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

Jackson da Silva 2, Andréia Rodrigues Ramos 3, Deoclécio Jardim Amorim 1, Mauricio Dutra Zanotto 1, Maria Márcia Pereira Sartori 3*

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 locality of Araçatuba. Progenies 1, 5, 6, 8, 15, 18, 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 Euphorbiaceae, 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
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 (Alves 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 tractorized, 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:

\[ h^2_m = \frac{QMP - QME}{QMP} \]  \hspace{1cm} (1)

\[ \text{In what: } h^2_m = \text{heritability at the level of progeny average} \]

\[ QMP = \text{Average square of progeny} \]

\[ QME = \text{Average square of the residue} \]

\[ \Delta G = \frac{\sigma^2_p}{\sqrt{\sigma^2_p + \sigma^2_r}} \]  \hspace{1cm} (2)
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       |             |

\(^{(1)}\) 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 progeny in general, as well as between types of pollination and between the progenies in each method of pollination, indicating 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\(^{(3)}\) | 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**| 968907.17**    |                |
| 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 | São Manuel | Araçatuba | Progeny | São Manuel | Araçatuba |
|---------|------------|-----------|---------|------------|-----------|
| Crop 2004/2005 |           |           | Crop 2005/2006 |           |           |
| 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 dB | 5        | 2988 bA | 2455 dA |
| 6       | 2240 bA | 2803 dA | 6        | 2208 dA | 2171 eA |
| 7       | 2887 aA | 1584 dB | 7        | 2928 bA | 2848 dA |
| 8       | 3282 bA | 3904 bA | 8        | 3276 bA | 2255 eB |
| 9       | 1709 cB | 2315 bA | 9        | 1674 eB | 3524 bA |
| 10      | 2750 aA | 1641 dB | 10       | 2796 cA | 2881 dA |
| 11      | 2048 cA | 2614 bA | 11       | 2028 dA | 3205 cA |
| 12      | 1960 cA | 2032 bA | 12       | 1890 dB | 2738 dA |
| 13      | 1255 dB | 2560 bA | 13       | 1080 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 dA | 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       | 2157 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 dA | 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| 3262 aA | 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 dA | 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 eB | 3639 bA |
| 59| 1443 dB | 2251 cA | 59 | 2106 dB | 2661 dA |
| 60| 1549 dB | 2793 bA | 60 | 1536 cA | 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 cA | 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 dA | 4453 bA |
| 82| 2830 aA | 1494 dB | 82 | 1608 eB | 2436 bA |
| 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\(^{(1)}\) | São Manuel | Araçatuba |
|-----------------------------|--------------|------------|-----------|
| Bloco/Crop                  | 4            | 2296415.82 | 360252.07 |
| 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\(^{(2)}\)               |              | 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 | Araçatuba |
|----------|------------|-----------|
|          | 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 dA  | 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 dA  | 2848 da |
| 8        | 3282 aA    | 3276 bA  | 8         | 3904 aA  | 2255 eB |
| 9        | 1709 ca    | 1674 ca  | 9         | 2315 cB  | 3524 bA |
| 10       | 2730 aA    | 2796 ca  | 10        | 1641 dA  | 2881 da |
| 11       | 2048 ca    | 2028 da  | 11        | 2614 bA  | 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 ca  | 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 dA  | 2103 cA |
| 21       | 2513 ca    | 2484 ca  | 21        | 2741 bA  | 3280 cA |
| 22       | 2976 aA    | 2958 ba  | 22        | 1359 dA  | 1132 ga |
| 23       | 1597 ca    | 1650 ca  | 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 ca  | 29        | 2123 cA  | 1536 fB |
| 30       | 1462 da    | 1488 ea  | 30        | 3066 aA  | 1440 fB |
| 31       | 2796 aA    | 2167 dB  | 31        | 2669 bA  | 3032 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 bA | 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 aA | 1815 dA | 47 | 2316 cA | 2667 dA |
| 48 | 2180 bA | 2409 cA | 48 | 2586 bA | 1994 eB |
| 49 | 2218 bb | 4711 aA | 49 | 3297 aA | 2253 eB |
| 50 | 1884 cB | 2785 cA | 50 | 1830 cB | 2695 dA |
| 51 | 2524 bA | 1973 cA | 51 | 2349 cA | 2034 cA |
| 52 | 2967 aA | 1725 cB | 52 | 1544 dB | 2825 dA |
| 53 | 1618 cB | 1953 cA | 53 | 2600 bA | 2561 dA |
| 54 | 2521 ba | 1973 cA | 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 bA | 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 dA | 2397 dA |
| 87 | 1253 da | 1668 cA | 87 | 1162 dA | 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 level of homozygous progenies. 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.

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**   | 107545.93     | 2189.36 | 15.46      |
|          |            | Cross P.  | 888429.87**   | 1089343.40**  | 2201.14 |            |
|          |            | Self P.   | 1395197.52**  | 139406.58     | 2270.01 |            |
|          | Araçatuba  | Free P.   | 1148519.56**  | 123262.50**   | 2029.68 |            |
|          |            | Cross P.  | 956515.92**   | 134217.39     | 2589.35 | 16.25      |
|          |            | Self P.   | 1148519.56**  |               | 2029.68 |            |
|          | São Manuel | Free P.   | 948342.28**   | 132538.89**   | 2105.22 | 13.00      |
|          |            | Cross P.  | 811487.90**   | 134217.39     | 2409.68 |            |
|          |            | Self P.   | 1112362.50**  |               | 2427.68 |            |
|          | Araçatuba  | Cross P.  | 1004970.94**  | 94122.13      | 2607.72 |            |
|          |            | 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 | \( \sigma^2 p \) (1) | \( \sigma^2 e \) (2) | \( h^2 m \) (3) | \( \Delta G \) (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\(^{-2}\)). 2: Estimates of environmental variance (kg ha\(^{-2}\)). 3: Estimates of the coefficient of heritability at the level of progeny average. 4: Estimated genetic progress with 20% of selection intensity (kg ha\(^{-2}\)). 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% (\(\Delta G\)) 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, Affetti 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.