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

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## 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 interaction 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


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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 Indonasia1 for first year (26 fruits), second year (214 fruits) and average year (120 fruits). Also, the lowest number of fruits were recorded in Indonasia2 (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 (601seeds) 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 (201seeds) 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 Indonasia1 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 Indonesia1for first year (29%), for second year (30%) and average year (29%) (Table 1).

Seed oil yield per plant was highest in Indonasia1 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 Indonasia1 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.

| | | Source of variation | | |
|---|---|---|---|---|
| | | Blocks (B) | Populations (G) | Error |
| Degree of freedom (d.f.) | | 3 | 5 | 15 |
| Characters | | | | |
| 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 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 average 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.

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 |

## 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

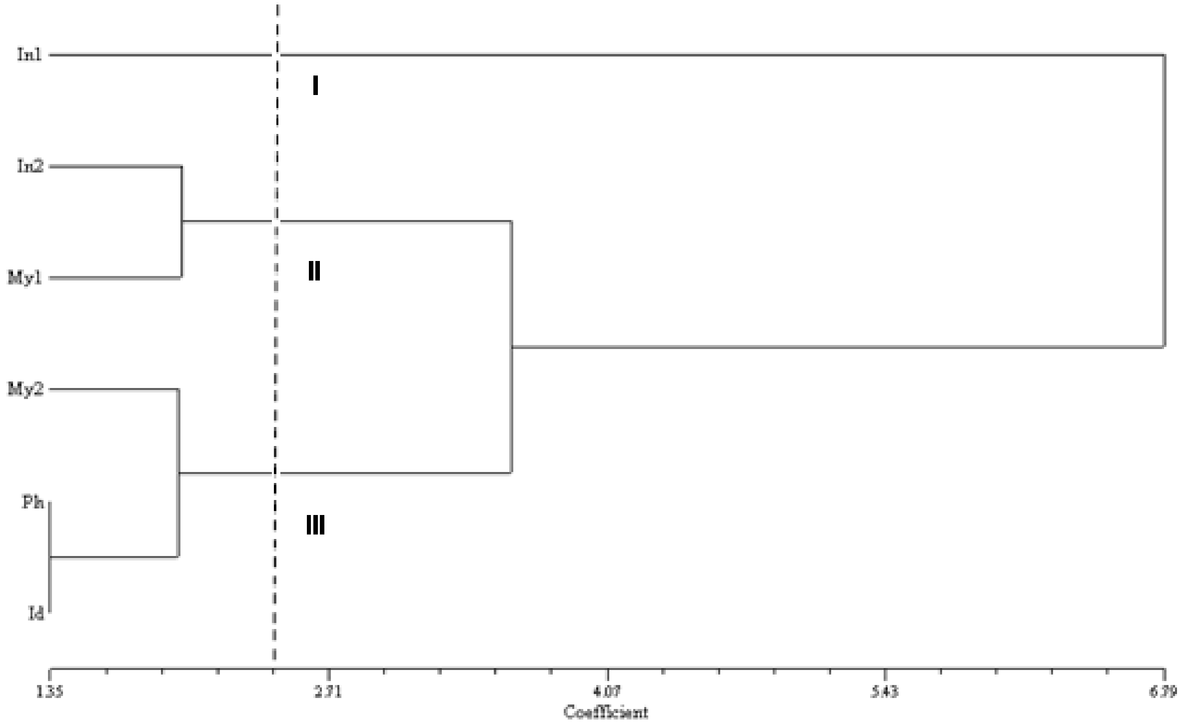


Figure 1 - The dendrogram of morphological traits derived from six *J. curcas* populations constructed using the UPGMA method.

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 | Cluster II | Cluster 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.

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## References

Achten W, Nielsen L, Aerts R, Lengkeek A, Kjær E, Trabucco A, Hansen J, Maes W, Graudal L, Akinnifesi 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 Bioenerg 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 Bioenerg 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 Bioenerg 31: 497-502

King A, He W, Cuevas J, Freudenberger M, Ramiaramanana 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 biofuel plant *Jatropha curcas* in China. Crop Sci 48: 1865-1871