

Phenotypic and genetic variation of *Jatropha curcas* L populations from different countries

Alireza Biabani¹, Mohd Y Rafii^{1,2*}, Ghizan B Saleh¹, Mahmoodreza Shabanimofrad¹, Md Abdul Latif¹

¹Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

²Institute of Tropical Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

*Corresponding author: E-mail: mrafii@putra.upm.edu.my

Abstract

Jatropha populations from Malaysia, India, Indonesia, and the Philippines were evaluated on inland soils at University Agriculture Park, Universiti Putra Malaysia with the main objectives are to select superior plants with high seed and oil yields production for commercial planting and to study inter-populations variation in morphological, seed and oil yields characteristics. Analysis of variance shows that all traits had significant variation among populations. Phenotypic correlations between seed yield per plant was positively and highly significantly correlated with days to flowering, number of inflorescences, number of fruits per plant, number of seeds per plant, seed yield per hectare, seed oil yield per plant, and seed oil yield per hectare. Seed yield per plant was highly significant negatively correlated with seed oil content. Cluster analysis based on standardized agro-morphological data, divided the *Jatropha* populations into three clusters through non-hierarchical clustering. Cluster I, II, III consisted of one, two and three populations respectively. Highly significant genotypic differences were obtained among the *Jatropha* populations for various traits measured. The relative large variations were observed for all traits except number of tertiary branches in first year of harvesting. The variation was large enough to suggest that six *Jatropha* populations could present appropriate genotypes to be used in intensive breeding programs.

Keywords: *Jatropha curcas* L, genetic variation, phenotypic correlation, cluster analysis

Introduction

Biodiesel, an alternative diesel fuel, is produced from renewable biological sources such as vegetable oils and animal fats (Sukarin et al, 1987; Kumar and Sharma 2008; Sujatha et al, 2008; Fangrui and Milford 1999; Sharama et al, 2011). *Jatropha curcas* is a drought-resistant perennial shrub with an economic planting of 30-50 years. With the increasing interest in biofuel, it is now considered as one of the promising sources of biofuel and has proved to be a viable feedstock because of the 30% oil composition of its nut (Achten et al, 2008; Cai et al, 2010; Divakara et al, 2010; Ganesh Ram et al, 2008; Gohil and Pandya 2009; Shabanimofrad et al, 2011). *Jatropha curcas* plantation has begun the world over for biodiesel production (King et al, 2009), but unfortunately there is a lack of availability of quality planting material (Ghosh and Singh 2011; Shuit et al, 2010).

Knowledge about the degree of genetic diversity inter and intra populations into and outside the center of origin is needed to gain the first ideas about where to find potentially important genetic material. *Jatropha* genetic resources has been reported and only limited and scattered knowledge is available on the basic reproductive biology of the species. In addition, little information has been reported on quantitative genetic variation, such as genetic variance components, heritability, heterosis and effects of in-

teraction between genotypes and environment. Also, one factor of key importance for conducting breeding programs is genetic variability (Franco et al, 2001; Achten et al, 2010; Sun et al, 2008).

Recently, some researchers reported genetic variation in the *Jatropha* populations from India, China, Latin America, Malaysia and Africa based on morphologic and agronomic characters revealed by using morphological and molecular techniques (Ginwal et al, 2005; Kaushik et al, 2007; Rao et al, 2008; Rafii et al, 2012a; Arolu et al, 2012; Shabanimofrad et al, 2013). We aimed at investigating the genetic variation of *Jatropha* in population and determined genetic components of the important characters in the *Jatropha* populations.

Materials and Methods

Description of the experimental site and plant material

The study was managed in University Agriculture Park, Universiti Putra Malaysia in 2009 and 2010. The experimental site is located at 101.71655°N, 3.0059°E and at an altitude of 88 meter above sea level. *Jatropha* populations were chosen from Malaysia, India, Indonesia, and Philippines countries. One hundred seeds from each *Jatropha* populations were germinated and sown in polyethylene bags. All six hundred seeds of the populations were planted in Polyethylene bags to produce seedlings. Polyethylene bags

filled with soil mixture (clay, sand and organic matter in a 1:1:1 ratio). Finally, after three months (nursery stage), sixty four plants were chosen in each *Jatropha* population and seedlings were transplanted in the experimental field of University Agriculture Park, Universiti Putra Malaysia.

Field experimental design and data collection

Experiments were conducted using a randomized complete block experimental design (RCBD) with four replications. Sixteen plants of each population were planted at four meters inter-row and two meters intra-row spacing in each plot.

Data for each character were recorded on 384 individual plants during 24 months. Data on all quantitative traits were collected as an average value of the sixteen plants.

Statistical analysis

For all morphological characteristics analysis of variance was conducted to determine significance of variability among the populations. Mean, range, standard deviation, and coefficient of variation for each characteristic were determined using Statistical Analysis System (SAS) version 9.1. Mean comparison was done using the Duncan's New Multiple Range Test (DNMRT). Correlation coefficients were used to evaluate the relationship among the different variables in the experiment. Simple correlation was estimated among traits. Cluster analysis was performed using NTSYS-PC version 2.1. Jaccard's similarity coefficient were used to produce a dendrogram for which the UPGMA (unweighted pair group method using arithmetic average) algorithm (Ovando et al, 2011).

Results

Variation in seed characters

The range for seed length was from 18.0 (Indonesia1) to 20.3 mm (Malaysia1), with a mean of 18.8 mm, while seed width ranged from 11.1 (Indonesia1) to 11.6 mm (Philippines) with a mean of 11.3 mm. Seed weight ranged from 0.65 (Indonesia1) to 0.84 g (Philippines), with a mean of 0.75 g, while 100 seed weight ranged from 66.21 (Indonesia1) to 76.72 g (Malaysia1), with a mean of 72.80 g (Table 1). Results showed low coefficients of variation for seed length (4.4%), seed width (1.3%), seed weight (9.4%) and 100 seed weight (2.8%), respectively (Table 1).

Results of analysis of variance (ANOVA) on seed characteristics indicated significant variation among populations at $p \leq 0.05$ and $p \leq 0.01$ (Table 2). Differences in seed length and seed weight were significant at $p \leq 0.05$, while seed width and hundred seed weight were significant at $p \leq 0.01$ (Table 2).

Variation in growth characters

India population was the tallest for first and second year and shortest population were Malaysia1 and Indonesia2 for first and second year, respectively. From Table 3, the range for plant height was from 158 cm (India) to 131 cm (Malaysia1), with a mean of 144

cm for first year, while plant height ranged from 191 (India) to 150 cm (Indonesia2), with a mean of 172 cm (Table 1).

Significant variation ($p \leq 0.05$) revealed among the populations for plant height (Table 2). Significant variations were among the populations with regard to the number of secondary branches in the plant for first and second year. The highest number of secondary branches were recorded in Malaysia2 (4.4) and Indonesia1 (6.4) for first and second year respectively. Also, the lowest number of secondary branches were recorded in Malaysia1 (3.4) and Indonesia2 (4.0) for first and second year respectively (Table 1).

No significant differences revealed among the populations for number of tertiary branches in first year, while significant differences ($p \leq 0.05$) occurred among the populations for number of tertiary branches in second year (Table 2). Maximum number of tertiary branches was observed in Malaysia2 (5.6). Also, minimum number of tertiary branches was recorded in Indonesia2 (1.5) for second year (Table 1).

Variation in yield and yield components

Days to flowering was highest in Philippines which recorded 276 days after planting and was closely followed by Indonesia2 with values of 274 days after planting. Minimum days to flowering was seen in Indonesia1 (241) in first year (Table 1). There was high significant variation among the populations with regard to the number of inflorescences per plant with means of 9, 35 and 22 inflorescences per plant in first, second and average year respectively. The highest total number of inflorescences per plant was recorded in Indonesia1. While the lowest total number of inflorescences per plant was recorded in Malaysia1 in first, second and average years (Table 1).

The highest number of fruits per plant was recorded in Indonesia1 for first year (26 fruits), second year (214 fruits) and average year (120 fruits). Also, the lowest number of fruits were recorded in Indonesia2 (10 fruits) for first year and Philippines for second year (101 fruits) and average year (58 fruits) (Table 1).

Populations were highly significantly different for number of seed per plant. Among all populations tested, Indonesia1 had the highest number of seed per plant in first year (70 seeds), second year (601 seeds) and average year (335 seeds) year. Also, the lowest number of seed per plant was seen in Indonesia2 (30 seeds) for first year and Malaysia1 for second year (201 seeds) and average (116 seeds) year (Table 1).

Results showed high coefficients of variations for number of inflorescences in first year (23.5%), number of fruits for first year (31.9%) and number of seed per plant for first year harvesting (22.7%), second year harvesting (21.7%) and average year harvesting (19.16%). The CV (%) was moderate in number of fruits per plant for second year harvesting (13.8%) and average harvesting years. Low CV (%) was obtained for days to flowering (6.0%), number of inflorescences per plant for second year harvest-

Table 1 - Mean of traits measured in *Jatropha* populations.

Trait	Year	In1	In2	My1	My2	Ph1	Id1	Mean	CV (%)
Seed length (mm)	1st yr	18.0b	18.9b	20.3a	18.5b	18.4b	18.8b	18.8	4.4
Seed width (mm)	1st yr	11.1c	11.5ab	11.5ab	11.2c	11.7a	11.3bc	11.4	1.3
Seed weight (g)	1st yr	0.65b	0.78a	0.78a	0.72ab	0.84a	0.74ab	0.75	9.4
100 Seed weight(g)	1st yr	66b	73a	76a	69a	74a	75a	72.8	2.8
Day to flowering	1st yr	241b	274a	267a	252ab	276a	260ab	262	6
Plant height (cm)	1st yr	136bc	138bc	131c	149ab	149ab	158a	144	7.1
	2nd yr	152bc	150c	173abc	186a	180ab	191a	172	10
No. of secondary branches per plant (no.)	1st yr	4.3a	3.4b	3.4b	4.4a	4.5a	4.4a	4.1	11.9
	2nd yr	6.4a	4.0c	4.5bc	5.3abc	5.8ab	5.6abc	5.3	19.2
No. of tertiary branches per plant (no.)	1st yr	2.2a	1.7a	1.5a	1.5a	1.7a	2.74a	1.8	54.8
	2nd yr	5.4a	1.8b	1.8b	5.6a	2.6ab	3.6ab	3.4	56.9
No. of inflorescences per plant (no.)	1st yr	16a	6b	6b	10b	8b	87b	9	23.5
	2nd yr	59a	27de	23e	37b	30dc	33bc	35	9.8
	average	38a	17de	15e	24b	19dc	21bc	22	9.4
No. of fruits per plant (no.)	1st yr	26a	10b	11b	14b	14b	16b	15	31.9
	2nd yr	214a	95cd	70d	136b	101c	108c	121	13.8
	average	120a	52dc	41d	75b	58c	62c	68	12.2
No. of seeds per plant (no.)	1st yr	70a	30c	32bc	45bc	47b	45bc	45	22.7
	2nd yr	601a	285bc	201c	377b	289bc	302bc	343	21.7
	average	335a	158bc	116c	211b	168bc	174bc	194	19.1
Seed yield per plant (g)	1st yr	46a	22c	24bc	31bc	35ab	34b	32	23.1
	2nd yr	399a	209bc	153c	262b	216bc	230bc	245	23.5
	average	222a	115bc	89c	146b	126bc	132bc	138	21.1
Seed yield per hectare (kg)	1st yr	116a	55c	61bc	79bc	89ab	86b	81	23
	2nd yr	997a	522bc	384c	655b	542bc	575bc	613	23.5
	average	556a	289bc	223c	367b	315bc	330bc	347	21
Seed oil content (%)	1st yr	29.1c	29.9bc	31.2ab	31.7a	31.0ab	30.8ab	30.6	2.7
	2nd yr	30.6c	31.5bc	32.8ab	33.4a	32.7ab	32.5ab	32.3	2.7
	average	29.9c	30.8bc	32.0ab	32.6a	31.8ab	31.6ab	31.5	2.7
Seed oil yield per plant (g)	1st yr	13.5a	6.7c	7.7bc	10.0abc	11.0ab	10.5ab	9.91	22.1
	2nd yr	122.5a	65.9bc	50.6c	87.3b	70.1bc	74.2bc	78.45	23.6
	average	67.9a	36.3bc	29.2c	48.6b	40.5bc	42.4bc	44.18	21.3
Seed oil yield per hectare (kg)	1st yr	33a	16c	19bc	25abc	27ab	26ab	24	22.1
	2nd yr	306a	164bc	126c	218b	175bc	185bc	196	23.6
	average	169a	90bc	72c	121b	101bc	105bc	110	21.3

Means with the same letter in the same row are not significantly different by Duncan New Multiple Range Test (DNMRT); My1 = Malaysia1; My2 = Malaysia2; In1 = Indonesia1; In2 = Indonesia2; Id1 = India1; Ph1 = Philippines1

ing (9.8%) and average year harvesting (9.4%) years. This indicates that the samples had values closer to the population mean for characteristics with low CV (Table 1). Results of analysis of variance (ANOVA) on day to flowering, number of inflorescences per plant and number of seed per plant indicated highly significant variation among populations for first year harvesting, second year harvesting and average year harvesting (Table 2).

Seed yield per plant was highest in Indonesia1 which recorded 46, 399 and 222 (g) for first, second and average year harvesting respectively and was closely followed by Philippines with values of 35 (g) for first year and Malaysia2 with values of 262 and 146 (g) for second and average year harvesting respectively. Minimum seed yield per plant was seen in Indonesia2 (22 g) for first year and Malaysia1 for second (153 g) and average year harvesting (89 g) (Table 1).

For seed yield per hectare the top ranking population was Indonesia1 for first (116.32 kg ha⁻¹), second (997.60 kg ha⁻¹) and average (556.95 kg ha⁻¹) year. The top ranking population differed significantly with all the remaining populations. Minimum seed yield per hectare was recorded in Indonesia2 (55.63 kg

ha⁻¹) for first year and Malaysia1 for second (384.60 kg ha⁻¹) and average (223.28 kg ha⁻¹) year harvesting (Table 1).

With attention to oil content percentage it was revealed that Malaysia2 with values of 31% for first year, 33% for second year and 32% for average year had maximum oil content percentage and was closely followed by Malaysia1 with values of 31.20% for first year, 32.85% for second year and 32% for average year harvesting. Minimum oil content percentage was seen in Indonesia1 for first year (29%), for second year (30%) and average year (29%) (Table 1).

Seed oil yield per plant was highest in Indonesia1 for first year of harvesting (13 g), second year of harvesting (122 g) and average year of harvesting (67 g). The top ranking population differed significantly with all the remaining populations. Minimum seed oil yield per plant was recorded in Indonesia2 (6 g) for first year of harvesting and Malaysia1 for second year (50 g) and average year of harvesting (29 g) (Table 1).

Seed oil yield per hectare was highest in Indonesia1 for first of harvesting (33 kg), second of harvesting (306 kg) and average year of harvesting (169 kg). The top ranking population differed significantly with all the remaining populations. Minimum seed oil yield

Table 2 - Mean squares of analysis of variance (ANOVA) for all studies traits of *Jatropha* populations.

Degree of freedom (d.f.) Characters		Source of variation		
		Blocks (B) 3	Populations (G) 5	Error 15
Seed length	1st yr	0.01 ^{ns}	2.41*	0.68
Seed width	1st yr	0.01 ^{ns}	0.19**	0.024
Seed weight	1st yr	0.001 ^{ns}	0.016*	0.005
100 Seed weight	1st yr	5.45 ^{ns}	63.48**	4.34
Day to flowering	1st yr	571.7*	720.98*	252.58
Plant height	1st yr	476.99*	402.07*	107.19
	2nd yr	332.03 ^{ns}	1,192.92*	297.81
No. of secondary branches per plant	1st yr	0.29 ^{ns}	1.09**	0.24
	2nd yr	3.11 ^{ns}	3.09*	1.03
No. of tertiary branches per plant	1st yr	1.50*	0.63 ^{ns}	1.03
	2nd yr	37.76**	12.78*	3.81
No. of inflorescences per plant	1st yr	58.76**	54.44**	5.32
	2nd yr	304.56**	639.31**	12.08
	average	147.37**	265.56**	4.59
No. of fruits per plant	1st yr	109.59 ^{ns}	135.34**	24.29
	2nd yr	3,144.77**	10,196.52**	281.13
	average	1,058.44 ^{ns}	3,132.00**	70.4
No. of seeds per plant	1st yr	436.05	834.56**	106.32
	2nd yr	18,412.34*	76,476.39**	5,560.02
	average	5970.31*	22,987.01**	1,386.02
Seed yield per plant	1st yr	202.29*	300.94**	56.46
	2nd yr	9,603.56 ns	27,696.20**	3,321.02
	average	3,068.52*	8,240.01**	857.88
Seed yield per hectare	1st yr	1,264.2	1,880.54**	352.86
	2nd yr	60,021.32 ns	173,104.93**	311,353
	average	19,177.56*	51,500.12**	5,361.66

n.s , *, and **: non-significant, significant at the 0.05 level, and significant at the 0.01 level respectively

per hectare was recorded in Indonesia² (16 kg) for first year of harvesting and Malaysia¹ for second year of harvesting (164 kg) and average year of harvesting (90 kg) (Table 1).

Results showed high coefficients of variation in seed yield for first year of harvesting (23.0%), second year of harvesting (23.5%) and average year of harvesting (21.1%) and seed oil yield for first year of harvesting (22.1%), second year of harvesting (23.6%) and average year of harvesting (21.3%). This indicates that there was a large difference between the maximum and minimum values achieved for these characteristics. While coefficient of variation for oil content were low in first year of harvesting (2.7%), second year of harvesting (2.7%) and average year of harvesting (2.7%) (Table 1).

Results of analysis of variance (ANOVA) among six *Jatropha* populations for seed yield per plant, seed yield per hectare, oil content percentage, seed oil yield per plant and seed oil yield per hectare indicated highly significant ($P \leq 0.01$) variation among populations for first, second and average year of harvesting (Table 2).

Correlation between characters

Phenotype correlation coefficients between important characters are given in Table 3. Phenotypic

correlations between seed yield per plant were found to be positively and highly significant with number of inflorescences (0.85), number of fruits per plant (0.87), number of seeds per plant (0.83), seed yield per hectare (0.82), seed oil yield per plant (0.82), seed oil yield per hectare (0.85) at 0.01 probability levels. Also correlation between seed yield per plant were found to be positively and significant with plant height (0.48) and day to flowering (0.40) at 0.05 probability levels. Seed yield per plant were significantly negative correlated with seed oil content (-0.59) at 0.01 probability levels (Table 3). Seed oil content showed high significant negative correlation ($P \leq 0.01$) with seed number of inflorescences (-0.53), number of fruits per plant (-0.55) and number of seeds per plant (-0.52).

Number of inflorescences per plant were significant positively correlated with number of second branches (0.41) at 0.05 probability level and day to flowering (0.55), number of fruits per plant (0.89), number of seeds per plant (0.83), seed oil yield per plant (0.73) and seed oil yield per hectare (0.77) at 0.01 probability levels. While number of inflorescences per plant was significantly negatively correlated with 100 seed weight at 0.01 probability levels (Table 3).

Also there were significant positive correlations of

Table 3 - Correlation coefficients among important quantitative morphological traits of *J. curcas*.

No.	Trait	2	3	4	5	6	7	8	9	10	11	12	13
1	Plant height	0.43*	0.21 ^{ns}	-0.01 ^{ns}	-0.31 ^{ns}	0.34 ^{ns}	0.32 ^{ns}	0.13 ^{ns}	0.48*	0.42*	-0.16 ^{ns}	0.42*	0.41*
2	No. of second branches		0.15 ^{ns}	0.46*	-0.41*	0.32 ^{ns}	0.38 ^{ns}	-0.29 ^{ns}	0.24 ^{ns}	0.40*	0.02 ^{ns}	0.40*	0.38 ^{ns}
3	No. of third branches			0.56**	0.30 ^{ns}	0.44*	0.25 ^{ns}	-0.02 ^{ns}	0.36 ^{ns}	0.21 ^{ns}	-0.15 ^{ns}	0.21 ^{ns}	0.23 ^{ns}
4	Day to flowering				0.60**	0.55**	0.44*	0.46*	0.40*	-0.36 ^{ns}	-0.24 ^{ns}	-0.33 ^{ns}	-0.33 ^{ns}
5	No. of Inflorescences					0.89**	0.83**	-0.61**	0.85**	0.73**	-0.53**	0.73**	0.77**
6	No. of fruits per plant						0.93**	-0.50**	0.87**	0.90**	-0.55**	0.86**	0.86**
7	No. of seeds per plant							-0.50**	0.83**	0.98**	-0.52**	0.96**	0.96**
8	100-Seed weight								-0.24 ^{ns}	-0.32 ^{ns}	0.29 ^{ns}	-0.32 ^{ns}	-0.35 ^{ns}
9	Seed yield per plant									0.82**	-0.59**	0.82*	0.85**
10	Seed yield per hectare										-0.48*	0.99**	0.99**
11	Seed oil content											-0.38 ^{ns}	-0.38 ^{ns}
12	Seed oil yield per plant												0.99**
13	Seed oil yield per hectare												

n.s. non significant. **. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

number of fruits per plant with day to flowering and, numbers of seed per plant, seed oil yield per plant, seed oil yield per hectare at 0.01 probability levels. While negative values of correlation coefficient were obtained between numbers of fruits per plant with 100 seed weight at 0.01 probability levels (Table 3). Days to flowering had positive correlation with number of secondary branches (0.46) at 0.05 probability levels and number of tertiary branches (0.56) at 0.01 probability levels (Table 3).

Cluster analysis

Cluster analysis based on standardized agro-morphological data, divided populations of *Jatropha* into three clusters through non-hierarchical clustering. Cluster analysis grouped populations together with greater genetic dissimilarity. Also, the clusters did not necessarily contain all populations from same origin (Figure 1).

Cluster I, II, III consisted of one, two and three populations respectively (Table 4). The cluster mean values of morphological traits are presented in Table 11. The cluster I consists of The highest characters including number of secondary branches, number of tertiary branches, number of fruits per plant, number of seeds per plant, seed yield per plant, seed yield per hectare, seed oil yield per plant and seed oil yield per hectare. While cluster I consisted of lowest plant height and seed oil content.

The lowest value for all trait observed in cluster II (Table 5). The cluster III consisted of the highest traits containing plant height and seed oil content. Also, cluster III possessed populations with the aver-

age cluster mean for number of secondary branches, number of tertiary branches, number of fruits per plant, number of seed per plant, seed yield per plant, seed yield per hectare, seed oil yield per plant and seed oil yield per hectare.

Discussion

Results of analysis of variance (ANOVA) on seed characteristics indicate significant variation among populations and low coefficients of variation for seed characters. This indicates that there was a low difference between the minimum and maximum values obtained for these characteristics. Also, the seed samples had values closer to the population mean for seed characteristics.

Seed sources variation in *Jatropha* with regards to their morphological characters could be because of fact that the species grows over a wide range of temperature, rainfall and soil type. Also, variations in relation to habitat have also been reported in a number of tree species. Various seed sources, provenances and ecotypes of *Jatropha curcas* presented variation in seed morphological traits by Kaushik et al (2007). Therefore, results of this study had same trend with Rao et al (2008) and Ginwal et al (2004) that reported phenotypic variation in seed characters.

Significant variation observed among the populations for plant height, number of secondary branches. Our result had same trend with Rao et al (2008), Ginwal et al (2005), and Rafii et al (2012b). Plant height, number of secondary branches and number of tertiary branches are important traits that could be considered as major selection index. From the other point of view the variation observed in reproductive characters can be applicable in selecting *Jatropha* plant types for block plantations with high yield as the initial objective. Number of branches are very important in *Jatropha* because inflorescences are terminally so for more yield must increase number of branches in plant.

There were high significant variations among the

Table 4 - *Jatropha curcas* population groupings revealed by cluster analysis

Cluster	No. of populations	Population names
I	1	Indonesia1
II	2	Indonesia2 - Malaysia1
III	3	Malaysia2 – Philippines - India

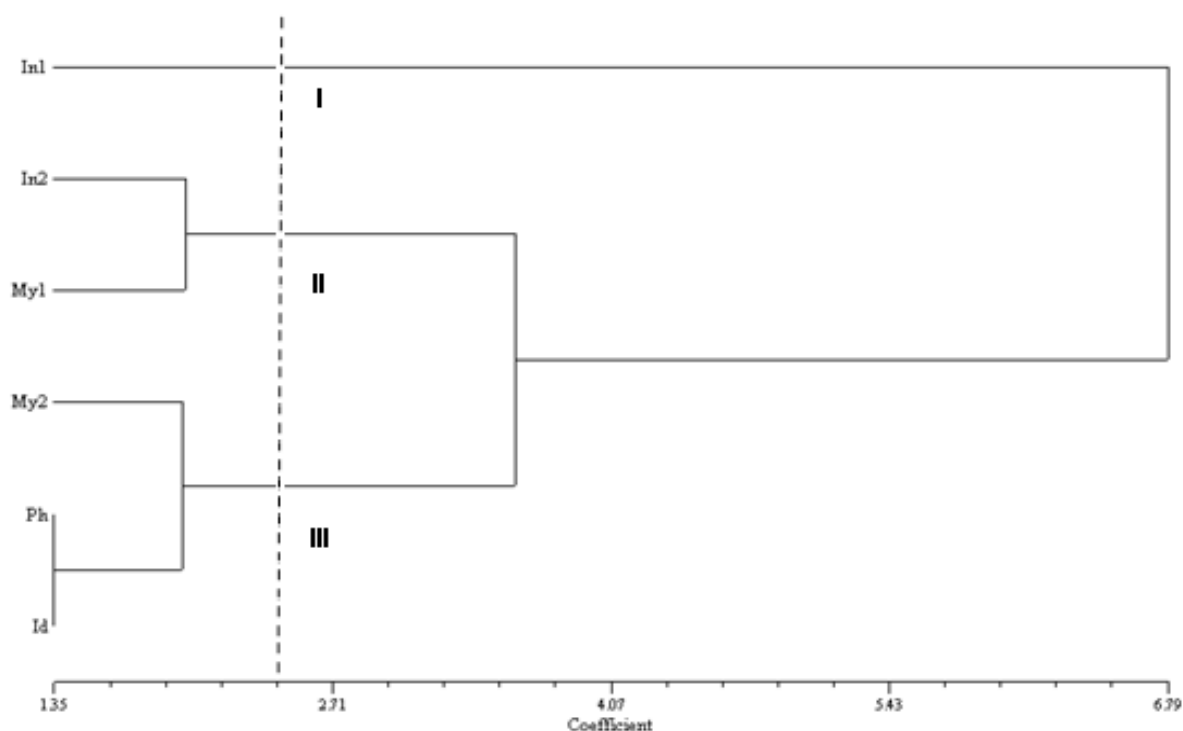


Figure 1 - The dendrogram of morphological traits derived from six *J. curcas* populations constructed using the UPGMA method.

populations with regard to the yield and yield components and results of analysis of variance (ANOVA) on these traits indicated highly significant variation among populations for first, second and average year of harvesting. Phenotypic variations recognized by Ghosh and Singh (2011), Kaushik et al (2007), and Rao et al (2008) in seed length, seed width, 100-seed weight, and oil content seed yield, oil content percentage, seed oil yield among *J. curcas* populations. Hence, results of this study had similar trend with previous findings.

Among populations were highly significant for most of the traits measured. This exhibits that there were major differences in the morphological traits measured on the *Jatropha* populations. The ANOVA results conform to the range of variations in morphological traits measured. Seed yield showed significant correlation with number of secondary branches, number of Inflorescences, number of fruits per plant and number of seeds per plant. Rao et al (2008) reported that seed yield per plant was moderately correlated with the number of branches. Also, seed yield had low correlation with the plant height and number of flowers. Saikia et al (2009) found that the 100 seed weight had higher significant positive relationship with number of branches and plant height, but our result was disagreeing with them.

In the present study, *Jatropha curcas* populations divided into three clusters through non-hierarchical clustering. Kaushik et al (2007) obtained six clusters among 24 accessions and suggested that the crossing between accessions of clusters IV and VI will

result in wide spectrum of variability in subsequent generations. Nine genotypes collected from the semi-arid region of India were grouped into five clusters by Gohil and Pandya (2008); also Rao et al (2008) observed four clusters among 32 high yielding candidate plus trees of *J. curcas* for seed traits.

Conclusions

In this study, highly significant genotypic differences were obtained among the *Jatropha* populations for various traits measured. The relative large variations were observed for the traits except number of tertiary branches in first year of harvesting. The variation was large enough to suggest that six *Jatropha* populations could present appropriate genotypes to be used in intensive breeding programs.

In the present study, number of Inflorescences, number of fruits per plant, number of seeds per plant, and plant height characters studied presented highly positive correlation with seed yield per plant. It can be concluded that selection should be in positive side for these traits studied which in turn automatically raise the seed yield in *Jatropha curcas*. While, seed oil content presented highly negative correlation with seed yield per plant. It can be concluded that selection should be in negative side for this trait.

It is supposed that maximum heterosis is proved in cross combinations including the populations belonging to most divergent clusters. However, for an applicable plant breeder, the objective is not only high heterosis but also to obtain high level of production. In the present research, the maximum distance existed between cluster I and II and cluster I and III.

Table 5 - Cluster mean values for morphological characters in six *Jatropha* populations

Trait	Cluster		
	I	II	III
Plant height (cm)	144.68	148.73	169.33
N° of second branches per plant (n°)	5.41	3.85	5.00
N° of third branches per plant (n°)	3.85	1.64	2.91
N° of inflorescences per plant(n°)	38.01	16.31	21.72
N° of fruits per plant(n°)	120.60	46.84	65.39
N° of seed per plant (n°)	335.99	137.48	184.91
Seed yield per plant (g)	222.78	102.51	135.15
Seed yield per hectare (kg ha ⁻¹)	556.95	256.26	337.87
Oil seed content (%)	29.87	31.40	32.02
Oil seed yield per plant (g)	67.99	32.74	43.87
Oil seed yield per hectare (kg ha ⁻¹)	169.97	81.85	109.68

Considering the yield and growth duration cluster I and II present high heterosis for yield as well as earliness whereas cluster I and III exhibit maximum heterosis for yield as well as plant height.

Acknowledgements

The authors are grateful to the authority of Univesiti Putra Malaysia for supporting this research project.

References

- Achten W, Nielsen L, Aerts R, Lengkeek A, Kjær E, Trabucco A, Hansen J, Maes W, Graudal L, Akinifesi F, 2010. Towards domestication of *Jatropha curcas*. *Biofuels* 1: 91-107
- Achten W, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B, 2008. *Jatropha* bio-diesel production and use. *Biomass and Bioenergy* 32: 1063-1084
- Arolu IW, Rafii MY, Hanafi MM, Mahmud TMM, Latif MA, 2012. Molecular characterization of *Jatropha curcas* germplasm using inter simple sequence repeat (ISSR) markers in Peninsular Malaysia. *Aust J Crop Sci* 6: 1666-1673
- Cai Y, Sun D, Wu G, Peng J, 2010. ISSR-based genetic diversity of *Jatropha curcas* germplasm in China. *Biomass and Bioenergy* 34: 1739-1750
- Divakara B, Upadhyaya H, Wani S, Gowda C, 2010. Biology and genetic improvement of *Jatropha curcas* L: a review. *Applied Energy* 87: 732-742
- Fangrui M, Milford AH, 1999. Biodiesel production: a review. *Bioresource Technol* 70: 1-15
- Franco J, Crossa J, Ribaut J, Bertran J, Warburton M, Khairallah M, 2001. A method for combining molecular markers and phenotypic attributes for classifying plant genotypes. *Theor App Genet* 103: 944-952
- Ganesh Ram S, Parthiban K, Senthil Kumar R, Thiruvengadam V, Paramathma M, 2008. Genetic diversity among *Jatropha* species as revealed by RAPD markers. *Genet Resour Crop Ev* 55: 803-809
- Ghosh L, Singh L, 2011. Variation in seed and seedling characters of *Jatropha curcas* L with varying zones and provenances. *Trop Ecol* 52: 113-122
- Ginwal H, Phartyal S, Rawat P, Srivastava R, 2005. Seed source variation in morphology, germination and seedling growth of *Jatropha curcas* L in central India. *Silvae Genetica* 54: 76-79
- Ginwal H, Rawat P, Srivastava R, 2004. Seed source variation in growth performance and oil yield of *Jatropha curcas* L in central India. *Silvae Genetica* 53: 186-191
- Gohil R, Pandya J, 2008. Genetic diversity assessment in physic nut (*Jatropha curcas* L). *Int J Plant Prod* 2: 321-326
- Gohil R, Pandya J, 2009. Genetic evaluation of *Jatropha* (*Jatropha curcas* L) genotypes. *J Agric Res* 47: 221-228.
- Kaushik N, Kumar K, Kumar S, Roy S, 2007. Genetic variability and divergence studies in seed traits and oil content of *Jatropha* (*Jatropha curcas* L) accessions. *Biomass and Bioenergy* 31: 497-502
- King A, He W, Cuevas J, Freudenberger M, Ramiaranana D, Graham I, 2009. Potential of *Jatropha curcas* as a source of renewable oil and animal feed. *J Exp Bot* 60: 2897-2905
- Kumar A, Sharma S, 2008. An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L): A review. *Industrial crops and products* 28: 1-10
- Ovando I, Espinosa-García F, Núñez-Farfán J, Salvador-Figueroa M, 2011. State of the art of genetic diversity research in *Jatropha* curcas. *Scientific Research and Essays* 6: 1709-1719
- Rafii MY, Shabanimofrad M, Puteri Edaroyati MW, Latif MA, 2012a. Analysis of the genetic diversity of physic nut, *Jatropha curcas* L accessions using RAPD markers. *Mol Biol Rep* 39: 6505-6511
- Rafii MY, Arolu IW, Omar MHA, Latif MA, 2012b. Genetic variation and heritability estimation in *Jatropha curcas* L population for seed yield and vegetative traits. *J Med Plants Res* 6: 2178-2183
- Rao G, Korwar G, Shanker A, Ramakrishna Y, 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
- Saikia S, Bhau B, Rabha A, Dutta S, Choudhari R, Chetia M, Mishra B, Kanjilal P, 2009. Study of accession source variation in morpho-physiological parameters and growth performance of *Jatropha curcas* L. Current Sci 96: 1631-1636
- Shabanimofrad M, Yusop MR, Saad MS, Megat PE, Wahab AB, Latif MA, 2011. Diversity of physic nut (*Jatropha curcas*) in Malaysia: application of DIVA-geographic information system and cluster analysis. Aust J Crop Sci 5: 361-368
- Shabanimofrad M, Rafii MY, Megat Wahab PE, Biabani AR, Latif MA, 2013. Phenotypic, genotypic and genetic divergence found in 48 newly collected Malaysian accessions of *Jatropha curcas* L. Ind Crop Prod 42: 543-551
- Sharama S, Kumar N, Reddy MP, 2011. Regeneration in *Jatropha curcas*: Factors affecting the efficiency of in vitro regeneration. Ind Crop Prod 34: 943-951
- Shuit S, Lee K, Kamaruddin A, Yusup S, 2010. Reactive extraction and in situ esterification of *Jatropha curcas* L seeds for the production of biodiesel. Fuel 89: 527-530
- Sujatha M, Reddy TP, Mahasi M, 2008. Role of biotechnological interventions in the improvement of castor (*Ricinus communis* L) and *Jatropha curcas* L. Biotechnology Adv 26: 424-435
- Sukarin W, Yamada Y, Sakaguchi S, 1987. Characteristics of physic nut, *Jatropha curcas* L as a new biomass crop in the Tropics. Japanese Agricultural Research Quarterly 20: 302-303
- Sun Q, Li L, Li Y, Wu G, Ge X, 2008. SSR and AFLP markers reveal low genetic diversity in the bio-fuel plant *Jatropha curcas* in China. Crop Sci 48: 1865-1871