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Agronomic characterization and heterosis in watermelon genotypes[1]

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ABSTRACT

In order to increase the yield of vegetables of agronomic interest, heterosis has been studied in view of the superiority of hybrids, if compared to genotypes obtained by free pollination. This study aimed to estimate the relative heterosis in watermelon hybrids, regarding the most important agronomic traits, in order to develop future cultivars. The genotypes 'JNY', 'ORA', 'KOD', 'SOL', 'CHG', 'PEA' and all hybrids among them were used, totaling 36 treatments. A randomized block design, with three replications and five-plant plots, was used. The genotypes 'ORA', 'SOL', 'CHG' and 'PEA' were promising for the development of watermelon hybrids with higher weight, whereas 'JNY' and 'KOD' provided combinations with lower fruit weight and smaller seeds, indicating their potential for the development of cultivars of the 'ice box' type. The hybrids 'CHG x ORA' and 'ORA x CHG' were promising to meet the market demand for larger fruits, while 'KOD x JNY' and 'JNY x KOD' could be targeted to the market of smaller fruits.

KEYWORDS: *Citrullus lanatus*; heterobeltiosis; watermelon hybrids.

RESUMO

Caracterização agronômica e
heterose em genótipos de melancia

Para o aumento da produtividade em hortaliças de interesse agronômico, tem sido realizado o estudo da heterose, devido à superioridade dos híbridos, em relação aos genótipos de polinização livre. Objetivou-se estimar a heterose relativa em híbridos de melancia para os principais caracteres de interesse agronômico, visando ao desenvolvimento de futuras cultivares. Foram utilizados os genótipos 'JNY', 'ORA', 'KOD', 'SOL', 'CHG', 'PEA' e todos os híbridos possíveis entre eles, totalizando 36 tratamentos. Empregou-se o delineamento de blocos casualizados, com três repetições e parcelas com cinco plantas. Os genitores 'ORA', 'SOL', 'CHG' e 'PEA' apresentaram-se promissores para o desenvolvimento de híbridos de maior massa, enquanto 'JNY' e 'KOD' proporcionaram combinações com menor massa de fruto e sementes pequenas, indicando o seu potencial para o desenvolvimento de cultivares do tipo "mini". Os híbridos 'CHG x ORA' e 'ORA x CHG' foram promissores para atender a demanda de mercado por frutos maiores, enquanto 'KOD x JNY' e 'JNY x KOD' podem ser destinados à comercialização de frutos menores.

PALAVRAS-CHAVE: *Citrullus lanatus*; heterobeltiose; híbridos de melancia.

INTRODUCTION

Watermelon is an important crop, with notorious economic and social benefits. In 2016, Brazil was the fourth world producer, reaching 2,090,432 t, behind China (79,043,138 t), Turkey (3,928,892 t) and Iran (3,813,850 t) (FAO 2018). Watermelon is the third most produced fruit in Brazil, generating an estimated value of R$ 1.3 million (Agrianual 2018).

Watermelon growing is considered a risky activity, mainly due to the low market prices of conventional, diploid and seeded fruits. In general, seedless fruits reach higher market prices and generate a better income for growers. The development of new seedless watermelon hybrids may increase the fruit quality and yield.

Various watermelon cultivars used in Brazil are very similar in appearance to the 'Crimson Sweet' variety. These cultivars present large and round fruits, weighing over 10 kg, with striped and dark green rind, red flesh, high soluble-solids content (11-13 ºBrix) and medium-size seeds. In addition, they are very susceptible to the main biotic stresses of the crop (Souza 2008).

Concerning the national market, a small number of seedless watermelon cultivars has been

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commercialized (Ramos et al. 2012), representing an opportunity for national breeding programs. However, due to the difficulty in the germination of triploid and tetraploid seeds, an appropriate infrastructure is required for the production of seedlings, what is one of the main obstacles to the production of seedless fruits (Aragão et al. 2006). The difficulty to obtain stable tetraploid lineages can be regarded as a factor that contributes to raising the cost of the seeds of such genotypes and, therefore, influences the price of their fruits. Thus, the development of new commercial high-yield hybrids (above 50 t ha^{-1}) with very small seeds, instead of being seedless, and small fruits, instead of big ones, increases the opportunities to reach a new market segment composed of singles, couples and small families, who look for the convenience and ease of fast consumption and occupying little space in the refrigerator.

In many cases, such as in watermelons, in order to develop new genotypes, it is crucial to explore the genetic variability of the species, with the ultimate aim of obtaining good hybrids. This strategy has been widely used in other crops such as pumpkin (Amaro et al. 2017) and onion (Faria et al. 2012).

Heterosis is a term used to describe the superiority or the decreased value of a trait in hybrids (F_1), in relation to their homozygous parents. In watermelon, the commercial exploitation of heterosis was reported by Sapovadiya et al. (2013) and Damaceno et al. (2016). In Brazil, studies on heterosis in watermelon hybrids are still scarce.

This study aimed to estimate relative heterosis for traits of agronomic interest in watermelon genotypes, in order to develop new future cultivars.

MATERIAL AND METHODS

The experiment was carried out from April to August 2016, at the Embrapa Semiárido experimental station, in Petrolina, Pernambuco state, Brazil (9º7'56"S; 40º17'59.57"W). According to the Köppen classification, the local climate is BSwh, meaning semi-arid conditions, with high average temperatures (> 26.1 ºC) and low precipitation (< 515 mm).

To obtain the F_1 hybrids and their reciprocal, the inbred lines 'JNY', 'ORA', 'KOD', 'SOL', 'CHG' and 'PEA' were sown in polystyrene trays and later transplanted to the field. The hybrids were obtained by artificial crosses between parents (Dias et al. 2001).

The seeds of the parents and hybrids were sown in trays of expanded polystyrene with 128 cells, containing a commercial substrate (Plantmax®). At 15 days after sowing, the seedlings were taken to the field. A randomized block design was used, with three replications and five-plant plots, spaced 2.5 m between rows and 1.0 m between plants.

Drip irrigation was used to supply the plants water needs, based on the soil and climate conditions, monitored by a local weather station. Fertilizers were supplied according to the soil analysis (Mendes et al. 2010). Fertilization included 30 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5 and 30 kg^{-1} of K_2O, plus 15 kg^{-1} of zinc sulphate and 10 kg ha^{-1} of copper sulphate. Topdressing nutrition was applied via irrigation, using 50 kg ha^{-1} of N (calcium nitrate) and 40 kg ha^{-1} of K_2O (potassium sulphate), applied at 50 and 60 days after sowing, respectively. The control of pests, diseases and weeds followed the technical and legal recommendations.

The first harvest occurred at 72 days after transplanting and included all early genotypes. On the other hand, late genotypes were harvested at 16 days after the first group. Genotypes were evaluated for the number of days to the anthesis of female flowers; fruit weight; number of fruits per plant; fruit yield; fruit shape length/width; soluble-solids content; seed length; seed width; and weight of 10 seeds.

The data were submitted to variance analysis and the averages were grouped using the Scott-Knott test. Estimates of heterosis were obtained in relation to the parents average, according to the formula:

$$Hmp(\%) = \left(\frac{F_1 - \left(\frac{P_1 + P_2}{2}\right)}{\left(\frac{P_1 + P_2}{2}\right)} \right) x\ 100$$

and heterobeltiosis by:

$$Hps(\%) = \left(\frac{F_1 - SP}{SP} \right) x\ 100$$

where F_1, P_1 and P_2 represent the mean values for hybrid, parent 1 and parent 2, respectively, by comparing the phenotype F_1 with the superior parent (SP). All analyses were performed with the Genes software, version 3.0 (Cruz 2013).

RESULTS AND DISCUSSION

Considering all traits and using the Scott-Knott test (Table 1), the genotypes were clustered in many groups, thus evincing the presence of high genetic variability.

The number of days to the anthesis of female flowers determines the precocity of the genotypes, which results in early harvesting, thus promoting a faster return of the investment made in the crop. As for the genotypes of the present study, the formation of eight groups was observed, with averages ranging from 33.7 in the parent 'SOL' to 48.0 in the parent 'PEA' (Table 1).

The hybrids 'ORA x SOL' and 'CHG x ORA' were the earliest ones, which began to bloom at

Table 1. Evaluation for number of days to the anthesis of female flowers (AFF), fruit weight (FW), number of fruits per plant (NFP), fruit yield (FY), fruit length/width ratio (FL/W), soluble-solids content (SSC), weight of 10 seeds (10SW), seed length (SL) and seed width (SW).

Genotypes	AFF	FW	NFP	FY	FL/W	SSC	10SW	SW	SL
	days	kg	unit	$t ha^{-1}$	cm	ºBrix	mg	mm	mm
'JNY' (1)	43.0 e*	4.4 c	2.4 b	38.3 b	1.1 g	9.9 c	20.0 j	3.6 j	5.9 h
'ORA' (2)	43.7 e	5.1 b	1.6 c	44.0 a	1.2 g	8.9 d	83.3 c	7.7 b	11.9 a
'KOD' (3)	43.3 e	3.1 d	2.9 a	24.7 b	1.1 g	9.7 c	33.3 i	4.9 f	7.8 e
'SOL' (4)	33.7 h	4.6 c	3.3 a	35.7 b	1.1 g	10.3 b	50.0 f	5.6 d	8.8 c
'CGH' (5)	43.7 e	7.3 a	2.2 c	59.5 a	1.8 a	8.6 d	100.0 a	8.0 a	12.0 a
'PEA' (6)	48.0 b	5.4 b	3.1 a	26.7 b	1.5 d	11.5 a	40.0 h	5.8 d	8.8 c
1 x 2	44.7 d	4.2 c	2.1 c	41.5 b	1.1 g	9.2 d	30.0 i	4.2 h	6.9 f
2 x 1	43.0 e	5.4 b	1.9 c	58.1 a	1.1 g	9.6 c	30.0 i	4.2 h	7.1 f
1 x 3	46.7 c	3.2 d	2.3 c	34.3 b	1.1 g	8.8 d	20.0 j	3.6 j	6.0 h
3 x 1	44.0 e	2.6 d	2.5 b	27.9 b	1.2 g	9.9 c	20.0 j	3.7 j	5.8 h
1 x 4	43.3 e	3.8 c	2.3 b	39.3 b	1.1 g	10.4 b	30.0 i	4.5 g	7.1 f
4 x 1	42.0 f	5.1 b	2.4 b	52.2 a	1.1 g	9.8 c	23.3 j	4.2 h	7.0 f
1 x 5	45.3 d	5.5 b	2.2 c	52.3 a	1.4 e	8.3 d	26.7 i	4.1 i	6.7 g
5 x 1	43.0 e	5.2 b	1.7 c	47.3 a	1.5 d	10.5 b	30.0 i	4.4 g	6.9 g
1 x 6	45.0 d	5.7 b	2.7 b	48.4 a	1.2 f	11.3 a	20.0 j	4.0 i	6.6 g
6 x 1	44.7 d	5.9 b	2.6 b	65.6 a	1.2 f	10.9 a	23.3 j	4.2 h	6.8 g
2 x 3	42.3 f	5.1 b	2.5 b	48.0 a	1.2 g	9.7 c	56.7 e	6.0 c	9.6 b
3 x 2	43.7 e	4.6 c	2.2 c	45.5 a	1.1 g	9.9 c	30.0 i	4.3 h	6.7 g
2 x 4	40.0 g	5.4 b	2.4 b	47.3 a	1.1 g	10.2 b	53.3 f	6.2 c	9.9 b
4 x 2	42.3 f	5.6 b	2.4 b	51.8 a	1.1 g	10.2 b	60.0 e	6.0 c	9.6 b
2 x 5	46.7 c	6.0 b	2.1 c	49.9 a	1.6 d	9.9 c	76.7 d	7.5 b	11.8 a
5 x 2	44.3 e	6.4 a	2.3 b	52.9 a	1.6 d	9.0 d	90.0 b	7.8 b	12.2 a
2 x 6	48.7 b	5.6 b	1.7 c	42.6 b	1.3 f	11.0 a	50.0 f	5.8 c	9.5 b
6 x 2	45.7 d	5.3 b	2.1 c	47.8 a	1.3 f	10.2 b	43.3 g	6.0 c	9.3 b
3 x 4	43.0 e	3.8 c	1.6 c	33.4 b	1.1 g	9.9 c	30.0 i	4.7 f	7.5 e
4 x 3	42.0 f	4.7 c	1.9 c	38.1 b	1.1 g	9.2 d	46.7 g	5.4 e	9.0 c
3 x 5	48.0 b	4.8 c	2.1 c	39.0 b	1.7 c	10.0 c	30.0 i	4.4 g	7.0 f
5 x 3	41.0 g	5.6 b	2.0 c	50.5 a	1.7 c	9.0 d	30.0 i	4.5 g	7.1 f
3 x 6	52.0 a	4.2 c	2.2 c	32.2 b	1.4 f	9.9 c	40.0 h	5.3 e	8.5 d
6 x 3	45.7 d	5.5 b	2.3 c	48.7 a	1.4 e	10.5 b	40.0 h	5.5 e	8.6 d
4 x 5	47.0 c	6.0 b	2.1c	45.4 a	1.5 d	9.5 c	56.7 e	6.1 c	9.6 b
5 x 4	42.3 f	6.5 a	2.0 c	50.7 a	1.5 d	10.0 c	53.3 f	6.1 c	9.7 b
4 x 6	45.0 d	6.3 a	1.9 c	53.4 a	1.2 g	11.4 a	46.7 g	5.6 d	9.3 b
6 x 4	41.7 f	5.1 b	1.5 c	47.3 a	1.3 f	11.5 a	40.0 h	5.6 d	9.1 c
5 x 6	46.0 c	7.0 a	1.9 c	59.3 a	2.0 a	10.7 b	50.0 f	6.0 c	9.5 b
6 x 5	46.0 c	7.3 a	1.6 c	50.8 a	1.9 b	9.9 c	53.3 f	6.0 c	9.6 b
CV (%)	2.3	14.0	19.2	21.7	4.5	5.5	9.1	2.8	2.5
Mean	44.2	5.2	2.2	45.3	1.3	10.0	43.2	5.3	8.5
Minimum	33.67	2.6	1.6	24.7	1.1	8.3	20.0	3.6	5.9
Maximum	48.0	7.3	3.3	65.6	2.0	11.5	100.0	8.0	12.2

* Averages followed by the same letter in the column do not differ significantly by the Scott-Knott test at the 0.05 significance level.

days 40 and 41, respectively. These hybrids may be very interesting to watermelon growers. Ramos et al. (2009) also found a variation in days for anthesis among the populations, which shows that, within the watermelon germplasm, there is a large variability for that trait.

Regarding fruit weight, there is a tendency for domestic consumers to prefer lower-weight genotypes. However, in Brazil, large watermelons are frequently sold as sliced pieces in supermarkets, so the demand for larger fruits will be continuous. The average for fruit weight values in the present study ranged from 3.1 kg ('KOD') to 7.33 kg ('CHG'). Among the hybrids, the combinations 'JNY x KOD' (3.2 kg) and 'KOD x JNY' (2.6 kg) showed a lower fruit weight, similar to that of the parent 'KOD'. According to the Ceagesp (2011), the small fruits are classified as 'mini', corresponding to 'ice box', in the US market. Lager fruit cultivars, such as the combinations 'CHG x PEA' (7.0 kg) and 'PEA x CHG' (7.3 kg), would be classified as 'common watermelon' (Table 1).

Concerning the number of fruits per plant, it is desired that the genotypes be prolific, once this trait is an important yield compound. The genotypes 'SOL' (3.3) and 'PEA' (3.1) were superior to the other parents, and 'PEA x JNY' (2.6) and 'JNY x PEA' (2.7) were superior to the other hybrid combinations (Table 1). These results diverged from those observed by Dantas et al. (2013), who found a mean value of 1.58 in *C. lanatus*. The values observed for the genotypes in this study were higher than 1.58, except for the combination 'PEA x SOL' (1.50). This contrast may be due to the specific characteristics of each germplasm, once this trait may present a large variability.

As regards fruit yield, 50 % of the genotypes of the group b, the lowest yield group, presented a satisfactory yield. In 2017, the average yield of 'Crimson Sweet', the main watermelon cultivar in Brazil, was 35 t ha^{-1} (Agrianual 2018). The highest yield group in this study included 'ORA' (44.0 t ha^{-1}) and 'CHG' (59.5 t ha^{-1}), and the hybrids 'PEA x JNY' (65.6 t ha^{-1}), 'CHG x PEA' (59.3 t ha^{-1}) and 'ORA x JNY' (58.1 t ha^{-1}).

With respect to the fruit length/width ratio, the mean values ranged from 1.8 to 1.9 (Table 1). Santos et al. (2017), when evaluating the fruit length/width ratio in watermelon genotypes, classified the fruits with a ratio value under 1.5 as rounded, whereas those above 1.6 were classified as long. Based on this classification, more than 69 % of the genotypes evaluated in the present study showed a rounded shape, what is an interesting fact, since it is easier to store and transport these fruits.

Regarding the soluble-solids content, more than 44.0 % of the evaluated genotypes presented values above 9.9 ºBrix (Table 1). According to Barros et al. (2012), the minimum acceptable value for commercialization is 10.0 ºBrix, what shows that the genotypes evaluated in the present study have potential to be released as commercial hybrids in the future.

In terms of seed weight, length and width, the hybrid combinations between the parents 'JNY' and 'KOD' (Table 1), which simultaneously expressed the lowest values for those three characteristics, showed a potential for smaller seed size, evidencing that they are promising genotypes for commercial exploitation.

Heterosis was negative in 7 of the 30 hybrids for days to the anthesis of female flowers (Table 2), indicating that these hybrids were early. Singh et al. (2009) found the highest value of -5.6 %, very similar to that observed in the present study (-5.8 %, in 'CHG x KOD'). Such a slight difference between results is possibly attributed to the behavior of the genotypes, which may vary depending on the environmental conditions observed.

Heterobeltiosis was negative in 28 hybrids for days to the anthesis of female flowers, and the combination 'ORA x SOL' showed the highest value (-16.7 %) (Table 2). Possibly, precocity is due to the behavior *per se* of the parents, since at least one of the parents involved in the crossing is considered to be early.

Regarding fruit weight, the heterosis related to the parental mean was negative in 13 hybrids (Table 2). These hybrids presented the lowest fruit weight, indicating the superiority of the combination 'KOD x JNY' (-31.1 %). Heterobeltiosis was negative in all combinations, especially in 'KOD x JNY' (-65.2 %), what shows a potential to produce fruits like 'mini watermelons'. Singh et al. (2009), when evaluating the same trait in watermelon hybrids, obtained the highest positive heterosis value of 14.03 %, whereas, in the present study, the highest value observed was 30.5 %, possibly due to differences in both germplasms.

For the number of fruits per plant, heterosis was positive in 13.0 % of the hybrids, especially for 'CHG x ORA' (22.8 %) (Table 2). These results differ from those found by Souza et al. (2005) and Santos et al. (2017), who observed that the heterosis for the trait in question was above 50.0 %. Possibly, such a contrast in the results could be attributed to the genetic difference of the populations studied.

Gusmini &Wehner (2004), evaluating yield in a watermelon hybrid, did not observe heterosis higher than 50 %. However, in the present study, heterosis above this level was observed for the hybrids 'PEA x JNY' (101.8 %), 'PEA x ORA' (89.8 %), 'SOL x PEA' (71.3 %) and 'PEA x SOL' (51.5 %) (Table 2), evidencing that this is a promising combination, in terms of fruit yield.

According to Santos et al. (2017), for forage watermelon, the most recommended fruit length/width ratio is higher than 1.0, since it indicates elongated fruits. However, in sweet watermelons, consumers prefer fruits with a fruit length/width ratio near 1.0, once they are easier to transport and store. In the present study, 21 of the 30 hybrid combinations presented a rounded shape.

These results are in contrast with those found by Santos et al. (2017), who, when evaluating the shape in forage watermelons, obtained values above 1.6, except for a single combination that presented a lower value (Table 2). The difference in the results between the present study and the one mentioned above may be attributed to the selection of elongated fruits for forage watermelons and rounded ones for sweet watermelons made by growers.

Concerning the soluble-solids content, 67.0 % of the hybrids presented a positive heterosis, notably

Table 2. Heterosis (Hmp) and heterobeltiosis (Hps) in watermelon genotypes, regarding days to the anthesis of female flowers (AFF), fruit weight (FW), number of fruits per plant (NFP), fruit yield (FY) and fruit length/width ratio (FL/W).

Hybrids*	Heterosis/heterobeltiosis (%)									
	AFF		FW		NFP		FY		FL/W	
	Hmp	Hps	Hmp	Hps	Hmp	Hps	Hmp	Hps	Hmp	Hps
1 x 2	3.1	-6.9	-12.1	-43.1	6.7	-36.0	0.8	-30.3	-3.26	-40.39
2 x 1	-0.8	-10.4	14.8	-25.7	-3.3	-42.0	41.2	-2.3	-1.14	-38.75
1 x 3	8.1	-2.8	-12.8	-56.0	-15.0	-32.0	9.0	-42.3	-0.19	-39.71
3 x 1	1.9	-8.3	-31.1	-65.2	-5.0	-24.0	-11.4	-53.1	-20.08	-36.01
1 x 4	13.0	-9.7	-16.0	-48.4	-18.6	-30.0	6.3	-33.9	-32.72	-38.33
4 x 1	9.6	-12.5	12.5	-31.0	-16.3	-28.0	41.2	-12.2	-17.45	-41.00
1 x 5	4.6	-5.6	-5.8	-24.9	-4.4	-34.0	6.9	-12.1	28.01	-22.65
5 x 1	-0.8	-10.4	-11.8	-29.7	-26.1	-49.0	-3.3	-20.5	38.19	-16.02
1 x 6	-1.1	-6.3	17.6	-21.9	-2.4	-19.0	48.9	-18.7	8.11	-32.82
6 x 1	-1.8	-6.9	21.2	-19.4	-6.0	-22.0	101.8	10.2	7.77	-32.29
2 x 3	-2.7	-11.8	25.8	-29.8	11.7	-24.0	39.8	-19.3	8.04	-34.82
3 x 2	0.4	-9.0	12.7	-37.1	-4.4	-35.0	32.3	-23.6	-8.38	-37.54
2 x 4	3.5	-16.7	10.4	-26.4	-2.7	-28.0	18.8	-20.4	-23.40	-38.21
4 x 2	9.5	-11.8	15.2	-23.2	-2.7	-28.0	30.0	-12.9	-19.07	-38.83
2 x 5	6.8	-2.8	-3.5	-18.0	10.5	-37.0	-3.6	-16.1	31.39	-11.38
5 x 2	1.5	-7.6	2.8	-12.6	22.8	-30.0	2.3	-11.0	28.77	-14.44
2 x 6	6.2	1.4	5.7	-24.1	-26.8	-48.0	20.4	-28.4	7.32	-31.51
6 x 2	-0.4	-4.9	0.3	-28.0	-9.9	-36.0	35.4	-19.6	12.81	-29.92
3 x 4	11.7	-10.4	-1.1	-48.1	-48.9	-52.0	10.4	-43.9	-3.02	-40.38
4 x 3	9.1	-12.5	22.3	-35.8	-38.3	-42.0	26.0	-36.0	-17.79	-38.43
3 x 5	10.3	0.0	-8.2	-35.0	-16.9	-36.0	-7.2	-34.4	6.08	-7.61
5 x 3	-5.8	-15.0	8.2	-23.4	-22.1	-40.0	20.0	-15.1	19.68	-7.81
3 x 6	13.9	8.3	0.2	-42.3	-27.5	-34.0	25.4	-45.8	7.33	-25.63
6 x 3	0.0	-4.9	30.5	-24.9	-25.3	-32.0	89.8	-18.1	20.86	-21.62
4 x 5	21.6	-2.1	0.9	-17.6	-25.3	-38.0	-4.6	-23.6	38.03	-16.36
5 x 4	9.5	-11.8	8.0	-11.8	-27.7	-40.0	6.6	-14.7	8.58	-16.41
4 x 6	10.2	-6.3	25.1	-14.4	-42.3	-44.0	71.3	-10.1	-31.10	-36.41
6 x 4	2.0	-13.2	2.3	-30.0	-53.6	-55.0	51.5	-20.5	-14.93	-29.16
5 x 6	1.8	-2.8	9.9	-4.7	-27.5	-42.0	37.6	-0.4	40.10	7.00
6 x 5	0.4	-4.1	14.5	-0.7	-40.0	-52.0	17.8	-14.7	26.20	2.24

* 1 = 'JNY'; 2 = 'ORA'; 3 = 'KOD'; 4 = 'SOL'; 5 = 'CHG'; 6 = 'PEA'.

the hybrid 'CHG x JNY' (13.6 %), with the highest value (Table 3). These results are in agreement with those reported by Souza et al. (2005), who observed that the most positive heterosis was lower than 50.0 %.

Considering the weight of 10 seeds, 90.0 % of the hybrids presented negative heterotic effects, except for 'KOD x PEA' (9.1 %), 'PEA x KOD' (9.1 %) and 'SOL x PEA' (3.7 %) (Table 3). Heterobeltiosis was negative in all hybrids, most notably in the combinations 'JNY x KOD' and 'KOD x JNY', which simultaneously showed a value of -80.0 %. The heterosis estimates for weight of 10 seeds, seed width and seed length validate the potential of the hybrids 'JNY x KOD' and 'KOD x JNY' to be exploited as small seed-size cultivars.

As regards the seed length, heterosis was negative in 67.0 % of the combinations, being 'JNY x ORA' (-22.3 %) the most heterotic one, considering that the breeding target was to reduce seed size. Heterobeltiosis was negative in most hybrids, mainly in the combination 'KOD x JNY' (-51.3 %) (Table 3).

In relation to seed width, heterosis was negative in 90.0 % of the hybrid combinations, being the hybrid 'KOD x CHG' (-31.8 %) the most heterotic one. There was no positive heterobeltiosis, indicating that a reduction in seed width occurred in all hybrids, mainly in 'JNY x KOD' (-55.1 %) (Table 3).

Currently, in the literature, there is no heterosis estimate for length and width of watermelon seeds, as well as for Cucurbitaceae species. However, Abidiam et al. (2016) observed that, when selecting

Table 3. Heterosis (Hmp) and Heterobeltiosis (Hps) in watermelon genotypes, regarding the soluble-solids content (SSC), weight of 10 seeds (10SW), seed width (SW) and seed length (SL).

Hybrids*	Heterosis/Heterobeltiosis (%)							
	SSC		10SW		SW		SL	
	Hmp	Hps	Hmp	Hps	Hmp	Hps	Hmp	Hps
1 x 2	-2.4	-20.3	-41.9	-70.0	-26.2	-48.0	-22.3	-42.0
2 x 1	1.5	-17.1	-41.9	-70.0	-25.0	-47.1	-20.0	-40.3
1 x 3	-10.1	-23.6	-25.0	-80.0	-15.6	-55.1	-11.7	-49.4
3 x 1	0.6	-14.6	-25.0	-80.0	-12.7	-53.6	-15.1	-51.3
1 x 4	3.3	-9.6	-14.3	-70.0	-1.5	-43.4	-3.1	-40.3
4 x 1	-2.8	-14.9	-33.3	-76.7	-8.3	-47.2	-4.7	-41.3
1 x 5	-10.7	-28.3	-55.6	-73.3	-29.8	-49.3	127.6	-43.9
5 x 1	13.6	-8.9	-50.0	-70.0	-24.2	-45.2	133.7	-42.4
1 x 6	5.2	-2.1	-33.3	-80.0	-14.2	-50.0	-10.4	-44.8
6 x 1	1.6	-5.4	-22.2	-76.7	-10.8	-48.0	-8.2	-43.4
2 x 3	4.1	-16.2	-2.9	-43.3	30.9	-24.9	28.2	-19.9
3 x 2	7.0	-13.9	-48.6	-70.0	-6.0	-46.1	-9.4	-43.3
2 x 4	6.5	-11.5	-20.0	-46.7	-2.3	-22.7	0.4	-17.0
4 x 2	6.7	-11.4	-10.0	-40.0	-4.8	-24.7	-3.0	-19.8
2 x 5	12.8	-14.6	-16.4	-23.3	-4.1	-5.8	97.7	-1.2
5 x 2	3.6	-21.5	-1.8	-10.0	-1.2	-2.9	105.0	2.5
2 x 6	7.4	-4.8	-18.9	-50.0	-13.6	-27.2	-8.3	-20.2
6 x 2	0.3	-11.2	-29.7	-56.7	-11.2	-25.2	-10.4	-22.1
3 x 4	-0.7	-14.2	-28.0	-70.0	-11.0	-41.1	-9.3	-36.9
4 x 3	-7.1	-19.8	12.0	-53.3	1.7	-32.7	8.0	-24.8
3 x 5	9.4	-13.6	-55.0	-70.0	-31.8	-44.9	80.5	-41.0
5 x 3	-0.9	-21.7	-55.0	-70.0	-31.1	-44.2	82.1	-40.5
3 x 6	-6.1	-13.7	9.1	-60.0	-0.2	-33.2	2.1	-28.8
6 x 3	-0.7	-8.7	9.1	-60.0	2.6	-31.3	3.2	-28.1
4 x 5	1.3	-17.3	-24.4	-43.3	-11.0	-24.1	118.2	-19.5
5 x 4	6.5	-13.0	-28.9	-46.7	-10.7	-23.8	119.3	-19.0
4 x 6	4.4	-1.4	3.7	-53.3	-0.9	-29.3	5.6	-22.0
6 x 4	5.8	-0.1	-11.1	-60.0	-2.3	-30.3	3.2	-23.7
5 x 6	6.2	-7.5	-28.6	-50.0	-12.0	-24.3	114.7	-20.5
6 x 5	-1.4	-14.1	-23.8	-46.7	-12.5	-24.7	116.3	-20.0

* 1 = 'JNY'; 2 = 'ORA'; 3 = 'KOD'; 4 = 'SOL'; 5 = 'CHG'; 6 = 'PEA'.

landrace watermelon seeds in an initial population of smaller length, the seeds of the individuals of the next generation had even smaller seeds, when compared to the previous generation. Based on this result, the authors proposed that the character is controlled by one or two genes. Thus, in the absence of epistatic effects, it was expected that, in the F_1 population, resulting from crosses between parents of smaller and larger seed size, their fruits had small seeds, a behavior observed in the present study.

The results presented here contributed to the identification of highly heterotic hybrids. This information may be used to support watermelon breeding programs, especially for reducing seed size.

CONCLUSIONS

1. The genotypes ‘ORA’, ‘SOL’, ‘CHG’ and ‘PEA’ showed to be promising in the hybrid combinations targeting larger fruits, whereas ‘JNY’ and ‘KOD’ provided combinations with small fruits and small seeds. Therefore, these genotypes may be used in breeding programs with different purposes;
2. The hybrids ‘CHG x ORA’ and ‘ORA x CHG’ showed to be promising, in terms of precocity, fruits of higher weight and higher soluble-solids content. These hybrids could be grown in order to meet the market demands for larger fruits. On the other hand, ‘KOD x JNY’ and ‘JNY x KOD’ showed a potential to produce small fruits and small seeds. Therefore, they could be grown to meet the market demands for ‘mini watermelons’.

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