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Full Length Research Paper

Genetic variation and heritability estimation in *Jatropha curcas* L. population for seed yield and vegetative traits

M. Y. Rafii[1,2]*, I. W. Arolu[1], M. H. A. Omar[2] and M. A. Latif[2,3]

[1]Institute of Tropical Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[3]Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh.

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An evaluation of six *Jatropha curcas* L. accessions was carried out at Field 10, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor. The aim of this study was to determine the seed yield and vegetative traits of the accessions, to estimate the genetic variability and heritability of the population and to study the relationships that exist among these traits. The experiment was conducted using Randomized Complete Block Design (RCBD) with three blocks, six accessions per block and 16 plants per plot. Most of the vegetative and yield traits showed no significant variation among the accessions except in plant height, seed thickness, seed breadth, and total seed per accession. The heritability study showed that the broad sense heritability values ranged from 0 to 23.04%, the highest value was at plant height. This study indicated that environmental factors played an important role than the genetic factor. The correlation study showed that seed length had positive correlation with seed thickness, seed breadth and seed weight. From this study, Accession V5 and V2 showed high potential for future breeding program.

Key words: *Jatropha curcas* L., genetic variation, heritability, seed yield, environmental factor, medicinal value.

INTRODUCTION

Jatropha curcas L., is a perennial Euphorbiaceae crop with potential such as medicinal and biodiesel crop recently introduced to Malaysia and is recognized as potential oil seed (Ahmadpour et al. 2010; Camellia et al*.,* 2011; Effendi et al., 2010; Rafii et al., 2012; Shabanimofrad et al., 2011). This plant has proved it great important as a medicinal plant in treating tropical diseases of dermatological origin (Igbinosa et al., 2009; Aiyelaagbe et al., 2007; Fagbenro-Beyioku et al., 1998). Also the attention on this crop has increased due to high rate of ozone layer depletion and global warming effect caused by increased usage of fossil fuel resulting in environmental pollution. Renewable biofuel feed stocks are perceived to be essential contributors to the energy supply portfolio as they contribute to the world energy supply security, reducing dependency on fossil fuel resources and provide opportunity for mitigating greenhouse gases (Sudhakar and Nalini, 2011). This newly introduced crop which grows abundantly in wild and abandoned land has its seed and oil yield unpredictable especially in tropical climate. Favourable environmental conditions that affect it production are yet to be known (Ovando et al., 2011, Divakara et al., 2010). In spite of the great potentials and attributes of Jatropha as a biodiesel crop, the full potentials of Jatropha have not been realized. One of the reasons for this, apart from the agronomic, social economic and institutional constraints is the facts that there is presently no planned rational conventional breeding and genetic programs. Ginwal et al. (2005) reported that, for the fact that Jatropha has adapted itself to wide range of environmental and ecological conditions suggests that, there exists considerable amount of genetic diversity yet to be detected for potential realization. Rao et al. (2008) reported variability observed in *J. curcas* in Central India

*Corresponding author. E-mail: mrafii@putra.upm.edu.my. Tel: +603 8947 4825. Fax: +603-8947 4918.

Table 1. Location, geographic descriptions and date of collection of six *J. curcas* accessions in Malaysia.

Name of accessions	Location	Geographical description
V1	Muar, Johor	2°3′00″N 102°34′00″E
V2	Beseri, Perlis	6°30′N 100°15′E
V3	Kluang, Johor	2°2′01″N 103°19′10″E
V4	Marang, Terengganu	4°45′N 103°0′E
V5	Field 2, UPM, Selangor	3°20′N 101°30′E
V6	Lundang, Kelantan	5°15′N 102°0′E

which was mainly limited to seed source variation in morphology, germination and seedling growth. Kaushik et al. (2007) have reported divergence in seed oil traits of *J. curcas* from a limited number of locally collected accessions. Since heritability estimate in perennial plants decrease with age because of compounded environmental effects masking genotypic differences, there is an urgent need for the knowledge of these estimates in the progenies (Rao et al., 2008).

However, one of the limitations to this conventional breeding program work is the wide genetic diversity, which has to be evaluated before selection of suitable accessions could be possible. Also breeding of high yielding variety is not possible without knowing the extent of variation that exists among the available germplasm in Malaysia, the growth, yield and extent of environmental influence on these factors, heritability and genetic gain of the material.

Therefore, the present work was undertaken to evaluate the six local accessions of *J. curcas* in Malaysia with the aim of selection for future breeding program.

MATERIALS AND METHODS

In this present study, six *J. curcas* accessions (Table 1) from different regions in Peninsular Malaysia were collected and planted at Field 10, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia (03°00.512N,101°42.101E).

The experimental design was a Complete Randomized Block Design (RCBD) with three blocks, six plots per block and 16 plants per plot, making a total of 288 plants. The cuttings of these accessions were raised in the nursery for 4 months with good irrigation facilities after which they are transplanted to the field. The cuttings were transplanted with spacing of 2 m × 3 m. Crop management such as weeding using motorized cutter supplemented with Round up (200 ml per 14 L of water) and fertilizer application at the dosage of 250 g per tree of NPK 12:12:17 were carried out to enhance the growth of the plant. Data collection on the vegetative traits commenced at one month after transplanting. The vegetative characters for each plant per accession include plant height, number of primary and secondary branches while the yield trait taken on fruits are seed length, seed thickness, seed breadth, total seed number, total seed weight, and finally the oil percentage were collected. Data on plant height were taken using calibrated measuring stick, seed length, breadth and thickness were measured using Ip54 moisture resistance digital calipers (Shan USA),weights of the seed were measured with Digital weighing balance (Japan Fisher scientific,. 2009) Oil extraction was carried after the seeds were milled using soxhlet extraction method with hexane as the solvent.

Analysis of variance was calculated for each trait using statistical Analysis System (SAS) software version 9.2 (SAS Ins.2002). Means, standard deviation, variance and coefficient of variation were also computed for each of the quantitative traits. Correlation coefficient among the characters was computed by Proc Corr. of SAS software.

Variance components and heritability estimates was calculated as described by Falconer and Mackay (1996) which included the phenotypic variance and broad-sense heritability.

Genotypic variance, $\sigma^2_g = (MSG - MSE)/r$

Error variance, $\sigma_e^2 = MSE$

Where MSG = mean square of accessions, MSE = mean square of error and r = number of replications.

$$\text{Phenotype variance } (\sigma^2_p) = \sigma^2_g + \sigma^2_{gr} + \sigma^2_e$$

$$\text{Broad sense heritability (\%)} = \frac{\sigma^2_g}{\sigma^2_g + \sigma^2_{gr} + \sigma^2_e}$$

σ^2_e represents variance error, and σ^2_{gr} represents variance accessions × replication interaction.

RESULTS AND DISCUSSION

In plant breeding program, evaluation of germplasm is the first step in exploring genetic variability. No significant differences among the accessions were observed for seed length, seed weight and oil content (Table 2). The highest mean for seed thickness (ST) was observed at Accession V6 but no observable significant difference was found when compared to other accessions except for Accession V3. Meanwhile for seed breadth (SB) character, Accession V6 had the highest mean and differed significantly with Accession V5 but not differed with other accessions. Likewise for total seed weight

Table 2. Means comparison for oil content, seed and vegetative characters.

Accessions	SL (mm)	ST (mm)	SB (mm)	TF (no)	TS (no/plant)	TSW (g/plant)	Oil content (%)	NB (no./plant)	HT (m)
V1	18.02	11.31^{ab}	8.36^{ab}	38.21	95.65	55.65^{ab}	27.22	3.4	1.17^{b}c
V2	17.94	11.31^{ab}	8.37^{ab}	41.25	101.23	58.80^{ab}	25.14	3.3	1.23^{ab}
V3	17.93	11.30^{b}	8.36^{ab}	38.71	95.46	52.93^{b}	26.17	3.2	1.15^{b}c
V4	18.08	11.34^{ab}	8.38^{ab}	40.67	101.06	57.60^{ab}	25.84	3.3	0.98d
V5	18.03	11.36^{ab}	8.35^{b}	40.96	102.06	60.48^{a}	26.09	3.3	1.26^{a}
V6	18.06	11.43^{a}	8.47^{a}	38.75	95.94	54.54^{ab}	25.09	3.4	1.00d
Mean	18.01	11.34	8.38	39.76	98.68	56.66	25.94	3.3	1.13
HSDRT	^{ns}	0.11	0.11	^{ns}	^{ns}	6.97	^{ns}	^{ns}	0.08

Means with the same letter are not significantly different base on Tukey's studentized range test (HSDRT) at probability level P ≤ 0.05; ns = not significant; SL= seed length; ST = seed thickness; SB = seed breadth; TF = Total number of fruits; TS = total see;TSW = total seed weight; NB= number of branches; HT= plant height

Table 3. Mean Squares of ANOVA, variance components and heritability value (h^2B) for seed and vegetative characters.

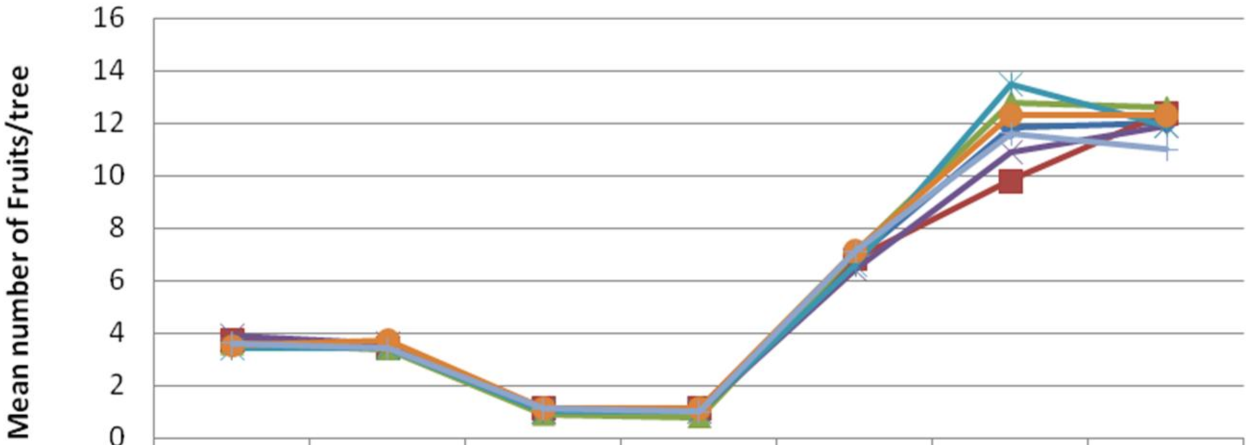
Source of variation	d.f	SL	ST	SB	TF	TS	TSW	Oil content (%)	NB	HT
Replications (R)	2	0.24^{ns}	0.23**	0.06^{ns}	68.15^{ns}	1902.15**	582.59**	26.91^{ns}	0.32^{ns}	0.25**
Accessions (G)	5	0.19^{ns}	0.11**	0.01*	86.51**	524.15^{ns}	379.36*	27.88^{ns}	0.26^{ns}	0.65**
GxR	10	0.21^{ns}	0.08*	0.07*	71.54**	622.44**	266.63*	15.71^{ns}	0.55**	0.20**
Error	270	0.13	0.04	0.04	24.01	274.68	141.64	15.77	0.21	0.02
Variance component										
σ^2_g		-0.0005	0.0006	0.0004	-0.0353	-2.0476	2.3486	0.2534	-0.006	0.0094
σ^2_{gr}		0.0049	0.0022	0.0023	2.9704	21.735	7.8115	-0.0032	0.0214	0.0112
σ^2_e		0.1343	0.0401	0.0383	24.0102	274.677	141.644	15.7653	0.207	0.0202
σ^2_p		0.1397	0.0429	0.041	27.0159	298.46	151.804	16.0219	0.2344	0.0408
h_2 ^{B}		0	1.4	0.98	0	0	1.5	0.02	0	23.07
E		100	98.6	99.2	100	100	98.5	99.08	100	76.96

SL= Seed length; ST = seed thickness; SB=seed breadth; TF= total number of fruits; TS = total seed number; TSW = total seed weight; HT = plant height; NB = number of branches; σ^2_g = genotypic variance; σ^2_{gr} = genotypic variance arising from genotype by replication interaction; σ^2_e = error variance; σ^2_p = genotypic variance; h^2 $_B$ = broad sense heritability; E= environmental effects.

character, Accession V5 had the highest mean but not differed significantly from the other accessions. However the other characters showed non-significant differences among the accessions. Accession V5 produced seed with better total seed number, and total seed weight compared to other accessions while Accession V2 had higher number of seed and seed weight.

These results agreed with the findings of Kaushika et al. (2007) who reported that *J. curcas* population in germplasm collected in India showed a significant (p ≤ 0.05) variation for seed length, breadth and100- seed weight. For the vegetative traits, this finding shows that there is high correlation between the number of branches, plant height and yield. This implies that, the accessions with more branches are able to produce more flowers part which result in higher number of fruits. Also, the plants with higher height have their leave able to gain access to sunlight compare to accession of short height which directly affects the photosynthesis.

Variance components and heritability values of each trait from the Table 3 showed that all characters had low heritability value which ranged from 0 to 1.95%. The highest values of heritability were recorded on seed weight (1.95%) followed by total seed weight (1.5%), and seed thickness (1.4%). Since phenotypic expression is the effect of genotype and environment on the plant, the result from the Table 3 therefore indicated that the impact of environmental factors is very high, and this ranged from 98.05 to 100% compared to genetics factor on their phenotypic expression. This result was not in agreement with the previous research of Kaushika et al. (2007) which shows that high estimate of heritability (broad



	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
POPULATION	3.6	3.5	1	1	6.8	11.8	12
VI	3.7	3.4	1.1	1.1	6.8	9.8	12.4
V2	3.6	3.4	0.9	0.8	7.1	12.8	12.6
V3	3.9	3.6	1	1	6.4	10.9	11.9
V4	3.4	3.4	1	1	6.6	13.5	11.9
V5	3.5	3.7	1.1	1.1	7.1	12.3	12.3
V6	3.6	3.4	1.1	1	7.1	11.6	11

Figure 1. Monthwise number of fruits per tree.

sense) for all characters under study revealed the heritable nature of variability present. High estimates of heritability (>54%) have envisaged that environment has low influence on the seed traits and oil content. Rao et al. (2008) said that yield and plant height showed maximum advance indicating that the progress in shifting the genotypic mean and gene frequencies of yield and plant height in the population could be achieved in the desired direction.

From Table 2, oil content (%) had no significant variation among the accessions in the germplasm used for this study. This result is in contrast with the findings of Freitas et al. (2011) which stated that variation was observed in the oil content in different *J. curcas* populations. The result suggested that sources of *J. curcas* accessions in this study are much different in terms of genetic background. Beside the fact that environments also play an important role on these six characters. This has been reported by many authors that oil content was greatly affected by environmental factors (Gupta, 1985; Baydar and Turgut, 1994). Hanamashetti et al. (2002) also observed that there was no significant difference among the sixteen accessions of curing percentage of turmeric.

The mean fruit production of the accessions over different months of the year is presented in the Figure 1. All the accessions had high mean fruit production in June, July and August. The highest fruit production was recorded in the month of July followed by August and June. These months are characterized by low to moderate amount of rainfall which favours high flowering and fruiting of Jatropha. While in February and March, the production was very low, with the fruits production ranging from 3.4 to 3.9 kg/tree, this is as a result of the fact that the trees are very young and they are just fruiting; on the other hand low production was observed in April and May due to large amount of rainfall which led to high flower abortion and embryo mortality of the developing fruits. This observation agrees with the findings of Freitas et al. (2011), who reported that a significant difference in terms of yield increment in the accession of *J. curcas* in the area of large amount of rainfall and lower yield in the Savanna area of Brazil with is known for its low amount of rainfall. Abou and

Table 4. Correlation coefficients among characters measured on six accessions.

Character	ST	SB	NF2	NF3	NF4	NF5	NF6	NF7	NF8	TF	TS	TSW	NB	HT	Oil content
SL	0.186**	0.320**	0.016^{ns}	0.009^{ns}	0.029^{ns}	0.031^{ns}	0.04^{ns}	0.094^{ns}	0.038^{ns}	0.022^{ns}	0.018^{ns}	0.15*	0.061^{ns}	0.046^{ns}	0.076^{ns}
ST		0.267**	0.124*	0.131*	0.037^{ns}	0.027^{ns}	0.034^{ns}	0.001^{ns}	0.001^{ns}	0.001^{ns}	0.039^{ns}	0.095^{ns}	0.086^{ns}	0.093^{ns}	0.041^{ns}
SB			0.004^{ns}	0.043^{ns}	0.024^{ns}	0.084^{ns}	0.002^{ns}	0.026^{ns}	0.043^{ns}	0.021^{ns}	0.019^{ns}	0.113^{ns}	0.028^{ns}	0.111^{ns}	0.085^{ns}
NF2				0.069^{ns}	0.015^{ns}	0.025^{ns}	0.013^{ns}	0.061^{ns}	0.096^{ns}	0.337**	0.223**	0.173**	0.058^{ns}	0.019^{ns}	0.020^{ns}
NF3					0.049^{ns}	0.096^{ns}	0.062^{ns}	0.107^{ns}	0.077^{ns}	0.232**	0.263**	0.209**	0.032^{ns}	0.077^{ns}	0.110^{ns}
NF4						0.085^{ns}	0.023^{ns}	0.043^{ns}	0.047^{ns}	0.204**	0.192**	0.155**	0.001^{ns}	0.014^{ns}	0.040^{ns}
NF5							0.025^{ns}	0.042^{ns}	0.027^{ns}	0.086^{ns}	0.045^{ns}	0.014^{ns}	0.039^{ns}	0.079^{ns}	0.024^{ns}
NF6								0.130*	0.034^{ns}	0.349**	0.299**	0.318**	0.023^{ns}	0.0^{ns}	0.052^{ns}
NF7									0.117^{ns}	0.637**	0.599**	0.474**	0.103^{ns}	0.043^{ns}	0.048^{ns}
NF8										0.520**	0.405^{ns}	0.313**	0.010^{ns}	0.117*	0.081^{ns}
TF											0.864**	0.696**	0.090^{ns}	0.076^{ns}	0.082^{ns}
TS												0.820**	0.034^{ns}	0.090^{ns}	0.091^{ns}
TSW													0.034*	0.121*	0.003^{ns}
NB														0.016^{ns}	0.126*
HT															0.066^{ns}

SL= Seed length; ST = seed thickness; SB = seed breadth; NF2 to NF8 = number of fruits from February to August, respectively; TF= total number of fruits; TS = total seed number; TSW = total seed weight; NB = number of branches; HT= plant height.

Atta (2009) reported that there is significant difference in terms of water response between the varieties of *J .curcas.* Ginwal et al. (2004a) also reported in the provenance trial experiment of *Eucalyptus tereticornis* that rainfall and temperature gradient are postulated to play an important role in the formation of clonal variation pattern in growth characters.

The correlation coefficient (r) of the plant vegetative and yield traits are presented in Table 4. Total seed weight was found to have higher significant positive relationship with seed length, total fruit production and production per month except for the month of May. The seed traits (seed thickness and seed breath) also showed higher positive relationships among themselves. These observations were similar to those of Ginwal et al. (2004b) in seed source variation of *J. curcas* in India. The oil content had higher significant positive relationship with the number of branches. From the previous research, it was found that statistically significant positive correlation existed between seed weight and high oil content, seed length, breadth and thickness (Kaushika et al., 2007), therefore, the seed weight can be consider as an important trait for early selection of seed sources. The high positive correlation between the number of branch and oil content is also similar to the finding of Rao et al. (2008). The highly positive correlation can be explained by the fact that during the phonological succession of appearance of physiological and morphological determinants of yield, the number of branches contributed to higher number of flower which in turn contributed to higher number of female flowers which finally culminated in higher yield. This is also similar to the findings of Bhargava et al. (2007) and Van Osteroma et al. (2006).

Conclusion

The highest broad sense heritability was recorded on seed weight (1.95%) followed by total seed weight (1.5), and seed thickness (1.4). The impact of environmental factors was very high, and this ranged from 98.05 to 100% compared to genetics factor on their phenotypic expression. Total seed weight was found to have higher significant positive relationship with seed length, total fruit production and production per month except for the month of May. The seed traits (seed thickness and seed breath) also showed higher positive relationships among themselves. Accession V5 had the highest total seed weight with 60.48 g/plant followed by Accession V2 (58.80 g/plant), V4 (57.60 g/plant), V1 (55.65 g/plant), V6 (54.54 g/plant), and V3 (52.93 g/plant). Accession V5 produced seed with better total seed number, total seed and weight characters compared to other accessions while Accession V2 produced higher number of seed and seed weight. From this study, Accession V5 and V2 were good potential genotypes for selection and utilization in future *J. curcas* breeding programmes. In conclusion, accession with large number of primary branches and secondary branches, and high plant height are good for selection since these are traits that result into high yield.

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REFERENCES

Abou KAA, Atta NMM (2009). Response of *Jatropha curcas* L. to water deficits Yield, water use efficiency and oilseed characteristics. Biomass Bioenergy, 33(10): 1343-1350.

Ahmadpour P, Nawi AM, Abdu A, Abdul-Hamid H, Singh DK (2010). Uptake of heavy metals by *Jatropha curcas* L. planted in soils containing sewage sludge. Am. J. Appl Sci., 7: 1291-1299.

Aiyelaagbe OO, Adeniyi BA, Fatunsin OF, Arimah BD (2007). *In vitro* Antimicrobial activity and photochemical analysis of *Jatropha curcas* roots. Int. J. Pharmacol., 3(1): 106-110.

Baydar H, Turgut U (1994). Effect of stability criteria on the acid composition of Sesame (*Sesamum indicum* L.). Turk. J. Agric. For., 18(5): 387-391,

Bhargava A, Shukla S, Ohri D (2007). Genetic variability and interrelationship among various morphological and quality traits in Quinoa (*Chenopodium quinoa* Wild). Field Crops Res., 101: 104-106.

Camellia NN, Thohirah LA, Abdullah NAP (2011). Flowering and Fruit Set under Malaysian Climate of *Jatropha curcas* L. Am. J. Agric. Biol. Sci., 6(1): 142-147.

Divakara BN, Upadhyaya HD, Wani SP, Laxmipathi CL (2010). Biology and genetics improvement of *Jatropha curcas* L. Appl. Ener., 87(3): 732-742.

Effendi Z, Ramli R, Ghani JA (2010). A back propagation neural networks for grading *Jatropha curcas* fruits maturity. Am. J. Appl. Sci., 7: 390-394.

Fagbenro-Beyioku AF, Oyibo WA, Anuforom BC (1998). Disinfectant/ antiparasitic activities of *Jatropha curcas*. East Afr. Med. J., 75: 508-511.

Falconer DS, Mackay TFC (1996). Introduction to Quantitative Genetics.4th Edition, Pearson Education Limited, Edinburgh Gate, Harlow Engl., pp. 160-163.

Freitas RG, Missio RF, Matos FS, Resende MDV, Dias LAS (2011). Genetic evaluation of Jatropha *curcas*: an important oilseed for biodiesel production. Genet. Mol. Res., 10(3): 1490-1498.

Ginwal HS, Pradip K, Sharma VK, Mandal AK , Harwood CE (2004a). Genetic Variability and Early Growth Performance of *Eucalyptus tereticornis* Sm. in Provenance cum Progeny Trials in India. Silvae Genet., 53: 148-156 .

Ginwal HS, Rawat PS, Srivastava R L (2004b). Seed Source Variation in Growth Performance and Oil Yield of *Jatropha curcas* Linn. Central India Silvae Genet., 53: 186-192.

Ginwal HS, Rawat PS, Srivastava R L (2005). Seed Source Variation in Morphology, Germination and seedling growth of *Jatropha curcas* Linn. Central India Silvae Genet., 54: 76-80.

Gupta RC (1985). Pharmacognostic studies on “Dravanti”. Part 1 *Jatropha curcas* Linn. Proc. Indian Acad. Sci. Plant Sci., 94(1): 65-82.

Hanamashetti SI, Narayanpur VB, Hegde NK (2002). Comparative Performance of Sixteen Promising Cultivars of Turmeric (*Curcuma longa* L.) when Finger and Mother Rhizomes were used as Planting Material. Proc. Placrosym., 85: 176-179.

Igbinosa OO, Igbinosa EO, Aiyegoro OA (2009). Antimicrobial activity and phytochemical screening of stem bark extracts from *Jatropha curcas* (Linn). Afr. J. Pharm. Pharmacol., 3(2): 58-62.

Kaushik N, Kumar K, Kumar S, Roy S (2007). Genetic Variability and divergence studies in the seed traits and oil content of Jatropha (*Jatropha curcas* .L) accessions. Biomass Bioenergy, 31: 497-502.

Ovando-Medina I, Espinosa-García FJ, Núñez-Farfán JS, Salvador-Figueroa M (2011). State of the art of genetic diversity research in *Jatropha curcas*. Sci. Res. Essays, 6(8): 1709-1719.

Rafii MY, Shabanimofrad M, Wahab PEM, Latif MA (2012). Analysis of the genetic diversity of physic nut, *Jatropha curcas* L. accessions using RAPD markers. Mol. Biol. Rep., DOI 10.1007/s11033-012-1478-2

Rao GR, Korwar GR, Shanker AK, Ramakrishna YS (2008). Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) accessions. Trees Struct. Funct., 22: 697-709.

SAS Institute Inc (2002). Statistical Analysis system, Version 9.2. Cary North Carolina,USA.

Shabanimofrad M, Yusop MR, Saad MS, Megat WPE, Biabanikhanehkahdani A, Latif MA (2011). Diversity of physic nut, *Jatropha curcas* in Malaysia–application of DIVA-GIS and cluster analysis. Aust. J. Crop Sci., 5(4): 361-368.

Sudhakar TJ, Nalini E (2011). Molecular approaches to improvement of *Jatropha curcas* Linn. as a sustainable energy crop. Plant Cell Rep., 30: 1573-1591.

Van Osteroma EJ, Weltzienb E, Yadav OP, Bidingerb FR (2006). Grain yield components of pearl millet under optimum conditions can be used to identify germplasm with adaptation to arid zones. Field Crops Res., 96: 407-421.