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Research article

Assessment of hybrid vigour, dominance effect and hybrids regeneration potential in the genus *Citrullus*

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ABSTRACT

The current research was directed to explore hybrid vigour for hybrids resulting from crosses among six genotypes of the genus *Citrullus*, including *C. mucosospermus*. For such purpose, the mid parent heterosis and the best parent heterosis were assessed. Non parametric method related to homogeneity Chi-square at 5 % likelihood was applied to compare the regeneration potential of progenies. Student's parametric test at 5% was used to separe two means. Six parental genotypes and 16 hybrid families were evaluated for heterosis. The results showed a heterosis effect for all the characters studied nevertheless, this one varies according to the crossing. The observed hybrid vigour would be due to a superdominance or partial dominance effect. In addition, progeny from crosses have the same regenerative potential on both study sites.

1. Introduction

A hybrid assortment is obtained from a particular cross between two great combiners. The prevalence of hybrid variety is ascribed to the hybrid vigor phenomenon (Koemel et al., 2004). Heterosis is the interpretation of the hybrid vigour (Demarly, 1977). It is the increasing of the resistance to pests/diseases, the size, the adaptability, fertility among other things, resulting from the interaction between two genome in cross (Shull, 1914). **There are two routes used to assess heterosis:** mid-parent heterosis **which is the general exhibition of a half breed contrasted with the mean of its folks and better parent heterosis. This one is the presentation of the crossover contrasted with the mean of its better parent. The hereditary bases of heterosis have been seriously looked for nearly a century with various methodologies. Several theories have been put forward by researchers to elucidate the basis of heterosis** (Khanna-Chopra, 1982). **Three theories i.e., dominance, superdominance, and epistasis, have been proposed for hereditary clarifications with respect to heterosis. In the strength theory, the parental sub-par alleles in the crossovers are supplemented by the unrivaled or predominant alleles of the other parent. In the superdominance theory, heterosis emerges from allelic collaborations inside every one of numerous hereditary loci. Another model, epistasis, hypothesizes that communications among various parental qualities in half breed lead to heterosis** (Gao et al., 2014). Accessing heterosis is reported to be a reliable approach to improve yield and yield stability in crops (Selva et al., 2020). **It speaks to an urgent issue in plant and creature rearing just as transformative science** (Fiévet et al., 2018). **Heterosis has been utilized in the reproducing and creation of numerous creature and plant species** (Springer and Stupar, 2007). It has been exploited extensively in agricultural production (Birchler et al., 2003) and has contributed significantly to global food security (Duvick, 1999).

Citrullus mucosospermus is native to sub-Saharan western Africa (Luan et al., 2019). It is an herbaceous food plant, belongs to the family Cucurbitaceae. The species of the Cucurbitaceae family are considered as orphan crops (Zoro Bi et al., 2006). **Orphan crops are significant for supporting maintainable and assorted cultivating frameworks. They give food and pay to ranchers in Africa, South America where they are adjusted to nearby conditions a as significant staples in local diets** (Ebert, 2014; Chiurugwi et al., 2019). *Citrullus mucosospermus*

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is one of the most widespread oilseed crops in Côte d'Ivoire and is one of the native plants known as "minor plants", "orphaned" or "underutilized". It is popular at ceremonies such as yam festivals, the first days of New Year, and during wedding and baptism ceremonies (Djè et al., 2006). The valorisation of these plants could make a significant contribution to the development of local communities **with regards to environmental change**. However, the cultivars of this previously enumerated species are unproductive and the increasing of production requires the development of large areas (Koffi et al., 2009). Thus, the development of new high-yielding ecotypes by studying the heterosis effect is now a major objective of the research. The heterosis effect was evaluated between two Ivorian cultigroups (bebu and wlêwlê) of *C. mucosospermus* on several agromorphological traits (Adjoumani et al., 2016). Heterosis is observed for the mass and size of the fruits. The objective of this study is to improve the production of *C. mucosospermus* by exploiting the heterosis effect. This phenomenon, widely exploited in plant breeding, ensures the development of more vigorous, high yielding cultivars with better performances.

2. Materials and methods

2.1. Study sites

The trials were directed at two destinations: Abidjan and Manfla located respectively in the South and West-central Côte d'Ivoire from March to July 2015.

Abidjan is situated somewhere in the range of 5°17′N and 5°31′N and 3°45′W and 4° 22′W. The atmosphere is a wet subequatorial, with the normal yearly precipitation of 1350 mm, and a normal yearly temperature of about 25°C with a sandy and ferralitic soil covered by the forest (Yao-Kouamé and Kane, 2008).

Manfla is a village situated somewhere in the range of 7°00′N and 7°26′N and 6°00′W and longitudes 6°30′W and 400 km North Abidjan (Côte d'Ivoire). Manfla has a two rainfall seasons with a longer one. The rainy season is isolated by a brief time of dry (July-August) and a long dry season (December-February). Yearly precipitation shifts from 800 to 1400 mm with a long-haul of 1200 mm and the yearly normal temperature is 27°C. The trials were set in sandy topsoil soil with pH = 6.45, sandy (57%), topsoil (36%), earth (7%), natural issue content (6%), N–NO3 (3.5 ppm), accessible P (24.4 ppm) and 0.45 ppm of K (0–20 cm profundity). The vegetation is a forest savanna (Kouassi and Zoro Bi, 2010).

2.2. Plant materials

The plant material used consisted of six genotypes of the genus *Citrullus*. To facilitate the writing style of genotypes, codes have been affected to different genotypes (Table 1). In addition, the performances of each genotype used in this study are presented (Table 2).

2.3. F1 hybrid developing, experimental design and cultural practices

The six genotypes of the genus *Citrullus* were used for the developing of hybrid families. A 6 × 6 complete diallel mapping system without selfing was used. This system consisted in direct and inverse crosses between individuals from each of the six genotypes. Five plants of each genotype were used for the hybridizations. The trial was conducted on a plot of 600m^2 (30 m × 20 m) in Manfla from October 2014 to January 2015. At the end of this first trial, 16 hybrid families were developed.

The six parental lines as well as the 16 hybrid families were subjected to the evaluation of heterosis. An experimental plot of 50 m × 50 m was set on each of the two sites. The experimental design put in place was a randomised complete block design with two replications. **Each surface** had 20 lines in 2 m apart and seedlings 2 m also. Ten plants from each parental line and from each hybrid family were sown in both blocks. **A weeding has been carried out to dodge any opposition with grass**.

2.4. Data collection and statistical analysis

Agronomic data collected from parental accessions and hybrid families of the *Citrullus* genus were measured by four performance traits. These are the weight of the fruit (PoFr), the number of seeds per fruit (NGFr), the weight of 100 seeds (P100), and the harvest index (InRe).

The weight of the fruit (PoFr) corresponds to the weight of the mature fruits weighed using a Roberval balance. The number of seeds per fruit (NGFr) corresponds to the number of seeds per fruit. The weight of 100 seeds corresponds to the weight of 100 seeds weighed using a Roberval balance. Harvest index is the ratio of total seed weight to fruit weight (Nerson, 2002). The traits such as the weight of fruit, the number of seeds

Table 1. List of genotypes used in this study.

Genotypes	Species	Type of fruit	Origin	Code of accessions
PI 299378	*Citrullus lanatus* var. *citroides*	Watermelon	Afrique du Sud	P_1
PI 306782	*Citrullus lanatus* var. *lanatus*	Oleaginous type	Nigéria	P_2
PI 307750	*Citrullus lanatus* var. *lanatus*	Watermelon	Philipine	P_3
PI 559994	*Citrullus lanatus* var. *lanatus*	Oleaginous type	Nigéria	P_4
NI 216	*Citrullus mucosospermus*	Oleaginous type	Côte d'Ivoire	P_5
NI 217	*Citrullus mucosospermus*	Oleaginous type	Côte d'Ivoire	P_6

Table 2. Mean values of genotypes for the traits studied.

Genotypes	Characters							
	P100 (g)		NGFr		PoFr (g)		InRe	
	Abidjan	Manfla	Abidjan	Manfla	Abidjan	Manfla	Abidjan	Manfla
PI 299378	10.335	5.898	296	304	1246	999	0.027	0.020
PI 306782	8.140	5.367	63	123	912	192	0.005	0.035
PI 307750	12.080	9.837	215	158	649	188	0.041	0.028
PI 559994	9.950	18.740	139	376	630	260	0.028	0.037
NI 216	7.290	7.133	424	157	500	226	0.061	0.025
NI 217	10.512	12.990	318	185	2009	250	0.016	0.032

per fruit, the weight of 100 seeds and the harvest index were used for the assessment of heterosis.

Heterosis was surveyed through the estimation of mid parent heterosis (MPH) and best parent heterosis (BPH).

Formula for calculation is as follows:

$$MPH = \frac{F_1\_MP}{MP} \times 100$$

$$BPH = \frac{(F_1 - BP)}{BP} \times 100$$

where F_1 = mean value of the hybrid, MP = (P1 + P2)/2 = mean value of the two **combiners** for that hybrid, and BP = better parent mean value for that hybrid. The importance of heterosis was tested as follows (Feyzian et al., 2009):

$$t_1 = \sqrt{3M_e/2r \times t}$$

$$t_2 = \sqrt{2M_e/r \times t}$$

where t_1, represents the significance of the average parent heterosis; t_2, the significance of the best parent heterosis; M_e represents the residual mean square; r, the number of repetitions; t, value of the table at 5 or 1%. In addition, Student's t-test was used to compare the effect of heterosis on both sites. It was made using Statistica 7.1 software.

Then, the mode of action (dominance or additivity) of the genes governing the expression of the characters considered was explored. Let δ is the degree of dominance defined by the ratio of the difference (d) between the value of the heterozygote and the mean of the two parental homozygotes (m) to the half difference (a) between the values of the two homozygotes. The mathematical formula of the degree of dominance is as follows:

$$\delta = \frac{d}{a} = \frac{2(G_{Aa} - m)}{G_{AA} - G_{aa}}$$

Depending on the value of the degree of dominance four situations are defined (Smith, 1952; Gallais, 2009).

- If $\delta = 1$, the dominance is called complete;
- If $\delta = 0$, there is additivity.
- If $-1 < \delta < 1$, there is partial dominance.
- If $\delta > \pm 1$, there is superdominance.

The bearing of strength of either parent is demonstrated by the positive and negative signs.

Finally, the regeneration potential of hybrids has been evaluated. It was made from the numbers of the progenies of the crosses. The non-parametric Pearson's homogeneity chi-square test was applied at 5% likelihood. It was made by using SPSS.22 software.

3. Results

3.1. Evaluation of heterosis

Estimates of mid parent heterosis (MPH) and best parent heterosis (BPH) were calculated for traits such as fruit weight (PoFr), number of seeds (NGFr), weight of 100 seeds (P100), and the harvest index (InRe). Heterosis values were calculated for both study sites (Tables 3 and 4). **Some hybrids showed positive and significant heterosis in contrast to negative and not significant heterosis by others.**

At the Abidjan site, all the characters studied showed a heterosis effect. The heterosis effect varied from cross to cross. Regarding the weight of 100 seeds (P100), the majority of crosses showed positive heterosis. Hybrids had high values than their parents. Mean parent heterosis ranged from 10.82% for $P_3 \times P_5$ to 98.45% for $P_2 \times P_5$. The best parent heterosis ranged from 5.89% for the $P_3 \times P_4$ cross to 98.29% for the $P_2 \times P_5$ cross.

For the number of seeds (NGFr), all crosses showed negative heterosis for the best parent heterosis with the exception of the $P_4 \times P_2$ cross, which showed positive heterosis. A best parent heterosis was 86.49%. Mean parent heterosis values ranged from 1.50% to 156.79%.

For fruit weight (PoFr), mean parent heterosis ranged from 9.07% for $P_4 \times P_1$ to 388.60% for $P_3 \times P_5$. The best parent heterosis spread out from 15.81% to 329.12%.

Table 3. Values of mean heterosis (MPH), best parent heterosis (BPH) and estimates of degree of dominance (δ) for the characters studied at the Abidjan site.

Crossing	P100*			NGFr*			PoFr*			InRe*		
	MPH*	BPH*	δ*	MPH	BPH	δ	MPH	BPH	δ	MPH	BPH	δ
P_4*P_1	24.36	22.97	21.54	- 2.65	- 28.51	- 0.07	9.07	- 28.21	0.17	4.56	- 19.56	0.15
P_4*P_2	30.43	11.62	1.81	156.79	86.49	4.16	24.14	- 2.78	0.87	63.33	- 0.67	0.98
P_4*P_5	42.25	21.65	2.50	- 15.48	- 43.85	- 0.31	123.61	98.94	9.97	- 41.82	- 57.63	- 1.12
P_4*P_6	24.01	20.04	7.26	- 2.79	- 30.20	- 0.07	- 25.33	- 50.96	- 0.48	32.10	7.50	1.40
P_3*P_2	53.20	24.29	2.29	26.05	- 18.57	0.48	- 12.31	- 30.58	- 0.47	61.27	- 7.69	0.82
P_3*P_4	12.95	5.89	1.94	18.38	- 2.61	0.85	38.95	36.91	26.22	- 4.45	- 20.24	- 0.23
P_3*P_1	- 0.39	- 7.59	- 0.05	- 4.96	- 17.97	- 0.31	- 19.21	- 46.44	- 0.38	- 9.23	- 38.24	- 0.20
P_3*P_5	10.82	- 10.14	0.46	19.55	- 9.78	0.60	388.60	329.12	28.04	- 72.38	- 76.78	- 3.82
P_6*P_1	28.81	23.34	6.50	- 12.19	- 15.25	- 3.38	- 35.49	- 35.77	- 79.87	73.41	61.14	9.64
P_2*P_5	98.45	98.29	1 234.83	4.98	- 39.70	0.07	60.69	15.81	1.57	- 34.61	- 64.08	- 0.42
P_2*P_6	38.17	15.10	1.90	1.50	- 39.24	0.02	- 53.83	- 64.13	- 1.87	187.69	93.42	3.85
P_5*P_1	83.38	58.32	5.27	- 23.28	- 34.75	- 1.32	50.38	- 6.28	0.83	- 32.24	- 57.79	- 0.53
P_5*P_2	45.51	45.39	570.74	- 4.20	- 44.98	- 0.06	15.31	- 16.90	0.40	8.55	- 40.37	0.10
P_5*P_4	65.40	41.45	3.86	- 25.31	- 50.38	- 0.50	89.71	68.78	7.24	- 24.45	- 44.99	- 0.65
P_6*P_3	56.91	30.62	2.83	- 45.44	- 52.17	- 3.23	- 10.27	- 44.17	- 0.17	- 28.70	- 54.14	- 0.52
P_6*P_5	76.88	47.34	3.83	7.02	-35.93	0.10	- 31.07	- 46.46	- 1.08	96.18	31.90	1.97
t *(0.05)	2.18	2.51	-	28.72	33.16	-	87.07	100.54	-	0.005	0 .004	-

Variables*: P100: weight of 100 seeds; NGFr: number of seeds per fruit; PoFr: weight of the fruit; InRe: harvest index.
MPH*: Mid Parent Heterosis; BPH: Best Parent Heterosis.
δ*: degree of dominance.
t*: significance of heterosis.

Table 4. Values of mean heterosis (MPH), best parent heterosis (BPH) and estimates of degree of dominance (δ) for the characters studied at the Manfla site.

Crossing	P100*			NGFr*			PoFr*			InRe*		
	MPH*	BPH*	δ*	MPH	BPH	δ	MPH	BPH	δ	MPH	BPH	δ
P_4*P_1	- 30.02	- 33.47	- 1.04	- 36.63	- 16.27	- 5.42	14.63	20.24	0.68	- 54.87	- 53.43	- 2.42
P_4*P_2	- 28.62	- 40.65	- 1.41	- 50.50	- 67.03	- 1.01	- 54.05	- 71.23	- 0.90	- 14.82	- 40.65	0.34
P_4*P_5	- 25.54	- 33.60	- 2.10	- 15.75	- 40.00	- 0.39	- 54.74	- 64.68	- 1.95	43.46	28.90	3.85
P_4*P_6	- 26.57	- 36.57	- 1.69	- 44.90	- 58.65	- 1.35	- 38.78	- 52.38	- 1.36	- 42.67	- 51.45	- 2.36
P_3*P_2	23.95	19.21	6.02	46.54	30.17	3.70	107.45	65.00	4.18	- 62.27	- 75.98	- 1.09
P_3*P_4	- 19.72	- 31.04	- 1.20	- 45.10	- 60.81	- 1.13	- 81.81	- 87.02	- 2.04	72.03	45.66	3.98
P_3*P_1	24.01	0.93	1.05	25.21	- 4.79	0.80	42.33	26.51	3.38	18.30	4.51	1.39
P_3*P_5	- 9.93	- 13.69	- 2.28	19.90	19.43	- 50.20	- 76.40	- 79.22	- 5.63	285.52	260.44	41.03
P_6*P_1	13.89	- 7.79	0.59	- 55.85	- 64.46	- 2.30	- 69.82	- 70.00	- 116.60	83.21	61.83	6.30
P_2*P_5	34.44	24.11	4.14	11.98	- 0.18	0.98	- 17.38	- 40.12	- 0.46	9.86	- 27.84	0.19
P_2*P_6	18.16	12.90	3.90	-10.46	- 25.54	- 0.52	3.17	- 25.00	0.08	- 46.57	- 65.99	- 0.82
P_5*P_1	116.29	8.14	1.16	252.87	- 8.85	- 2.53	139.84	19.92	1.40	147.78	23.89	1.48
P_5*P_2	15.74	6.85	1.89	- 35.69	- 42.68	- 2.93	- 48.75	- 62.86	- 1.28	- 43.96	- 63.19	- 0.84
P_5*P_4	- 3.65	- 14.09	- 0.30	- 29.92	- 50.09	- 0.74	- 23.73	- 40.48	- 0.84	- 19.87	- 28.00	- 1.76
P_6*P_3	- 2.69	- 6.14	- 0.73	- 40.79	- 45.31	- 4.93	- 79.09	- 79.19	- 165.74	150.31	134.08	21.67
P_6*P_5	- 18.56	- 22.18	- 3.98	- 21.81	- 34.98	- 1.08	- 70.52	- 78.57	- 1.88	36.37	- 13.20	0.64
t* (0.05)	0.77	0.90	-	35.32	40.78	-	143.76	166.01	-	0.03	0.036	-

Variables*: P100: weight of 100 seeds; NGFr: number of seeds per fruit; PoFr: weight of the fruit; InRe: harvest index.
MPH*: Mid Parent Heterosis; BPH: Best Parent Heterosis.
δ*: degree of dominance.
t*: significance of heterosis.

For the harvest index, the average parent heterosis ranged from 4.56% for the $P_4 \times P_1$ cross to 187.69% for the $P_2 \times P_6$ cross. The best parent heterosis ranged from 7.50% for $P_4 \times P_6$ to 93.42% for $P_2 \times P_6$.

At the Manfla site, all the characters studied also showed the heterosis effect. The heterosis effect varied from cross to cross. The weight character of 100 seeds (P100) showed a heterosis effect for some crosses. Mid parent heterosis ranged from 13.89% for $P_6 \times P_1$ to 116.29% for $P_5 \times P_1$. The best parent heterosis ranged from 0.93% for $P_3 \times P_1$ to 24.11% for $P_2 \times P_5$. The $P_2 \times P_5$ crossover showed the highest degree of heterosis.

For the number of seeds and the weight of the fruit, only five crosses showed the heterosis effect. The $P_5 \times P_1$ cross had the highest mean parent heterosis for both characters. The average parent heterosis was 252.87% for the number of seeds and 139.84% for the weight of the fruit.

At harvest index level, $P_3 \times P_5$ crosses indicated high values for the 285.52% mid parent heterosis and the 260.44% best parent heterosis.

A comparison of the expression of the heterosis effect at both sites was assessed through Student's t-test. The results showed that the study site did not influence the manifestation of the heterosis effect for all traits with the exception of the weight of 100 seeds (P100) (Table 5). Expression of heterosis in hybrids at both sites did not vary for fruit weight (PoFr), harvest index (InRe), and number of seeds per fruit (NGFr). For the 100-seed weight (P100) trait, hybrids expressed better heterosis at the Abidjan site compared to the Manfla site.

3.2. Analysis of the mode of action of genes

The values of the estimates of the mode of action of the genes are illustrated in Tables 3 and 4.

At the Abidjan site, for the number of seeds, the values ranged from -3.37 to 4.15. Values ranged from ± 1 for 12 crosses to more than ± 1 for four crossings indicating partial dominance and superdominance for this trait. For the harvest index, the values ranged from -0.42 to 9.64. Values ranged from ± 1 for 10 crosses to more than ± 1 for six crossings indicating partial dominance and superdominance for this trait. For the weight of the fruit, eight crosses showed a superdominance while eight others showed partial dominance. For the weight of 100 seeds, 15 crosses showed a superdominance reaction whereas one cross showed partial dominance for the transmission of this trait (Table 3).

At the Manfla site, for the number of seeds 11 crosses showed superdominance while five crosses showed partial dominance for the transmission of this trait. The harvest index showed that the values ranged from -0.82 to 41.03 and were greater than ± 1 for 11 cross indicating super dominance while ± 1 for five crosses indicating partial dominance. For the weight of the fruit, 11 crosses expressed a super dominance as against five crosses showed partial dominance. For the weight of 100 seeds, the values ranged from -3.98 to 6.02. Nine crosses had values greater than ± 1 indicating superdominance whereas three crosses had values between ± 1 indicating partial dominance (Table 4).

Table 5. Comparison of mean heterosis (MPH) and best parent heterosis (BPH) values from both sites.

Variables	P100*			NGFr*			PoFr*			InRe*		
Site	Abidjan	Manfla	*P*	Abidjan	Manfla	*P*	Abidjan	Manfla	*P*	Abidjan	Manfla	*P*
MPH*	43.19	5.07	˂ 0.01	6 .12	-1.93	0.71	38.30	-19.22	0.07	17.45	35.11	0.54
BPH*	28.03	-10.44	˂ 0.01	-23.58	-29.37	0.52	11.05	-38.62	0.07	-18.01	8.72	0.29

Variables*: P100: weight of 100 seeds; NGFr: number of seeds per fruit; PoFr: weight of the fruit; InRe: harvest index.
MPH*: Mid Parent Heterosis; BPH: Best Parent Heterosis.

3.3. Potential for regeneration of hybrids

The regeneration potential of hybrids has been tested through the equality of the cross-breeding progeny. For this purpose, the Pearson's Chi-square test for homogeneity was performed. The results of the statistical tests showed that the numbers were equal (p-value ˃ 0.05) suggesting that the regeneration potential of the crossover progenies is the same for all crosses. The ability to give viable hybrids is the same for all crosses as well as on both study sites (Tables 6 and 7).

4. Discussion

Heterosis is an important genetic event used to increase yield and improve crop quality. **The heterosis effect expressed in certain cereal crops such as maize, rice and sorghum have made it possible to develop and cultivate hybrids** (Qi et al., 2009). The study of heterosis involving the species *C. mucosospermus* was assessed here. Hybrids showed superiority over their parents; in other words, hybrids showed heterosis for traits related to yield.

Table 6. Homogeneity of the number of crossing progenies of the 6 × 6 diallele without self-fertilization obtained from Abidjan using the homogeneity chi-square test.

Crossing	Observed workforce	Theoretical staff	Residue	Sources	Statistical
P_4*P_1	10	8.3	1.7	chi-square	10.519
P_4*P_2	8	8.3	-0.3	df	15
P_4*P_5	9	8.3	0.7	p-value	0.786
P_4*P_6	10	8.3	1.7		
P_3*P_2	7	8.3	-1.3		
P_3*P_4	9	8.3	0.7		
P_3*P_1	4	8.3	-4.3		
P_3*P_5	10	8.3	1.7		
P_6*P_1	7	8.3	-1.3		
P_2*P_5	2	8.3	-6.3		
P_2*P_6	10	8.3	1.7		
P_5*P_1	10	8.3	1.7		
P_5*P_2	10	8.3	1.7		
P_5*P_4	7	8.3	-1.3		
P_6*P_3	10	8.3	1.7		
P_6*P_5	10	8.3	1.7		
Total	133				

Table 7. Homogeneity of the number of crossing progenies of the 6 × 6 diallele without self-fertilization obtained from Manfla using the homogeneity chi-square test.

Crossing	Observed workforce	Theoretical staff	Residue	Sources	Statistical
P_4*P_1	3	3.3	-0.3	chi-square	17.340
P_4*P_2	2	3.3	-1.3	df	15
P_4*P_5	3	3.3	-0.3	p-value	0.299
P_4*P_6	6	3.3	2.7		
P_3*P_2	4	3.3	0.7		
P_3*P_4	3	3.3	-0.3		
P_3*P_1	4	3.3	0.7		
P_3*P_5	8	3.3	4.7		
P_6*P_1	2	3.3	-1.3		
P_2*P_5	1	3.3	-2.3		
P_2*P_6	3	3.3	-0.3		
P_5*P_1	1	3.3	-2.3		
P_5*P_2	1	3.3	-2.3		
P_5*P_4	2	3.3	-1.3		
P_6*P_3	5	3.3	1.7		
P_6*P_5	5	3.3	1.7		
Total	53				

There is a heterosis effect for the fruit weight, the number of seeds (NGFr), the weight of 100 seeds (P100) and the harvest index (InRe). **These results are identical to those of** Adjoumani et al. (2016) **who proved that hybrids derived** from the cross between two *C. mucosospermus* cultivtigroups cultivated in Côte d'Ivoire were larger than their parents. In other words, the hybrids showed a heterosis effect for the weight of the fruit. In addition, the work done by Feyzian et al. (2009) on melon showed that there is also a heterosis effect for the weight of the fruit. According to these authors, the effect heterosis observed in melon is due to an additive effect of the genes. However, analyzes of the mode of action of the genes performed in this study on *C. mucosospermus* revealed that the traits studied were governed by either partial dominance or super domination according to the crosses performed. Indeed, three main models can explain the hybrid vigor in plants: dominance (partial dominance), superdominance and epistasis (Użarowska et al., 2007). Hybrid vigor due to a partial dominance effect theoretically shows the possibility of some lineages to surpass hybrids (Tsaftaris, 1995). However, superdominance would result from the interaction between the different alleles present in F1 hybrids that would outperform the effect of homozygous genotypes in parents (Fu et al., 2015). The heterosis effect observed in this study could be explained either by a partial dominance or superdominance effect.

Heterosis values for fruit weight, number of seeds, 100-seed weight, and harvest index were high for some crosses. These high values of observed heterosis may be explained by the fact that the characters studied are quantitative. They are under the control of many genes and are therefore likely to show a high degree of heterosis (Nerson, 2012).

The study site did not influence the expression of heterosis for the traits studied and all hybrids had the same regenerative potential. This result could find an explanation through the climatic conditions of these two zones of study were favourable to the development of cultivated plants. All hybrids created are viable at both sites. This result suggests the possibility of using these hybrids in different agroecological zones.

5. Conclusions

The improvement of *C. mucosospermus* was initiated by the study of hybrid vigour. The results showed that this improvement is possible. The degree of heterosis varies according to crosses. The genotype × environment interaction was taken into account in the assessment of hybrid vigour. For the majority of the characters studied on the two sites, the hybrid vigour is the same. The P_1 and P_5 parents, respectively of the watermelon and oleaginous type involved in crosses, showed good values for heterosis. They can be used in breeding programs for hybrid development.

Declarations

Author contribution statement

Chia Michelle Valérie Angui, Bi Irié Arsène Zoro: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Kouamé Kevin Koffi, Auguste Emmanuel Issali: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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