

Original Research Article

Title: Genetic parameters for fruits, seeds and oil content traits of *Jatropha curcas* L. in a semi-arid region of Senegal

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 ~~Superior~~-National Advanced 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 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 the 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 material is interesting enough to perform breeding programs and support national sustainable production of biofuel.

Key words: *Jatropha curcas*, genetic parameters, oil content, Senegal.

26 1. INTRODUCTION

27 *Jatropha curcas* L. an Euphorbiaceae is diploid ($2n = 22$ chromosomes), monoecious diclinous and
28 can sometimes bear hermaphrodite flowers. The species is mainly cross-pollinated, insects being
29 the major agents of pollination [1]. *Jatropha curcas* (*J. curcas*) was introduced in Africa in the
30 16th century via the Cape Verde Islands by Portuguese sailors [1].

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

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

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

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

52 Works on the estimation of genetic parameters in *J. curcas* were mainly carried out in Asia [4, 5,
53 6]. They showed great inter-origin morphological and morpho-metric seed traits variability, and
54 broadly a high heritability (57.0 to 99.61) of some characters: weight of 100 seeds (80.5 to 96%),
55 oil content (67.6 to 99.61%), seed length (77 to 85.4%), width of seeds (57 to 81.8%), and
56 female flower to male flower ratio (99.95%).

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

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

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

69 2. MATERIAL AND METHODS

70 2.1 Study area

71 The present study has been conducted at the research station of “Ecole Nationale Supérieure
72 d’Agriculture” known as ENSA located in Thies city, Senegal (latitude 14° 42'N; longitude 16°
73 28' O). The climate is tropical semi-arid with an annual average rainfall of about 450 mm. Mean
74 annual temperature range from 20°C to 36°C, with a marked seasonal variation [9]. The soils are
75 poorly developed with a sandy loam texture and a pH of 5.0. Their level of fertility is poor with
76 organic carbon and nitrogen, respectively, less than 5% and 0.3% [10]

77 2.2 Observations and measures

78 2.2.1 Fruit and seed traits

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

81 The accessions were collected in the form of cuttings in the three main ecological zones of Senegal:
82 Sahelian zone (200-600 mm), Sudanese zone (600-1200 mm) and Guinean zone (>1200 mm) [11].

83 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°C).

For each accession, 30 fruits were randomly selected. They were pre-dried in an oven at a temperature of 65°C 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 calipers.

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°C for 48 hours. Then, they were crushed

105 using a mortar. Thereafter, it was taken 2 g of kernel (sample) for Soxhlet extraction with 3
106 replications per accession. The oil content of the kernel was determined by the following formula:
107 % oil = (oil mass / mass of sample) * 100

108 2.3 Statistical analysis

109 Analysis of variance was performed using the software called Statistix to highlight the influence
110 of the accession factor over the seed and fruit-shape variables as well as the oil content.
111 Comparison of means was performed using Tukey's test at 5%.
112 Genetic parameters were estimated to identify the genetic variability between accessions and
113 determine the effects of the genotype and environment on various studied traits. These genetic
114 parameters (genotypic and phenotypic components of variance, coefficients of variability, broad
115 sense heritability and genetic advance) were calculated by adjusting the formula suggested by
116 Allard [12] and Singh and Chaudhary [13]:

$$117 \sigma_G^2 (\text{genotypic variance}) = (MS_G - MS_E) / r \quad (1)$$

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

$$120 \sigma_P^2 (\text{phenotypic variance}) = (\sigma_G^2 + \sigma_E^2) \quad (2)$$

$$121 PCV (\text{phenotypic coefficient of variation}) = \sqrt{\sigma_P^2} / \bar{X} \times 100 \quad (3)$$

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

$$123 GCV (\text{genotypic coefficient of variation}) = \sqrt{\sigma_G^2} / \bar{X} \times 100 \quad (4)$$

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

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

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 gfor100-seed weight, 44.68% for oil content, and 1.26 for K/Sratio. For fruits,

143 the average values of the measured parameters were 25.68 mm for length, 20.19 mm for
 144 diameter and 2.34 g for weight.

145 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
DiassimeMan dina	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
GourelBowe	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 ^{l-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
MadiopBoye	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
MalemeHodd ar	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
MalemeNiani	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 ^{b-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 ^{j-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	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
DiattaFolere	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
Soutra	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}	-
Tanzanie	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
Peykoul	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	1.19	1.17	1.43	5.78	7.60	5.65	7.69	8.98	23.92	

variation (%)									
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

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: MadiopBoye (seed length), Ngoule (seed width), Fois (seed thickness), Ndary (K/S, oil content, 100-seed-weight), MalemeNiani (fruit length), Fimela (fruit diameter) and Soutra (100-seed-weight and fruit weight). Remarkably, the two accessions Ndary and Soutra have been noticed for ~~these reasons: their highest~~ values of 100-seed-weight, K/S, fruit weight and oil content, ~~which are highest.~~

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%).

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

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 ($r = 0.84$).

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

3.4 Regression equations for estimating oil content

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

187 Table4. Equations for oil content estimation in *Jatropha curcas*.

N°	Equations	R^2	P
1	$OC (\%) = 0.95 \times (P100) - 12.69$	0.96	< 0.0001
2	$OC (\%) = 34.67 \times (K/S) + 0.97$	0.75	< 0.0001
3	$OC (\%) = 19.94 \times (FW) - 2.44$	0.58	< 0.0001

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

189 3.4 Cluster analysis

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

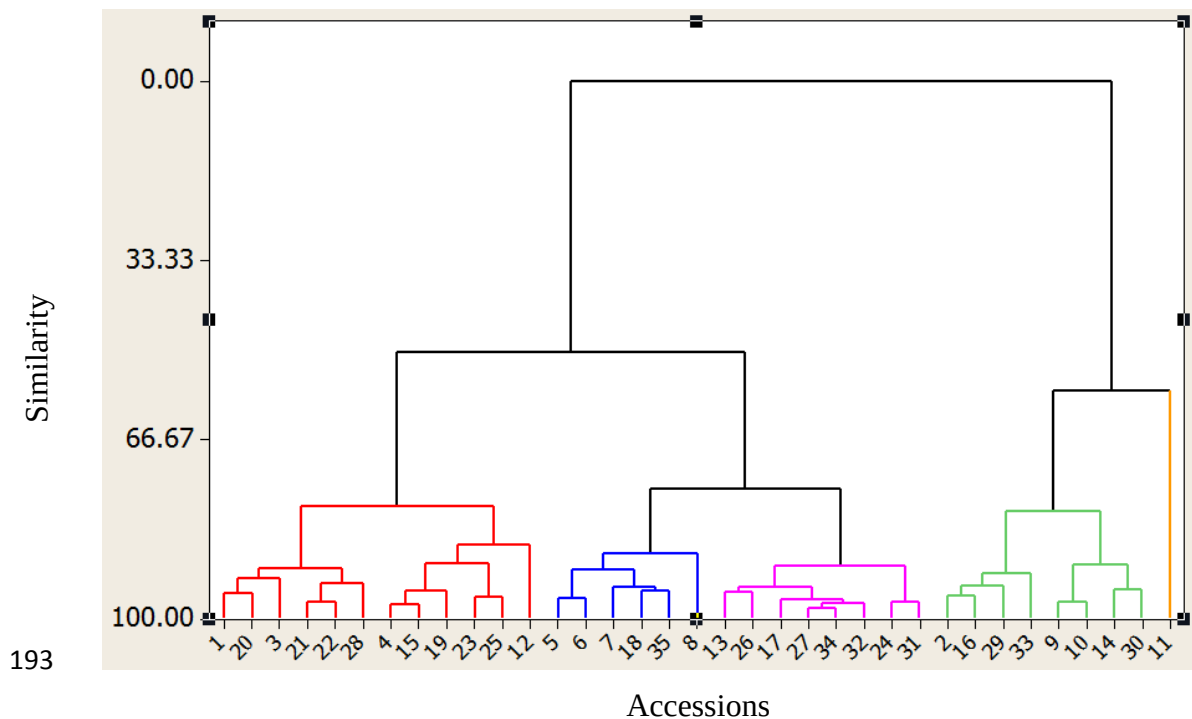


Fig. 1. The dendrogram of 9 morphological traits derived from 35 *Jatropha curcas* accessions constructed using hierarchical analysis method.

(1: Karang, 2: Daroumousty, 3: Dianamalary, 4: DiassimeMandina, 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: MadiopBoye, 18: MalemeHoddar, 19: MalemeNiani, 20: Medina Sabakh, 21: Mozambique, 22: Mpack, 23: Ndande, 24: Ndary, 25: Nguekokh, 26: Notto 3, 27: Ouassadou, 28: Porokhane, 29: Sangalkham, 30: SareDiattaFolere, 31: Soutra, 32: Tanzanie, 33: Tapha Kane, 34: ToubapEykouk, 35: Velingara).

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).

206 Table5.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

207 K/S = kernel weight / shell weight

208 4. DISCUSSION

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

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

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

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

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

233 High genetic gain values were also obtained in our study for 100-seed-weight, oil content, K/S
234 ratio and fruit weight. Previous studies reported slightly lower values, which vary between 4.22
235 and 18.19% [4, 5, 6, 7]. This difference could be attributed to the fact that we worked on clones
236 as these authors used plants from seeds. Strong genetic gain values indicate that there is a real
237 potential for improving Senegalese accessions by selection. Parameters such as oil content, 100-
238 seed weight, K/S ratio and fruit weight appear to be the most interesting for breeding programs.

239 These four characters have the highest values of heritability in broad sense (51.25 to 100%),
240 genotypic coefficient of variation (14.96 to 24.4%) and genetic advance (28.77 to 39.32%).

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

246 The hierarchical analysis performed to classify accessions based on nine (09) studied traits
247 revealed seven (07) clusters. Cluster IV that contains eight (08) accessions with highest values for
248 all characters, is the most interesting for breeding programs; If one refers to Kaushik[21], we can
249 see that 50% of the accessions of this cluster have high oil content (> 55%); these accessions are
250 26 (55.16%), 13 (55.33%), 31 (56.15%) and 24 (57.16%). The hierarchical analysis also showed
251 that the maximum distance between groups was observed between clusters I, II, III and IV on
252 one side and V, VI and VII on the other. According to Kaushik et al. [5], this shows a great
253 diversity among the trees of these two groups whose crossing would provide new hybrids.

254 Consequently, trees belonging to these two groups of clusters should be chosen as parents in *J.*
255 *curcas* breeding programs in Senegal.

256 Finally, this study showed that the geographic diversity of accessions does not necessarily reflect
257 their genetic diversity. Indeed, the groups shown by the hierarchical classification are each of
258 them made up with accessions from three main eco-geographical areas of the country. Our
259 observations are consistent with the results of many studies conducted in Senegal [3, 7] and Asia
260 [4, 5].

5. CONCLUSION

This study has shown that there is a high variability of seeds and fruits traits as well oil content in *J. curcas* in Senegal. Based on the calculated genetic parameters, all traits examined, with the exception of fruit diameter, can be considered as heritable characters. However, the oil content, K/Sratio, the 100-seed weight and fruit weight are the most interesting characters for breeding programs.

The hierarchical analysis revealed a cluster of eight (08) promising accessions(oil content > 55%) for biofuel production among them, 7 are local while the eighth is from Tanzania. These results show that the local *J. curcas* plant material is interesting enough to perform breeding programs and support domestic production of biofuel.

Finally, this study 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.

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REFERENCES

280 [1] Heller, J. (1996): Physic nut. *Jatropha curcas* L. Promoting the conservation and use of
 281 underutilized and neglected crops. 1. Institute of Plant Genetics and Crop Plant Research,
 282 Gatersleben/ International Plant Genetic Resources Institute, Rome; 1996.

283 [2] Diédhiou I, Dia D, Fall CS. *Jatropha curcas* L. au Sénégal : enjeux, état des lieux de sa culture
 284 et possibilités d'intégration dans les aménagements de la grande muraille verte. In: Dia A,
 285 Duponnois R, editors. La Grande Muraille Verte. Capitalisation des recherches et valorisation
 286 des savoirs locaux. IRD: Paris; 2012a.

287 [3] Diédhiou I, Diédhiou PM, Ndir KN, Bayala R, Ouattara B, Mbaye B, Kâne M, Dia D, Wade I.
 288 Diversity, Farming Systems, Growth and Productivity of *Jatropha curcas* L. Sudano-Sahelian
 289 Zone in Senegal, West Africa. In: Carels N, Sujatha M, Bahadur B, editors. *Jatropha*, Challenges
 290 for a New Energy Crop. Springer Science + Business Media: New York; 2012b.

291 [4] Shabanimofrad M, Rafii MY, Wahab PEM, Biabani AR, Latif MA. Phenotypic, genotypic
 292 and genetic divergence found in 48 newly collected Malaysian accessions of *Jatropha curcas* L.
 293 Ind Crops Prod. 2013;42:543–551.

294 [5] Kaushik N, Kumar K, Kumar S, Kaushik N, Roy S. Genetic variability and divergence studies
 295 in seed traits and oil content of *Jatropha* (*J. curcas* L.) provenances. Biomass Bioenergy
 296 2007;31:497–502.

297 [6] Rao G, Korwar G, Shanker AK, Ramakrishna Y. Genetic associations, variability and diversity
 298 in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) provenances.
 299 Trees. 2008;22:697–709.

300 [7] Ouattara B, Diédhiou I, Ndir KN, Agbangba EC, Cissé N, Diouf D, Akpo EL, Zongo
301 JD. Variation in seed traits and distribution of *Jatropha curcas* L. in Senegal. Int J Curr
302 Res. 2013;5(2):017-021.

303 [8] Ginwal HS, Rawat PS, Srivastava RL. Seed source variation in growth performance and oil
304 yield of *Jatropha curcas* L. in Central India. Silvae Genet. 2004;53:186–192.

305 [9] Kizito F, Dragila MI, Sène M, Lufafa A, Dick RP, Diedhiou I, Dossa E, Khouma M, Ndiaye
306 S, Badiane A. Seasonal soil water variation and root patterns among two semi-arid shrubs
307 coexisting with Pearl millet in Senegal, West Africa. J Arid Environ. 2006;67:436–455.

308 [10] Zante P. Etude pédologique du domaine de l'institut National du développement rural
309 (Thiès-Sénégal). Ed. ORSTOM: Dakar; 1983.

310 [11] Le Houérou H.N. The grazing land ecosystems of the African Sahel. Springer, Berlin; 1989.

311 [12] Allard R. Principles of Plant Breeding. John Willey and Sons, Inc.: New York; 1960.

312 [13] Singh R, Chaudhary B. Biometrical Methods in Quantitative Genetic Analysis. New Delhi;
313 1977.

314 [14] Anonymous. XLSTAT 2007. Addinsoft; 2007. Accessed 13 November 2015. Available:
315 <http://www.addinsoft.com> (Accessed 13 November 2015).

316 [15] Hammer Ø, Harper DAT, Ryan, PD. 2001. PAST: Paleontological statistics software
317 package for education and data analysis. Palaeontol Electronica. 2001;4(1): 1-9.
318 Available: http://palaeo-electronica.org/2001_1/past/issue1_01.htm

319 [16] Halilu AD, Misari SM, Echekwu CA, Alabi O, Abubakar IU, Saleh MK, Adeyanju AO,
320 Ogunwale J. Survey and collection of *Jatropha curcas* L. in the northwestern Savannas of
321 Nigeria. Biomass Bioenergy. 2011;35:4145–4148.

- 322 [17] Montes LJM, Technow F, Bohlinger B, Becker K. Seed quality diversity, trait associations
323 and grouping of accessions in *Jatropha curcas*. Ind Crops and Prod. 2013;51:178– 185.
- 324 [18] Ndoye NK, Kane M, Ouattara B, Bayala R, Diedhiou I. Variability in seed traits, oil content
325 and genetic diversity in local and exotic accessions of *Jatropha curcas* L. in Senegal. Afr J
326 Biotechnol 2013;12:5267–5277.
- 327 [19] Ahoton LE, Quenum F. Floral Biology and Hybridization Potential of Nine Accessions of
328 Physic Nut (*Jatropha curcas* L.) Originating from Three Continents. Tropicultura 2012;(30)4:193-
329 198
- 330 [20] Bressan EA, Sebbenn AM, Ferreira RR, Lee TSG, Figueira A. *Jatropha curcas* L.
331 (Euphorbiaceae) exhibits a mixed mating system, high correlated mating and apomixis. Tree
332 Genetics & Genomes 2013;(9)4:1089-1097.
- 333 [21] Kaushik N. *Jatropha* germplasm characterization for biodiesel production. Energy
334 biosciences strategy for India. Workshop summary, New Delhi, Sept. 10-11; 2007b.