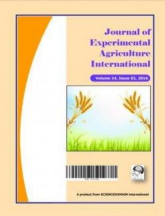

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# Comparison of Castor Beans Hybrids Produced by the Conventional Method and by the Cryptic Hybrid Method

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors EVBT and JS were responsible for the installation, conduction, data tabulation and study writing. The author MMPS performed the statistical analysis and writing of the study. The author MDZ was responsible for supervising and writing the study. All authors read and approved the final manuscript.*

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## ABSTRACT

In Castor beans population's improvement, new ideas and methods are required in seeking to improve efficiency of obtaining lines and hybrids, as well as decreasing the development time. In this context, the Cryptic Hybrids method appears as an alternative to these questions, which can be configured as an effective tool in breeding programs of species that have the\ZZ mixed type reproductive system. Thus, the objective of this study was of to compare of castor bean hybrids produced by the conventional method, with those of the Cryptic Hybrids method. Experiments to evaluate hybrids on grain productivity were developed in the 2006/2007, 2007/2008 and 2008/2009 agricultural years simultaneously in the municipalities of Lins-SP and Penápolis-SP. This was conducted using randomized block design with four replications. The oil productivity and plant height were determined over the last two years. The results of the castor hybrids grain and oil productivity demonstrated the ability of the cryptic hybrids to overcome the hybrids obtained conventionally. In

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addition, it was verified that there were no differences in the oil content of the seeds as a function of the method of obtaining hybrids. Regarding the size of the plants, good agronomic characteristics and low size was observed, yet, compared to conventional hybrids, had, on average, greater stature. Thus, the Cryptic Hybrids method was efficient in obtaining superior lines and hybrids of castor bean, when compared to conventional "Standard" method.

*Keywords: Inbred lines; allogamous species; mixed species; double cryptic hybrids.*

## 1. INTRODUCTION

Hybridization in the broader sense is of great interest in the improvement of most cultivated species, both for the exploration of heterosis and for the promotion of genetic variability in populations. Several types of hybrids can be synthesized, the most important being those obtained with the use of inbred lines [1].

The development of lines of hybrids has been mainly done by the so-called "Standard" method. The base populations, made up of adapted varieties of open population, are self-fertilized. Selection is practiced between and within the lineages until they reach a good level of homozygosity. These lines are selected in a set of crosses called "topcross" and later evaluated for specific combining ability. The genetic fixation in the lineages is random and nothing is known about the combinatorial ability until they are obtained. The time taken to obtain and evaluate the lineages is very large, making the conventional process of production of hybrid long and costly [1].

However, several attempts have been suggested to make it more efficient in obtaining lines of good combinatorial capacity. Many methods for improving lineages have been used with relative success, but always dependent on the pre-existence of superior lines, corroborating, thus, the "Standard" is still the most used in the various programs of plant breeding, with considerable success [2].

Regarding the inherent problems of the "Standard" method of obtaining lines, [3] report another methodology, in which the method is based on the behavior of cryptic hybrids, and needs prolific populations for its execution. This is necessary because self-fertilizations and crosses occur simultaneously in the same plant. Maximum emphasis is placed on the selection of lines that have high specific capacity of combination, where each generation is tested for self-fertilization. At the end of the program, the lines are obtained in simple combinations, which can later be used in the synthesis of different types of hybrids [4].

One of the main explicit observations about the method, is that the Cryptic Hybrid presented very limited use in breeding programs of allogamous species, preponderantly by the excessive loss of vigor of the female line with the endogamy series. Of course the massive production of F1 seeds, with a view to commercial hybridization, requires highly productive females, due to relatively low levels of inbreeding depression. The vigor of the female lines is indispensable for the hybrid seed to be affordable to the farmer [5].

The observed exposure of the method in allogamous, is assumed that Cryptic Hybrids methodology may be a potential tool in the improvement of species that present the mixed-type reproductive system, such as castor bean (*Ricinus communis* L.), because in these species, of mixed reproduction type, the inbreeding depression due to successive self-fertilizations is considered insipid [6].

Thus, the present work had the objective of to compare of castor bean hybrids produced by the conventional method, with those of the Cryptic Hybrids method of analyzing the responses of castor bean hybrids produced by the conventional method, in which the strains are extracted by the "Standard" method, with those of the Cryptic Hybrids method.

## 2. MATERIALS AND METHODS

### 2.1 Materials

In this work, experiments were performed to verify the agronomic traits of grain productivity, oil content, oil productivity and plant height of 24 inter-population hybrids of castor bean among which12 hybrids were conventionally produced by "Standard" method and remaining 12 hybrids by Hybrid Cryptic method. all synthesized in the Department of Plant Production, Agriculture Sector, Faculty of Agronomic Sciences of the Paulista State University "Júlio de Mesquita Filho".

The lines consisted of two populations of hybrids with a broad genetic base, one composed of plants F2 of commercial hybrid B-9 and the other cultivar FCA-PB. The lines were isolated by conducting four cycles of self-fertilization through the respective methods, being extracted thus, the female (S4) lines of the B-9 population and the male (S4) lines of the FCA-PB population. The remarkable characteristics of the materials used as basic populations are low size and precocity, for the lines coming from the commercial hybrid B-9 is its sexual expression, in which apparently does not present the phenomenon of reversion which is important for the maintenance of the pistil lines.

## 2.2 Experiments

The experiments to evaluate the grain productivity of the hybrids of S4 x S4 crosses were developed in the 2006/2007, 2007/2008 and 2008/2009 agricultural years simultaneously in two municipalities of the State of São Paulo, Lins and Penápolis. The same were established in the second harvest condition "safrinha", being sown in both localities on 02/20/2007, 02/19/2008 and 02/17/2009, respectively. Observations were made on oil content, oil productivity and plant height only from the second year of experimentation.

The experiments were implanted in randomized block design with four replicates. In all experiments, the plots constituted by rows of 5 m in length with a spacing of 0.5 m between plants and 1.0 m between rows, totaling a useful area of 5 m². Three seeds were sown per planting hole and thinned to one plant approximately 35 days after sowing, resulting in a total of 40 plants per plot, equivalent to 20,000 plants $ha^{-1}$. Experimental areas were fertilized according to the cultural practices and recommendations described by [7], and the cultural treatments used were the usual ones.

## 2.3 Data Collection

All variables were collected at 180 days after planting. For the grain yield (PG) measurement, in kg $ha^{-1}$, the grains of the peeled fruits were collected, per plot and dried on a wax to achieve a moisture content of 10%, later this value was estimated for one hectare. The quantification of the seed oil content (TO), in %, was carried out by magnetic resonance method, using a homogenized sample of 15 g of seed from each plot. Once in possession of the grain yield data and the seed oil content, the determination of the oil productivity (PO), in kg $ha^{-1}$, was obtained by the product of these two variables. Plant heights (AP), in cm, was measured between the soil surface and the apex of the highest branch, with each observation coming from an average of 10 plants, using a tape measure.

## 2.4 Statistical Procedure

The initial statistical procedures consisted of analyzing the variance individually for each location in the respective years and, the Bartlett test (p = 0.05) was applied to verify the homogeneity of the mean squares of the residues, making possible the accomplishment of the analysis of joint variance between places and years using the fixed model, taking into account the favorable relation of the residual mean squares among the different experiments and, for the comparison of means of treatments, the Scott-Knott test (p = 0.05) was used.

## 3. RESULTS AND DISCUSSION

A joint analysis of variance between sites and years (Table 1) demonstrates non-significance of the mean square of the interaction between hybrids by sites and years. Indicating that the materials behaved similarly for grain productivity at the two assessment sites and for the three years of experimentation, thus, it is suggested that the best performance genotypes can be indicated for cultivation in these sites, due to good interaction between the genotype and the environment.

The same analysis of joint variance explained that the mean square of the comparison of the different hybrid production methods is significant (P = 0.05) by the F test, denoting that the cryptic and conventional hybrids have different behaviors for the productivity of grains.

Interestingly, both the mean square of the cryptic hybrids and conventional hybrids are significant. Therefore, in addition to differing grain yields for the method, the hybrids differed within the same group of materials. The analysis of variance only has the power to indicate the significant difference, but it is not able to report the magnitude of the difference between the means of the hybrids. For this, the test of comparison between means was done, which was Scott-Knott (P = 0.05).

**Table 1. Joint analysis of variance between sites and years of cryptic and conventional hybrids in Lins-SP and Penápolis-SP, in the 2006/2007, 2007/2008 and 2008/2009 agricultural years (for grain productivity) and 2007/2008 and 2008/2009 (for oil content, oil productivity and plant height)**

| FV | QM[1] | | | |
|---|---|---|---|---|
| | PG[2] | TO | PO | AP |
| Blocks/experiment | ----- | ----- | ----- | ----- |
| Sites | 1099656.336* | 92.452* | 343466.828* | 771.603ns |
| Years | 4482033.831* | 0.746ns | 1954828.994* | 60538.341* |
| Hybrids | 2808954.907* | 20.298* | 349932.142* | 5069.071* |
| Cryptics | 2037435.556* | 19.987* | 206307.400* | 1458.341* |
| Conventional | 3475344.532* | 21.705* | 463921.654* | 7371.933* |
| Cryptics vs Conventional | 3965381.893* | 8.250ns | 675919.671* | 19455.615* |
| Sites x Years | 151.714ns | 24.470* | 15751.211ns | 8216.039* |
| Hybrids x Sites | 121697.096ns | 24.343* | 26577.822ns | 2034.549* |
| Hybrids x Years | 290264.213* | 26.211* | 104567.078* | 4300.398* |
| Hybrids x Sites x Years | 101897.901ns | 24.433* | 52603.182* | 3598.866* |
| Residue | 82080.511 | 4.90 | 19880.888 | 336.774 |
| CV[3] | 16.49 | 4.76 | 17.39 | 11.84 |

*[1/] Mean square. [2/] PG: grain productivity (kg ha$^{-1}$); TO: oil content (%); PO: oil productivity (kg ha$^{-1}$); AP: plant height (cm). [3/] Coefficient of variation. * and ns: Significant and not significant, respectively, at P = 0,05 by the test F*

In relation to the comparison of grain productivity averages of the genotypes, it can be observed, in Table 2, that the best performance was observed in the conventional hybrid 10, for the three evaluated agricultural years. Nevertheless, the materials that integrated the worst grain productivity also belong to the group of conventional hybrids. This duality, coupled with the more regular performance of cryptic hybrids (63% of materials with productivities above the total average), justified why the average of conventional hybrids was lower.

The best productive performance among the three agricultural years was cryptic hybrids, with an average of 1,819 kg ha$^{-1}$ of grain mass, having a productivity of more than 10%, in relation to the hybrids obtained by the conventional process, which presented an average of 1,653 kg ha$^{-1}$ of grain mass. This superiority of the cryptic hybrids consubstantially can be based on the theoretical foundation of the method Since, the genotypes in question were evaluated for four cycles for specific combining ability. Similar results were found by [8] that studied the productive behavior of several maize genotypes and observed that the materials coming from the process of Cryptic Hybrids, had the best results.

However, the limited use of the Cryptic Hybrid method in plant genetics breeding programs may be due to lack of information that allows for broader discussions. Especially, when the intention is to draw a comparative parallel with the productive potential of the conventionally synthesized hybrids. Anyway, the results of grain productivity experiments carried out in the municipalities of Lins and Penápolis, demonstrated the ability of the method to obtain superior castor beans hybrids, since the average values of cryptic hybrids exceeded conventional hybrids.

Nonetheless, when the interpretation of grain productivity averages of hybrids is performed holistically, considering the reality of the available genotypes in the market and the productivity of the crop in the State of São Paulo, historically the highest averages in Brazil, both groups of materials exceeded the state average for the years of experimentation, which presented values close to 1,444 kg ha$^{-1}$ of grain mass [9]. This evidence corroborates that the two populations used in this study are good germplasm for obtaining lineages, and after, to obtain good hybrids.

In the analysis of joint variance between sites and years (Table 1) for oil content, oil production and plant height, the significance of the mean square of the interaction between hybrids by sites and years was detected, indicating that the hybrids showed no coincident behavior at the two assessment sites and / or for the two years of experimentation, requesting that a joint analysis of variance be performed between years for each of the sites.

**Table 2. Average of the castor beans hybrids in relation to grain productivity (kg ha$^{-1}$) evaluated in Lins-SP and Penápolis-SP, during 2006/2007, 2007/2008 and 2008/2009 agricultural years**

| Hybrid | Agricultural years |
|---|---|
| | 2006/2007, 2007/2008 and 2008/2009 |
| Cryptic 01 | 1919.6 C |
| Cryptic 02 | 1524.3 E |
| Cryptic 03 | 2214.1 B |
| Cryptic 04 | 1767.8 D |
| Cryptic 05 | 1719.4 D |
| Cryptic 06 | 1403.9 F |
| Cryptic 07 | 1613.3 E |
| Cryptic 08 | 1589.6 E |
| Cryptic 09 | 1739.5 D |
| Cryptic 10 | 2138.0 B |
| Cryptic 11 | 2359.4 A |
| Cryptic 12 | 1.846.9 D |
| Conventional 01 | 1498.0 E |
| Conventional 02 | 1655.7 E |
| Conventional 03 | 1448.9 F |
| Conventional 04 | 1156.9 G |
| Conventional 05 | 1066.9 G |
| Conventional 06 | 1707.1 D |
| Conventional 07 | 2239.7 B |
| Conventional 08 | 1764.9 D |
| Conventional 09 | 1855.8 D |
| Conventional 10 | 2366.9 A |
| Conventional 11 | 1575.7 E |
| Conventional 12 | 1508.1 E |
| Method | |
| Cryptic | 1819.6 |
| Conventional | 1653.7 |
| Total | 1736.7 |

*Means followed by the same letter, in the column, did not differ significantly (P = 0.05) by the Scott-Knott test.*

The analysis of joint variance between years for the municipality of Lins (Table 3), has for confirmation the significance of the mean square of the interaction between hybrids for years. This implies that the hybrids diverged to the character oil content in the agricultural years, it being understood. Although there is the effect of the above-mentioned interaction, the analysis of variance describes the non-significance of the mean square of the comparison between the methods of obtaining hybrids, that is, there is no distinction in the oil content between the two groups of materials, that is, it is not recommended to use the cryptic hybrid method only to increase the oil content, being more appropriate to use other methods for this purpose.

The analysis of the joint variance between the years for the municipality of Lins was detected to be differences between the genotypes of the same group of materials, being necessary to apply the test of comparison between the means, in order to size the difference of the genotypes. (Table 4).

The interpretation of the averages of oil content of the hybrids, in the 2007/2008 agricultural year in Lins, discriminated that the best percentage is composed of several genotypes of the different groups of materials under study. However, during 2008/2009 crop year, it verified a considered variation in the oil concentration potential of some of these hybrids. For example, the conventional hybrid 11 and the cryptic 01 if characterized in the 2007/2008 harvest because they have, statistically, the best oil contents, and for the aforementioned year of 2008/2009 their averages were the worst. Similar situation happened with the conventional hybrid 03, when suddenly it is placed between the materials of better oil content.

The oscillation established in the experiments conducted in Lins justifies not only the interaction between hybrids for years in the specified locality, as rhetorically the interaction between hybrids by sites and years. Despite this, it is not possible to categorize if only the discrepancies occurring in Lins respond for the significance of the interaction of hybrids by sites and years, since remains accurate analysis of the experiments installed in Penápolis.

Regarding the ponderations related to the joint analysis between years for the municipality of Penápolis (Table 3), it is important to state that, similarly to the one observed for the municipality of Lins, there is significance of the mean square of the interaction between hybrids for years, reaffirming, once again, the disparity of the hybrids in the evaluation years. Moreover, it can be inferred that in comparison to the methods of obtaining hybrids there are no significant differences for the F test (P = 0.05).

Also, the mean squares of cryptic hybrids and that of conventional hybrids are significant, that is, there are genotypes that overlap others as to the oil content in the seeds. Thus, the mean of test, which enables the identification of the best performances, should be performed for each of the years (Table 4), as occurred in Lins, due to the exposure of the significance of the interaction between hybrids for years.

**Table 3. Analysis of joint variance between years of the cryptic and conventional hybrids in Lins-SP and Penápolis-SP, in 2007/2008 and 2008/2009**

| FV | QM[1] | | | | | |
|---|---|---|---|---|---|---|
| | TO[2] | | PO | | AP | |
| | Lins | Penápolis | Lins | Penápolis | Lins | Penápolis |
| Blocks/ experiment | ----- | ----- | ----- | ----- | ----- | ----- |
| Years | 8.335ns | 16.880ns | 809816.673* | 1160763.532* | 12075.051* | 56679.329* |
| Hybrids | 19.909* | 24.732* | 190019.777* | 186490.187* | 3670.594* | 3433.026* |
| Cryptic | 17.196* | 34.439* | 130229.420* | 101964.752* | 1387.408* | 1811.527* |
| Conventional | 24.245* | 16.645* | 246120.234* | 245627.107* | 5772.611* | 4013.452* |
| Cryptic vs Conventional | 2.0502ns | 6.917ns | 230608.680* | 465763.847* | 5663.450* | 14884.829* |
| Hybrid x Years | 24.227* | 26.417* | 19832.964ns | 137337.296* | 3075.464* | 4823.800* |
| Residue | 4.685 | 5.115 | 18398.588 | 21363.187 | 234.731 | 438.818 |
| CV[3] | 4.71 | 4.82 | 17.37 | 17.39 | 9.80 | 13.65 |

*[1/] Mean square. [2/] TO: oil content (%); PO: oil productivity (kg ha$^{-1}$); AP: plant height (cm). [3/] Coefficient of variation. * and ns: Significant and not significant, respectively, (P = 0.05) for the F test*

**Table 4. Average of the castor hybrids in relation to the characteristic oil content (TO), in %, evaluated in Lins-SP and Penápolis-SP, during2007/2008 and 2008/2009**

| Hybrid | Lins | | Penápolis | |
|---|---|---|---|---|
| | Year | | Year | |
| | 2007/2008 | 2008/2009 | 2007/2008 | 2008/2009 |
| Cryptic 01 | 48.3 A | 42.7 C | 45.3 B | 47.3 A |
| Cryptic 02 | 45.6 B | 45.2 B | 46.8 B | 48.0 A |
| Cryptic 03 | 43.3 C | 45.2 B | 51.1 A | 48.8 A |
| Cryptic 04 | 46.3 A | 46.0 B | 46.5 B | 45.0 B |
| Cryptic 05 | 47.6 A | 46.6 B | 45.8 B | 48.0 A |
| Cryptic 06 | 45.0 B | 45.6 B | 50.3 A | 48.7 A |
| Cryptic 07 | 45.0 B | 47.5 B | 51.1 A | 46.7 B |
| Cryptic 08 | 46.1 A | 46.9 B | 48.6 B | 47.8 A |
| Cryptic 09 | 49.1 A | 43.9 C | 48.0 B | 49.5 A |
| Cryptic 10 | 44.7 B | 41.1 C | 42.6 C | 46.2 B |
| Cryptic 11 | 50.2 A | 46.9 B | 40.9 C | 46.4 B |
| Cryptic 12 | 48.3 A | 46.2 B | 46.2 B | 43.7 C |
| Conventional 01 | 43.8 B | 44.4 B | 43.5 C | 51.3 A |
| Conventional 02 | 46.8 A | 45.9 B | 46.2 B | 48.8 A |
| Conventional 03 | 41.9 C | 50.1 A | 46.0 B | 48.2 A |
| Conventional 04 | 45.9 A | 45.5 B | 47.0 B | 42.8 C |
| Conventional 05 | 48.1 A | 44.9 B | 47.6 B | 41.1 C |
| Conventional 06 | 46.4 A | 49.3 A | 46.5 B | 46.5 B |
| Conventional 07 | 48.2 A | 50.1 A | 48.5 B | 45.5 B |
| Conventional 08 | 46.1 A | 47.5 B | 47.8 B | 47.0 B |
| Conventional 09 | 43.7 B | 47.1 B | 44.7 C | 51.3 A |
| Conventional 10 | 44.2 B | 41.8 C | 41.8 C | 46.7 B |
| Conventional 11 | 48.3 A | 40.1 C | 47.8 B | 46.0 B |
| Conventional 12 | 43.1 C | 45.4 B | 47.1 B | 50.5 A |
| Method | | | | |
| Cryptic | 46.6 | 45.3 | 46.9 | 47.2 |
| Conventional | 45.5 | 46.0 | 46.2 | 47.1 |
| Average | 46.1 | 45.7 | 46.6 | 47.2 |

*Means followed by the same letter, in the same column, did not differ significantly (P = 0.05) by the Scott-Knott test*

Against of exposed, the averages of oil content of hybrids evaluated in Penápolis, it is noted since some genotypes have had great changes in their performances over the years. Conventional hybrids 09 and 01 during the 2007/2008 crop year gave the worst averages. In the following year both appear to be leading the averages of the 24 hybrids. In addition, it is worth mentioning that some materials performed similarly in the two years of evaluation in Penápolis, for cryptic hybrid 03. The homogeneous performance of the hybrids in the different agricultural years is an exception for the characteristic oil content. Although the cryptic hybrid 03 repeated similar indices for the two Penapolis experiments, this genotype was not among the best results when evaluated in Lins. In short, no genotype holds the same means, for the oil content parameter, in three experiments, elucidating the significance of the interaction of hybrids by sites and years.

One of the possible explanations for the large variations in the oil data measured in experiments could be due to the genetic nature of the inheritance of oil content character, which is classified as quantitative. Quantitative traits are generally conditioned by many genes with small individual effects on the phenotype and, as the environment is fundamental to the expression or silently of certain genes, the environmental factor is of great relevance for certain characteristics. The occurrence of some specific environmental stimulus, in each of the agricultural years and / or sites, may have triggered a considered expression of a particular gene that until then had not found the necessary conditions for its pronouncement.

Despite the instability observed in the behavior of the materials in relation to the oil content, it is necessary to show that the means of the genotypes are similar to commercial cultivars and, in some cases, are up until superior to some varieties.

According to studies of [10] and [11], the preponderant factor for qualification of any castor genotype is not the oil content, but rather the oil productivity, which is positively correlated with grain yield and less influenced by the oil content. Seen what, that the oil yield is the product of the multiplication between the oil content and the grain yield.

The abovementioned comments, which could not be typified, which genotype showed the best performance for the oil content. It is worth noting the importance attached to the parameter oil productivity, product of oil content and grain yield.

On the analysis of joint variance between years for the municipality of Lins (Table 3), in relation to oil productivity, one of the main records reports the non-significance of the mean square of the interaction between hybrids for years, leading, of course, that the materials behaved homogeneously for the two experiments conducted in that locality.

In addition, there was a distinction in the mean performance of the two types of hybrids for oil productivity (P = 0.05). The cryptic hybrids obtained an average of 815 kg $ha^{-1}$ of oil content, while the conventional hybrids exhibited an average of 745 kg $ha^{-1}$ of oil (Table 5).

The hybrids oil productivity evaluated in Lins (Table 5), reveals that the oil productivity character is highly influenced by grain productivity. The result shows that hybrids with the lowest mean for oil productivity also gave the least grain yields which was classified as the worst among the 24 hybrids. Considering the cryptic hybrids 11, 03 and 10 and the conventional 07 and 10 genotypes with high potentials of cultivation in the locality, unlike conventional hybrids 04 and 05.

In summary, the cryptic hybrids had 66% of the materials that were above the average of the productivities of the oil for the municipality of Lins, reflecting the excellent prospect of using this method of obtaining hybrids in breeding programs of mixed species.

As for the relevant arguments for analysis of joint variance between years for the municipality of Penápolis (Table 3), is certified sure that, unlike for Lins, there is a significance of the mean square of the interaction between hybrids for years, so, the hybrids differentiated in the agricultural years of experimentation in that locality for the characteristic oil productivity.

There was significance difference in the mean square of the comparison of the different methods of obtaining hybrids. Similarly to Lins, the oil productivity performance was among the hybrids. In the locality in question, considering the two years, the cryptic hybrids were on average 11% more productive, totaling 889 kg $ha^{-1}$ oil, than conventional hybrids, with 791 kg $ha^{-1}$ oil (Table 5).

**Table 5. Average of the castor hybrids in relation to the characteristic oil productivity (kg ha$^{-1}$) evaluated in Lins-SP and Penápolis-SP, in the agricultural years of 2007/2008 and 2008/2009**

| Hybrid | Lins | Penápolis | |
|---|---|---|---|
| | Year | Year | |
| | 2007/2008 e 2008/2009 | 2007/2008 | 2008/2009 |
| Cryptic 01 | 853.4 B | 708.0 C | 1059.8 B |
| Cryptic 02 | 647.7 C | 764.4 C | 817.4 C |
| Cryptic 03 | 961.4 A | 1060.2 A | 1266.8 A |
| Cryptic 04 | 777.0 B | 1124.5 A | 778.4 C |
| Cryptic 05 | 766.8 B | 756.5 C | 949.4 B |
| Cryptic 06 | 683.5 C | 928.1 B | 602.5 D |
| Cryptic 07 | 762.2 B | 913.1 B | 724.3 C |
| Cryptic 08 | 692.2 C | 780.5 C | 885.5 C |
| Cryptic 09 | 791.3 B | 653.6 C | 1012.5 B |
| Cryptic 10 | 940.4 A | 589.1 C | 1199.4 A |
| Cryptic 11 | 1084.5 A | 739.4 C | 1335.8 A |
| Cryptic 12 | 825.7 B | 752.3 C | 950.5 B |
| Conventional 01 | 701.5 C | 493.4 C | 820.4 C |
| Conventional 02 | 777.1 B | 721.8 C | 865.6 C |
| Conventional 03 | 664.5 C | 623.7 C | 791.4 C |
| Conventional 04 | 551.8 D | 633.6 C | 469.3 D |
| Conventional 05 | 468.3 D | 678.5 C | 436.3 D |
| Conventional 06 | 746.9 B | 822.0 B | 936.3 B |
| Conventional 07 | 1098.2 A | 912.8 B | 1165.4 A |
| Conventional 08 | 781.3 B | 600.5 C | 1035.5 B |
| Conventional 09 | 774.4 B | 1030.2 A | 1009.3 B |
| Conventional 10 | 1026.6 A | 871.0 B | 1219.4 A |
| Conventional 11 | 697.1 C | 544.6 C | 825.5 C |
| Conventional 12 | 663.6 C | 602.8 C | 879.4 C |
| Method | | | |
| Cryptic | 815.3 | 814.1 | 965.2 |
| Conventional | 745.9 | 711.2 | 871.1 |
| Average | 780.6 | 762.7 | 918.2 |

*Means followed by the same letter, in the same column, did not differ significantly (P = 0.05) by the Scott-Knott test*

Consequently, the average of the hybrids oil productivity were larger in Penápolis compared to those measured in Lins. The oil productivity of the cryptic hybrids in Penápolis was approximately 8.3% higher than those of Lins. Conventionally synthesized hybrids increased by 5.8%.

Not unlike that found for all characters until then, the mean square of the critical hybrids as well as the conventional hybrids are significant (P = 0.05), confirming, to have superior genotypes within the same material group. The achievement of the comparison test between means for the identification of the best genotypes, in reason of Penápolis is a critical location for the behavior of materials in the different years of experimentation (Table 3).

The presentation of the average oil productivity of the hybrids when evaluated in Penápolis shows that the agricultural year preeminently responsible for the interaction between hybrids by sites and years is that of 2007/2008, because it is in the experiment of that year that there are the most sensible variations in the performances of the hybrids. Aside from this, the behavior of the 24 genotypes in the 2008/2009 experiment is very consistent with that reported for the Lins locality. These statements can be exemplified by comparing the means of the cryptic hybrid 10 and 11, which have the worst oil productivity

averages in the year 2007/2008 in Penápolis and the best for the two years of evaluation in Lins and in the 2008/2009 agricultural year in Penápolis.

Despite the irregular behavior of the materials between the agricultural years in Penápolis, it was emphasized that hybrids obtained by the Cryptic Hybrids method presented better oil productivity not only in the general averages, but also in each of the evaluation years, determining the theirinteraction between hybrids by sites and years. In addition, cryptic hybrid 03 wasthe only material characterized with the best average productivity in all experiments.

Due to the pioneering nature of the work proposal, as commented before, there is some restriction in the deepening of the discussions, however, it is undeniable that the results obtained for the characteristic oil productivity, even with the exceptionality of an agricultural year in Penápolis, are hopeful and suggest the possibility of diffusion of the method of the Cryptic Hybrids, considering the superiority of the genotypes synthesized and time savings in hybrids production.

The analysis of joint variance among the hybrids for the years in the municipality of Lins (Table 3), detected the significance of the mean square of the interaction between hybrids for years.

**Table 6. Average of castor hybrids in relation to the characteristic height of plants (cm) evaluated in Lins-SP and Penápolis-SP, in the agricultural years of 2007/2008 and 2008/2009**

| Hybrid | Lins | | Penápolis | |
|---|---|---|---|---|
| | Year | | Year | |
| | 2007/2008 | 2008/2009 | 2007/2008 | 2008/2009 |
| Cryptic 01 | 200.6 B | 163.0 A | 97.8 D | 211.3 A |
| Cryptic 02 | 116.0 D | 165.3 A | 184.7 A | 190.1 A |
| Cryptic 03 | 189.5 B | 165.6 A | 159.8 B | 174.4 B |
| Cryptic 04 | 111.8 D | 163.6 A | 113.0 C | 163.6 B |
| Cryptic 05 | 155.8 C | 170.5 A | 177.3 A | 162.2 B |
| Cryptic 06 | 154.7 C | 167.0 A | 112.7 C | 193.6 A |
| Cryptic 07 | 155.7 C | 173.6 A | 158.6 B | 172.2 B |
| Cryptic 08 | 172.5 C | 171.6 A | 106.6 C | 182.6 B |
| Cryptic 09 | 165.9 C | 161.6 A | 204.7 A | 170.7 B |
| Cryptic 10 | 152.0 C | 151.3 A | 158.9 B | 173.6 B |
| Cryptic 11 | 156.0 C | 171.2 A | 133.4 C | 176.4 B |
| Cryptic 12 | 156.2 C | 169.0 A | 152.1 B | 162.7 B |
| Conventional 01 | 176.4 B | 163.1 A | 159.6 B | 193.1 A |
| Conventional 02 | 165.7 C | 168.1 A | 82.9 D | 213.9 A |
| Conventional 03 | 181.3 B | 168.2 A | 123.2 C | 206.1 A |
| Conventional 04 | 141.7 C | 166.6 A | 141.2 B | 214.4 A |
| Conventional 05 | 152.2 C | 164.5 A | 156.1 B | 167.3 B |
| Conventional 06 | 68.9 E | 162.3 A | 125.6 C | 159.8 B |
| Conventional 07 | 58.2 E | 163.4 A | 117.2 C | 150.0 C |
| Conventional 08 | 67.9 E | 158.5 A | 78.5 D | 139.4 C |
| Conventional 09 | 159.6 C | 172.0 A | 113.3 C | 138.2 C |
| Conventional 10 | 146.0 C | 146.2 A | 74.6 D | 161.3 B |
| Conventional 11 | 129.1 C | 147.7 A | 154.9 B | 106.4 D |
| Conventional 12 | 255.6 A | 166.1 A | 182.7 A | 110.8 D |
| Method | | | | |
| Cryptic | 157.2 | 166.1 | 146.6 | 177.8 |
| Conventional | 139.4 | 162.2 | 125.8 | 163.4 |
| Average | 148.3 | 164.2 | 136.2 | 170.6 |

*Means followed by the same letter, in the same column, did not differ significantly (P = 0.05) by the Scott-Knott test*

Thus, according to the already verified in that site for the characteristic content of oil, the height averages of the hybrids are unequal, statistically, in the evaluation years.

The mean height performance of each genotypes obtained in each of the years in two sites is as shown in Table 6, due to the significance of the interaction between hybrids by years.

The exposure of the height average of the castor hybrids when evaluated in Lins which indicates that 2008/2009 gave the most homogeneous results for the character. Since, on average, all 24 genotypes presented the same statistical value.

Considering that the smallest size of the plants is of great importance when one glimpses the mechanized harvest of the castor bean crop, it is necessary to consider the size of those materials that obtained the best grain and oil productivity averages for the experiments conducted in Lins. Among these, highlights are given to conventional hybrids 07 and 10, which had the shortest height, not only among the materials of better productivity, but also all 24 genotypes. For the respective agricultural years, the cryptic hybrid 10 presented smaller stature of the cryptic hybrids of better productivity in the two years of experimentation considering all the genotypes, and in the agricultural year of 2008/2009 the same genotype obtained the smaller stature of the cryptic hybrids.

This observation about the height of the genotypes of better productive performance can be very interesting. Several scientific studies, such as [12] and [13], reported the presence of a positive correlation between height of castor bean plants and yield which is an indicator of productivity. The highest productivities belonged to the higher stature materials, and, apparently, this can not be affirmed for the evaluations carried out in Lins. However, if we restrict the reasoning only for the means of the groups of materials, the cryptic hybrids have a greater stature and productivity.

It is useful to mention that, according to the classification scale of the castor bean size proposed by [14], the material of low size is one that does not exceed 150 cm in height and the medium sized one with height between 150 cm and 200 cm. Therefore, only the average of conventional hybrids in the 2007/08 crop year can be typified as low stature. The height of plants, as well as the other agronomic traits studied in this work, is genetically controlled by several genes, quantitative nature, and its expression has strong influence of the environment. This helps to explain the reason of certain genotypes, such as conventional hybrids 06, 08 and 07, which showed height variation between the years of experimentation.

In relation to the analysis of joint variance between the hybrids and the years for the municipality of Penápolis (Table 3), it is perceived, again, that genotypes also expressed changes in plant height between one year and another of experimentation, because there is significance of the mean square of the interaction between hybrids for years.

In addition, it was evidence that both genotypes and groups of materials have distinct plant height since the mean square of the comparison between methods of obtaining hybrids is significant to the F test (P = 0.05). In Penápolis, and Lins, the average squares of the cryptic hybrids and the conventional hybrids are significant, so there are different sizes of height within the same group of materials.

In Penápolis, similar to what happened in Lins, the mean squares of cryptic hybrids and conventional hybrids are significant, so there are different sizes of height within the same group of materials. In order to identify these genotypes of higher and lower height, such as observing the differences in height of genotypes between the years of experimentation, the test of comparison between means was applied, in which in the evaluation conditions of Penápolis, the conventional hybrids reaffirmed the status of smaller genotypes when they reached, on average, the height of 144 cm, while the cryptic hybrids were 162 cm (Table 6).

Attaining for the means of the 24 genotypes in the respective years of experimentation in Penápolis, it is easy to understand the reasons for the significance of the interaction between hybrids for years of the analysis of joint variance. Conventional hybrid 12 in the 2007/2008 crop year is classified statistically as one of those higher stock materials and in the following crop year it is one of the two lowest value averages. Something very similar happens with conventional hybrid 11.

Of those genotypes that have the best grain productivity, in Penápolis, it is highlighted, again,

the conventional hybrid 10, now in the agricultural year of 2007/2008, holder of the smallest average among the 24 genotypes, and the conventional hybrid 07, which has the lowest height of the materials with the best productive performance, in the agricultural year of 2008/2009.

In relation to the stature of the hybrids of the best averages of oil productivity in Penápolis, the lowest heights are from the cryptic hybrid 04, in the 2007/08 crop year, and from the conventional hybrid 07, for the 2008/2009 crop year. Having said all this, in general, for the plant height character, the conventional hybrids stood out to the cryptic hybrids, having as background the importance of the low size of the plants for the castor bean crop, since they have the smallest mean plant size. However, there are cryptic hybrids of the same excellent productivities that also have the height classified as of low size, even though it presents greater stature when compared to the conventional hybrid.

## 4. CONCLUSION

The results of grain and oil yields show the superiority of the cryptic hybrids in overcoming the conventional hybrids for both parameters, however the average oil productivity of cryptic hybrids was always been higher than conventional hybrids.

In terms of plant height, conventional hybrids are the genotypes with the lowest mean overall height, but there are good genotypes of cryptic hybrids that are also low in size.

The study identified no differences in oil content as a function of the method of obtaining hybrids.

The cryptic hybrids method was efficient in obtaining lineages and hybrids superior of castor beans when compared to the standard "Standard" method.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES


1. Borém A, Miranda GV, Fritsche-Neto R. Plant breeding. 7 th ed. Viçosa: Publishing company UFV; 2017.
2. Lopes MTG, Viana JMS, Lopes R. Adaptability and stability of inbred maize hybrids obtained by the cryptic hybrid method. Rev. Bras. Agroec. 2001;36(3): 483-491.
3. Severino LS, Auld DL, Baldanzi M, Cândido MJD, Chen G, Crosby W, et al. A review on the challenges for increased production of castor. Agron. Jou. 2012; 104(4):853-880.
4. Silva GJ, Lopes MTG, Viana JMS, Lopes R. Molecules for gene characterization gametophyte (IG1) in maize genotypes. Viçosa, Federal University of Viçosa; 2009.
5. Toppa EVB, Silva CJ, Zoz T, Silva TMN. Comparative analysis of methods of obtaining "standard" and cryptic hybrid strains. Ver. Verd. 2012;7(1):29-32.
6. Toppa EVB. Castor beans hybrids (*Ricinus communis* L.) obtained through conventional hybridization and the cryptic hybrid method. Botucatu, Paulista State University; 2015.
7. EMBRAPA. Brazilian Company of Agricultural Research. Soil correction, mineral nutrition and manure fertilizer. Brasília: Embrapa; 2007.

   Available:http://www.agencia.cnptia.embrapa.br/gestor/mamona/arvore/CONT000h4sfwun202wx7ha0awymty46xpw5x.html
8. Lopes MTG, Viana JMS, Lopes R. Productive capacity of hybrids of maize endogamic families (Zea mays L.), obtained by the cryptic hybrid method. Rev. CERES. 2005;52(303):613-632.
9. CONAB. National Supply Company. Harvests: Historical series. Brasília: Conab; 2017.

   Available:http://www.conab.gov.br/conteudos.php?a=1252&t=2
10. Severino LS, Ferreira GB, Moraes CRA, Gondim TMS, Freire WSA, Castro DA, et al. Growth and productivity of castor beans fertilized with macronutrients and micronutrients. Mag. Braz. Agroec. 2006; 41(4):563-568.
11. Souza AS, Távora FJA, Pitombeira JB, Bezerra FML. Times of planting and irrigation management for castor bean. II - Growth and productivity. Rev. Ciênc. Agron. 2007;38(4):422-429.
12. Pinto CM, Pinto ORO, Sizenando Filho FA, Pitombeira JB. Castor bean intercropped with sunflower plantations lagged in: path

analysis of yield and its components. Rev Verde. 2011;6(4):219-229.

13. Zoz T. Correlation and analysis of yield traits of grains and their components and plant characteristics in safflower (*Carthamus tinctorius* L.) and castor bean (*Ricinus communis* L.). Botucatu, Paulista State University; 2011.

14. Savy Filho A. Hybridization in castor bean. In: Borém A, editors. Artificial Hybridization of Plants. Viçosa: Publishing company UFV; 1999.



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