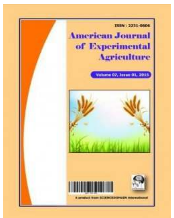

American Journal of Experimental Agriculture
11(5): 1-11, 2016, Article no.AJEA.15139
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

Genetic Parameters for Fruits, Seeds and Oil Content Traits of *Jatropha curcas* L. in a Semi-arid Region of Senegal

Ibrahima Diédhiou[1*], Youssouph Séwéhi Sambou[1], Moustapha Diéré Sagna[1] and Pape Madiallacké Diédhiou[2]

[1]Ecole Nationale Supérieure d'Agriculture (ENSA), Université de Thiès (UT), BP A 296, Route de Khombole, Thiès, Sénégal.
[2]UFR des Sciences Agronomiques d'Aquaculture et de Technologies Alimentaires (UFR S2ATA)/Université Gaston Berger de Saint-Louis (UGB), Route de Ngallele BP 234 Saint-Louis, Sénégal.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2016/15139
Editor(s):
(1) Igor GradislavovichLoskutov, Department of Genetic Resources of Oat, Barley and Rye, Vavilov Institute of Plant Industry, Russia and Department of Agrochemistry, Biology Faculty, Sankt-Petersburg State University, Russia.
Reviewers:
(1) Sanjay Singh, Institute of Forest Productivity, Ranchi, India.
(2) Hariom Kumar Sharma, ICAR-Central Research Institute for Jute and Allied Fibres, Kolkata, India.
(3) Penjit Srinophakun, Kasetsart University, Thailand.
(4) Leonardo Lopes Bhering, University of Viçosa, Brazil.
(5) Claude Bakoume, High Institute of Medical Technology (HIMT), Yaounde, Cameroun.
(6) Marina Purelli, Geneticlab Srl, Via Corte Ferrighi, Italy.
(7) Danilo Hottis Lyra Hottis, Southeast Bahia State University, Brazil.
(8) Naresh Kaushik, CCSAHU Regional Research Station, Haryana, India.
Complete Peer review History: http://sciencedomain.org/review-history/13659

Original Research Article

Received 8th November 2014
Accepted 26th January 2016
Published 13th March 2016

ABSTRACT

Aim: The aim of this work was to study the genetic parameters of fruits, seeds and oil content of *Jatropha curcas* accessions in a semi-arid region of Senegal.
Methodology: The study was conducted on 35 accessions of *J. curcas* planted at the research station of National School of Agriculture located in Thies, Senegal. Fruits were collected from 1-4 years old plantations. Then, for each accession, 30 dry fruits were randomly selected and were

Corresponding author: E-mail: idiedhiou@univ-thies.sn;

subjected to measurements of the size parameters and weight. Fruits were peeled and shells weighed. A sample of 20 seeds per accession was selected with 3 replications for seed traits measurements and seed oil content by Soxhlet method.

Results: The results showed significant differences (p <.001) in seed and fruit traits as well as in oil content between accessions. Oil content, kernel weight/shell weight ratio and 100-seed weight are highly correlated quantitative characters which have also, high heritability broad sense (92.51%, 100% and 87.14%, respectively) and genetic advance values (39.32%, 36.44%, and 28.77%, respectively). Also, this study has highlighted four local accessions (Keur Samba Gueye, Notto 3, Ndary and Soutra) with high oil content (> 55%).

Conclusion: There is high genetic variability of *Jatropha curcas* in Senegal in terms of seed, fruit and oil traits. The quantitative characters such as oil content and 100-seed weight might be used for early selection of promising accessions. The local *J. curcas* plant materiel is interesting enough to perform breeding programs and support national sustainable production of biofuel.

Keywords: Jatropha curcas; diversity; genetic parameters; morphological traits; oil content; cluster analysis; Senegal.

1. INTRODUCTION

Jatropha curcas L. an Euphorbiaceae is diploid (2n = 22 chromosomes), monoecious diclinous and can sometimes bear hermaphrodite flowers. The species is mainly cross-pollinated, insects being the major agents of pollination [1]. *Jatropha curcas* (*J. curcas*) was introduced in Africa in the 16th century via the Cape Verde Islands by Portuguese sailors [2].

Integration of *J. curcas* into farming systems in Senegal dates back to the colonial period and most likely resulted from the country proximity to the Cape Verde islands. The shrub spread quickly throughout the country owing to the many benefits attached to its cultivation: hedgerow for land delineation or crop protection, multiple medicinal virtues, fuel wood for rural households and raw material for soap production [1].

In 2005, large scale cultivation of the shrub was initiated in Senegal within the framework of a biofuel promotional program aimed at diversifying agricultural production, alleviating rural poverty and attaining energetic sufficiency. Within this program, 321, 000 ha of *Jatropha* are anticipated to be established in partnership with the private sector and farmers based organizations.

Successful implementation of this national bio fuel program is subject to lifting of the agronomic constraints confronting large scale promotion of *J. curcas* in Senegal. Most importantly, the low yield performance of the shrub needs to be improved to ensure profitability of *J. curcas* cultivation [3].

However, *J. curcas* being a perennial species, selection for a complex character such as yield, which is under the influence of genotype, environment and their interaction, appears difficult and would require a long time to come to fruition [4]. Therefore, identification and use of yield determining characters with high heritability and strongly correlated is of paramount importance in a *J. curcas* improvement program. Heritability is an important genetic parameter in plant breeding as it provides an indication of the relative importance of heredity and environmental factors in the expression of various traits [5].

Works on the estimation of genetic parameters in *J. curcas* were mainly carried out in Asia [4-6]. They showed great inter-origin morphological and morpho-metric seed traits variability, and broadly a high heritability (57.0 to 99.61) of some characters: weight of 100 seeds (80.5 to 96%), oil content (67.6 to 99.61%), seed length (77 to 85.4%), width of seeds (57 to 81.8%), and female flower to male flower ratio (99.95%).

It also appeared from these works that there is a significant correlation between female flower to male flower ratio and yield on the one hand [6] and weight of 100 seeds and the oil content on the other hand [5].

In Africa, with the exception of the study carried out in Senegal by Ouattara et al. [7], little research has been devoted to the estimation of genetic parameters of the characters contributing to the performance of *J. curcas*, to identify characters and promising genotypes to be used in early selection. Moreover, the work of Ouattara et al. [7] was conducted on seeds from sites with varying ecological conditions, suggesting that environmental factors might have contributed significantly to the variations observed on seed traits as reported in previous studies on *J. curcas* [5,8].

The objective of this study was to assess the genetic parameters of fruits, seeds and oil content of *J. curcas* accessions grown on a same site in a semi-arid region of Senegal.

2. MATERIALS AND METHODS

2.1 Study area

The present study has been conducted at the research station of National School of Agriculture known as ENSA located in Thies city, Senegal (latitude 14° 42' N; longitude 16° 28' O). The climate is tropical semi-arid with an annual average rainfall of about 450 mm. Mean annual temperature range from 20℃ to 36℃, with a marked seasonal variation [9]. The soils are poorly developed with a sandy loam texture and a pH of 5.0. Their level of fertility is poor with organic carbon and nitrogen, respectively, less than 5% and 0.3% [10].

2.2 Observations and Measures

2.2.1 Fruit and seed traits

Thirty-five accessions of *J. curcas* were used in this study. Thirty-three are from Senegal while 2 others were introduced from Mozambique (Southern Africa) and Tanzania (East Africa).

The accessions were collected in the form of cuttings in the three main ecological zones of Senegal: Sahelian zone (200-600 mm), Sudanese zone (600-1200 mm) and Guinean zone (> 1200 mm) [11]. These cuttings were planted on a plot of ENSA research station at 6 per accession and a density of 2500 cuttings per hectare. The plantation was not fertilized nor irrigated. Only weeding was done to reduce weed competition.

Fruits were collected in this plantation between September and December 2013; over 4 to 6 vigorous trees aged 1 (30 accessions) to 4 years (5 accessions). Only ripe fruits of yellow or brown color were collected and then dried in the laboratory at ambient temperature (25℃).

For each accession, 30 fruits were randomly selected. They were pre-dried in an oven at a temperature of 65℃ for 72 hours to obtain a constant weight. Then, each fruit has its length and diameter measured using an electronic caliper, the weight was also determined with an electronic balance (1/1000 g). At the end of these measurements, the fruits were peeled and shells were weighed with the same balance as before. To determine seeds traits, a sample of 20 seeds per accession was selected with three (3) replications. The Length (longitudinal axis of the seed), the width (lateral axis of the seed) and the thickness (radial axis) of seeds were measured with an electronic caliper.

The weight of each lot of 20 seeds was measured with an electronic balance (1/1000 g). From the weight of 20 seeds, 100-seed weight was calculated as follows:

Weight of 100 seeds (g) = (Weight of 20 seeds / 20) x 100

2.2.2 Oil content

For each accession, the three lots of 20 seeds that were used to determine seed traits were used also, to measure the average seed oil content by Soxhlet method [5]. To do this, the kernel was separated from husks and placed in an incubator at 65℃ for 48 hours. Then, they were crushed using a mortar. Thereafter, it was taken 2 g of kernel (sample) for Soxhlet extraction with 3 replications per accession. The oil content of the kernel was determined by the following formula:

% oil = (oil mass / mass of sample) * 100

2.3 Statistical Analysis

Analysis of variance was performed using the software called Statistix to highlight the influence of the accession factor over the seed and fruit-shape variables as well as the oil content. Comparison of means was performed using Tukey's test at 5%.

Genetic parameters were estimated to identify the genetic variability between accessions and determine the effects of the genotype and environment on various studied traits. These genetic parameters (genotypic and phenotypic components of variance, coefficients of variability, broad sense heritability and genetic advance) were calculated by adjusting the formula suggested by Allard [12] and Singh and Chaudhary [13]:

$$\sigma_G^2(\text{genotypic variance}) = (MS_G - MS_E)/r \quad (1)$$

where MS_G = mean square of accession, MS_E = mean square of error and r = number of replications

$$\sigma_P^2 \text{ (phenotypic variance)} = (\sigma_G^2 + \sigma_E^2) \quad (2)$$

$$\text{PCV (phenotypic coefficient of variation)} = \sqrt{\sigma_P^2}/\bar{X} \times 100 \quad (3)$$

where $\bar{X}$ = mean of the trait

$$\text{GCV (genotypic coefficient of variation)} = \sqrt{\sigma_G^2}/\bar{X} \times 100 \quad (4)$$

$$h_B^2 \text{ (Broad sense heritability)} = \sigma_G^2/\sigma_P^2 \quad (5)$$

$$\text{GA (Genetic gain)} = K \times \sigma p \times h_B^2 \quad (6)$$

where K = selection intensity at 5% population selected = 2.06; σ = phenotypic standard deviation; h_B^2= broad sense heritability.

The XLSTAT [14] software was used for testing significance of Pearson correlation coefficients and thus assesses the relationships between the different variables studied.

Clustering analysis was done and a dendrogram was constructed using complete linkage and squared Euclidean distance method [15].

3. RESULTS

3.1 Variability in Fruits, Seeds and Oil Content Traits

The results of the analysis of variance (Table 1) have shown that the accession-factor has a significant influence on all morphological parameters of fruits and seeds and the oil content (p<.0001).

The coefficients of variation were highest for fruits traits with values of 23.92% for weight, 8.98% for diameter and 7.69% for length. For seeds, the highest coefficients of variation were obtained with Kernel weight/Shell weight (K/S) ratio (7.60%), 100-seed weight (5.78%) and oil content (5.65%).

The average values of seeds traits were 18.25 mm for length, 11.04 mm for width, 8.70 mm for thickness, 60.25 g for 100-seed weight, 44.68% for oil content, and 1.26 for K/S ratio. For fruits, the average values of the measured parameters were 25.68 mm for length, 20.19 mm for diameter and 2.34 g for weight.

In general, whatever the trait taken into consideration for both seeds and fruits, the weakest values have been obtained with accession Kagnobon. However, the highest values have been noticed between the seven accessions that follow: Madiop Boye (seed length), Ngoule (seed width), Fois (seed thickness), Ndary (K/S, oil content, 100-seed-weight), Maleme Niani (fruit length), Fimela (fruit diameter) and Soutra (100-seed-weight and fruit weight). Remarkably, the two accessions Ndary and Soutra have been noticed for their highest values of 100-seed-weight, K/S, fruit weight and oil content.

3.2 Estimates of Genetic Variables for Seed, Fruit and Oil Traits in *Jatropha curcas*

Results of the values of genetic parameters for different agro-morphological traits of the seeds and fruits are shown in Table 2. These data revealed that the coefficients of variation were relatively low. The traits with highest values of coefficient of genotypic variation were the following in decreasing order: fruit weight (24.40%), oil content (19.84%), K/S ratio (17.74%) and 100-seed weight (14.96%). For the coefficient of phenotypic variation, the tendencies were the same. Just to notice that the values of genetic variances and that of phenotypic variances were too closed.

The broad sense heritability was high for all of the studied characters except the fruit diameter for which the average value was 43.21%. However, the values were highest for K/S ratio (100%), oil content (92.51%), seed-length (90.40%), seed-thickness (89.65%) and 100-seed weight (87.14%).

3.3 Analysis of Correlation Coefficients among 9 Morphological Traits

The oil content was more significantly correlated with 100-seed-weight (r = 0.98) followed by K/S ratio (r = 0.87), then fruit weight (r = 0.85) and seed thickness (r = 0.80) (Table 3). The 100-

seed weight was highly correlated with oil content, K/S ratio (r = 0.89) and fruit weight (r = 0.87). The K/S ratio was significantly correlated with all other traits except the seed width. The seed length was more significantly correlated with the fruit diameter (r = 0.81) and seed thickness (r = 0.80). The seed width was less correlated with other traits with non-significant values for its relationship with K/S ratio, fruit diameter and fruit weight. In fact, the seed thickness was significantly more correlated with oil content (r = 0.80). The best correlation for fruit length was with its diameter (r = 0.83). However, we stated that there was no significant correlation between seed length and fruit diameter. Finally, like the fruit length, the best correlation for the fruit weight was with its diameter (r = 0.84).

3.4 Regression Equations for Estimating Oil Content

Regression analyses of seed oil content on the independent variables are presented in Table 4. It was noted that the p values for all the model coefficients were significant. Using R^2 values as an indicator of model fit, 100-seed weight and K/S ratio was the best predictor of seed oil content.

3.5 Cluster Analysis

The dendrogram revealed 7 clusters (Fig. 1). Cluster IV had the biggest accessions number (8). Clusters I, II and III had each one, 6 accessions whereas clusters V and VI are constituted with 4 accessions each. Cluster VII consisted of only one accession.

According to Table 5, cluster IV presented the highest mean values for all traits while, the lowest values noticed with cluster VII. It is very important to notice that accessions have not been grouped according to their geographical origin. Even introduced accessions from Southern Africa were in two different clusters: I (accession 21 from Mozambic) and IV (accession 32 from Tanzania).

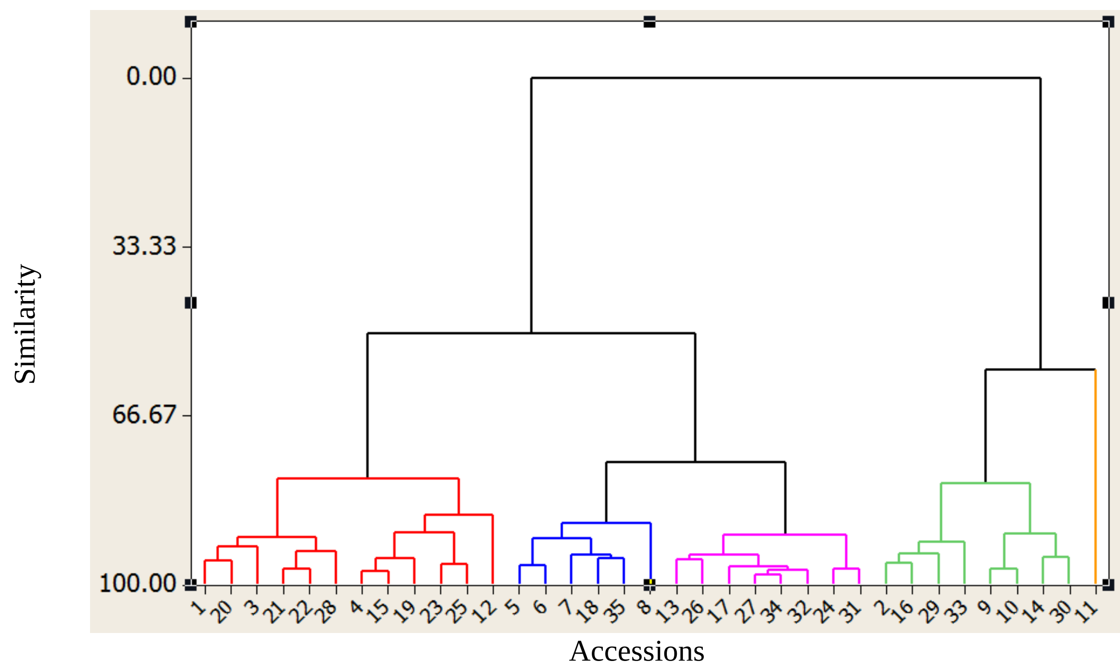

Fig. 1. The dendrogram of 9 morphological traits derived from 35 *Jatropha curcas* accessions constructed using hierarchical analysis method

(1: Karang, 2: Darou mousty, 3: Dianamalary, 4: Diassime Mandina, 5: Diouroup, 6: Fimela, 7: Fois 1, 8: Gandiaye, 9: Ngoule, 10: Gourel Bowe, 11: Kagnobon, 12: Kamonghone, 13: Keur Samba Gueye, 14: Koumbal, 15: Linguere, 16: Lompoul, 17: Madiop Boye, 18: Maleme Hoddar, 19: Maleme Niani, 20: Medina Sabakh, 21: Mozambique, 22: Mpack, 23: Ndande, 24: Ndary, 25: Nguekokh, 26: Notto 3, 27: Ouassadou, 28: Porokhane, 29: Sangalkham, 30: Sare Diatta Folere, 31: Soutra, 32: Tanzanie, 33: Tapha Kane, 34: Touba Peykouk, 35: Velingara)

Table 1. Variability for seed, fruit and oil content traits in *Jatropha curcas*

Locality	Seed						Fruit			Ecological zone
	Length (mm)	Width (mm)	Thickness (mm)	100 seed weight (g)	K/S	Oil content (%)	Length (mm)	Diameter (mm)	Fruit weight (g)	
Karang	18.37^{c-j}	11.02^{a-h}	8.78^{b-g}	64.65^{a-f}	1.40^{a-g}	47.00^{c-i}	25.38^{a-g}	20.36^{a-g}	2.45^{a-f}	Sudanese
Darou mousty	17.44^{k-o}	11.31^{ab}	8.30^{h-l}	52.00^{g-i}	1.05^{i-l}	36.66^{j-n}	25.10^{c-h}	19.23^{d-g}	2.10^{e-h}	Sahelian
Dianamalary	18.74^{a-g}	11.04^{a-h}	8.86^{a-f}	62.30^{a-g}	1.19^{d-j}	46.33^{d-i}	26.55^{a-f}	21.10^{a-c}	2.48^{a-f}	Guinean
Diassime Mandina	18.06^{g-l}	10.65^{h-j}	8.62^{d-j}	56.65^{d-h}	1.15^{e-k}	42.33^{g-l}	25.96^{a-g}	20.33^{a-g}	2.20^{d-h}	Guinean
Diouroup	18.88^{a-e}	11.08^{a-g}	8.96^{a-d}	67.30^{a-e}	1.25^{c-i}	53.00^{a-d}	26.51^{a-f}	20.56^{a-f}	2.44^{a-g}	Sudanese
Fimela	18.65^{a-g}	11.09^{a-f}	8.74^{b-g}	65.65^{a-f}	1.32^{b-i}	52.66^{a-e}	27.16^{ab}	21.54^{ab}	2.67^{a-d}	Sudanese
Fois 1	19.03^{a-c}	11.24^{a-d}	9.22^{a}	67.00^{a-e}	1.23^{c-i}	51.83^{a-f}	25.35^{a-g}	20.18^{a-g}	2.16^{d-h}	Sudanese
Gandiaye	18.17^{e-j}	10.99^{a-h}	8.65^{d-i}	64.65^{a-f}	1.29^{b-i}	48.83^{b-h}	26.99^{a-c}	20.59^{a-f}	2.70^{a-d}	Sudanese
Ngoule	17.25^{m-o}	11.41^{a}	8.23^{g-m}	43.75^{i}	0.77^{lm}	30.16^{no}	24.41^{g-i}	18.61^{gh}	1.89^{h}	Sahelian
Gourel Bowe	17.39^{l-o}	10.81^{e-i}	8.39^{g-l}	48.00^{h-i}	0.92^{j-m}	30.33^{no}	24.66^{e-i}	18.62^{gh}	1.90^{gh}	Sudanese
Kagnobon	16.93^{o}	10.32^{j}	7.84^{m}	31.30^{j}	0.74^{m}	23.00^{o}	21.48^{j}	17.14^{h}	1.30^{i}	Guinean
Kamonghone	16.89^{o}	10.87^{c-i}	8.16^{k-m}	56.30^{e-h}	1.37^{a-h}	43.00^{g-l}	23.23^{h-j}	19.07^{e-g}	1.94^{f-h}	Guinean
Keur Samba Gueye	18.93^{a-d}	11.21^{a-e}	9.09^{ab}	71.00^{a}	1.46^{a-e}	55.33^{ab}	26.96^{a-d}	21.22^{a-c}	2.49^{a-f}	Sudanese
Koumbal	18.31^{d-j}	10.75^{f-i}	8.11^{l-m}	48.65^{h-i}	1.06^{h-l}	32.16^{mn}	25.63^{a-g}	20.43^{a-f}	2.19^{d-h}	Sudanese
Linguere	18.66^{a-g}	10.93^{b-i}	8.73^{b-g}	58.00^{b-h}	1.11^{g-k}	42.66^{g-l}	26.34^{a-g}	20.35^{a-g}	2.26^{c-h}	Sahelian
Lompoul	17.17^{n-o}	11.28^{a-c}	8.25^{i-l}	52.30^{g-i}	1.23^{c-i}	35.33^{l-n}	24.61^{f-i}	19.24^{d-g}	2.15^{d-h}	Sahelian
Madiop Boye	19.16^{a}	11.30^{ab}	9.06^{a-c}	68.00^{a-d}	1.41^{a-g}	54.00^{a-d}	26.71^{a-d}	21.45^{ab}	2.70^{a-d}	Sudanese
Maleme Hoddar	18.43^{b-i}	10.96^{b-h}	8.82^{a-f}	67.00^{a-e}	1.48^{a-d}	50.16^{a-g}	26.08^{a-g}	19.83^{b-g}	2.32^{b-h}	Sudanese
Maleme Niani	19.11^{ab}	11.26^{a-d}	8.73^{b-g}	57.65^{c-h}	1.06^{h-l}	42.33^{g-l}	27.29^{a}	20.20^{a-g}	2.30^{b-h}	Sudanese
Medina Sabakh	17.76^{i-n}	11.35^{ab}	8.88^{a-e}	63.30^{a-g}	1.32^{b-i}	46.33^{d-i}	25.23^{b-g}	19.07^{e-g}	2.23^{c-h}	Sudanese
Mozambique	18.13^{f-k}	10.84^{d-i}	8.75^{b-g}	61.65^{a-g}	1.36^{a-h}	44.00^{f-k}	25.64^{a-g}	20.56^{a-f}	2.28^{b-h}	-
Mpack	18.07^{g-l}	10.53^{ij}	8.52^{e-k}	62.30^{a-g}	1.40^{a-g}	44.50^{e-k}	26.39^{a-f}	20.37^{a-g}	2.70^{a-d}	Guinean
Ndande	18.09^{f-l}	11.00^{a-h}	8.47^{f-l}	56.00^{e-h}	1.11^{g-k}	40.83^{h-l}	25.96^{a-g}	20.41^{a-f}	2.35^{b-h}	Sahelian
Ndary	19.00^{a-d}	11.15^{a-f}	8.89^{a-e}	72.65^{a}	1.65^{a}	57.16^{a}	26.04^{a-g}	20.54^{a-f}	2.69^{a-d}	Sudanese
Nguekokh	17.88^{h-m}	10.67^{g-j}	8.64^{d-j}	56.00^{e-h}	1.23^{c-i}	39.83^{i-m}	25.13^{c-h}	20.08^{a-g}	2.16^{d-h}	Sudanese
Notto 3	18.78^{a-f}	11.04^{a-h}	$8,71^{b-g}$	70.65^{a}	1.58^{ab}	55.16^{a-c}	25.44^{a-g}	20.69^{a-e}	2.70^{a-d}	Sahelian
Ouassadou	18.63^{a-g}	11.10^{a-f}	8.92^{a-e}	69.30^{ab}	1.43^{a-f}	54.50^{a-d}	26.71^{a-d}	21.64^{a}	2.77^{a-c}	Guinean
Porokhane	18.11^{f-k}	11.28^{a-c}	9.01^{a-d}	62.00^{a-g}	1.20^{d-j}	44.66^{e-j}	25.02^{d-h}	18.86^{f-h}	2.06^{e-h}	Sudanese
Sangalkham	18.32^{d-j}	11.09^{a-g}	8.53^{e-k}	54.65^{f-i}	1.13^{f-k}	36.33^{k-n}	25.60^{a-g}	20.13^{a-g}	2.24^{c-h}	Sahelian
Sare Diatta Folere	18.30^{d-j}	11.32^{ab}	8.67^{c-h}	48.65^{h-i}	0.87^{k-m}	30.83^{no}	26.69^{a-d}	20.82^{a-e}	2.03^{f-h}	Guinean

Soutra	18.89^{a-d}	11.22^{a-e}	8.85^{a-f}	72.65^{a}	1.63^{a}	56.50^{ab}	26.48^{a-f}	21.27^{a-c}	2.91^{a}	Sudanese
Tanzanie	18.68^{a-g}	11.31^{ab}	8.74^{b-g}	68.70^{a-c}	1.53^{a-c}	54.16^{a-d}	25.97^{a-g}	20.66^{a-e}	2.61^{a-e}	-
Tapha Kane	17.69^{j-n}	10.84^{d-i}	8.47^{f-l}	53.00^{g-i}	1.35^{a-i}	36.50^{j-n}	22.81^{ij}	19.66^{c-g}	1.87^{h}	Sudanese
Touba	18.57^{a-h}	11.03^{a-h}	8.96^{a-d}	68.65^{a-c}	1.47^{a-d}	54.00^{a-d}	26.62^{a-d}	20.69^{a-e}	2.65^{a-d}	Sahelian
Peykouk										
Velingara	18.30^{d-j}	11.06^{a-h}	8.70^{b-h}	66.30^{a-e}	1.36^{a-i}	51.33^{a-f}	26.59^{a-e}	20.98^{a-d}	2.82^{ab}	Guinean
Mean	18.25	11.04	8.66	60.25	1.26	44.68	25.68	20.19	2.34	
Coefficient of variation (%)	1.19	1.17	1.43	5.78	7.60	5.65	7.69	8.98	23.92	
Minimum	16.89	10.32	7.84	31.30	0.74	23.00	21.48	17.14	1.30	
Maximum	19.16	11.41	9.22	72.65	1.65	57.16	27.29	21.64	2.91	
MSE	0.047	0.017	0.015	0.486	0.009	6.364	3.898	3.286	0.313	

Means with the same letter(s) are not significantly different ($p < 0.05$) according to Tukey's test; K/S: kernel weight/shell weight

Table 2. Estimates of genetic variables for seed, fruit and oil traits in *Jatropha curcas*

Traits	Variance		Coefficient of variation (%)		Heritability broad sense (%)	Genetic advance (%)
	Genotypic	Phenotypic	Genotypic	Phenotypic		
Length (mm)	0.37	0.41	3.36	3.53	90.40	6.58
Width (mm)	0.06	0.07	2.21	2.39	85.71	4.23
Thickness (mm)	0.08	0.09	3.39	3.59	89.65	6.62
100-seed weight (g)	3.25	3.73	14.96	16.03	87.14	28.77
Fruit weight (g)	0.32	0.63	24.40	34.08	51.25	35.87
Fruit diameter (mm)	2.48	5.75	7.80	11.87	43.21	4.50
Fruit length (mm)	4.46	8.34	8.22	11.24	53.52	12.39
Oil content (%)	78.63	84.99	19.84	20.63	92.51	39.32
K/S	0.05	0.05	17.74	17.74	100.00	36.44

K/S = Kernel weight/ shell weight

Table 3. Pearson correlation coefficients among 9 morphological traits of *Jatropha curcas*

Variables	Length	Width	Thickness	100-seed weight	K/S	Oil content	Fruit length	Fruit diameter	Fruit weight
Length									
Width	0.338*								
Thickness	0.803*	0.462*							
100-seed weight	0.748*	0.375*	0.834*						
K/S	0.508*	0.155	0.571*	0.886*					
Oil content	0.739*	0.340*	0.800*	0.979*	0.869*				
Fruit length	0.777*	0.385*	0.656*	0.660*	0.360*	0.614*			
Fruit diameter	0.807*	0.250	0.630*	0.731*	0.578*	0.702*	0.834*		
Fruit weight	0.712*	0.296	0.614*	0.867*	0.755*	0.846*	0.798*	0.844*	

**Pearson correlation coefficient significant at the 0.05 level; K/S = kernel weight/ shell weight*

Table 4. Equations for oil content estimation in *Jatropha curcas*

N°	Equations	R²	*P*
1	OC (%) = 0.95 x (P100) – 12.69	0.96	< 0.0001
2	OC (%) = 34.67 x (K/S) + 0.97	0.75	< 0.0001
3	OC (%) = 19.94 x (FW) – 2.44	0.58	< 0.0001

OC: oil content (%), P100: 100-seed weight (g), FW: fruit weight (g), K/S: kernel weight / shell weight ratio

4. DISUCSSION

The study of morphological characters of seeds from natural populations or low anthropic of a species is an important step for the study of genetic variability [5]. This work revealed that there are significant differences between the 35 studied accessions for the seed traits (length, width, thickness, 100-seed weight, K/S ratio, oil content), and fruit traits (length, diameter, weight). Previous studies have also reported a high variability of morphological traits [3,7] and seed oil content [3] of *J. curcas* in Senegal. Similar results were obtained from other accessions collected in Africa including Nigeria [16] and Mozambique [17], but also in Asia [4-6, 8]. They can be attributed to the fact that *J. curcas* grows in a wide range of rainfall, temperatures, and soil [5].

This study showed that the values of genetic variances and that of phenotypic variances were too closed for seeds traits and seed oil content. These observations suggest that the influence of the environment on these characters is low. Therefore, they might have a particular interest in breeding programs.

It was also noted that coefficients of variation values are low except that of 100-seed weight, K/S, oil content and fruit weight. This result could be explained by the fact that in Senegal, vegetative propagation is the main way of multiplication of *J. curcas* [18]. It should be added that, many authors [19,20] have reported in *J. curcas*, a mixed mating system, high correlated mating and apomixis.

Our results showed that except for fruit diameter, all studied characters have high broad sense heritability values (> 45%); therefore we can consider that these characters are highly heritable.

Similar results were obtained on accessions from India by Kaushik et al. [5] (≥54 %) and by Rao et al. [6] (>61.71). Shabanimofrad et al. [4] also, reported comparable values on 48 accessions from Malaysia (>67.6 %). These results suggest that the environment has low influence on seeds and fruits traits. This hypothesis is reinforced by the fact that the genotypic and phenotypic variation coefficients are very close.

High genetic gain values were also obtained in our study for 100-seed-weight, oil content, K/S ratio and fruit weight. Previous studies reported slightly lower values, which vary between 4.22 and 18.19% [4-7]. This difference could be attributed to the fact that we worked on clones as these authors used plants from seeds. Strong genetic gain values indicate that there is a real potential for improving Senegalese accessions by selection. Parameters such as oil content, 100-seed weight, K/S ratio and fruit weight appear to be the most interesting for breeding programs. These four characters have the highest values of heritability in broad sense (51.25 to 100%), genotypic coefficient of variation (14.96 to 24.4%) and genetic advance (28.77 to 39.32%).

Table 5. Cluster mean value for fruit, seed and oil traits in *Jatropha curcas* accessions

Cluster	No of accessions	Accessions	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	100 seed weight (g)	K/S	Oil content (%)	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)
I	6	1, 3, 20, 21, 22, 28	18.20	11.01	8.80	62.70	1.31	45.47	25.70	20.05	2.37
II	6	4, 12, 15, 19, 23, 25	18.12	10.90	8.56	56.77	1.17	41.83	25.65	20.07	2.20
III	5	5, 6, 7, 8, 18, 35	18.58	11.07	8.85	66.32	1.32	51.30	26.45	20.61	2.52
IV	8	13, 17, 24, 26, 27, 31, 32, 34	18.83	11.17	8.90	70.20	1.52	55.10	26.37	20.94	2.69
V	4	2, 16, 29, 33	17.66	11.13	8.39	10.60	1.19	36.21	24.53	19.57	2.09
VI	4	9, 10, 14, 30	17.81	11.07	8.35	9.45	0.91	30.87	25.35	19.62	2.00
VII	1	11	16.93	10.32	7.84	31.30	0.74	23.00	21.48	17.14	1.30

K/S = Kernel weight / shell weight

This study found a strong correlation between the different traits of seeds and fruits but especially between the oil content and 100-seed-weight. In addition, oil content broad sense heritability value is higher than that of 100-seed-weight. Given this, it is thus possible to select indirectly high oil content (secondary character) accessions by 100-seed-weight (primary character).

The hierarchical analysis performed to classify accessions based on nine (09) studied traits revealed seven (07) clusters. Cluster IV that contains eight (08) accessions with highest values for all characters, is the most interesting for breeding programs; If one refers to Kaushik [21], we can see that 50% of the accessions of this cluster have high oil content (> 55%); these accessions are 26 (55.16%), 13 (55.33%), 31 (56.15%) and 24 (57.16%). The hierarchical analysis also showed that the maximum distance between groups was observed between clusters I, II, III and IV on one side and V, VI and VII on the other. According to Kaushik et al. [5], this shows a great diversity among the trees of these two groups whose crossing would provide new hybrids. Consequently, trees belonging to these two groups of clusters should be chosen as parents in *J. curcas* breeding programs in Senegal.

Finally, this study showed that the geographic diversity of accessions does not necessarily reflect their genetic diversity. Indeed, the groups shown by the hierarchical classification are each of them made up with accessions from three main eco-geographical areas of the country. Our observations are consistent with the results of many studies conducted in Senegal [3,7] and Asia [4,5]. The absence of association between collection geographical areas and phenotypic diversity might be attributed to genetic component and the dispersal mode of *Jatropha curcas* in Senegal, that is based on cuttings exchange.

5. CONCLUSION

This study has shown that there is a high genetic and phenotypic variability of seeds and fruits traits as well as oil content in *J. curcas* in Senegal, indicating the possibility of selection of genetically superior plants. As a result, oil content, K/S ratio, 100-seed weight and fruit weight are the most interesting characters for breeding programs.

Based on the hierarchical analysis, the *J. curcas* variability evaluated is enough to perform a local breeding program and support domestic production of biofuel. In addition, in this study, we used 100-seed-weight to develop a simple linear regression, which allows a simple, rapid and inexpensive estimation of the oil production potential of *J. curcas* plantations.

ACKNOWLEDGEMENTS

The authors are grateful to African Union and to European Union for financial assistance to this study through "10th European Fund for Development" and African Union Research Grant (EU – financed grant contracts for external actions), grant contract N° AURG/094/2012 CRS N° 2012/289-014. The authors are thankful to Moussa NDIONE, Dame SY and Sidy SIDIBE for help in collection of *J. curcas* seeds and management of the plantations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Heller J. Physic nut. *Jatropha curcas* L. Promoting the conservation and use of underutilized and neglected crops. 1. Institute of Plant Genetics and Crop Plant Research, Gatersleben/ International Plant Genetic Resources Institute, Rome; 1996.
2. Diédhiou I, Dia D, Fall CS. *Jatropha curcas* L. au Sénégal: Enjeux, état des lieux de sa culture et possibilités d'intégration dans les aménagements de la grande muraille verte. In: Dia A, Duponnois R, editors. La Grande Muraille Verte. Capitalisation des recherches et valorisation des savoirs locaux. IRD: Paris; 2012a.
3. Diédhiou I, Diédhiou PM, Ndir KN, Bayala R, Ouattara B, Mbaye B, Kâne M, Dia D, Wade I. Diversity, farming systems, growth and productivity of *Jatropha curcas* L. Sudano-Sahelian Zone in Senegal, West Africa. In: Carels N, Sujatha M, Bahadur B, editors. Jatropha, Challenges for a New Energy Crop. Springer Science + Business Media: New York; 2012b.
4. Shabanimofrad M, Rafii MY, Wahab PEM, Biabani AR, Latif MA. Phenotypic, genotypic and genetic divergence found in 48 newly collected Malaysian accessions

of *Jatropha curcas* L. Ind Crops Prod. 2013;42:543–551.
5. Kaushik N, Kumar K, Kumar S, Kaushik N, Roy S. Genetic variability and divergence studies in seed traits and oil content of *Jatropha* (*J. curcas* L.) provenances. Biomass Bioenergy. 2007;31:497–502.
6. Rao G, Korwar G, Shanker AK, Ramakrishna Y. Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) provenances. Trees. 2008;22:697–709.
7. Ouattara B, Diédhiou I, Ndir KN, Agbangba EC, Cissé N, Diouf D, Akpo EL, Zongo JD. Variation in seed traits and distribution of *Jatropha curcas* L. in Senegal. Int J Curr Res. 2013;5(2):017-021.
8. Ginwal HS, Rawat PS, Srivastava RL. Seed source variation in growth performance and oil yield of *Jatropha curcas* L. in Central India. Silvae Genet. 2004;53:186–192.
9. Kizito F, Dragila MI, Sène M, Lufafa A, Dick RP, Diedhiou I, Dossa E, Khouma M, Ndiaye S, Badiane A. Seasonal soil water variation and root patterns among two semi-arid shrubs coexisting with Pearl millet in Senegal, West Africa. J Arid Environ. 2006;67:436–455.
10. Zante P. Etude pédologique du domaine de l'institut National du développement rural (Thiès-Sénégal). Ed. ORSTOM: Dakar; 1983.
11. Le Houérou HN. The grazing land ecosystems of the African Sahel. Springer, Berlin; 1989.
12. Allard R. Principles of plant breeding. John Willey and Sons, Inc.: New York; 1960.
13. Singh R, Chaudhary B. Biometrical Methods in Quantitative Genetic Analysis. New Delhi; 1977.
14. Anonymous. XLSTAT 2007. Addinsoft; 2007. Available:http://www.addinsoft.com (Accessed 13 November 2015)
15. Hammer Ø, Harper DAT, Ryan, PD. PAST: Paleontological statistics software package for education and data analysis. Palaeontol Electronica. 2001;4(1):1-9. Available:http://palaeo-electronica.org/2001_1/past/issue1_01.htm
16. Halilu AD, Misari SM, Echekwu CA, Alabi O, Abubakar IU, Saleh MK, Adeyanju AO, Ogunwole J. Survey and collection of *Jatropha curcas* L. in the northwestern Savannas of Nigeria. Biomass Bioenergy. 2011;35:4145–4148.
17. Montes LJM, Technow F, Bohlinger B, Becker K. Seed quality diversity, trait associations and grouping of accessions in *Jatropha curcas*. Ind Crops and Prod. 2013;51:178–185.
18. Ndoye NK, Kane M, Ouattara B, Bayala R, Diedhiou I. Variability in seed traits, oil content and genetic diversity in local and exotic accessions of *Jatropha curcas* L. in Senegal. Afr J Biotechnol 2013;12:5267–5277.
19. Ahoton LE, Quenum F. Floral biology and hybridization potential of nine accessions of physic nut (*Jatropha curcas* L.) originating from three continents. Tropicultura. 2012;4(30):193-198.
20. Bressan EA, Sebbenn AM, Ferreira RR, Lee TSG, Figueira A. *Jatropha curcas* L. (Euphorbiaceae) exhibits a mixed mating system, high correlated mating and apomixis. Tree Genetics & Genomes. 2013;4(9):1089-1097.
21. Kaushik N. *Jatropha* germplasm characterization for biodiesel production. Energy biosciences strategy for India. Workshop summary, New Delhi; 2007b.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/13659