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Estimates of genetic parameters with selection within and between half-sib families of *Jatropha curcas* L.

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ABSTRACT

Jatropha curcas L., the most promising oilseed plant for biodiesel and biokerosene, is in the process of domestication, and the economic, social and environmental viability of the crop depends on increasing its yield performance. Low seed yield is due, above all, to planting of non-improved cultivars. We evaluated 16 half-sib families in the 2nd, 3rd and 4th years after planting. The components evaluated were seed yield, number of trusses per plant, number of fruits per truss, fruit maturation rate, plant height and canopy diameter. We also estimated the genetic parameters of these components with a view toward quantifying genetic gain from plant selection. The main seed yield components exhibited predominant genetic control. Nevertheless, the environmental effect was the main determinant of uniformity in fruit maturation. Thus, management strategies have greater potential for having an impact on concentration of fruit production of this oilseed plant. Genetic gains related to seed yield in the cropping of genotypes selected in the 2nd, 3rd, and 4th years were 33.3%, 41.6% and 56.7%, respectively. The development of new genotypes should furthermore consider strategies for generation of variability using crosses between divergent plants with better agronomic characteristics.

1. Introduction

Among oilseeds, *Jatropha curcas* L. has been studied for its seed yield potential and oil quality for biodiesel and biokerosene. The economic, social and environmental viability of this crop depends on a quantitative increase in yield (Dias, 2011; Dias et al., 2012). Uneven maturation of the fruits and low seed yield are its main limitations (Dias et al., 2007). From the initial seed yield expectation of 4 t ha^{-1} or more, yields of less than 2 t ha^{-1} are being observed under different edaphic and climatic conditions, whether due to water stress and/or to the incidence of pests and diseases (Spinelli et al., 2014). The incidence of powdery mildew (*Oidium* sp.) in cerrado (tropical savanna) regions and incidence of leafhopper (*Empoasca* spp.) have been observed in planted areas in diverse regions of the world, including Brazil (Dias et al., 2007; Laviola et al., 2010).

Sources of variability for resistance to powdery mildew, for absence of toxicity in seeds and for proportion of male and female flowers have been characterized (Laviola et al., 2010). Other studies have confirmed expressive variation in seed yield of this oilseed, from 0.2 to 2 kg $plant^{-1}$ of seeds (Francis et al., 2005; Jongschaap et al., 2007). Different selection strategies have been used. Drumond et al. (2010) characterized accessions responsive to environmental improvement that yielded 2.1 kg $plant^{-1}$ of seeds in an irrigated system in the 1st year after planting. On the other hand, under cerrado conditions and without irrigation, Laviola et al. (2010) observed variation in seed yield from 0 a 180 g $plant^{-1}$ among 110 accessions, also in the 1st year of evaluation.

Since it is a crop in the domestication phase, the use of repeated measurements and evaluation of plants of productive age are especially important for obtaining more accurate seed yield estimates. In this case, estimation of the repeatability coefficient, which measures the capacity of the individual in maintaining its superiority over time (Cruz et al., 2004), is especially important. The use of repeated measurements and environmental stratification increase the accuracy of mass selection, assisting in attainment of estimates of genetic progress and minimum number of assessments (Resende et al., 2002). In the selection of plants of greater stability and adaptability, the method of harmonic mean of relative performance of predicted genetic values (HMRPGV) has been used. This method, proposed by Resende (2004), allows simultaneous selection of plants with superior performance and yield stability, while aggregating the advantages of mixed models.

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Table 1
Soil chemical attributes in the 0–20 cm layer, evaluated in 2009–2011 in the experimental area located in the municipality of Porto Velho, RO, Brazil.

Date	pH	P $mg\,dm^{-3}$	K $mmol_c\,dm^{-3}$	Ca $mmol_c\,dm^{-3}$	Mg $mmol_c\,dm^{-3}$	Al + H $mmol_c\,dm^{-3}$	Al $mmol_c\,dm^{-3}$	O.M. $g\,kg^{-1}$	V %
09/2009	4.4	3.0	2.54	13.1	9.7	174.9	33.6	23.1	13
09/2010	4.8	2.0	1.03	26.3	17.0	108.9	14.8	25.2	29
09/2011	5.0	2.0	1.23	45.1	21.5	90.8	6.8	27.4	43

P: Phosphorus (Mehlich^{-1}); K: exchangeable potassium (Mehlich^{-1}); Ca: exchangeable calcium; Mg: exchangeable magnesium; Al + H: titratable acidity; Al: exchangeable aluminum; O.M.: organic matter and V: base saturation.

Plant selection is based on the additive genetic values of the parent plants that will be recombined and on the genotypic values of the genotypes that may be propagated in a vegetative manner. For prediction of gains in selection, it is necessary to estimate the additive genetic variance and the non-additive genetic variance, depending on the propagation method used. Success in genetic breeding depends on the accuracy of selection of individuals bearing the greatest number of favorable alleles (Cruz et al., 2004). Among the main procedures for estimation of genetic parameters, restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) stands out. This procedure has been consolidated in genetic evaluation of perennial species through allowing prediction of genetic values associated with phenotypic observations, fitting the data to fixed effects and to the uneven quantity of information per plot (Resende, 2002).

The aim of this study was to estimate genetic parameters related to the seed yield and its components, and growth traits in 16 half-sib families of *J. curcas* in the 2nd, 3rd and 4th years after planting, and quantify genetic gain with plant selection.

2. Material and methods

2.1. Field trial

The trial is composed by 16 half-sib families, all of them derived from a population of wild seed of unknown genetic origin from visually selected plants in Ariquemes, RO, Brazil. The trial was set up in the experimental field of the Agriculture and Forest Research Center (latitude 09°23′49″S, longitude 62°01′10″W, and altitude 198 m above sea level) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA-CPAFRO), Porto Velho, RO, Brazil, in February 2008.

Families were set up in randomized blocks design with 8-plant linear plots, three replications, spacing of 3.0 × 2.0 m and assessed in the 2nd, 3rd and 4th years after planting. Final planting was made in February 2008, with 30-day old seedlings grown in a nursery. At planting, fertilization was applied in 20 × 20 × 20 cm hills. As of the second year, it was carried out in topdressing, three months before the main harvests of the crop in the region (Spinelli et al., 2014), which occurred in January and June. Weed control was carried out manually and chemically. No agricultural chemicals were used for pest and disease control of the crop.

The soil of the experimental area (Table 1) is classified as an Oxisol, with a very clayey texture, being improved through fertilization. Climate in the region of the experiment is tropical type Aw, according to Köppen climate classification. It is hot and wet, with a well-defined dry period from June to September, mean annual temperature of 25.4 °C and mean annual rainfall of 1965 mm (Rondônia, 2009).

2.2. Evaluation of seed yield and its components and of growth traits

Seed yield was evaluated in five harvests: June/2009, December/2009, January/2010, June/2010 and December/2011, during three crop years (2009–2011). The June 2011 harvest was not made. Severe incidence of leafhopper (*Empoasca* spp.) in the flowering and seed-filling period, from March to May 2011, compromised yield. In the region, the plant bears fruit during the entire rainy period (November to June) (Spinelli et al., 2014).

The fruits in the final stage of maturity were gathered from the trees and from the projections of their canopies, dried in the shade for around seven days, and then processed. After processing, seed moisture was measured. Seed lots with moisture content of less than 9% were weighed and noted, resulting in seed yield. The number of ripe fruits was interpreted as fruit maturation rate estimated through the ratio of the number of ripe fruits and the total number of fruits produced. The number of trusses per plant and fruits per truss were also computed. The following vegetative traits were measured on an individual level: (a) plant height, in m; (b) number of branches, counting those above one meter of plant height as of the soil; (c) canopy diameter in the direction of greater space, in m and (d) canopy diameter in the direction of less space, in m.

2.3. Estimates of genetic parameters

For estimation of variance components, the restricted maximum likelihood (REML) method was used, while prediction of genetic values was processed with the best linear unbiased prediction (BLUP) method. These procedures are associated with a mixed linear model, which contains, in addition to the overall mean, random effects of treatments and of plots and the fixed effect of environments. Estimates of genetic values were obtained using the program Selegen-REML/BLUP, considering the following mixed linear model (Resende, 2002):

$$y = Xr + Za + Wp + e$$

in which y is the data vector; r is the block effects vector, taken as fixed and added to the overall mean; a is the individual additive genetic effects vector, taken as random; p is the plot effects vector, taken as random; e is the random errors vector. Capital letters represent the incidence matrices for said effects.

Among the most important genetic parameters for characterization of genetic control of the traits, heritability, repeatability and accuracy of selection stand out. Narrow-sense heritability measures the relative proportion of the genotypic effects on expression of the traits. It is one of the most important components of expression of genetic gain in plant selection:

$$h_a^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2 + \sigma_p^2}$$

in which h_a^2 = narrow-sense heritability, σ_a^2 = additive genetic variance, σ_e^2 = environmental variance, σ_p^2 = variance among plots.

Evaluation of repeated measurements over time is of great importance for breeding of perennial species because it allows maintenance of the superiority of a genotype over time to be quantified. In these cases, selection should be based on models that consider the permanent effect of the environment and the

Table 2
Estimates of genetic parameters for eight traits in 16-half sib families of *Jatropha curcas* L., in the 2nd year after planting.

Genetic parameters[b]	Traits[a]							
	Yield	NT	NFT	FMR	NB	PH	CD_1	CD_2
σ^2_a	7908.79	35.51	1.84	0.00264	10.55	0.0170	0.045	0.0005
σ^2_p	524.12	0.208	0.27	0.00025	0.46	0.0001	0.001	0.0001
σ^2_e	12540.38	78.65	1.39	0.03327	13.44	0.0270	0.034	0.0720
σ^2_y	20973.29	114.37	3.50	0.03616	24.45	0.0441	0.080	0.0725
h^2_a	0.38	0.31	0.52	0.07	0.43	0.39	0.56	0.01
	[0.18]	[0.16]	[0.20]	[0.07]	[0.18]	[0.18]	[0.30]	[0.01]
c^2_p	0.024	0.001	0.077	0.01	0.018	0.002	0.016	0.00012
$\hat{r}_{gg}$	0.49	0.45	0.56	0.22	0.51	0.5	0.57	0.72
CV_g	19.73	15.16	33.06	7.34	30.16	6.45	24.99	2.66
CV_e	31.72	27.18	43.85	27.07	45.48	10.38	33.11	32.05
CV_r	0.62	0.56	0.75	0.27	0.66	0.62	0.75	0.08
Overall mean	450.85	39.31	4.1	0.70	10.77	2.02	0.85	0.84

[a] Seed yield (Yield); number of trusses of the first harvest of the year (NT); number of fruits per truss (NFT); fruit maturation rate (FMR); number of branches (NB); plant height (PH); canopy diameter in the direction of greater spacing (CD_1) and canopy diameter in the direction of less spacing (CD_2).
[b] σ^2_a: additive genetic variance; σ^2_p: environmental variance among plots; σ^2_e: residual variance; σ^2_y: individual phenotypic variance; h^2_a: individual narrow-sense heritability; c^2_p: coefficient of determination of the plot effects; $\hat{r}_{gg}$: accuracy; CV_g: coefficient of genetic variation; CV_e: coefficient of experimental variation; CV_r: coefficient of relative variation.

phenotypic correlation between repeated measurements from the same individual, which is known as repeatability:

$$y = Xm + Za + Wp + Ts + e$$

in which y is the data vector, m is the measurement-replication combination effects vector (taken as fixed), added to the overall mean value, a is the individual additive genetic effects vector (taken as random), p is the plot effects vector (random), s is the permanent effects vector (random) and e is the errors vector, taken as random. Capital letters represent the incidence matrices for said effects.

Repeatability (ρ), which measures the permanent genotypic constancy, was interpreted to evaluate the precision of the clones being selected with repeated measurements and obtained according to the estimator (Resende, 2002):

$$\rho = \frac{\sigma^2_a + \sigma^2_{ep} + \sigma^2_a}{\sigma^2_y}$$

in which ρ repeatability, σ^2_a = additive genetic variance, σ^2_{ep} = variance of the permanent effects of the environment, σ^2_y = phenotypic variance.

Selective accuracy ($\hat{r}_{gg}$) is an estimate of correlation between the true genotypic value and the estimated genotypic value, and is considered to be an important measure of the quality of the selection procedures. Selective accuracy for selection of individuals based on the behavior of the half-sib families was obtained according to Resende (2002):

$$\hat{r}_{gg} = 0.5\left[\frac{m\mathrm{N}h^2_a}{1 + (m-1)\rho + (N-1)\,\mathrm{m}0.25\mathrm{h}^2_a}\right]$$

in which m = number of measurements, h^2_a = narrow-sense heritability, ρ = repeatability, N = number of observations. Selective accuracy ranges from 0 to 1 and according to the classification of Resende (2002), it may be considered as very high ($\hat{r}_{gg} \geq 0.9$), high ($0.7 \leq \hat{r}_{gg} < 0.9$), moderate ($0.5 \leq \hat{r}_{gg} < 0.7$) and low ($\hat{r}_{gg} < 0.5$).

2.4. Criterion for plant selection

Procedures that allow adaptability, better performance, stability and maintenance of superiority over time to be interpreted simultaneously should be considered in selection of perennial plants. For selection within and between families, the procedure of harmonic mean of relative performance of genetic values (HMRPGV) was considered, with a view toward simultaneous selection for yield and stability. This method is based on a property of the harmonic mean, which favors the genotypes of higher genetic value with lower variation between harvests (Resende, 2002):

$$\mathrm{HMRPGV}_i = \frac{m}{\sum_{1}^{m} \frac{1}{\mathrm{GV}_{ij}}}$$

HMRPGV_i = harmonic mean of relative performance of genetic values, m = number of measurements (years), GV_{ij} = genotypic value of the i-th plant in the j-th year, expressed as a proportion of the mean value.

3. Results and discussion

In modern plant breeding programs, planning and conducting experiments are based on interpretation of the estimates of the genetic parameters that allow the experimental quality, the proportion of total variance due to genetic differences and prediction of gain in plant selection to be inferred (Cruz et al., 2004). In perennial plants, estimation of genetic parameters must consider measurements over time, growing plants with plant density, and plants at a productive age (Resende, 2002). Certainly in breeding of *J. curcas*, few studies show results that fulfill these conditions.

Additive genetic variance is one of the most important components of genotypic variance. The relationship between additive genetic variance (σ^2_a) and phenotypic variance (σ^2_y), known as narrow-sense heritability (h^2_a), measures the contribution of additive genes in the expression of traits. In the 2nd year after planting, greater estimates of narrow-sense heritability were observed for most of the traits (Table 2). In general, some coincidence is observed in the arrangement of estimates of heritability in the 3rd year after planting (Tables 2 and 3). This good arrangement indicates the usefulness of these traits for plant selection since additive genetic variance is associated with the average effect of gene substitution obtained from the recombination of selected plants.

In the 2nd year after planting, the plant height, number of branches and canopy diameter in the direction of greater spacing traits showed narrow-sense heritability estimates from 0.39 to 0.56, indicating the importance of the additive genetic component in their expression (Table 2). Laviola et al. (2010) observed that vegetative traits showed greater estimates of narrow-sense heritability. Nevertheless, a trend toward reduction in these estimates was observed over time. It is likely that heritabilities go down over

Table 3
Estimates of genetic parameters for eight traits in 16-half sib families of *Jatropha curcas* L., in the 3rd year after planting.

Genetic parameters[b]	Traits[a]							
	Yield	NT	NFT	FMR	NB	PH	CD_1	CD_2
σ_a^2	36175.26	12.9405	0.4025	0.0001	20.05	0.021	0.021	0.0005
σ_p^2	9037.61	2.459	0.009	0.0000	0.029	0.0000	0.00018	0.0001
σ_e^2	45144.74	53.148	0.326	0.0160	19.87	0.047	0.0567	0.081
σ_y^2	90357.61	68.55	0.7375	0.0161	39.949	0.068049	0.07788	0.0816
h_a^2	0.40	0.19	0.55	0.01	0.50	0.31	0.27	0.01
	[0.18]	[0.12]	[0.21]	[0.01]	[0.19]	[0.15]	[0.15]	[0.01]
c_p^2	0.10	0.03	0.01	0.00	0.07	0.01	0.02	0.01
$\hat{r}_{gg}$	0.50	0.35	0.57	0.07	0.54	0.44	0.43	0.06
CV_g	22.90	13.66	17.10	1.57	17.91	5.31	4.88	0.78
CV_e	34.34	30.86	23.01	18.94	25.27	9.55	9.39	9.95
CV_r	0.67	0.44	0.74	0.08	0.71	0.56	0.52	0.08
Overall mean	830.53	26.34	3.71	0.67	25.00	2.73	2.97	2.87

[a] Seed yield (Yield); number of trusses of the first harvest of the year (NT); number of fruits per truss (NFT); fruit maturation rate (FMR); number of branches (NB); plant height (PH); canopy diameter in the direction of greater spacing (CD_1) and canopy diameter in the direction of less spacing (CD_2).
[b] σ_a^2: additive genetic variance; σ_p^2: environmental variance among plots; σ_e^2: residual variance; σ_y^2: individual phenotypic variance; h_a^2: individual narrow-sense heritability; c_p^2: coefficient of determination of the plot effects; $\hat{r}_{gg}$: accuracy; CV_g: coefficient of genetic variation; CV_e: coefficient of experimental variation; CV_r: coefficient of relative variation.

time because the environmental effects are compounded, increasing the genotype-environment interaction.

The use of a 2-m spacing between plants reduced the growth of canopy diameter of the plants as of the 2nd year after planting, and this limited assessment of this trait in subsequent years (Tables 2 and 3). Assessment of plants in less restricted spacings shows a trend of decrease in narrow-sense heritability over the years. Ginwal et al. (2005) quantified broad-sense heritability estimates at 0.89 for plant height, assessed at six months of age. Rao et al. (2008) found broad-sense heritability of 0.88 for plant height at 34 months of growth.

Still considered as a plant in the domestication phase, the viability of this crop depends on an increase in seed yield. Positive associations between the number of branches and plant height with seed yield were observed by Rao et al. (2008) and by Spinelli et al. (2010). The coefficients of variation of seed yield (Tables 2 and 3) are the same magnitude to that observed in other studies (Juhász et al., 2010; Laviola et al., 2010). According to Cruz et al. (2004), traits derived from counting, such as the number of branches and the fruit maturation rate, tend to show greater values of the coefficient of variation. In general, for these traits, a trend toward reduction of the values of the environmental coefficient of variation as of the 2nd year after planting is observed.

The genetic coefficient of variation expresses the magnitude of genetic variation in relation to the mean value of the trait and indicates the presence of genetic variability in the population evaluated (Tables 2 and 3). The relative coefficient of variation (CV_r), for its part, measures the ratio between the genetic coefficient of variation and the environmental coefficient of variation. In the 2nd year after planting, greater ratios between the genetic coefficient of variation and the experimental coefficient of variation were observed for the traits canopy diameter in the direction of greater spacing and number of fruits per truss (Table 2). In the 3rd year after planting, the arrangement changed (Table 3). According to Vencovsky (1987), the greater value of this estimate is associated with the traits with greater possibilities of attaining gains in selection.

With a view toward better understanding of yield potential, other seed yield components were evaluated in the 2nd and 3rd years after planting. The fruit maturation rate, which represents the percentage of mature fruits at the time of harvest, indicates predominance of the environmental effect in fruit development of this oilseed (Tables 2 and 3). The lack of uniformity of maturation of the fruits is a characteristic of this oilseed plant, which flowers constantly throughout the rainy period, and harvest is made after the accumulation of three to four blossoming periods with greater vigor. The predominance of the environmental component in relation to the genetic component indicates small gains from selection of this trait.

The female flowers open on different days, forcing cross pollination; the stigmas become receptive after the flower opens and they remain that way for three days; the unpollinated flowers fall on the fourth day. Artificial hybridization of plants is one of the resources used for joining desirable traits in different parents in a single individual, meeting a certain need of the breeding program for the species, the needs of the producer or the needs of a niche market.

For its part, the number of fruits per truss showed greater potential for selection than the number of trusses per plant, in contrast with that observed by Borges (2012). This author did not observe genetic variability for number of fruits per trusses in a population structured by origin. The evaluation of half-sib families in this study allows exploitation of additive genetic variance in plant selection to obtain gains in traits of lower heritability, increasing the possibility of achieving gains in selection.

In the 4th year after planting, with complete development of the plants, resulting in interweaving of the canopies, the vegetative traits, such as number of fruits per truss, fruit maturation rate and number of branches could not be evaluated. Therefore, only assessment of seed yield and of the main plant architecture traits of the canopy were made, just as already assessed for the 2nd and 3rd years after planting (Table 4).

Agronomic assessments have shown variability of the yield components of this oilseed plant (Mishra, 2009). Brittaine and Lutaladio (2010) and Jongschaap et al. (2007) reported accessions that showed variation in their yield from 0.2 to 2 kg plant^{-1} of seed. According to Jongschaap et al. (2007), the great variation that has been observed in seed yield of this oilseed is mainly due to differences in the edaphic and climatic conditions in which it is grown, established in an extensive range between the latitudes of 30°N and 35°S. Nevertheless, even within a single environment, it was observed that growing unselected materials is an important variation factor for seed production. Of the 384 genotypes evaluated in the present study, 40 of them (10%) produced less than 300 g year^{-1} of fruit, without exhibiting response to improvement of the environment. The selection of genotypes responsive to environmental improvement is a determining factor for yield increase in this oilseed. Improvements in experimental conditions were obtained by application of lime over the entire area and

Table 4
Estimates of genetic parameters for seed yield (g/plant) and for main plant architecture traits, evaluated in 16-half sib families of *Jatropha curcas* in the 4th year after planting.

Parameter[b]	Traits[a]			
	Yield	PH	CD_1	CD_2
σ^2_a	17842.89	0.01463	0.0023	0.0001
σ^2_p	8053.09	0.01097	0.04479	0.00001
σ^2_{perm}	3715.24	0.00004	0.00006	0.00006
σ^2_e	27449.98	0.04016	0.074	0.018
σ^2_y	57061.2	0.0658	0.12115	0.01817
h^2_a	0.31	0.22	0.02	0.01
	[0.10]	[0.08]	[0.01]	[0.01]
r	0.52	0.39	0.38	0.02
	[0.06]	[0.05]	[0.06]	[0.06]
c^2_p	0.14	0.16	0.36	0.16
c^2_{perm}	0.06	0.0007	0.0005	0.001
Overall mean	222.96	2.78	2.40	2.19

[a] Seed yield (Yield); plant height (PH); canopy diameter in the direction of greater spacing (CD_1) and canopy diameter in the direction of less spacing (CD_2).
[b] σ^2_a: additive genetic variance; σ^2_p: environmental variance among plots; σ^2_{perm}: variance of permanent environmental effects; σ^2_e: residual variance; σ^2_y: individual phenotypic variance; h^2_a: individual narrow-sense heritability; r: individual repeatability; c2p: coefficient of determination of the plot effects; c2perm: coefficient of determination of the permanente environmental effects.

topdressed chemical fertilization undertaken before the main harvests according to results of soil analyses performed from August 2008 to September 2010 (Table 1).

According to Dias et al. (2007) and Brittaine and Lutaladio (2010), *J. curcas* needs from three to four years to reach productive age. The interpretation of measurements over time is fundamental for characterization of yield performance of perennials that manifest a long reproductive cycle and differentiated expression of traits over time (Resende, 2002). Jongschaap et al. (2007) and Laviola et al. (2010) observed a coefficient of repeatability from 0.4 to 0.6 for seed yield of *J. curcas,* values which are compatible with the estimate obtained in this study, in case $\rho = 0.5$ (Table 4).

The correlation between the real genetic values and the estimated ones, interpreted as the accuracy of the selection procedure, quantifies the efficacy of the inference of the genotypic value as a function of the number of harvests evaluated. According to the classification of Resende (2002), the value of selection accuracy showed satisfactory precision in inferences of the genotypic values ($r_{g\hat{g}} = 0.68$), indicating that the experiment was carried out appropriately and that evaluation of the five harvests was sufficient for characterization of superior genotypes.

Selection of plants of greater yield potential is considered one of the best alternatives for increasing yield without increasing costs. Yield projections based on isolated observations or on plants of only a few months' growth have contributed to creating yield expectations that have not been observed in the field (Dias et al., 2012). Here, two criteria were considered for selection of mother trees: the intensity of selection, defined by maximization of the lower limit of the confidence interval of genetic gain corrected for endogamy, and the effective number. Genetic gain is directly proportional to the intensity of selection. Maximization of the lower limit of the confidence interval of genetic gain occurred with the selection of the twelve best plants originating from only 7 families. The genetic progress in accumulated yield estimated from the selection of these individuals was 42% (Table 5). In addition to this criterion, the need for working with a greater number of individuals was also considered so as to ensure a minimum effective number, which will allow maintenance of variability in the following stages of selection (Resende, 2002). Through the association of these two criteria, in addition to the 12 individuals with best performance, the best individuals from each family were also selected, which allowed raising the effective number from 7.7 to 18.2. The genetic progress in accumulated yield estimated from the selection of these individuals was 25% (Table 6).

Plant selection under the edaphic and climatic conditions of the tropics favors local characterization of genotypes adapted to high temperature and moisture, more solar radiation and well-defined dry period. The cloning of plants, whether through planting of cuttings from the plant stem or through tissue culture, allows exploitation of the complete genotypic value of the individual.

Table 5
Estimates of genotypic values added to the mean overall seed yield (g/plant) and selection gain of *Jatropha curcas* in relation to 12 plants selected for vegetative propagation.

Order	Block	Family	Plant	Years after planting			Yield	HMRPGV
				2nd	3rd	4th		
1	1	10	7	541.83	1501.53	1004.34	3047.70	1.60
2	3	8	7	693.21	1158.55	713.86	2565.62	1.46
3	1	7	4	570.68	1297.20	736.39	2604.26	1.43
4	3	12	1	644.69	1138.45	721.14	2504.29	1.42
5	3	12	4	564.67	1302.04	719.83	2586.54	1.42
6	3	7	5	657.40	1107.90	681.75	2447.05	1.39
7	2	6	2	684.15	1061.67	686.63	2432.46	1.39
8	1	14	3	604.57	1029.22	809.57	2443.36	1.39
9	1	1	6	623.03	988.42	806.69	2418.15	1.38
10	1	7	8	461.43	1212.33	880.02	2553.77	1.35
11	2	10	2	625.11	1138.02	751.41	2354.53	1.35
12	3	7	1	540.75	1176.67	689.13	2406.54	1.34
Overall mean				450.85	830.53	489.27	1773.07	
New mean				600.96	1176.00	766.73	2530.36	
Gain from selection (%)				33.29	41.60	56.71	42.71	

Yield: seed yield; MHPRVG: harmonic mean of relative performance of genetic values.

Table 6
Estimates of additive genetic values added to the overall mean of seed yield (g/plant) of *Jatropha curcas* in relation to 23 plants selected to compose a recombination unit.

Order	Block	Family	Plant	Years after planting			YIELD	HMRPGV	Ne
				2nd	3rd	4th			
1	1	10	7	513.43	1254.3	828.89	2596.62	1.41	1.0
2	1	7	4	541.4	1179.29	660.54	2381.23	1.31	2.0
3	3	12	1	574.64	1061.4	651.35	2287.38	1.29	3.0
4	3	7	5	593.44	1065.71	627.75	2286.91	1.29	3.5
5	3	12	4	526.63	1159.55	650.56	2336.74	1.29	4.1
6	3	8	7	607.02	1029.33	625.8	2262.15	1.28	5.1
7	1	14	3	564.87	978.09	708.1	2251.06	1.28	6.1
8	1	7	8	475.86	1128.37	746.71	2350.94	1.28	6.3
9	3	7	1	523.45	1106.98	632.18	2262.6	1.26	6.3
10	2	14	3	529.08	1007.17	665.47	2201.73	1.24	6.9
11	2	10	2	563.4	976.19	641.13	2180.72	1.24	7.6
12	3	7	8	529.46	1056.21	628.69	2214.37	1.24	7.7
13	1	1	6	536.8	905.0	667.2	2109.0	1.20	8.6
14	2	2	1	514.7	1032.5	561.7	2108.9	1.20	9.5
15	2	3	2	524.4	1033.1	576.8	2134.2	1.20	10.4
16	2	4	7	443.7	952.5	669.0	2065.3	1.10	11.4
17	3	5	8	514.4	918.7	679.2	2112.4	1.20	12.3
18	2	6	2	604.6	970.3	599.0	2173.9	1.20	13.3
19	3	9	5	391.8	786.0	399.0	1576.8	0.90	14.3
20	2	11	5	506.3	945.5	599.7	2051.5	1.20	15.2
21	2	13	4	471.1	812.3	432.3	1715.7	1.00	16.2
22	2	15	1	475.2	1002.5	601.7	2079.5	1.20	17.2
23	2	16	3	467.8	880.5	543.5	1891.8	1.10	18.2
Overall mean				450.85	830.53	489.27	1773.07		
New mean				526.33	1047.32	643.517	2217.17		
Gain from selection (%)				16.74	26.10	31.53	25.05		

Yield: seed yield; MHPRVG: harmonic mean of relative performance of genetic values; Ne: effective populational size.

Among the genotypes of superior yield performance, the 12 best clones that maximize genetic gain were grouped (Table 5).

The genetic gain percentages for seed yield from growing the selected genotypes in the 2nd, 3rd and 4th years after planting were 33.3, 41.6, and 56.7 (Table 5), respectively, which are equivalent to a yield of 1.0, 2.0 and 1.3 t ha^{-1}. The gain in selection obtained from planting clones was less than that observed in other crops. The occurrence of different levels of endogamy in the families resulting from self-pollinations is the most probable hypothesis for the moderate gains estimated. Observation of segregation of albino plants in the proportion of 3:1 reinforces the hypothesis of evaluation of related plants. According to Rosado et al. (2010), growing of isolated plants of this oilseed for many years in Brazilian territory has favored self-pollination in plants. Using molecular markers, Laviola et al. (2012) observed that even in dense plantings, this oilseed has a natural rate of 30% self-pollination.

In some aspects, the results of the present study lead to more questions than answers in regard to the best form of using this oilseed plant for biodiesel production. The finding that uniformity of maturation exhibits a predominant environmental effect indicates that management practices have greater potential for concentrating harvest of this oilseed. Recent studies indicate promising results from the use of growth regulators for increasing the uniformity of fruit maturation and yield of this oilseed (Abdelgadir et al., 2010; Ghosh et al., 2010; Pan and Xu, 2011; Gouveia et al., 2012). In addition, the good adaptation of this oilseed to the region, characterized by high rainfall and well-defined water deficit, stands out, which contributes to an earlier harvest in relation to other regions of the country, outside the time period of the incidence of the main pests of this crop.

Although expressive and accurate, the genetic progress estimated in this study does not appear to be sufficient to provide a quantitative increase in the yield of this oilseed. The development of new materials should consider strategies of generation of variability, using crosses between divergent plants and those with better agronomic characteristics.

4. Conclusions

i) Seed production exhibits predominant genetic control, and gains may be obtained from selection of this oilseed.
ii) The environmental effect is the main determinant in uniformity of maturation of the fruits, and management methods show greater potential for having an impact on the concentration of fruit production of this oilseed.
iii) The selection method within and between families using repeated measurements proved to be adequate for plant selection.
iv) The development of new cultivars should consider strategies for generation of variability using crosses between divergent plants and those with better agronomic characteristics.
v) *J. curcas* shows potential for greater yield gains.

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