Productive potential and castor bean selection of the FCA-PB cultivar progenies[1]

Jackson da Silva[2], Andréia Rodrigues Ramos[3], Deoclécio Jardim Amorim[3], Mauricio Dutra Zanotto[3], Maria Márcia Pereira Sartori[3]*

10.1590/0034-737X202067010007

ABSTRACT

Castor bean is a very important crop, however, in Brazil it still has relatively low productivity, 0.47 Mg ha^{-1} as a mean. Besides that the Country has significant castor oil demand and depends on international commerce to complement its production. The solution of these problems goes through the development of genotypes highly productive and adapted to the producing regions. So, the objective of this research was to evaluate the productive potential and selection of castor progenies of the cultivar FCA-PB, resulting from three types of pollination, in two crops and in two localities of the State of São Paulo. Grain productivity was evaluated, and some genetic parameters were estimated. In relation to the 2005/2006 crop, the progeny 49 cultivated in the locality of São Manuel produced 4170.66 kg ha^{-1} of grains. The highest heritability coefficients were observed in the 2005/2006 crop in the locacity of Araçatuba. Progenies 1, 5, 6, 8, 15, 18, 19, 21, 27, 31, 35, 36, 38, 45, 49, 55, 56 and 58 were selected. Genotype interaction with the location indicated productive materials and adapted to the state of São Paulo.

Keywords: *Ricinus communis* L.; breeding; pure lines; stability.

INTRODUCTION

The castor bean belongs to the family Euphorbiacea, genus Ricinus and species *Ricinus communis* L. according to Ferreira (2006), this culture belongs to the center of origin Absinthia, classified by Vavilov, being this region the place that one finds the greater genetic diversity of the species. This crop has many applications in the industrial area and in the production of biodiesel, having thus, relevant economic importance (Goneli *et al*., 2018).

Brazil is the fourth largest producer in the world, with production of 24 thousand tons and relatively low productivity with 0.47 Mg ha^{-1}, being the national production concentrated in the Northeast with 88.54%, where the State of Bahia is the country's largest producer with a production of 10.4 thousand tons, presenting productivity of 0.49 Mg ha^{-1} (FAO, 2016; CONAB, 2017).

Although the country is one of the world's leading producers of this crop, according to FAO (2016), this year the Brazil imported 3621 tons to meet the industry demand this oil. Thus, there is a demand for the production of castor oil, which can be achieved with the development of highly productive genotypes besides being adapted to the edaphoclimatic conditions of each producing region (Daronch *et al.*, 2019).

The development of these genotypes depends on genetic improvement, in which one can glimpse the obtaining of varieties, hybrids and pure lines, being the pollination a factor that reflects in the homozygous level and, consequently, on the purpose of the genotype. In addition, genetic improvement still involves the study of the adaptation of a given genotype to a certain location, hence the importance of evaluating in different years and

Submitted on March 1st, 2019 and accepted on November 1st, 2019.

[1] This work is part of the master's thesis of first author.

[2] Universidade Federal Rural de Pernambuco, Recife, Pernambuco, Brazil. jackson.silva.batalha@gmail.com

[3] Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, São Paulo, Brazil. andreia-agro@hotmail.com; deocleciojardim@hotmail.com; zanotto@fca.unesp.br; maria.mp.sartori@unesp.br

*Corresponding author: maria.mp.sartori@unesp.br

places, because this increases the accuracy of the breeder when selecting the best genotypes (Cruz *et al*., 2012).

Selection of superior genotypes can be hampered because the characteristics are controlled by several genes, in particular the quantitative characteristics, such as grain yield. However, the use of genetic parameters, such as heritability and genetic gain, can guide the selection, in order to make it more efficient (Gaya *et al*., 2006).

In view of the foregoing, the objective of the present research was to evaluate the productive potential and castor bean selection of the FCA-PB cultivar progenies, resulting from three types of pollination, in two crops and in two localities of the State of São Paulo.

MATERIAL AND METHODS

Location and characterization of experimental areas

The experiments were developed in the 2004/2005 and 2005/2006 crop seasons, in the months of October to May, simultaneously in two localities of the State of São Paulo, São Manuel and Araçatuba. The climate of the city of São Manuel-SP, is of type Cfa, the average annual temperature is between 18 to 20 °C, with annual average rainfall between 1000 and 1300 mm and altitude between 600 and 800 meters. In relation to the city Araçatuba, according to the classification of Köppen-Geiger is type Aw, presenting an average annual temperature of 22.2 °C, with annual average rainfall of 1206 mm and altitude around 401 meters (Alvares *et al*., 2014).

Experimental design and treatments

The experiments were in design in randomized blocks, in the factorial scheme 90 x 2 x 2, being 90 progenies (coming from three types of pollination, free pollination (progenies 01 to 30), cross-pollination (progenies 31 to 60) and self-fertilization (progenies 61 to 90)), 2 localities (São Manuel and Araçatuba) and 2 agricultural crops (2004/2005 and 2005/2006), with three replications. It is noteworthy that castor bean progenies were obtained from the FCA-PB population (developed by Program for the Improvement of castor beans of UNESP/FCA).

Installation and conduction of experiments

Prior to the installation of the experiment, soil samples were drawn at a depth of 0.0 to 0.2 m. With the results, was carried out the fertilization of foundation with 400 kg ha^{-1} of formulated fertilizer 04-14-08.

Soil preparation was carried out in a traditional way with two plows and two harrows. Subsequently, the grooves were opened and the fertilizer was distributed with a seeder-fertilizer tratorized, adjusted according to the spacing of 1.0 m between rows.

Plantings of the experiments occurred in October 2004 and 2005, where three seeds were manually placed every 0.5 m of furrows, with depths of 4 to 8 centimeters, and ten days after the emergency the thinning was left leaving two plants per linear meter.

The experimental plot consisted of 3 lines of 7 m in length, having used the spacing of 1.0 x 0.5 m, where they were considered as useful area, for data collection, the central row, discarding the first two plants of each end.

To ensure the germination and uniformity of the plants, so that the maintenance of soil moisture for the crop occurred ideally, a sprinkler irrigation system was installed, with a blade varying according to the evapotranspiration of castor bean, this system was only used in the initial phase of the culture.

Due to the long cycle of this culture, weed control was carried out at three times during the crop cycle, being this control occurred manually.

Evaluated characters

The crops were harvested in May 2005 and 2006, in which the evaluation was given of grain yield (PG), in kg ha^{-1}, having weighed the seeds of the five central plants of the plot, corrected to 13% moisture and, in followed estimated for hectare.

Statistical analysis

The measured data were submitted to analysis of variance and joint analysis of variance, considering the effects of treatments as fixed. And when necessary, the comparison was applied between the means of the treatments by the Scott-Knott test, at the 5% probability level, with the use of AgroEstat software (Barbosa & Maldonado Junior, 2015).

Determination of genetic parameters

With the productivity data in hand, were calculated some genetic parameters: heritability to the average level, expected genetic gain and the estimated genetic progress in percentage, as detailed in equations 1, 2, 3 and 4, reported by Cruz *et al*. (2012), being the equations expressed as follows:

$$h^2m = \frac{\text{QMP - QME}}{\text{QMP}} \tag{1}$$

In what: h² m = heritability at the level of progeny average

QMP = Average square of progeny

QME = Average square of the residue

$$\Delta G = i \frac{\sigma^2 p}{\sqrt{\sigma^2 p + \frac{\sigma^2 e}{r}}} \tag{2}$$

In which: ΔG = Estimate of expected genetic progress with 20% of selection intensity in kg ha^{-1}.

i = 1.4 standardized selection differential, corresponding to 20% of selection intensity (Vencovsky, 1980).

$\sigma^2 p$ = Genetic variance between progenies (kg ha^{-1})^2, obtained by

$$\sigma^2 p = \frac{QML - QME}{r} \quad (3)$$

r = Number of repetitions.

$\sigma^2 e$ = QME

$$G\ \% = \frac{\Delta G}{\hat{m}} \cdot 100 \quad (4)$$

In which: G% = Genetic progress estimated in percentage in relation to the average of productivity of each progeny.

ΔG = Estimated expected genetic progress with 20% of selection intensity in kg ha^{-1}.

$\hat{m}$ = Average productivity of each progeny.

RESULTS AND DISCUSSION

It is observed by the analysis of joint variance between progenies, localities and crops (Table 1) that the interaction between and harvests showed no significant behavior at 5% probability by the F test, indicating that there was no influence between locality and crop, suggesting that the progeny group, on average, shows similar behavior for grain in the two localities and two crops.

Table 1: Analysis of joint variance between progenies, localities and crops in relation the characteristic grain yield (kg ha^{-1})

Source of variation	GL(1)	QM(2)
Block / Location	4	2444572.63
Location	1	6191957.57**
Crop	1	2011912.03**
Progeny	89	1383597.44**
Free pollination	29	1517654.72**
Cross pollination	29	937153.98**
Self-pollination	29	1361299.33**
Between Progeny	2	6236519.81**
Location x Crop	1	159870.00ns
Location x Progeny	89	1093284.65**
Crop x Progeny	89	918884.95**
Location x Crop x Progeny	89	1132049.00**
Treatment	359	
Residue	716	119344.65
Total	1079	
CV(3)	15.92	

**: Significant at the 1% probability level and ns not significant at 5% probability, both by test F. 1: Degrees of freedom; 2: Average square; 3: Coefficient of variation.

However, in all other sources of variation were detected the respective significance at the 1% probability level by the F test, thus observing variation among the progenies in general, as well as between types of pollination and between the progenies in each method of pollination, indicating significant gains with the selection of the best progenies.

Due to the significance of the interaction progeny x crop x location at the 1% probability level by the F test, the analysis of joint variance was broken down into two, being a joint analysis of variance, progenies and local and the other progenies and crops.

In the analysis of joint variance between progenies and local for each crop (Table 2), It is observed that the progenies and the localities obtained the same behavior in the two crops, taking the local and progeny factors, in general, presented significant non-significant effects at the 5% probability level and the interaction progeny x location, free pollination, cross-pollination, self-pollination and between these three types of pollination significance at the 1% probability level by the F test.

Due to the significance of the analysis of joint variance, it was necessary to apply the comparison test between averages (Table 3), it can be observed that, in crop 2004/2005, 54% of the progenies presented a difference in productivity between the localities, and in the 2005/2006 crop 44%.

As the progeny x local interaction was significant and most of the progenies present differences between the production localities it is natural and important in genetic breeding that each progeny best suit a given environment, because in this way the breeders can act to select genotypes with a higher level of phenotypic stability, as well as the development of cultivars or lines adapted to a specific region, at the expense of genetic gains and precision in selection (Torres *et al*., 2015).

Thus, the progenies that presented the highest productivity of grains in the 2004/2005 crop in São Manuel were: 1, 3, 5, 7, 10, 22, 31, 33, 35, 37, 38, 40, 52, 78, 82, 86 and 89, with a variation of 2729 to 3262 kg ha^{-1} and in Araçatuba 8, 28, 30, 32, 42, 43, 44, 46, 49, 55, 56, 57, 61 and 68, being the variation of 3107 to 3904 kg ha^{-1}. Indicating the genetic potential of the aforementioned progenies, and detaining yields about five times higher in comparison to the national productivity in the crop of the experiments (CONAB, 2017).

In relation to the 2005/2006 crop, the progeny 49 grown in the locality of São Manuel reached 4171 kg ha^{-1} of grain yield and, the progeny 81 in the city of Araçatuba obtained yield of 4453 kg ha^{-1}. In that the high productivity of the progeny 49 can be explained by the type of fertilization that originated, which was by cross-pollination, being this method that causes the highest level of heterosis, and this progeny can result in highly productive hybrids, as it is

Table 2: Analysis of joint variance between progenies and localities, for each crop, in relation to the characteristic grain yield (kg ha^{-1})

Source of variation	GL[(1)]	QM[(2)]	
		Crop 2004/2005	Crop 2005/2006
Block / Location	4	1515510.49	1141257.40
Location	1	4170855.12ns	2180972.45ns
Progeny	89	1042230.68ns	1260251.71ns
Free pollination	29	1235607.81**	986907.17**
Cross pollination	29	647885.86**	929027.44**
Self-pollination	29	827185.07**	1360333.61**
Between Progeny	2	7074423.67**	8575311.77**
Progeny x Location	89	1235473.31**	989860.34**
Treatment	179		
Residue	356	123476.26	114169.77
Total	539		
CV[(3)]		15.87	14.66

** and ns: Significant at the 1% probability level and not significant at 5% probability, respectively, both by the test F. 1: Degrees of freedom; 2: Average square; 3: Coefficient of variation.

Table 3: Averages of grain yield (kg ha^{-1}) of progenies and localities, for each crop

Progeny	Crop 2004/2005		Progeny	Crop 2005/2006	
	São Manuel	Araçatuba		São Manuel	Araçatuba
1	2887 aA[(1)]	2494 bA	1	2946 bA	2686 dA
2	1867 cA	1463 dA	2	1860 dA	2412 dA
3	2821 aA	1772 dB	3	2772 cA	2662 dA
4	1990 cA	1503 dA	4	2004 dB	3096 dA
5	3002 aA	2055 cB	5	2988 bA	2455 dA
6	2240 bA	2805 bA	6	2208 dA	2171 eA
7	2887 aA	1584 dB	7	2928 bA	2848 dA
8	3282 aB	3904 aA	8	3276 bA	2255 eB
9	1709 cB	2315 cA	9	1674 eB	3524 bA
10	2750 aA	1641 dB	10	2796 cA	2881 dA
11	2048 cA	2614 bA	11	2028 dB	3205 cA
12	1960 cA	2032 cA	12	1890 dB	2738 dA
13	1255 dB	2560 bA	13	1086 eB	2487 dA
14	1431 dA	1037 dA	14	1476 eB	3064 dA
15	2368 bA	2870 bA	15	2364 cA	2535 dA
16	1591 cA	3122 aB	16	1500 eB	2930 dA
17	1454 dA	1930 cA	17	1494 eB	2685 dA
18	2144 bA	2247 cA	18	2130 dB	2982 dA
19	2189 bB	2778 bA	19	2190 dA	2622 dA
20	1914 cA	1258 dB	20	1884 dA	2103 eA
21	2513 bA	2741 bA	21	2484 cB	3280 cA
22	2976 aA	1359 dB	22	2958 bA	1132 gB
23	1597 cB	2635 bA	23	1650 eA	1645 fA
24	2491 bA	2562 bA	24	2574 cA	1885 eB
25	2228 bA	1762 dA	25	2136 dA	1506 fB
26	2497 bA	1911 cB	26	2520 cA	2187 eA
27	2372 bA	2479 bA	27	2352 cA	2213 eA
28	2333 bB	3478 aA	28	2184 dA	1666 fA
29	1421 dB	2123 cA	29	1524 eA	1536 fA
30	1462 dB	3066 aA	30	1488 eA	1440 fA
31	2796 aA	2669 bA	31	2167 dB	3052 dA
32	1874 cB	3158 aA	32	2305 cB	3862 bA
33	2832 aA	2004 cB	33	2046 dA	2341 dA
34	2006 cA	2080 cA	34	2125 dB	2706 dA

Continua...

Continuação

35	2985 aA	2864 bA	35	2782 cA	2606 dA
36	2214 bA	2299 cA	36	2170 dA	2576 dA
37	2967 aA	1894 cB	37	3102 bA	2121 eB
38	3262aA	2390 bB	38	2459 cA	2578 dA
39	1695 cA	1645 dA	39	2338 cA	2706 dA
40	2776 aA	1708 dB	40	2125 dB	3693 bA
41	2090 bA	2360 cA	41	2314 cB	3759 bA
42	1895 cB	3154 aA	42	2317 cA	2609 dA
43	1107 dB	3300 aA	43	2638 cA	2575 dA
44	1681 cB	3307 aA	44	2864 bA	2696 dA
45	2393 bA	2941 bA	45	2481 cA	2532 dA
46	1621 cB	3407 aA	46	2508 cA	2151 eA
47	1524 dB	2316 cA	47	1815 dB	2667 dA
48	2180 bA	2586 bA	48	2409 cA	1994 eA
49	2218 bB	3297 aA	49	4171 aA	2253 eB
50	1884 cA	1830 cA	50	2785 cA	2695 dA
51	2524 bA	2349 cA	51	1973 dA	2034 eA
52	2967 aA	1544 dB	52	1725 eB	2825 dA
53	1618 cB	2600 bA	53	1953 dB	2561 dA
54	2521 bA	2485 bA	54	1973 dA	1517 fA
55	2220 bB	3107 aA	55	3361 bA	2960 dA
56	2519 bB	3377 aA	56	2536 cA	2424 dA
57	2358 bB	3219 aA	57	2587 cA	1761 fB
58	2316 bA	2748 bA	58	2620 cB	3639 bA
59	1443 dB	2251 cA	59	2106 dB	2661 dA
60	1549 dB	2793 bA	60	1536 eA	1677 fA
61	1462 dB	3665 aA	61	1916 dA	1144 gB
62	2369 bA	2733 bA	62	2279 cA	1873 eA
63	2237 bA	2193 cA	63	2392 cA	1067 gB
64	1761 cA	1763 dA	64	1700 eB	2404 dA
65	2095 bA	1980 cA	65	1804 dA	1906 eA
66	2299 bA	2809 bA	66	1590 eA	1686 fA
67	1563 dB	2305 cA	67	1488 eA	1219 gA
68	1658 cB	3227 aA	68	2348 cA	1751 fB
69	1461 dA	1927 cA	69	1794 dA	1711 fA
70	1337 dB	2824 bA	70	2646 cA	2237 eA
71	2158 bB	2808 bA	71	1564 eB	2489 dA
72	1149 dB	1776 dA	72	2618 cA	2126 eA
73	2433 bA	1881 cA	73	2424 cA	1054 gB
74	1338 dA	1632 dA	74	2732 cA	2379 dA
75	2507 bA	1963 cA	75	3150 bA	1968 eB
76	2229 bA	2207 cA	76	1332 eB	2275 eA
77	2512 bA	1618 dB	77	2484 cA	2085 eA
78	3197 aA	1261 dB	78	2292 cA	2057 eA
79	1224 dB	2042 cA	79	3078 bA	3173 cA
80	2484 bA	1479 dB	80	1340 eA	1633 fA
81	2107 bA	906 dB	81	1950 dB	4453 aA
82	2830 aA	1494 dB	82	1608 eB	2436 dA
83	1231 dB	1985 cA	83	3480 bA	2212 eB
84	1792 cA	2244 cA	84	1620 eA	1843 eA
85	1478 dA	1473 dA	85	1968 dB	2558 dA
86	3200 aA	1582 dB	86	2642 cA	2397 dA
87	1253 dA	1162 dA	87	1668 eB	2301 eA
88	1709 cA	1997 cA	88	1152 eA	1480 fA
89	2729 aA	1619 dB	89	2172 dA	1614 fB
90	1335 dB	2338 cA	90	1926 dA	1660 fA
Average	2121	2296	Average	2231	2358

1: Averages followed by the same lowercase letter in the same column and capital letters in the line (in each crop), do not differ significantly at 5% probability by the Scott-Knott test.

Table 4: Analysis of joint variance between progenies and crops, for each locality, with respect to the characteristic grain yield (kg ha^{-1})

Source of variation	GL[(1)]	QM[(2)]	
		São Manuel	Araçatuba
Bloco/Crop	4	2296415.82	360352.07
Crop	1	1653028.02ns	518754.02ns
Progeny	89	1289843.20**	1187038.89ns
Free pollination	29	1861564.31**	1130569.31**
Cross pollination	29	917613.48**	844791.89**
Self-pollination	29	957129.58**	676509.46**
Between Progeny	2	3221565.69**	14371105.81**
Crop x Progeny	89	642306.05**	1408627.90**
Treatment	179		
Residue	356	120881.67	116764.36
Total	539		
CV[(3)]		15.95	14.61

** and ns: Significant at the 1% probability level and not significant at 5% probability, respectively, both by the test F. 1: Degrees of freedom; 2: Average square; 3: Coefficient of variation.

Table 5: Average grain yield (kg ha^{-1}) of progenies and crops, for each locality

Progeny	São Manuel		Progeny	Araçatuba	
	Crop			Crop	
	2004/2005	2005/2006		2004/2005	2005/2006
1	2887 aA[(1)]	2946 bA	1	2494 bA	2686 dA
2	1867 cA	1860 dA	2	1463 dB	2412 dA
3	2821 aA	2772 cA	3	1772 dB	2662 dA
4	1990 cA	2004 dA	4	1503 dB	3096 dA
5	3002 aA	2988 bA	5	2055 cA	2455 dA
6	2240 bA	2208 dA	6	2805 bA	2171 eB
7	2887 aA	2928 bA	7	1584 dB	2848 dA
8	3282 aA	3276 bA	8	3904 aA	2255 eB
9	1709 cA	1674 eA	9	2315 cB	3524 bA
10	2750 aA	2796 cA	10	1641 dB	2881 dA
11	2048 cA	2028 dA	11	2614 bB	3205 cA
12	1960 cA	1890 dA	12	2032 cB	2738 dA
13	1255 dA	1086 eA	13	2560 bA	2487 dA
14	1431 dA	1476 eA	14	1037 dB	3064 dA
15	2367 bA	2364 cA	15	2870 bA	2535 dA
16	1591 cA	1500 eA	16	3122 aA	2930 dA
17	1454 dA	1494 eA	17	1930 cB	2685 dA
18	2144 bA	2130 dA	18	2247 cB	2982 dA
19	2189 bA	2190 dA	19	2778 bA	2622 dA
20	1914 cA	1884 dA	20	1258 dB	2103 eA
21	2513 bA	2484 cA	21	2741 bA	3280 cA
22	2976 aA	2958 bA	22	1359 dA	1132 gA
23	1597 cA	1650 eA	23	2635 bA	1645 fB
24	2491 bA	2574 cA	24	2562 bA	1885 eB
25	2228 bA	2136 dA	25	1762 dA	1506 fA
26	2497 bA	2520 cA	26	1911 cA	2187 eA
27	2372 bA	2352 cA	27	2479 bA	2213 eA
28	2332 bA	2184 dA	28	3478 aA	1666 fB
29	1421 dA	1524 eA	29	2123 cA	1536 fB
30	1462 dA	1488 eA	30	3066 aA	1440 fB
31	2796 aA	2167 dB	31	2669 bA	3052 dA
32	1874 cA	2305 cA	32	3158 aB	3862 bA
33	2832 aA	2046 dB	33	2004 cA	2341 dA

Continua...

Continuação

34	2006 cA	2125 dA	34	2080 cB	2706 dA
35	2985 aA	2782 cA	35	2864 bA	2606 dA
36	2214 bA	2170 dA	36	2299 cA	2576 dA
37	2967 aA	3102 bA	37	1894 cA	2121 eA
38	3262 aA	2459 cB	38	2390 bA	2578 dA
39	1695 cB	2338 cA	39	1645 dB	2706 dA
40	2776 aA	2125 dB	40	1708 dB	3693 bA
41	2090 bA	2314 cA	41	2360 cB	3759 bA
42	1895 cA	2317 cA	42	3154 aA	2609 dA
43	1107 dB	2638 cA	43	3300 aA	2575 dB
44	1681 cB	2864 bA	44	3307 aA	2696 dB
45	2393 bA	2481 cA	45	2941 bA	2532 dA
46	1621 cB	2508 cA	46	3407 aA	2151 eB
47	1524 dA	1815 dA	47	2316 cA	2667 dA
48	2180 bA	2409 cA	48	2586 bA	1994 eB
49	2218 bB	4171 aA	49	3297 aA	2253 eB
50	1884 cB	2785 cA	50	1830 cB	2695 dA
51	2524 bA	1973 dA	51	2349 cA	2034 eA
52	2967 aA	1725 eB	52	1544 dB	2825 dA
53	1618 cA	1953 dA	53	2600 bA	2561 dA
54	2521 bA	1973 dA	54	2485 bA	1517 fB
55	2220 bB	3361 bA	55	3107 aA	2960 dA
56	2519 bA	2536 cA	56	3377 aA	2424 dB
57	2358 bA	2587 cA	57	3219 aA	1761 fB
58	2316 bA	2620 cA	58	2748 bB	3639 bA
59	1443 dB	2106 dA	59	2251 cA	2661 dA
60	1549 dA	1536 eA	60	2793 bA	1677 fB
61	1462 dA	1916 dA	61	3665 aA	1144 gB
62	2369 bA	2279 cA	62	2733 bA	1873 eB
63	2237 bA	2392 cA	63	2193 cA	1067 gB
64	1761 cA	1700 eA	64	1763 dB	2404 dA
65	2095 bA	1804 dA	65	1980 cA	1906 eA
66	2299 bA	1590 eB	66	2809 bA	1686 fB
67	1563 dA	1488 eA	67	2305 cA	1219 gB
68	1658 cB	2348 cA	68	3227 aA	1751 fB
69	1461 dA	1794 dA	69	1927 cA	1711 fA
70	1337 dB	2646 cA	70	2824 bA	2237 eB
71	2158 bA	1564 eB	71	2808 bA	2489 dA
72	1149 dB	2618 cA	72	1775 dA	2126 eA
73	2433 bA	2424 cA	73	1880 cA	1054 gB
74	1338 dB	2732 cA	74	1632 dB	2379 dA
75	2507 bB	3150 bA	75	1962 cA	1968 eA
76	2229 bA	1332 eB	76	2207 cA	2275 eA
77	2512 bA	2484 cA	77	1618 dA	2085 eA
78	3197 aA	2292 cB	78	1261 dB	2057 eA
79	1224 dB	3078 bA	79	2042 cB	3173 cA
80	2484 bA	1340 eB	80	1479 dA	1633 fA
81	2107 bA	1950 dA	81	906 dB	4453 aA
82	2830 aA	1608 eB	82	1494 dB	2436 dA
83	1231 dB	3480 bA	83	1985 cA	2212 eA
84	1792 cA	1620 eA	84	2244 cA	1843 eA
85	1478 dA	1968 dA	85	1473 dB	2558 dA
86	3200 aA	2642 cA	86	1582 dB	2397 dA
87	1253 dA	1668 eA	87	1162 dB	2301 eA
88	1709 cA	1152 eA	88	1997 cA	1480 fA
89	2729 aA	2172 dA	89	1619 dA	1614 fA
90	1335 dB	1926 dA	90	2338 cA	1660 fB
Average	2119	2231	Average	2296	2358

1: Averages followed by the same lowercase letter in the same column and capital letters in the line (in each crop), do not differ significantly at 5% probability by the Scott-Knott test.

also explained by the good combining ability between its parents, in which each parent had favorable complementary genes with the other parent (Bernini *et al*., 2013).

With regard to progeny 81, because it is a progeny originated by self-pollination, which provides the highest level of homozygousness, their grain yield is somewhat surprising, since its productivity was about six times the national average of the 2005/2006 crop (714 kg ha^{-1}, CONAB, 2017), however as castor bean is a kind of reproduction type taken as mixed, may have decreased the deleterious effects deriving from the increase of homozygosity.

In this crop, several of the progenies presented high grain yield in São Manuel were: 1, 5, 7, 8, 22, 37, 75, 79 and 83 showing variation from 2928 to 3480 kg ha^{-1}, and in Araçatuba 9, 11, 21, 40, 41 and 79, presenting variation from 3173 to 3759 kg ha^{-1}.

Based on the joint analysis of variance between progenies and crops, for each locality (Table 4), it is possible to notice for the locality of São Manuel that only the vintages factor was not significant, presenting all the other factors significance at 1% probability by the F test. With regard to the locality of Araçatuba, the factors crops and progenies were not significant, however, when pollination types are observed and the interaction crop x progeny is sharp the significance at 1% probability by the test F. Due to the significance of the crop x progeny interaction in the two localities the mean comparison test was applied.

Concerning the grain yield of progenies and crops, for each locality (Table 5), it is observed that the locality of Araçatuba provided the highest average productivity, presenting 19 progenies with productivity above 3000 kg ha^{-1}, which can be attributed to more favorable environmental conditions. However, there were progenies that exhibited high yields in São Manuel presenting 10 progenies with productivity above 3000 kg ha^{-1}, due to the adaptive capacity of each progeny.

In the analysis of the crop factor, it is noted that in general that the 2005/2006 crop obtained the highest general averages, in the order of 2231 and 2358 kg ha^{-1} for São Manuel and Araçatuba, respectively, indicating that in this crop there may have been better conditions for expression of progenies productive potential.

The best combinations in San Manuel, average between crops, were progenies 1, 5, 7, 8, 22, 37, 49 and 86, ranging from 2907 to 3279 kg ha^{-1}, noting that progenies 37 and 49 were the most productive. For the locality of Araçatuba, the best average values between the crops, were derived from the combination of progenies 8, 9, 11, 16, 21, 32, 41, 43, 44, 49, 55, 56 and 58, these progenies having yields varying from 2900 to 3510 kg ha^{-1}, and the progeny 81 with crop 2005/2006 with yield of 4453 kg ha^{-1}.

It should be noted that the best progenies in São Manuel not repeated from one crop to another, as well as for the locality of Araçatuba, indicating that the vast majority of progenies exhibit low productivity stability (Ribeiro *et al.*, 2008).

However, productivity stability is an important element taken into account in the choice of cultivar by the producer, in this way it can be noticed that the progenies as intermediate productivities, within the sampled group, were the most stable, and it is emphasized that their productivities are excellent when compared to the regional average of 443 kg ha^{-1} in the 2016/2017 crop (CONAB, 2017).

Progenies 1, 5, 6, 8, 15, 18, 19, 21, 27, 31, 35, 36, 38, 45, 49, 55, 56, and 58 exhibit a certain level of stability with productivity at over 2100 kg ha^{-1}, in different cities and crops, being selected by these aspects, and can be used to obtain new cultivars and hybrids (Machado *et al*., 2008).

Table 6: Summary of variance analyzes of the three types of pollination for castor bean progenies in two localities in the State of São Paulo and in two crops

Crops	Localities	Progenies	QMP[1]	QME[2]	Average	CV[3]
2004/2005	São Manuel	Free P.	918868.97**		2189.36	
		Cross P.	888429.87**	107545.93	2201.14	15.46
		Self P.	1089343.40**		1971.23	
	Araçatuba	Free P.	1395197.52**		2270.01	
		Cross P.	956515.92**	139406.58	2589.35	16.25
		Self P.	1148519.56**		2029.68	
2005/2006	São Manuel	Free P.	948342.28**		2178.80	
		Cross P.	811487.90**	134217.39	2409.68	16.41
		Self P.	1012533.89**		2105.22	
		Free P.	1112362.50**		2427.68	
	Araçatuba	Cross P.	1004970.94**	94122.13	2607.72	13.00
		Self P.	1335967.10**		2039.61	

** Significant at 1% probability by F test. 1: Mean square of progenies; 2: Mean square of the residue; 3: Coefficient of variation.

Table 7: Estimates of genetic parameters with relation to the three types of pollination for castor bean progenies in two localities in the State of São Paulo and in two crops

Crops	Localities	Progenies	σ^2 p [1]	σ^2 e [2]	h^2 *m* [3]	ΔG [4]	G % [5]
2004/2005	São Manuel	Free P.	270441.01**	107545.94	0.88	684.12	31.25
		Cross P.	260294.64**	107545.94	0.88	669.64	30.42
		Self P.	327265.82**	107545.94	0.90	760.34	38.57
	Araçatuba	Free P.	418596.98**	139406.58	0.90	859.34	37.86
		Cross P.	272369.78**	139406.58	0.85	675.31	26.08
		Self P.	336370.99**	139406.58	0.88	761.09	37.50
2005/2006	São Manuel	Free P.	271374.96**	134217.39	0.86	675.73	31.01
		Cross P.	225756.83**	134217.39	0.83	607.70	25.22
		Self P.	292772.16**	134217.39	0.87	705.53	33.51
	Araçatuba	Free P.	339413.45**	94122.13	0.92	780.36	32.14
		Cross P.	303616.27**	94122.13	0.91	734.41	28.16
		Self P.	413948.32**	94122.13	0.93	868.43	42.58

** Significant at 1% probability by F test. 1: Estimates of genetic variance between progenies (kg ha^{-1})^2. 2: Estimates of environmental variance (kg ha^{-1})^2. 3: Estimates of the coefficient of heritability at the level of progeny average. 4: Estimated genetic progress with 20% of selection intensity (kg ha^{-1}). 5: Genetic progress estimated in relation to the average of each pollination type for the characteristic grain yield.

It can be observed that of the more stable preselected progenies, 9 are from free pollination and the other 9 from cross-pollination, can these 9 progenies of cross-pollination resulting in highly productive hybrids (Bernini *et al*., 2013).

There was variation in the means of pollination types both for the 2004/2005 and 2005/06 crop how much for the cities of São Manuel and Araçatuba at the 1% probability level by the F test, indicating the possibility of success with the selection of the best genotypes (Table 6).

The estimated coefficients of heritability at the level of progeny averages in relation to grain yield character varied from 0.83 to 0.93, being observed the highest values in the 2005/2006 crop in the city of Araçatuba (Table 7), it is noteworthy that in the same condition, it is also noticeable the highest genetic gains estimated with the selection of progenies 20% better, reaching a gain of 42.58% in relation to the means of the progenies that were self-pollinated.

The significance of the variances of progenies (genetic) at the 1% probability level by the F test, for the four experiments, indicates the existence of genetic variability between the progenies of each type of pollination and allows for genetic gains through selection (Silveira *et al*., 2016). This significant effect, in particular the progenies from self-pollination, in which of the four experiments obtained greater percentage gains in three of them, may be related to the higher level of homozygosis, expressing with it greater divergence between the progenies, the one that allows the percentage of larger genetic gains (Vargas-Reeve *et al*., 2013).

Its valid mention that, generally, in the city of Araçatuba were observed the highest estimates of heritability, indicating that besides the possibility of genetic gain with the progeny selection, this environment also favors the choice of more stable progenies, being this reasoning shared by Silva *et al*. (2011), that observed relation between heritability and phenotypic stability face of environmental variations (Silveira *et al*., 2016; Passos *et al*., 2010). High estimates of heritability also demonstrate good genetic control, assuming that the most of the observed variation in castor bean plants was genetic in nature (Cruz Neto *et al*., 2016).

To the what it concerns estimated genetic gains with selection intensity of 20% (ΔG) and the estimated genetic gains in percentage of the average of each type of pollination (G%), it can be stated that they presented the highest values for the locality of Araçatuba, being this the local more suitable for selection, because the progenies selected for this environment may have greater stability.

It is noteworthy, which at the time in which the experiments were conducted, the region of the two cities is characterized by higher rainfall and higher temperatures, these conditions, appropriate for the good development of the castor bean crop, the what may have influenced the progenies to express their genotypic potential, which reflected in high estimates of heritability, allowing greater genetic gains with the selection (Cruz Neto *et al*., 2016).

CONCLUSIONS

Both the locality of Araçatuba and the 2005/2006 crop provided better expressions of the productive potential of the progenies, indicating their genetic potential, which facilitates and increases the precision of the selection of the best genotypes.

The progenies selected were progenies 1, 5, 6, 8, 15, 18, 19, 21 and 27 (caused by free pollination), as well as progenies 31, 35, 36, 38, 45, 49, 55, 56 and 58 (resulting from cross-pollination) all present productivity above 2100 kg ha^{-1}, regardless of the crop and the city, suggesting that there was some level of stability, and can they be used to obtain new cultivars and hybrids.

The locality of Araçatuba presented the highest estimates of heritability, especially progenies self pollinated, in which they provided that lines presented more stable productive behavior, which increases the efficiency of the selection of superior genotypes.

Genotype interaction with the location indicated productive materials and adapted to the state of São Paulo, showing that there are managements that can solve the productivity problem, and consequently, increase the production of this crop.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

To the National Council of Scientific and Technological Development Brazil (CNPq), for the financial assistance (process nº 310794/2015-3) and (process nº 134541 / 2016-2).

There is no conflict of interests in the conduction and publication of this article.

REFERENCES

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM & Sparovek G (2014) Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22:711-728.

Barbosa JC & Maldonado Junior W (2015) AgroEstat - sistema para análises estatísticas de ensaios agronômicos. Jaboticabal, FCAV/UNESP. 396p.

Bernini CS, Paterniani MEAGZ, Duarte AP, Gallo PB, Guimarães OS & Rovaris SRS (2013) Depressão endogâmica e heterose de híbridos de populações F_2 de milho no estado de São Paulo. Bragantia, 72:217-223.

CONAB - Companhia Nacional de Abastecimento (2017) Safras: série histórica das safras. Available at: <https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=10>. Accessed on: May 20th, 2018.

Cruz Neto AJ, Rosa RCC, Oliveira EJ, Sampaio SR, Santos IS, Souza PU, Passos AR & Jesus ON (2016) Genetic parameters, adaptability and stability to selection of yellow passion fruit hybrids. Crop Breeding and Applied Biotechnology, 16:321-329.

Cruz AD, Regazzi AJ & Carneiro PCS (2012) Modelos Biométricos Aplicados ao Melhoramento Genético. Viçosa, Editora UFV. 514p.

Daronch DJ, Peluzio JM, Afferri FS, Tavares AT & Souza CM (2019) Eficiência ambiental e divergência genética de genótipos de soja na região central do Tocantins. Cultura Agronômica, 28:01-18.

FAO - Food and Agriculture Organization of the United Nations (2016) Faostat - Countries by commodity. Available at: <http://www.fao.org/faostat/en/#rankings/countries_by_commodity>. Accessed on: May 20th, 2018.

Ferreira PV (2006) Melhoramento de plantas: métodos de melhoramento. Maceió, Edufal. 110p.

Gaya LG, Mourão GB & Ferraz JBS (2006) Aspectos genético-quantitativos de características de desempenho, carcaça e composição corporal em frangos. Ciência Rural, 36:709-716.

Goneli ALD, Corrêa PC, Oliveira APLR, Hartmann Filho CP & Oba GC (2018) Castor beans quality subjected to different storage temperatures and periods. Engenharia Agrícola, 38:361-368.

Machado JC, Souza JC, Ramalho MAP & Lima JL (2008) Estabilidade de produção de híbridos simples e duplos de milho oriundos de um mesmo conjunto gênico. Bragantia, 67:627-631.

Passos AR, Silva SA, Souza CS, Souza CMM & Fernandes LS (2010) Parâmetros genéticos de caracteres agronômicos em genótipos de mamoneira. Pesquisa Agropecuária Brasileira, 45:709-714.

Ribeiro ND, Antunes IF, Souza JF & Poersch NL (2008) Adaptação e estabilidade de produção de cultivares e linhagens-elite de feijão no Estado do Rio Grande do Sul. Ciência Rural, 38:2434-2440.

Silva JAG, Bandeira TP, Manjabosco CD, Krüguer CAMB, Silva SDA, Crestani M & Carbonera R (2011) Caracterização e herdabilidade em caracteres morfológicos e fisiológicos da mamona. Revista Brasileira Agrociência, 17:348-358.

Silveira LCI, Brasileiro BP, Kist V, Weber H, Daros E, Peternelli LA & Barbosa MHP (2016) Selection in energy cane families. Crop Breeding and Applied Biotechnology, 16:298-306.

Torres FE, Teodoro PE, Sagrilo E, Ceccon G & Correa AM (2015) Interação genótipo x ambiente em genótipos de feijão-caupi semiprostrado via modelos mistos. Bragantia, 74:15-20.

Vargas-Reeve F, Mora F, Perret S & Scapim CA (2013) Heritability of stem straightness and genetic correlations in *Eucalyptus cladocalyx* in the semi-arid region of Chile. Crop Breeding and Applied Biotechnology, 13:107-112.

Vencovsky R (1980) Herança quantitativa. In Paterniani E (Ed.) Melhoramento e produção de milho no Brasil. Piracicaba, Fundação Cargill. p.122-201.