar presented unfavorable values for the varietal and heterotic effects for most of the traits. The use of this genotype in hybridizations that aim to extract lineages or to explore per se performance would be interesting. With respect to all the traits evaluated herein, there was a discrepancy between favorable estimates of the varietal effect and favorable estimates of the heterotic effect. Therefore, when the objective is to promote selection to increase the number and yield in fruits, consideration should also be given to the estimates for varietal effect (V_{ij}), which reflects the importance of additive genetic effects.

Regarding the specific combining ability effects (s_{ij}) (Table 4), the cross between the MAXGU#01 and MAXGU#04 genotypes had the best positive effect on FD (6.93 mm), FL (4.35 mm), and MW (8.57 g). The cross between MAXGU#05 and Feltrin® Nordeste had the best combining effect for PF (4.52 N), and the most favorable value for Y was found in the cross between MAXGU#03 and MAXGU#05 (22.54 t ha^{-1}).

Lalla et al. (2010) observed similar results in their study. In other words, the genotypes with the most favorable values for varietal and heterotic effects do not always result in the best hybrid combinations, which shows that non-additive genetic effects are important in the expression of these traits.

The greatest negative effects of specific combining ability were found in the cross between MAXGU#01 and MAXGU#05 for FD (-14.82 mm), FL (-13.57 mm), MW (-20.46 g), PF (-12.99 N), and Y (-23.91 t ha^{-1}) (Table 4).

Table 4. Estimates of the specific combining ability effects (s_{ij}) and means for five traits in maxixe genotypes obtained from diallel crosses during 2 years of evaluation.

G[1]	FD			FL			MW			PF			Y		
	ss_{ij}	μ		s_{ij}	μ		sS_{ij}	μ		s_{ij}	μ		s_{ij}	μ	
1 × 1	---	29.46	c[2]	---	39.22	c	---	38.94	b	---	27.29	b	---	41.03	a
1 × 2	0.91	15.03	d	1.70	24.45	d	2.57	11.81	c	0.32	12.17	c	-6.20	18.25	b
1 × 3	1.89	33.38	c	1.78	41.33	c	3.41	37.83	b	0.89	27.55	b	5.96	42.94	a
1 × 4	6.93	40.35	b	4.35	44.90	a	8.57	44.58	a	4.09	32.11	a	13.42	54.95	a
1 × 5	-14.82	14.49	d	-13.57	23.49	d	-20.46	11.36	c	-12.99	11.12	c	-23.91	18.00	b
1 × 6	4.77	36.54	b	-0.98	37.37	c	1.86	36.43	b	2.56	28.84	a	12.66	56.06	a
1 × 7	-2.61	29.33	c	1.14	40.01	c	0.06	35.31	b	0.12	26.64	b	-13.39	24.89	b
1 × 8	2.13	36.79	b	2.72	43.64	b	1.86	39.51	b	2.93	30.74	a	0.20	44.43	a
1 × 9	0.80	33.79	c	2.85	42.41	b	2.13	37.77	b	2.06	28.86	a	11.26	51.18	a
2 × 2	---	15.80	d	---	24.76	d	---	12.60	c	---	13.34	c	---	18.76	b
2 × 3	-0.09	14.14	d	-0.55	23.75	d	0.29	12.46	c	0.63	13.57	c	6.50	22.83	b
2 × 4	-0.15	16.01	d	0.17	25.47	d	-1.84	11.93	c	0.34	14.64	c	0.07	20.95	b
2 × 5	1.68	13.73	d	0.93	22.74	d	1.16	10.74	c	2.03	12.42	c	-0.50	20.74	b
2 × 6	0.21	14.72	d	-0.01	23.09	d	-1.63	10.70	c	-1.43	11.14	c	-2.09	20.67	b
2 × 7	0.55	15.23	d	0.49	24.12	d	0.54	13.55	c	0.53	13.33	c	3.66	21.28	b
2 × 8	-1.85	15.55	d	-1.89	23.78	d	-0.72	14.68	c	-1.42	12.67	c	-0.55	23.03	b
2 × 9	-1.26	14.47	d	-0.84	23.48	d	-0.37	13.02	c	-1.01	12.08	c	-0.90	18.36	b
3 × 3	---	36.50	b	---	42.95	b	---	39.13	b	---	29.52	a	---	53.86	a
3 × 4	-2.96	30.57	c	-2.20	39.90	c	-3.56	35.39	b	-2.75	26.35	b	-8.51	24.90	b
3 × 5	4.80	34.22	c	1.11	39.72	c	3.15	37.91	b	0.53	25.73	b	22.54	56.31	a
3 × 6	-1.20	30.68	c	0.80	40.70	c	-0.78	36.73	b	0.69	28.06	b	-4.47	30.82	b
3 × 7	1.41	33.46	c	0.40	40.83	c	0.83	39.03	b	0.04	27.65	b	-1.39	28.76	b
3 × 8	-3.33	31.44	c	-0.81	41.67	b	-1.66	38.93	b	0.94	29.84	a	-11.15	24.95	b
3 × 9	-0.52	32.58	c	-0.52	40.59	c	-1.69	36.89	b	-0.97	26.92	b	-9.48	22.31	b
4 × 4	---	39.56	b	---	40.63	c	---	40.49	a	---	29.26	a	---	49.30	a
4 × 5	1.37	32.71	c	2.01	41.63	b	5.24	41.6	a	1.17	27.73	b	3.78	42.10	a
4 × 6	-1.98	31.83	c	-0.51	40.39	c	-0.97	38.13	b	-0.81	27.92	b	-11.93	27.90	b
4 × 7	1.28	35.26	c	-0.36	41.07	c	-1.89	37.90	b	-0.43	28.53	a	10.87	45.57	a
4 × 8	-2.44	34.26	c	-1.31	42.16	b	-2.65	39.53	b	-0.89	29.36	a	-5.96	34.7	b
4 × 9	-2.05	32.98	c	-2.15	39.96	c	-2.90	37.27	b	-0.71	28.54	a	-1.75	34.59	b
5 × 5	---	41.19	b	---	42.43	b	---	43.47	a	---	30.4	a	---	36.02	b
5 × 6	2.15	31.85	c	2.86	40.27	c	4.59	39.51	b	2.39	27.21	b	5.42	45.63	a
5 × 7	1.52	31.39	c	2.44	40.37	c	1.43	37.03	b	4.52	29.58	a	-0.42	34.65	b
5 × 8	2.01	34.59	c	0.83	40.81	c	2.25	40.24	a	0.93	27.28	b	5.06	46.09	a
5 × 9	1.28	32.20	c	3.40	42.02	b	2.63	38.62	b	1.41	26.75	b	-11.97	24.74	b
6 × 6	---	26.44	c	---	38.97	c	---	31.68	b	---	25.44	b	---	22.93	b
6 × 7	-3.00	29.33	c	-2.07	37.15	c	-1.09	37.26	b	-2.14	25.10	b	-6.56	30.01	b
6 × 8	-2.01	33.04	c	-0.52	40.75	c	-3.67	37.07	b	-2.14	26.38	b	0.56	43.09	a
6 × 9	1.07	34.44	c	0.42	40.34	c	1.68	40.41	a	0.88	28.39	a	6.41	44.62	a
7 × 7	---	32.26	c	---	38.06	c	---	34.56	b	---	26.33	b	---	26.19	b
7 × 8	2.83	38.05	b	1.05	42.84	b	3.08	44.50	a	-0.68	28.08	b	6.32	43.73	a
7 × 9	-1.99	31.56	c	-3.09	37.35	c	-2.97	36.44	b	-1.97	25.78	b	0.92	34.00	b
8 × 8	---	48.94	a	---	46.82	a	---	43.74	a	---	32.97	a	---	60.32	a
8 × 9	2.66	38.93	b	-0.07	42.41	b	1.49	43.3	a	0.32	29.35	a	5.51	44.55	a
9 × 9	---	31.73	c	---	40.00	c	---	38.47	b	---	26.21	b	---	39.02	a

[1] - G, Genotypes; FD, Fruit diameter in mm; FL, Fruit length in mm; MW, Mean fruit weight in g; PF, Pulp firmness in N; and Y, Yield in t ha^{-1}; 1 – MAXGU#01; 2 – MAXGU#02; 3 – MAXGU#03; 4 – MAXGU#04; 5 – MAXGU#05; 6 – MAXGU#06; 7 – Feltrin® Nordeste; 8 – Feltrin® Calcutá; 9 – Topseed®. [2] - Means followed by a different letter in the column differ statistically based on the Scott–Knott test ($p \leq 0.05$).

Cultivars with the highest values for the effects of V_j and H_j do not always result in crosses with high effects of s_{ij}. Comparing different methods of diallel analyses, Cruz and Vencovsky (1989) found that crossing two genotypes with a high overall combining ability did not always result in the best hybrid.

In the cross between MAXGU#01 and MAXGU#04, the MAXGU#01 genotype had a varietal effect (V_j) with positive values for MW (3.04 g) and negative values for FD (-4.08 mm) and FL (-0.10 mm). The MAXGU#04 genotype had a varietal effect (V_j) with positive values for FD (6.02 mm), FL (1.31 mm), and MW (4.59 g). This genotype had the third highest value in the estimate for heterotic effect for FL (2.60 mm) and PF (1.92 N) (Table 3).

As for the estimates of the heterotic effect (H_j), the MAXGU#01 genotype had positive values for FD (3.30 mm) and FL (0.75 mm) and a negative value for MW (-1.83 g). The MAXGU#04 genotype had a heterotic effect (H_j) with positive values for FD (0.29 mm), FL (2.60 mm), and MW (1.93 g). Only the MAXGU#04 genotype had an estimate for V_j with positive effects on FD (6.02 mm), MW (4.59 g), and Y (10.70 t ha^{-1}). The MAXGU#04 genotype had the third highest values for H_j relative to FL (2.60 mm) and PF (1.92 N) (Table 3).

As reported by Godoy, Higuti, and Cardoso (2008), the highest estimates for heterosis in free-range cucumber lineages did not necessarily result in the highest mean values for fruit yield.

In the case of maxixe, it was not possible to predict the behavior of a hybrid based only on the parents' performance, as the genotypes with the highest estimates for varietal and heterotic effects did not always result in specific deviations expressed in the specific combining ability effect. The importance of varietal and heterotic effects is associated with deviations due to additive genetic effects, whereas favorable specific combining ability effects are associated with non-additive genetic effects (dominance, overdominance, and epistasis).

By comparing the means of the hybrids to the estimates for specific combining abilities, the best means were obtained from the cross between MAXGU#01 and MAXGU#04 for FD (40.35 mm), FL (44.90 mm), MW (44.58 g), and PF (32.11 N). For yield, the highest mean was found in the cross between MAXGU#03 and MAXGU#05 (56.31 t ha^{-1}). The cross between MAXGU#01 and MAXGU#04 had the highest estimates for the specific combining ability for these traits, whereas the cross between MAXGU#03 and MAXGU#05 had the highest estimates for yield. Based on this criterion, for all the evaluated traits, favorable values for estimates of specific combining ability coincided with the largest estimated means, except for the hybrid MAXGU# 05 × Feltrin® Nordeste, where the values for s_{ij} and the means agreed with the estimates of the crosses for the other traits (Table 4).

CONCLUSION

The commercial Feltrin® Calcutá genotype demonstrated superior behavior for fruit diameter and length, mean weight, pulp firmness, and yield. It stood out among the others genotypes relative to per se performance or to the predominance of additive effects.

Similarly, among the experimental genotypes, when the objective is per se performance relative to the fruits' diameter, mean weight, and firmness, the MAXGU#05 and MAXGU#03 genotypes were notable for length and yield.

Among the hybrid combinations, the combinations MAXGU#03 × MAXGU#05 and MAXGU#01 × MAXGU#06 were noteworthy for fruit diameter, length, mean weight, and pulp firmness. No variation in the estimates for non-additive effects were observed that merited attention.

For the average fruit yield, the highest estimates for non-additive genetic effects were observed in the combinations MAXGU#03 × MAXGU#05, MAXGU#01 × MAXGU#04, and MAXGU#01 × MAXGU#06, which indicates that both additive and non-additive genetic effects are important for this trait.

With respect to maxixe, the development of hybrids is mainly viable for fruit yield. However, it is not possible to predict a hybrid's behavior based only on the parents' performance, as the genotypes with the highest estimates for varietal and heterotic effects did not always result in specific deviations expressed in the specific combining ability effect.

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REFERENCES

AKIMOTO, J.; FUKUHARA, T.; KIKUZAWA, K. Sex expression and genetic variation in a functionally androdioecious species, *Schizopepon bryoniaefolius* (Cucurbitaceae), **American Journal of Botany**, 86: 880-886, 1999.

ALVES, C. Z. et al. Efeito do estresse hídrico e salino na germinação e vigor de sementes de maxixe. **Interciencia**, 39: 333-337, 2014.

BAHARI, M. et al. Combining ability analysis in complete diallel cross of watermelon (*Citrullus lanatus* L. (Thunb, Matsun & Nakai). **The Scientific World Journal**, 2012: 1-6, 2012.

BOUALEM, A. et al. A conserved mutation in an ethylene biosynthesis enzyme leads to andromonoecy in melons. **Science**, 321: 836-838, 2008.

CRUZ, C. D. Genes Software – extended and integrated with the R. Matlab and Selegen. **Acta Scientiarum**, 38: 547-552, 2016.

CRUZ, C. D.; VENCOVSKY, R. Comparação de alguns métodos de análise dialélica. **Revista Brasileira de Genética**, 12: 425-438, 1989.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Manual de Métodos de Análise de**

Solo. 2 ed. Rio de Janeiro, RJ: EMBRAPA, 2011, 230 p.

GARDNER, C. O.; EBERHART. S. A. Analysis and interpretation of the variety cross diallel and related population. **Biometrics**, 22: 439-452, 1966.

GODOY, A. R.; HIGUTI, A. R. O.; CARDOSO, A. I. I. Produção e heterose em cruzamentos entre linhagens de pepino do grupo caipira. **Bragantia**, 67: 839-844, 2008.

GOMES, L. P. et al. Produtividade de cultivares de maxixeiro em função de doses de biofertilizante. **Revista Agro@mbiente On-line**, 9: 275-283, 2015.

JUHÁSZ, A. C. P. et al. Biologia floral e polinização artificial de pinhão-manso no norte de Minas Gerais. **Pesquisa Agropecuária Brasileira**, 44: 1073-1077, 2010.

KÖPPEN, W. **Climatología: con un estúdio de los climas de la Tierra**. 1 ed. México: Fondo de Cultura Económica, 1948. 478 p.

LALLA, J. G. et al. Capacidade combinatória e heterose de linhagens de pepino do grupo japonês para caracteres de produção. **Horticultura Brasileira**, 28: 337-343, 2010.

LI, D. et al. Gene Interactions Regulating Sex Determination in Cucurbits. **Frontiers in Plant Science**, 10: 1-12, 2019.

MATSUMOTO, Y.; WATANABE, N.; KUBOYAMA, T. Cross-species amplification of 349 melon (*Cucumis melo* L.) microsatellites in gherkin (*Cucumis anguria* L.). **Journal of Plant Breeding and Crop Science**, 4: 25-31, 2012.

MEDEIROS, A. S. et al. Produção de maxixeiro cultivado em fibra de coco fertirrigado com diferentes concentrações de nitrogênio. **Agropecuária Científica no Semiárido**, 10: 60-64, 2014.

NASCIMENTO, I. R. D. et al. Capacidade combinatória de linhagens de pimentão a partir de análise dialélica multivariada. **Acta Scientiarum Agronomy**, 32: 235-240, 2010.

NASCIMENTO, A. M. C. B.; NUNES, R. G. F. L.; NUNES, L. A. P. L. Elaboração e avaliação química, biológica e sensorial de conserva de maxixe (*Cucumis anguria* L.). **Revista ACTA Tecnológica**, 6: 123-136, 2011.

OLIVEIRA, F. A. et al. Desenvolvimento do maxixeiro cultivado em substrato fertirrigado com diferentes soluções nutritivas. **Revista Brasileira de Ciências Agrárias**, 7: 777-783, 2012.

SAPOVADIYA, M. H. et al. Combining ability in watermelon (*Citrullus lanatus* (Thumb.) Mansf.), **Eletrocnic Journal of Plant Breeding**, 5: 327-330, 2014.

SEPASAL - Survey of Economic Plants for Arid and Semi-Arid Lands. **Cucumis anguria vars, anguria and longipes. Database. Royal Botanic Gardens, Kew, Richmond, United Kingdom**. 2016. Disponível em: <http://www.kew.org/ ceb/sepasal/>. Acesso em: 06 set. 2021.

SOUZA, F. F. et al. Capacidade de combinação de linhagens avançadas e cultivares comerciais de melancia. **Horticultura Brasileira**, 31: 595-601, 2013.

SOUSA, P. B.; LIMA, F. G. S.; LIMA, A. Propriedades Nutricionais do Maxixe e do Quiabo. **Revista Saúde em foco**, 2: 113-129, 2015.

TAVARES, A. T. et al. Heterose em híbridos de melancia. **Revista de Agricultura Neotropical**, 6: 26-33, 2019.