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Evaluation of Agronomic Performances of Eleven Ecotypes of *Jatropha curcas* L. Grown in Poor Soil of Batéké Plateau near Kinshasa (DRC)

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ABSTRACT

Description of subjet. Eleven ecotypes of *Jatropha curcas* L. collected in various agro-ecological regions of the DRC were cultivated near Kinshasa on very poor soil to identify elite germplasm.
Objective. The objective of this study is to evaluate the agronomic performance of 11 ecotypes of *J. curcas* grown on very poor soil on the Batéké Plateau near Kinshasa in order to select elite germplasm for breeding purpose.
Methods. The *J. curcas* seed sample collection was carried out in seven provinces of the DRC, from May to July 2009. Samples of collected seeds were sown in polythene bags. They were cultivated in a nursery (three months) from 5 July to 3 October 2009 in Mbankana. The plantation was laid out in a randomized complete block design (RBD) with three replicates at a density of 2 500 plants ha^{-1} (spacing of 2 m x 2 m) on land that was previously prepared after a fallow of five years. The total number of plants per ecotype varied from 20 to 36.
Results. After 42 months of cultivation, significant differences ($p<0.05$) were found for plant height (1.4±0.0 – 1.7±0.0 cm), collar diameter (6.8±0.6 – 8.9±0.4 cm), number of branches per plant (22.1±4,7 – 38.8±7.2), days to first flowering (236.3±5.7 – 273.0±5.7 days), fruit maturation duration (67.3±3,5 – 84,6±4.7 days), capsule abortion rates (21.0±3,7 – 32.6±3.0 %), number of capsules per plant (19.4±6.5 – 96.4±8.5), number of seeds per capsule (2.5±0.1 – 3,0±0.0), seed index (100 seeds weight) (48.7±1.8 – 79.1±1.1 g), dry seed yield (68.6±3.6 – 473.1±3.6 kg ha^{-1}), oil content (23.3±4.0 – 35.1±1.8 %), content in mono-unsaturated fatty acids (45.2 – 49.5 %). No plant resistant to the main insect pests attacking *J. curcas* in the region was observed. The ecotype originating from Panu (Bandundu Province) showed by far the best performance for seed yield and seed oil content.
Conclusion. The existence of a large variability in yield components and quality of the oil opens up good prospect for obtaining *J. curcas* varieties adapted to the growing conditions of the region. Considering their growth attributes and yield potential, some of the collected ecotyps constitute very promising genetic stocks to start a breeding program of *J. curcas*.

Keywords: Ecotypes, *Jatropha*, Oil Yield, Elite, Kinshasa

RESUME

Evaluation des performances agronomiques de onze écotypes de *Jatropha curcas* L. cultivés dans un sol pauvre du plateau de Batéké près de Kinshasa (RDC).
Description du sujet. Onze écotypes de *Jatropha curcas* L. collectés dans diverses régions agro-écologiques de la RDC ont été cultivés près de Kinshasa sur un sol très pauvre en vue d'identifier le matériel génétique élite.
Objectif. L'objectif de cette étude est d'évaluer les performances agronomiques de 11 écotypes de *J. curcas* cultivés sur des sols très pauvres sur le plateau de Batéké près de Kinshasa afin de sélectionner du matériel génétique d'élite à des fins de sélection.
Méthodes. La collecte d'échantillons de semences de *J. curcas* a été réalisée dans sept provinces de la RDC, de mai à juillet 2009. Des échantillons de semences collectées ont été semés dans des sacs en polythène. Ils ont été cultivés dans une pépinière (trois mois) du 5 juillet au 3 octobre 2009 à Mbankana. La plantation a été aménagée selon un plan en blocs complets randomisés (RBD) avec trois répétitions à une densité de 2500 plantes ha^{-1} (écartement de 2 mx 2 m) sur un terrain qui avait été préparé après une jachère de cinq ans. Le nombre total de plantes par écotype variait de 20 à 36.

Résultats. Après 42 mois de culture, des différences significatives (p <0,05) ont été trouvées concernant la hauteur de la plante (1,4±0,0 à 1,7±0,0 cm), le diamètre au collet (6,8±0,6 - 8,9±0,4 cm), le nombre de branches par plante (22,1±4,7 - 38,8±7,2), le nombre de jours de plantation à la première floraison (236,3±5,7 - 273,0±5,7 jours), la durée de maturation des fruits (67,3±3,5 - 84,6±4,7 jours), le taux d'avortement des capsules (21,0±3, 7 - 32,6±3,0 %), le nombre de capsules par plante (19,4±6,5 - 96,4±8,5), le nombre de graines par capsule (2,5±0,1 - 3,0±0,0), le poids des graines (poids de 100 graines) (48,7±1,8 - 79,1±1,1 g), le rendement en graines sèches (68,6±3,6 - 473,1±3,6 kg ha^{-1}), la teneur en huile (23,3±4,0 - 35,1±1,8 %), la teneur en acides gras mono-insaturés (45,2 - 49,5%). Aucune plante résistante aux principaux insectes nuisibles de *J. curcas* dans la région n'a été observée. L'écotype originaire de Panu (Province du Bandundu) a montré une meilleure performance en termes de rendement en graines et de teneur en huile de graines.

Conclusion. L'existence d'une grande variabilité dans les composants de rendement et la qualité de l'huile ouvre de bonnes perspectives pour l'obtention de variétés de *J. curcas* adaptées aux conditions de croissance de la région. Compte tenu de leurs attributs de croissance et de leur potentiel de rendement, certains des écotypes collectés constituent des stocks génétiques très prometteurs pour lancer un programme de sélection de *J. curcas.*

Mots clés : Ecotypes, *Jatropha*, rendement en huile, élite, Kinshasa

1. INTRODUCTION

Jatropha curcas L. is a tree or shrub that ranges in height from 2 to more than 10 m, which is believed to originate from Central America (Domergue and Pirot, 2008); this species is now found in all tropical and subtropical regions (Openshaw, 2000). Its seeds are rich in oil, which can be easily converted into biofuel (Li *et al*., 2010). It is widely grown in Africa and Asia, mainly because of its ease of propagation, tolerance to drought, rapid growth and ability to thrive on marginal land (Heller, 1996; Sujatha *et al*., 2008). The multiplication of *J. curcas* is easily accomplished by seeds or branch cuttings, but the trees propagated by cuttings have a shorter life span and are less resistant to disease, pests and water stress than those propagated by seeds (Heller, 1996; Achten *et al*., 2008).

One of the major constraints for the sustainable production of *J. curcas*, all over the world is the lack of selected or improved propagating material. This makes it difficult to predict the yields of plantations and limits the interest of the investors for the sector.

Most *J. curcas* plantations in the world were created using seeds harvested from wild trees, which had undergone no prior selection (Francis *et al*., 2005). This largely explains the poor performance of these plantations and the great variability of yields from one field to another (Jongchaap *et al*., 2007). As for all other crops, the selection and multiplication of superior germplasm is a prerequisite to obtain profitable yields (Srivastava *et al*., 2011). As part of a program to improve the production of *J. curcas* in the Kinshasa region, seed samples of local ecotypes were collected in several areas of the DRC to serve as raw material for the selection of elite plants.

The vegetative development, dry seed yield and oil content, and resistance to pests are criteria which should be considered for the selection of elite *J. curcas* plants; unfortunately, very few studies have been performed in this direction in Africa (Kumar and Sharma, 2008; Divakara *et al*., 2010; Singh et al., 2013). The modern techniques based on molecular markers show that genetic diversity is significantly lower for African and Indian ecotypes than for ecotypes collected in Central America, which is the supposed center of origin of the species (Diedhiou *et al.*, 2012).

Paradoxically, this reduced genetic diversity is not reflected by low phenotypic variability (Srivastava *et al*., 2011; Rao *et al*., 2008).

The objective of this study is to evaluate the agronomic performance of 11 ecotypes of *J. curcas* grown on very poor soil on the Batéké Plateau near Kinshasa in order to select elite germplasm for breeding purpose.

2. MATERIALS AND METHODS

2.1. Study Site

The study was conducted from July 2009 to December 2012 near Mbankana, on Batéké Plateau at 4° 47' south latitude, 16° 12' east longitude and at an altitude of 684 m. The soil was very poor and the arable horizon contained 94.2% sand, 1.4 % silt, 3.3 % clay and 1.1 % humus. The climate corresponds to AW4 type according to the Köppen classification. The average annual temperature is 25 °C and rainfall varies around 1500 mm per year (Biseaux et al., 2009). The vegetation of the Bateke Plateau consists mainly of shrub savannahs (Vermeulen and Lanata, 2006).

2.2. Collection of Samples

The *J. curcas* seed sample collection was carried out in seven provinces of the DRC (Table 1) from May to July 2009. The selection criteria were the number of seeds produced per tree and the health status of mother plants. The seeds were collected from a single tree in each site. Cuttings were not collected because of the remoteness of many regions.

Table 1. Ecotypes collected and site characteristics

Ecotypes names based on collect site	Province	Vegetation	Soil	Rainfall (mm)	Length of the dry season (month)	Approximate age of the mother trees (years)
Bendele	Bandundu	Grassland	Sandy-clay	1800	2-3	20
Botala	Kasaï oriental	Forest	Sandy-clay	1700	3	11
Budjala	Equateur	Forest	Sandy-clay	1800	2-3	16
Gbadolite	Equateur	Wooded savannah	Sandy-clay	1800	2-3	10
Ilebo	Kasaï occidental	Forest	Sandy-clay	1650	3	16
Kasongo	Maniema	Grassland	Clay	1300	3 à 4	12
Kindu	Maniema	Grassland	Clay	2200	2 à 3	13
Milangala	Kasaï occidental	Forest	Sandy clay	1600	4	17
Mont-Ngafula	Kinshasa	Grassland	Sandy	1500	4	8
Mwabo	Bandundu	Grassland	Sandy	1550	4	19
Panu	Bandundu	Grassland	Clay	1650	4	14

2.3. Plantation

Samples of collected seeds were sown in polythene bags. They were cultivated in a nursery (three months) from 5 July to 3 October 2009 in Mbankana.The plantation was laid out in a randomized complete block design (RBD) with three replicates at a density of 2 500 plants ha^{-1} (spacing of 2 m x 2 m) on land that was previously prepared after a fallow of five years. The total number of plants per ecotype varied from 20 to 36.

2.4. Plantation Maintenance

Weeding was carried out three times per year (March, September and December); pruning was performed once a year (in August) according to the method described by Achten *et al.* (2008) and a single phytosanitary treatment was applied each year at the end of September using dimethoate (1 liter ha^{-1} 40 % EC).

2.5. Observations

Observations were carried out on all plants of each ecotype in all blocks and concerned the vegetative growth, seed yield components, oil content, as well as fatty acid composition. Morphological traits were assessed after 42 months of cultivation. Dry seed yield and yield components were evaluated on the harvests made from the 30th to the 42th month of cultivation corresponding to the last two peaks of fructification. In the area of Kinshasa, two peaks of production occur every year, corresponding with the two rainy seasons observed in the region. The first peak of production takes place between April and July and the second between September and December.

The following data were taken:

Plant collar diameter and height was measured 42 months after planting in the nursery.

Branching was assessed by counting the number of lateral branches per plant.

Number of days to first flowering was determined by counting the number of days between establishment and the moment where 50 % of the plants of an ecotype have started to flower.

Fruit maturation duration was determined by counting the number of days from blossoming to fruit maturity during each peak of production.

Capsule abortion rates were calculated by counting the number of fallen fruits compared to the total number of fruits formed by the plant during the last 12 months of production.

Number of capsules per plant was obtained by counting fruits present on each plant during the last 12 months of production.

Number of seeds per capsule was determined by counting the total number of seeds in 30 harvested fruits taken at random in the harvest of each experimental unit.

Seed index was obtained by weighing 100 seeds per plant chosen at random on three plants for each ecotype after drying for 48 hours in an oven at a temperature of 37 °C.

Evaluation of the ecotypes reaction to insect pests and diseases: no disease was reported during our trial. The major insect pests of *J. curcas* in the Kinshasa region are tobacco crickets *Brachytrupes membranaceus* Drury (Orthoptera, Grillidae), flea beetles *Aphthona sp*. (Coleoptera, Chrysomelidae), leaf miner *Stomphastis thraustica* Meyrick (Lepidoptera, Gracillariidae), and shield bug *Calidea sp.* (Heteroptera, Scutelleridae) (Minengu *et al*., 2015).

As all the plants of each ecotypes showed symptoms of attacks, the evaluation of the susceptibility of the ecotypes to these pests focused on the proportion of leaves showing attacks. Leaves which were observed were taken on the third branch from the collar in three randomly chosen plants on each experimental unit (plot. The estimating of proportion leaves showing attacks was assessed at the end of each month during three years (2010 to 2012) and at each period of pest outbreaks from October to January.

Dry seeds yield was obtained by measuring the weight of dry seed harvested during the two annual peaks of production in 2010, 2011, and 2012, of each plot and converted to ha.

Oil Content was determined at the Walloon Agricultural Research Centre of Belgium by the infrared spectroscopy method developed by Terren *et al*. (2013) from three seed samples of each ecotype selected at random during the harvest in December 2012. Each sample consisted of 50 seeds in each of 3 plants. The oil content was expressed as a percentage of seed dry matter.

Oil yield was determined by multiplying the yield of dry seeds of each ecotype by its oil content.

Composition of fatty acids was determined at the Walloon Agricultural Research Centre of Belgium by the infrared spectroscopy method of Terren *et al*. (2013) from the oil of the seed samples used to determine the oil content. The different fatty acids were expressed as a percentage of the total fat content.

2.6. Statistical Analysis

The data were subjected to analysis of variance (ANOVA) by MINITAB 16. The LSD test (Least Significant Difference) was used for comparison of the averages (probability level of 5 %). Values are presented as mean ± standard deviations of the mean. The linear regression was used to test correlations between variables.

3. Results and Discussion

3.1. Vegetative Development

Significant differences ($p<0.05$) were observed between ecotypes regarding the collar diameter, height and number of lateral branches per plant (Table 2). Srivastava *et al.* (2011) and Rao *et al.* (2008) also found significant differences between different ecotypes of *J. curcas* regarding their vegetative growth in two studies carried out in India.

Table 2. Vegetative development

Ecotypes	Collar diameter (cm)	Height (m)	Branching (total number of branches)
Bendele (Bandundu)	$8.7±0.7^{ab}$	$1.6±0.1^{ab}$	$27.5±4.1^{bcde}$
Botala (Kasaï oriental)	$7.9±0.6^{abcd}$	$1.7±0.2^{ab}$	$27.0±5.0^{bcde}$
Budjala (Equateur)	$7.3±0.4^{de}$	$1.5±0.0^{cd}$	$29.2±4.5^{abcde}$
Gbadolite (Equateur)	$7.0±0.6^{de}$	$1.6±0.0^{ab}$	$31.7±5.6^{abcde}$
Ilebo (Kasaï occidental)	$6.8±0.6^{e}$	$1.4±0.1^{d}$	$22.1±4.7^{e}$
Kasongo (Maniema)	$8.9±0.4^{a}$	$1.7±0.0^{a}$	$26.3±4.0^{cde}$
Kindu (Maniema)	$7.2±0.5^{de}$	$1.4±0.1^{cd}$	$23.6±3.5^{de}$
Milangala (Kasaï occidental)	$7.6±0.5^{cde}$	$1.5±0.1^{cd}$	$32.3±6.2^{abcd}$
Mont-Ngafula (Kinshasa)	$7.7±0.6^{bcde}$	$1.6±0.0^{bc}$	$35.2± 5.0^{abc}$
Mwabo (Bandundu)	$7.8±0.5^{bcd}$	$1.5±0.1^{cd}$	$36.4±6.1^{ab}$
Panu (Bandundu)	$8.5±0.5^{abc}$	$1.6±0.0^{ab}$	$38.8±7.2^{a}$

The results are presented as mean ± standard deviations of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % ($p<0.05$; ANOVA-LSD).

The highest collar diameter and the largest height were recorded in the ecotype Kasongo (8.9±0.4 cm and 1.7±0.0 m) and the lowest in the ecotype Ilebo (6.8±0.6 cm and 1.45±0.1 m). The total number of branches per ecotype ranged from 22.1±4.7 (ecotype Ilebo) to 38.8±7.2 (ecotype Panu).

3.2. Days to Flowering, Capsule Abortion Rates, and Capsule Maturation Duration

Significant differences ($p<0.05$) were observed between the ecotypes regarding the flowering precocity (number of days to first flowering), the capsule abortion rates, and the fruit maturation duration (Table 3). Contrary to what is often observed in other tropical areas of the world (Singh *et al.,* 2013), all ecotypes started flowering during their first year of cultivation The number of days to first flowering ranged from 236,3±5,7 for Mont-Ngafula ecotype to 84.6±4.1 days for the Kindu ecotype.

The ecotypes studied generally showed a shorter fruit maturation duration compared to the figures presented by Münch and Kiefer (1986) under the conditions of Cape Verde where fruit maturity is reached 3-4 months after fertilization. Brittaine and Lutaladio (Brittaine and Lutaladio, 2010) indicated that the *J. curcas* fruits are ripe and ready for harvest about 90 days after flowering in wetter climates and in semi-arid regions.

Table 3. Flowering precocity, duration of the fruit maturation, capsule abortion rates

Ecotypes	Number of days to first flowering	Fruit maturation duration (days)	Capsule absorption rates (%) (1)
Bendele (Bandundu)	244.6±7.5^{cd}	73.2±3.5^{bcd}	24.0±3.6^{bc}
Botala (Kasaï oriental)	260.0±6.2^{ab}	71.6±4.7^{cd}	29.0±3.0^{a}
Budjala (Equateur)	266.6±5.8^{a}	80.4±6.4^{ab}	31.2± 4.9^{a}
Gbadolite (Equateur)	260.6±9.2^{ab}	78.6±5.0^{abc}	32.6±3.0^{a}
Ilebo (Kasaï occidental)	265.3±5.1^{a}	75.6±3.6^{bcd}	29.1±3.6^{a}
Kasongo (Maniema)	273.0±8.5^{a}	83.4±4.1^{a}	23.7±3.5^{c}
Kindu (Maniema)	264.3±7.9^{ab}	84.6±4.7^{a}	28.6±4.2^{ab}
Milangala (Kasaï occidental)	251.0±6.5^{bc}	69.7±5.2^{d}	22.1± 4.0^{c}
Mont-Ngafula (Kinshasa)	236.3±5.7^{d}	67.3±3.5^{d}	21.0± 3.7^{c}
Mwabo (Bandundu)	244.6±6.2^{cd}	72.8±6.4^{bdc}	23.0±3.6^{c}
Panu (Bandundu)	262.6±7.0^{ab}	78.7±4.7^{abc}	21.3±2.5^{c}

(1) Calculated during the last 12 months of production.
The results are presented as mean ± standard deviations of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % ($p<0.05$; ANOVA-LSD).

The climatic and soil conditions play an important role in the development of *J. curcas*. In the Kinshasa region, *J. curcas* produces fruits twice a year (Minengu *et al.*, 2015). The first production takes place between April and July (first peak) and the second between September and December (second peak). During the first peak of production a premature fruit drop is recorded due to poor soil water retention (Minengu *et al.*, 2015).The ecotypes Gbadolite and Budjala showed the highest abortion rates of fruits with 32.6±3.0 % and 31.2±4.9 %, respectively, in the 42th month of cultivation. These two ecotypes were collected in an area with clay soil and an average annual rainfall of 1800 mm per year, which could explain their poor adaptation in Mbankana area, which is characterized by poor soils (sandy) and irregularities of precipitation (1500 mm per year), resulting in fruit drop under moisture stress.

The lowest capsule abortion rates (close to 20 %) were generally observed for ecotypes originating from drier areas. The premature fruit drop of *J. curcas* in the Kinshasa region is higher (70 %) in the first year of production and decreases from one year to another when the root system develops in depth (Minengu *et al.*, 2015).

3.3. Yield Components

The number of fruits per plant also showed significant differences ($p<0.05$) between ecotypes from the beginning of the production (Table 4). In the 42th month of cultivation, the highest yielders in terms of number of fruits per tree were ecotypes Panu and Mwabo with 96.4±8.5 and 80.6±5.0 fruits per tree, respectively.

Table 4. Yield components

Ecotypes	Number of capsules per plant	Number of seeds per capsule	Seed index (100 seeds weight) (g)
Bendele (Bandundu)	27.3±5.4^{e}	2.6±0.0^{bc}	56.6±1.3^{d}
Botala (Kasaï oriental)	44.9±5.1^{d}	2.5±0.1^{c}	70.8±2.5^{b}
Budjala (Equateur)	54.4±9.5^{c}	2.5±0.1^{c}	54.3±1.1^{de}
Gbadolite (Equateur)	61.5±6.0^{c}	2.5±0.1^{c}	68.7±1.6^{b}
Ilebo (Kasaï occidental)	19.4±6.5^{e}	2.5±0.1^{c}	48.7±1.8^{f}
Kasongo (Maniema)	25.8±6.3^{e}	3.0±0.0^{a}	66.9±4.5^{bc}
Kindu (Maniema)	19.6±7.0^{e}	2.6±0.5^{bc}	68.1±1.1^{bc}
Milangala (Kasaï occidental)	76.3± 4.9^{b}	2.7±0.0^{b}	55.5±1.2^{de}
Mont-Ngafula (Kinshasa)	58.0±12.8^{c}	2.6±0.1^{bc}	63.8±2.2^{c}
Mwabo (Bandundu)	80.6± 5.0^{b}	2.6±0.1^{bc}	51.1±1.6^{ef}
Panu (Bandundu)	96.4±8.5^{a}	2.7±0.0^{b}	79.1±1.1^{a}

The results are presented as mean ± standard deviation of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % ($p<0.05$; ANOVA-LSD).

The number of fruits per tree obtained in our study is higher than that observed by Barro *et al.* (2013) in their study on *J. curcas* ecotypes from different provenances (Casablanca et Diobass) conducted in Bargny in Senegal (11±0.9 fruits per tree in the fourth year of cultivation).

From our observations, none of the ecotypes studied had one seed per fruit. The number of seeds per capsule varied between 2.5 and 3. In the ecotype Kasongo, all fruits harvested contained three seeds. The 100 seed weight ranged from 51.1±1.6 (Milangala) to79.1±1.0 g (Panu). Ginwal *et al.* (2005) found the same high range of seed index or 100 seed weight variations between Indian ecotypes of *J. curcas*.
The 100 seed weight is a very useful yield component in order to determine accurately the amount or number of seeds required for seeding.

3.4. Reaction of Ecotypes to Insect Pests and Diseases

In the Kinshasa region, *J. curcas* is susceptible to four main insect pests (Minengu *et al*., 2015). The insecticidal property of the plant does not prevent the attacks of these organisms. All *J. curcas* ecotypes showed the same susceptibility to attacks by flea beetle and leaf miner, but no disease and no attacks of shield bug were observed (Table 5). On an average, between 55.2 ± 7.8 and 60.3 ± 6.7 % of leaves observed plants showed symptoms of attacks by *Aphthona sp*., and the percentage of leaf of plant presenting symptomps of attacks by *S. thraustica* ranged from 22.9 ± 4.6 to 29.5 ± 6.1 %. Statistical analysis showed no significant differences between the ecotypes regarding the reaction to insect pests.

Table 5. Evaluation of the ecotypes reaction to insect pests

Ecotypes	*Aphthona sp.*	*S. thraustica*
	Percentage of leaf with symptoms of attack	Percentage of leaf with symptoms of attack
Bendele (Bandundu)	55.2±7.8	23.0±3.6
Botala (Kasaï oriental)	60.3±6.7	26.3±3.9
Budjala (Equateur)	59.7±3.5	22.9±4.6
Gbadolite (Equateur)	57.2±5.6	27.3±5.8
Ilebo (Kasaï occidental)	56.1±7.2	25.4±6.7
Kasongo (Maniema)	54.8±4.0	29.5±6.1
Kindu (Maniema)	55.4±6.2	26.8±7.0
Milangala (Kasaï occidental)	57.6±4.3	28.6±6.7
Mont-Ngafula (Kinshasa)	58.1±4.6	24.5±6.4
Mwabo (Bandundu)	55.5±5.7	24.5±4.3
Panu (Bandundu)	59.6±7.6	26.8±6.1

N.S: not significant

The sustainability of *J. curcas* cultivation in the region of Kinshasa, as in all humid tropical areas, depends on the finding of adapted solutions to control pest attacks. The identification of ecotypes that are resistant to this biotic constraint is one of these solutions for the sustainability of *J. curcas* cultivation in the region of Kinshasa (Anitha and Varaprasad, 2012).

3.5. Yield of Dry Seeds

The results of our study (Table 6) show an increase in dry seed yields of *J. curcas* from the second to the fourth year of cultivation and significant differences between ecotypes ($p<0.05$). The ecotype Panu gave a higher seed yield compared to the 10 other ecotypes for all production cycles. In the third year of production, the highest yield observed was 473.1±4.6 kg ha^{-1} for the ecotype Panu and the lowest was 68.6±3.7 kg ha^{-1} for the ecotype Ilebo. These variations in performance may be due to the fact that the ecotypes tested were collected from different sites characterized by variations in habitat, climate and soil conditions. The genotype-environment interactions are strong for *J. curcas* (Domergue and Pirot, 2008).

Table 6. Yield of Dry Seeds

Ecotypes	**Yield (kg ha^{-1})**		
	First year of production (1st and 2nd fruiting peaks) **2010**	Second year of production (3rd and 4th fruiting peaks) **2011**	Third year of production (5th and 6th fruiting peaks) **2012**
Bendele (Bandundu)	$20.7±7.8^{e}$	$24.4±5.4^{g}$	$92.3±5.7^{h}$
Botala (Kasaï oriental)	$41.4±6.5^{cd}$	$74.6±3.3^{e}$	$188.7±6.1^{f}$
Budjala (Equateur)	$38.4±10.6^{cd}$	$67.1±5.5^{ef}$	$223.6±5.3^{e}$
Gbadolite (Equateur)	$37.3±7.8^{d}$	$63.0±3.2^{f}$	$268.4±5.9^{c}$
Ilebo (Kasaï occidental)	$10.1±4.3^{e}$	$22.2±4.8^{g}$	$68.6±3.6^{i}$
Kasongo (Maniema)	$19.4±8.0^{e}$	$23.1±6.5^{g}$	$125.6±6.2^{g}$
Kindu (Maniema)	$16.0±4.0^{e}$	$20.4±3.7^{g}$	$70.4±3.9^{i}$
Milangala (Kasaï occ.)	$48.3±5.0^{c}$	$85.2±4.4^{d}$	$276.6±3.9^{b}$
Mont-Ngafula (Kinshasa)	$60.5±4.9^{b}$	$153.6±5.9^{c}$	$246.8±4.8^{d}$
Mwabo (Bandundu)	$60.2±5.1^{b}$	$189.3±5.5^{b}$	$283.4±5.6^{b}$
Panu (Bandundu)	$95.7±6.4^{a}$	$346.2±5.6^{a}$	$473.1±3.6^{a}$

The results are presented as mean ± standard deviations of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % ($p<0.05$; ANOVA-LSD).

Although ecotypes are adapted to marginal land conditions, *J. curcas* require the use of effective methods for managing soil fertility to ensure high yields for commercial production. As shown in our investigations, yield of the ecotypes tested would be higher with the application of fertilizer and ground cover with *Stylosanthes guianensis*. Yields of our ecotypes are lower than those reported by Openshaw (2000), Heller (1996), Francis *et al.* (2005) and Tewari (2007). However, most yields reported in the literature were calculated from older trees, and there is a lack of information on the type of planting material used (seeds or cuttings), the age of the plantation, climatic conditions of site, fertilization and pest control.

3.6. Oil Content and Oil Yield

The oil content and oil yield showed significant differences ($p<0.05$) between the ecotypes of *J. curcas* (Table 7). They can be classified in three groups according to their oil content: those in which the oil average content was ≥ 30 % (Panu, Gbadolite, Kasongo and Botala), those whose content varies between 25 and 29 % (Mont-Ngafula, Kindu, Budjala, Bendele and Milangala) and those whose oil content is less than 25 % (and Mwabo and Ilebo). Our results are consistent with those found by Srivastava *et al*. (2011) who reported that the oil content of *J. curcas* ecotypes from the district of Gurgaon in India ranged from 17.1±1.0 % to34.4±0.7 %. Kaushik *et al.* (2007) also found significant differences with regard to oil content (28-39 %) among Indian ecotypes of *J. curcas*.

Table 7. Oil content and oil yield (Third year of production)

Ecotypes	Oil content (%)	Oil yield (kg ha^{-1})
Bendele (Bandundu)	25.5 ± 3.9^{cde}	23.6 ± 1.4^{h}
Botala (Kasaï oriental)	31.5 ± 0.7^{bcd}	59.7 ± 1.9^{f}
Budjala (Equateur)	26.6 ± 0.4^{def}	59.5 ± 1.4^{f}
Gbadolite (Equateur)	30.6 ± 0.8^{bc}	82.3 ± 1.8^{b}
Ilebo (Kasaï occidental)	24.8 ± 1.4^{b}	17.0 ± 0.9^{j}
Kasongo (Maniema)	31.1 ± 1.7^{fg}	39.1 ± 1.9^{g}
Kindu (Maniema)	29.3 ± 1.2^{efg}	20.6 ± 1.1^{i}
Milangala (Kasaï occidental)	27.2 ± 0.6^{b}	75.3 ± 1.0^{c}
Mont-Ngafula (Kinshasa)	28.0 ± 0.9^{def}	69.3 ± 1.3^{d}
Mwabo (Bandundu)	23.3 ± 4.0^{g}	66.0 ± 1.3^{e}
Panu (Bandundu)	35.1 ± 1.8^{a}	166.0 ± 1.6^{a}

The results are presented as mean ± standard deviations of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % (p<0.05; ANOVA-LSD).

The oil yield ha^{-1} is directly related to the dry seed yield and to the oil content of the seed. It showed significant differences between the ecotypes. An oil yield of more than 150 kg ha^{-1} was observed for the ecotype Panu in the third year of production. The ecotypes Ilebo, Kindu and Bendele gave an oil yield of less than 25 kg ha^{-1}. Plant development and oil production of *J. curcas* are strongly influenced by the environment (Achten *et al*., 2008; Maes *et al*., 2009).

3.7. Fatty Acid Composition

Determination of the fatty acid composition (table 8) is important to assess the combustible quality of the oil because it influences parameters such as fuel oil cetane and cold flow (Akbar *et al*., 2009). The highest polyunsaturated fatty acid content (linoleic and linolenic) was observed in the ecotype Gbadolite (38.0 %) and the lowest content in ecotypes Bendele (33.0 %), Mwabo (33.2%) and Ilebo (33.8 %).

The vegetable oils rich in polyunsaturated fatty acids (linoleic and linolenic) tend to produce fuels with poor stability to oxidation and acidification (Domergue and Pirot, 2008; Akbar *et al*., 2009). Such oils have poor flow characteristics because it can solidify at low temperatures (Gustone, 2004; Hamed, 2009). Ideally, vegetable oil fuel must be rich in monounsaturated acids (Gustone, 2004). The highest mono-unsaturated acids (oleic and palmitoleic) contents were observed in ecotypes Ilebo (49.5 %), Bendele (48.8 %), Panu (48.6%), Botala (48.6 %) and Mont-Ngafula (48.1 %) and the lowest in the ecotype Gbadolite (45.2 %). The selection of plant material must also take into account the fatty acid composition of different ecotypes.

Table 8. Fatty acid composition

Ecotypes	Saturated fatty acids		Unsaturated fatty acids			
	Palmitic	Stearic	Linoleic	Linolenic	Oleic	Palmitoleic
Bendele (Bandundu)	24.4 ± 1.5^{a}	5.9 ± 0.4^{a}	32.9 ± 1.1^{b}	0.0 ± 0.0^{a}	47.6 ± 2.3^{a}	1.1 ± 0.1^{a}
Botala (Kasai oriental)	24.8 ± 0.9^{a}	5.3 ± 0.3^{a}	35.4 ± 1.0^{ab}	0.0 ± 0.0^{a}	47.6 ± 0.9^{a}	1.0 ± 0.0^{a}
Budjala (Equateur)	23.5 ± 0.4^{a}	5.6 ± 0.4^{a}	36.0 ± 0.5^{ab}	0.1 ± 0.0^{a}	46.1 ± 1.1^{a}	0.9 ± 0.1^{a}
Gbadolite (Equateur)	25.5 ± 0.7^{a}	5.4 ± 0.6^{a}	37.9 ± 0.0^{a}	0.0 ± 0.0^{a}	44.0 ± 1.4^{a}	1.1 ± 0.0^{a}
Ilebo (Kasai occidental)	23.7 ± 1.1^{a}	5.2 ± 0.2^{a}	33.8 ± 3.6^{b}	0.0 ± 0.0^{a}	48.4 ± 2.6^{a}	1.1 ± 0.0^{a}
Kasongo (Maniema)	25.0 ± 1.6^{a}	5.5 ± 0.8^{a}	37.2 ± 0.0^{a}	0.0 ± 0.0^{a}	44.9 ± 3.0^{a}	1.0 ± 0.0^{a}
Kindu (Maniema)	23.9 ± 0.3^{a}	4.7 ± 0.6^{a}	28.0 ± 2.5^{a}	0.1 ± 0.0^{a}	45.1 ± 1.4^{a}	1.0 ± 0.1^{a}
Milangala (Kasaï occidental)	24.8 ± 2.0^{a}	5.6 ± 0.3^{a}	35.3 ± 0.3^{ab}	0.0 ± 0.0^{a}	45.7 ± 3.7^{a}	1.1 ± 0.0^{a}
Mont-Ngafula (Kinshasa)	23.8 ± 1.0^{a}	5.4 ± 0.2^{a}	35.5 ± 1.7^{ab}	0.0 ± 0.0^{a}	47.0 ± 1.8^{a}	1.0 ± 0.1^{a}
Mwabo (Bandundu)	23.9 ± 0.5^{a}	5.9 ± 0.8^{a}	33.0 ± 1.6^{b}	0.1 ± 0.1^{a}	46.7 ± 2.3^{a}	0.9 ± 0.1^{a}
Panu (Bandundu)	26.8 ± 1.5^{a}	5.6 ± 0.7^{a}	36.9 ± 2.2^{a}	0.0 ± 0.0^{a}	47.6 ± 1.2^{a}	0.9 ± 0.0^{a}

The results are presented as mean ± standard deviations of the mean. The values assigned to the same superscript letter in the same column are not significantly different at the probability level of 5 % (p<0.05; ANOVA-LSD).

3.8. Correlation between Vegetative Parameters and Production (r)

Table 9 shows correlations between the variables studied. The dry seeds yield is significantly and positively correlated with oil yield ($r = 0.9$, $p<0.05$) and the number of capsules per plant ($r = 0.9$, $p<0.05$). The oil yield is significantly and positively correlated with the number of capsules per plant ($r = 0.8$, $p<0.05$). A positive and significant correlation was also found between oil content of the seeds and the weight of 100 seeds ($r = 0.8$, $p<0.05$). The only vegetative parameter that is highly and positively correlated with yield components is branching with a strong correlation with the number of capsules per plant ($r = 0.7$, $p<0.05$). Similar correlations were observed by Kaushik *et al*. (2007) and Rao *et al*. (2008).

Table 9. Correlation between the observed parameters (r)

Parameters	Diameter	Height	Branching	NDFF	FMD	CAR	NSC	NCP	Seed Index	Yield of dry seeds	Oil content	Oil yield
Colar diameter	**1**											
Height	$\mathbf{0.5}^{*}$	**1**										
Branching	0.2^{-}	0.1^{-}	**1**									
NDFF	0.0^{-}	0.0^{-}	0.3^{-}	**1**								
FMD	0.0^{-}	0.1^{-}	$\mathbf{0.3}^{*}$	$\mathbf{0.6}^{*}$	**1**							
CAR	$\mathbf{0.4}^{*}$	0.1^{-}	0.2^{-}	$\mathbf{0.4}^{*}$	0.2^{-}	**1**						
NSC	$\mathbf{0.5}^{*}$	0.3^{-}	0.0^{-}	0.0^{-}	0.2^{-}	$\mathbf{0.4}^{*}$	**1**					
NCP	0.1^{-}	0.0^{-}	${}^{*}\mathbf{0.7}^{-}$	0.2^{-}	0.2^{-}	0.2^{-}	0.0^{-}	**1**				
Seed Index	0.2^{-}	$\mathbf{0.6}^{*}$	0.1^{-}	0.2^{-}	0.2^{-}	0.0^{-}	0.3^{-}	0.2^{-}	**1**			
Yield of dry seeds	0.1^{-}	0.2^{-}	$\mathbf{0.6}^{*}$	0.1^{-}	0.1^{-}	0.2^{-}	0.1^{-}	$\mathbf{0.9}^{*}$	$\mathbf{0.3}^{*}$	**1**		
Oil content	0.1^{-}	$\mathbf{0.5}^{*}$	0.1^{-}	0.3^{-}	0.1^{-}	0.0^{-}	0.2^{-}	0.1^{-}	$\mathbf{0.8}^{*}$	$\mathbf{0.3}^{*}$	**1**	
Oil yield	0.1^{-}	0.3^{-}	$\mathbf{0.6}^{*}$	0.0^{-}	0.1^{-}	0.2^{-}	0.1^{-}	$\mathbf{0.8}^{*}$	$\mathbf{0.5}^{*}$	$\mathbf{0.9}^{*}$	$\mathbf{0.5}^{*}$	**1**

* : Significant at 5 % level ; - : No significant at 5 % level; NDFF : number of days to first flowering; FMD : fruit maturation duration; CAR : capsule aborption rates; NSC: number of seed per capsule; NCP : number capsule per plant; Seed index : weight of 100 seeds.

4. Conclusion

The ecotypes of *J. curcas* grown in the Kinshasa region showed significant variability in their morphology, seed yield and oil content. Dry seeds yield ranged from 68.6±3.6 kg ha^{-1} to 473.1±3.6 kg ha^{-1} after 42 months of cultivation. Oil content varied from 23.3 % to 35.1 %.

Based on our study, the ecotype Panu showed the best performance in terms of vegetative development, seed yield, oil content, and mono-unsaturated fatty acids content. *Jatropha curcas* is still a wild plant in most areas where it grows; therefore, the careful selection and improvement of appropriate genetic stocks is essential before considering large-scale plantations.

The existence of a large variability in yield components and quality of the oil opens up good prospect for obtaining *J. curcas* varieties adapted to the growing conditions of the region. Considering their growth attributes and yield potential, some of the collected ecotyps constitute very promising genetic stocks to start a breeding program of *J. curcas*.

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