Electronic Journal of Plant Breeding, 6(3): 813-825 (Sep 2015)
ISSN 0975-928X

Research Article

Dynamics of flowering and fruiting in *jatropha curcas* l. and its implications

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(Received: 23 March 2015 ; Accepted: 10 June 2015)

Abstract
Low fruit yield is a major constraint in *Jatropha curcas* plantations in South India.The variations in flowering and fruiting characters across years was studied in a three year old Jatropha plantation. The relationship among the characters and their stability revealed existence of significant genetic differences among different phenotypes. The reproductive success was high as evidenced by the high correlation between female flowers and fruit set. It also suggested that *J. curcas* displays phenomenon of alternate bearing. The limitation of low count of female flowers needs to be tackled by adoption of silvicultural practices to enhance female flower production per plant. The study suggests need to understand the planting material selected for breeding and crossing programmes should aim at increasing yield.

Key words: Jatropha, curcas, phenology, flowering, fruiting, variability, stability

Introduction

Productivity in oilseeds is directly correlated to flowering and fruiting. According to Schmidt (2000) flowering designates the period from opening of flower buds to setting of fruits which is referred as 'anthesis' and fruiting is the period from the end of flowering to shedding of mature fruits . Owing to high kernel oil content ranging between 30-35%, *Jatropha curcas* is one of the most promoted tree borne oilseed (Yang *et al.*, 2009) across the globe. In India, *Jatropha curcas* L, has been prioritised as a promising Tree Borne Oilseed (TBO) for biofuel production by the National Oilseeds and Vegetable Oils Development (NOVOD) Board and has identified fruiting, as one of the major constraints limiting collection and utilization of Jatropha. FAO (2010) has suggested increasing the ratio of pistillate (female) flowers per inflorescence to staminate (male) flowers, inorder to improve the potential for fruit formation and increase the number of branches, flowers, fruits and seeds in its recommendations for *J. curcas* breeding.

Jatropha is mainly cultivated for seeds. The seed production is affected by factors like growing environment, the genotype and their interaction. The quantity of flowers and fruits produced varies across different phenotypes and years. It is a monoecious plant possessing both male and female flowers separately (Raju and Ezradanam, 2002). Formation of female flowers in a season directly affects the fruit production of a phenotype. Studies on the number of male and female flower production, relationship between these floral traits and stability of these traits across different years can improve the scope of the seed production in Jatropha. This study discusses the flowering and fruiting studies conducted in a three year old *J. curcas* plantation.

Materials and Methods

A three year old plantation raised at Anaikatti (10° 30' N; 77° 15' E), in Tamil Nadu, India using rooted stem cuttings of *Jatropha curcas* was used for the study. These phenotypes represented the plants selected in areas such as Attapady, Sathyamangalam and Coimbatore. Anaikatti was chosen for the study as the climatic conditions of this locality is suitable for Jatropha cultivation. The experimental site was situated at an elevation of 450 msl and had lateritic type of soil. The mean annual temperature was in the range of 25-30 °C receiving an annual mean rainfall of 600 mm. There were seventeen different phenotypes planted in three replications each with three ramets planted in randomized block design. The study was initiated when the trial was three years old since 2006 and continued for three consecutive years upto 2008 for observing flowering and fruiting phenology. Every year during the peak flowering and fruiting season (May to August) observations were recorded on flowering and fruiting and the vegetative characters. The details of the phenotypes are as follows,

Phenotype	Accession number
1	Att/IFGTB-1
2	Att/IFGTB-2
3	Att/IFGTB-3
4	Att/IFGTB-4

5	Att/IFGTB-5
6	Att/IFGTB-6
7	Sathy/IFGTB-1
8	Sathy/IFGTB-2
9	Sathy/IFGTB-4
10	Sathy/IFGTB-8
11	Sathy/IFGTB-10
12	Sathy/IFGTB-12
13	Coimbatore/IFGTB-2
14	Coimbatore/IFGTB-5
15	Coimbatore/IFGTB-7
16	Coimbatore/IFGTB-9
17	Coimbatore/IFGTB-10

a) Flowering:
During the peak of flowering period (May - June), the number of inflorescence present in a plant was counted. The inflorescences in each individual were tagged just before their emergence. All the inflorescence in the plant was observed and the total number of buds, flowers per inflorescence, number of female and male flowers per inflorescence and estimated the male to female ratio for three consecutive years.

b) Fruiting:
During the peak fruiting period (July – August), the total number of fruits present in the entire plant was counted and average fruit per inflorescence was calculated. Within an inflorescence based on the total number of flowers and total number of fruits finally produced calculated the fruiting percentage and fruiting success percentage.

c) Vegetative growth:
The vegetative growth of the plants were also assessed during three consecutive years for the parameters such as such as plant height (m), collar diameter (mm) and number of branches.

d) Statistical analysis:
A separate Two-way ANOVA was performed to determine the significant differences in flower and fruit characters between phenotypes across different years. Prior to statistical analyses, the percentage data were arcsine transformed to meet the normality assumption for the analysis of variance (Zar, 2010). The genotype mean of different years were analysed to find correlations with fruiting yield. Simple correlation coefficients were worked out based on Pearson method using SPSS 16.0. The data collected in the three different years were subjected for G x E interaction analysis to identify the stability of phenotypes in varied environments.

Results and Discussion

Flower production:
The number of inflorescence produced varied from 1.00 to 7.33 per plant over the three years of study period. The phenotype 9 showed consistently profuse inflorescence production across all the three years. The phenotypes 2, 3, 7 and 12 did not exhibit significant change in the number of inflorescence production over the years (Table 1). The number of flowers per inflorescence varied from 4.67 to 239.33. The flowering was profuse during 2006 (90.53) followed by poor flowering (65.22) during 2007. Across the years, the flowering in certain phenotypes like 4, 5, 9, 10 and 17 were observed to be above the average (76.25), while certain other phenotypes like 2, 6, 7 and 12 showed poor flower production across the years. Some of the phenotypes flowered profusely, producing as high as 239.33 flowers per inflorescence and average production of 1273 flowers per plant. Poor flowering was observed in few phenotypes with about 4.67 flowers per inflorescence. Among the 17 phenotypes studied, both abundant and poor flowering phenotypes were observed in equal numbers across different years, while many were average or inconsistent in flower production.

The average flower production and the average male and female flower production across different years were observed to have a peak after every alternate year. Similar alternate bearing have been observed in many fruit trees like ‘Haden’ Mango cultivar in Mexico (Nunez- Elisea, 1984) and Olive (Bustan *et al*., 2011). In Olive, alternate bearing is reported to be a built-in character and it varies with environmental conditions which are the main trigger to induce changes in metabolic pathways leading to alternate bearing (Lavee, 2007). Inspite of this fact, the production of number of inflorescence per plant was observed to be increasing with the age of the plants. Similar study in Jatropha conducted at Gujarat, in about 23 selected provenances, showed as high as 847 and 1383 flowers per plant in two successive years (Prakash *et al.,* 2007).

South West monsoon period in the study area generally extends from May to July which coincided with the phenological studies conducted. During the first year of study, 2006, there was a delay in onset of showers recording a rainfall (South West monsoon) of 141.4 mm (below normal) while in 2007 the rains were timely and was 197.5 mm (normal). Stress is generally known to induce more flowering as reported by Southwick and Davenport (1986) in Citrus where both continuous and cyclical water-stress treatment induced flowering. Similarly, it can be construed that prolonged stress followed by rains could have resulted in increased flowering during the first year unlike the second year which had a shorter spell of stress. It has been reported that flowering and fruit set are very sensitive to water deficits (Moriana *et al.*, 2003).

Proportion of male and female flowers:

There is an apparent year to year variation with respect to female flower production. The average number of female flowers during 2006 was 4.86 and the same was significantly reduced to 1.43 during 2007 and again increased to 3.61 during 2008 (Table 2). The female flower production was also observed to be highly varying across different phenotypes. It varied from nil female flowers to as high as 13.33 per inflorescence. The phenotypes 5, 9, 10 and 17 showed significantly high female flower production while it was not significantly varying in phenotype 1, 6, 15 and 16. The phenotypes 8 and 12 did not produce any female flowers during all the three observation years. The average number of male flowers per inflorescence was 73.12. The production of male flowers was altered in different years from 86.00 during 2006 to 63.98 during 2007 and again increased to 69.38 during 2008. Certain phenotypes like 4, 5, 9 and 10 produced more male flowers than others phenotypes viz., 1, 2, 3, 6, 7, 8, 11, 12, 13 and 15. A ratio of 27.22:1 was recorded for male: female flowers. The phenotypes 2, 6, 7 and 10 produced relatively few number of male flowers (less than 20) when compared to other phenotypes like 4 and 16 which produced more than 40 male flowers per female flower. The phenotypes 2, 4, 9 and 17 produced 3 to 8 times more male flowers during 2007.The average female flower production per inflorescence was observed to be 4.17%. The average female flower production in phenotypes 6 and 9 were high across different years, except the poor flowering year of 2007. The average female flower percentage was less than the mean in phenotypes 1, 4, 5, 13, 14, 15 and 16. At the same time phenotypes 8 and 12 did not produce any female flowers.

Jatropha is monoecious carrying fewer female than male flowers on the apex of the inflorescence, with numerous males borne on the lower side. On an average about 3.3 female flowers was recorded in the present study while Das *et al.* (2010) recoded about 9.32 female flowers per bunch. However, Raju and Ezradanum (2002) observed 1-5 female flowers per inflorescence. It was clear that in certain phenotypes like 6 and 17, the female flowers per inflorescence (3-5 flowers) and fruits per plant (8-23 fruits) were more stable across different years. Certain phenotypes like 5, 9 and 10 produced more female flowers per inflorescence (1-13 flowers) and fruits per plant (5-73) with high variability across the years. This trend reveals that the tendency of alternate fruit bearing is more prominent in high yielders. Hence selection of phenotypes could be made considering fruit yielding capacity across the years. Importance could be given to selection of high yielders (like 5, 9 and 10) as well as stable phenotypes with moderate fruit yielding capacity (like 6 and 17).

The genetic influence on reproductive characters were high as reported by Das *et al.* (2010), as shown by high heritability (78.6%) and genetic gain (27%) for female flower per bunch and selection would be effective for female flowers per bunch and fruit per plant. Association and path analysis also revealed the selection for flowering bunches/plant and fruits/plant would be highly effective in bringing out improvement in yield (Das *et al.*, 2010). Studies by Rao *et al.* (2008) in *J. curcas*, reported female to male flower ratio near to 100% heritability followed by yield (83.61) and plant height (87.73). In this study, the average male to female flower ratio was 27:1 within an inflorescence. It varied from 19 to 103 between different phenotypes. Similar observation was recorded by Raju and Ezradanum, (2002) in Jatropha with average male to female flower ratio of 29:1 with a range of 25-93 male flowers per female flower. Further it is also reported that the male-to-female flower ratio declines as the plant ages (Achten *et al.*, 2008), suggesting that fruiting capacity may increase with age.

During 2007, the average flower per inflorescence was reduced from 90.33 to 65.22 and at the same time the male to female flower ratio was increased from 17.7 to 44.7. The increase in the male: female flower ratio is due to reduction in female flower production during 2007. Similar observations made in Jatropha provenances showed that the ratio of male to female flower was 24.7:1 when the flowering was poor and it was reduced to 13.2:1 when the general flowering was profuse (Prakash *et al.*, 2007). Hence it is understood that female flower production is more sensitive than male flowers.

It is reported that the ratio of male to female flower averages to 29:1 but this is highly variable and may range from 25-93 male flowers to 1-5 female flowers produced on each inflorescence (Raju and Ezradanum, 2002). The unisexual flowers of Jatropha depend on pollination by insects, including bees, flies, ants and thrips and fruit set generally results from cross pollination with other individual plants, as the male flowers shed pollen before the female flowers on the same plant become receptive. But in the absence of pollen arriving from other plants, Jatropha has the ability to self pollinate, a mechanism to facilitate colonization of new habitats (Raju and Ezradanum, 2002).

Fruit production:
The average number of fruits per inflorescence was 2.59, however, the same was as high as 3.53 during 2006. Significantly low fruiting was observed during 2007 producing only 1.37 fruits per inflorescence. The fruit production was more than the average in phenotypes viz., 5, 6, 9 and 10 across all the years. The phenotypes 8, 11, 12, 15 and 16 produced less than average fruits per inflorescence for the corresponding years (Table 3 and Figure 1). The average fruit percentage was only 3.31% of the flowers produced within an inflorescence. The fruit percentage was not significantly different between years except 2007 which expressed only 2.10%. Across different phenotypes the fruiting percentage was significantly different.

The average fruiting success was 82.55 % of the female flowers produced within an inflorescence. The fruiting success percentage was significantly different between years and across different phenotypes. During 2007 many phenotypes viz., 2, 3, 4, 5, 6, 10, 11, 16 and 17 expressed 100% setting. The phenotype 6 showed 100% fruiting success across all the years. On the other hand, the average of three years was less than 65% in phenotype 9 and 15. The average number of fruits per plant was 9.87. Across all the years the phenotype 8 and 12 showed no fruiting. On an average the fruiting during 2007 was low (5.30 fruits per plant), however, the phenotypes 1, 6, 10 and 17 showed above average fruiting. Parthiban *et al.* (2009) reported that fruit yield in hybrid clones of Jatropha was more than 300% than the local seed source, which was only 200 to 300 g/plant at three years age and hence the hybrid clone proved to be promising. Studies by Rao *et al.* (2008) in *J. curcas*, reported female to male flower ratio was near to 100% heritability and female to male flower ratio had highest positive direct relationship with seed yield. The present study showed an average flower production of 90.53, 65.22 and 72.99 with fruiting success percentage of 72.63, 95.8 and 79.22 during 2006, 2007 and 2008 respectively. The fruiting success was increased to 95.8% during 2007 when the flower production was as low as 65.22. The increase in fruiting success during 2007 could be due to sufficient rainfall accompanied by availability of nutrients to a few flowers unlike the first year. Study conducted in nine genotypes of Jatropha revealed that plant canopy, seed yield and number of leaves, seed oil and kernel oil content showed high heritability coupled with high genetic advance. So these characters may be considered for selection to improve Jatropha varieties/genotypes (Gohil and Pandya, 2009).

Studies by Maes *et al.* (2009) demonstrate that Jatropha is not common in regions with arid and semi-arid climates and does not naturally occur in regions with less than 944 mm year $^{-1}$. This contrasts with popular claims on preferred climate (Heller, 1996; Kumar and Sharma, 2008) and with the limiting rainfall levels stated, ranging from 200 mm (Kheira *et al.*, 2009) to 300 mm (ICRAF, 2008). However, there are studies which report that seed production in sites with 900–1200 mm rainfall can be up to double (5 t dry seed /ha) of the production in semi-arid regions (2–3 t dry seed /ha) (Francis *et al.*, 2005; Atchen *et al.*, 2008). It indicates that plantations in arid or semi-arid regions (19.5% of the sampled plantations in this study) may show a low productivity or requires additional irrigation.

Vegetative growth:
Significant variation in vegetative characters namely, plant height, collar diameter and number branches was recorded across the three years (Table 6). The mean plant height for first, second and third year of study were found to be 4, 4.7 and 5.8 respectively and the phenotype 4 recorded the highest mean plant height (5.6). The mean collar diameters for the three consecutive years were 85.7,97.8 and 109.4 and the phenotype 6 recorded the highest value for collar diameter (111.3). The mean number of branches across the three years were 3.8, 5.6 and 9.0 respectively and the phenotype 11 recorded the maximum number of branches (7.9).

Significant but weak correlation was found between number of branches and number of fruits/ plant ($p<0.05$). However the characters such as plant height, collar diameter and number of branches were not found to be significantly correlated. The quantity of fruit or seed crop is negatively correlated with vegetative growth in many crops (Davis, 1957). Studies by Tar *et al.* (2011) in *J. curcas* also, reported weak correlation between canopy height, canopy diameter, stem base diameter, secondary branches per plant with seed yield.

In general this study suggested that substantial trade-off did not exist between vegetative growth and fruit production in *J.curcas.* However, studies in species like Litchi have shown that the greater the number of lateral branches the greater the fruit yield as the bearing shoot with more leaves is the major source of carbohydrates for fruit growth, mainly through leaf CO_2 assimilation and its carbohydrate reserves (Chang and Lin, 2008).

Relationship between flowering and fruiting characters:

There was significant relationship between many flowering and fruiting characters within and across years (Table 4). Significant positive relationship in female flowers per inflorescence, between the first and the second year (0.523), first with third year (0.865) and second with third year (0.549) was observed. With reference to number of fruits per plant among the different years, significant relationship was observed between the first and the third year (0.602) alone. The number of female flowers per inflorescence was highly related with the number of flowers per inflorescence of the corresponding year. The number of male flowers per inflorescence was also significantly related with the number of flowers per inflorescence of corresponding year which were, 0.999, 1.00 and 0.998 during the first, second and third years respectively. With respect to fruits per inflorescence, the number of female flowers per inflorescence showed significant positive relationship during the first (0.853), second (1.000) and third year (0.982). With reference to number of fruits per plant, all the characters showed positive significance for all the years. The fruits per inflorescence across different years were significantly related. Among the different characters, the female flowers and fruits per inflorescence showed significant positive relationship.

Strong relationship between flowering and fruiting traits within and across different years was observed. The correlation between the number of inflorescence per plant of first year with second year and third year expressed -0.102 and 0.570. This showed that the first year flowered phenotypes did not flower much during second year but flowered during third year. Similarly, the second year flower and fruit characters were correlated with third year traits. This phenomenon confirms the tendency for alternate year bearing. The variable relationship across years was observed in all the flowering and fruiting traits except production of male flowers when compared to female flowers and fruits produced. This reveals that the male flower production is more consistent across different years. A strong correlation between female flowers and fruits per inflorescence was observed across all the years. The fruiting success was as high as 82.55% and in certain phenotypes the success rate was 100%. It revealed that in most of the cases, the female flowers were successfully converted into fruits. In the present study, it was evident that there was no serious problem in anthesis, fertilization and subsequent fruit maturation. The flowers of Jatropha depend on pollination by insects, including bees, flies, ants and thrips. Generally cross pollination is favoured due to protandry. In the absence of foreign pollen it has the ability to self pollinate (Raju and Ezradanum, 2002; Ambrosi *et al.*, 2009).

As such low number of female flower is a major constrain for fruit production. Although there can be maximum of 73 female flowers and fruits per plant, many produce less than 10 female flowers and fruits per plant. The female flowers per inflorescence was observed to be related with number of flowers per inflorescence during the year. Increasing the female flowers can increase the fruit production. Silvicultural practices will have to be standardized to increase the general flower production that will have direct bearing on the female flowers and fruit production.

Stability of flowering and fruiting characters:

The flower and fruit characters of 17 phenotypes for three years for their stability revealed significant ($P<0.01$) differences for genotype x environment, interaction for all the characters studied (Table 5). For all the studied characters, the environmental variation term is high or equal to the genetic term. The characters like number of inflorescence/plant, female flowers/ inflorescence, fruits per inflorescence and number of fruits per plant were all highly influenced by environment than due to genotype and although the interaction between environment and genotype was found to be significant, the values are very low. The flowers / inflorescence and male flowers / inflorescence were observed to be highly influenced by genotype and the interaction between the genotype and the environment was observed to be one fourth of the genotype contribution.

The flowering and fruiting characters in three consecutive years showed variable response with various floral characters. However, few phenotypes were stable across different years. The phenotypes 2, 3, 7 and 12 were stable for number of inflorescence per plant while phenotype 14 was stable for number of total flowers and male flowers per inflorescence. Phenotypes 1, 6, 15 and 16 recorded stability for number of female flowers per inflorescence, phenotypes 1, 6, 11, 15, 16 and 17 for number of fruits per inflorescence and phenotype 6 for number of fruits per plant across different years. In general, the phenotypes 1, 6, 14, 15 and 16 were consistent across three consecutive years with respect to most of the flowering characters.

Most of the phenotypes showed high level of interaction with year. The observation on the flowering in different years showed that flowering is profuse during alternate years. However, the response was not uniform for all the phenotypes. Certain phenotypes like 15, 16 and 17 flowered profusely during 2007 while phenotypes like 2, 5, 11, 12 and 13 flowered profusely during 2006 and 2008. Those phenotypes that flowered profusely during the 2006 recorded limited flowering during 2007. While the phenotypes which recorded limited flowering during 2006 flowered profusely during 2007. The observation was prominent for flowers per inflorescence.

In general, phenotype 6 was found to be more stable and above average values especially with reference to female flower production, fruits per inflorescence and number of fruits per plant. Whereas, the phenotypes 1, 15 and 16 were found to be stable recording below average values for female flower and number of fruits per plant. In phenotypes like 5, 9, 10 and 17, although not consistent, the female flower production and number of fruits per plant were higher across all the years when compared to other phenotypes.

Studies on the flower and fruit characters across three consecutive years showed that the environment and genotype plays major role and the interaction effect is minimum. The characters studied showed an alternate year pattern of profuse flowering and fruiting. Although the phenomenon was common for all the phenotypes, it was not synchronised for all the phenotypes. Profuse flowering and fruiting was observed during 2006 in phenotypes 5, 9 and 10 while phenotypes 15, 16 and 17 showed profuse flowering only during 2007. There could be two sets of phenotypes that flower and fruit alternatively. This indicates that the alternate bearing is not influenced by environment alone, phenotype also influences the flowering and fruiting. The expression of alternate bearing involves a wide range of changes in activation and repression of endogenous metabolic pathways, the signal transduction and the genes involved (Lavee, 2007). In addition, cultivar differences within species for alternate bearing are widespread and this tendency has been reported in apple and pear cultivars (Jonkers, 1979). In this study, the fruiting was consistent and above average in phenotype 6 across the three years.

Conclusion

Across the years, an apparent year to year variation with respect to female flower production was noticed. It was observed that the male flower production is more consistent across different years, while the female flower production is more sensitive to environment. Low number of female flowers is proved a major constraint for fruit production. The female flower production was observed to be related with total flowers produced. Increasing the female flowers can increase the fruit production. Strong correlation between female flowers and fruits per inflorescence and high fruiting success imply that there is no noticeable problem in anthesis, fertilization and subsequent fruit maturation. From the flowering pattern across years in this species a phenomena of alternate year bearing could be deduced. Vegetative growth characters did not strongly influence the reproductive growth, especially, fruit production, in *J. curcas*.

The environmental and genetic influence on flowering and fruiting is equal. Hence, selection of genotype and silvicultural inputs are equally important. There is lot of scope for selection of genotype with stable and high fruit yielding capacity. Silvicultural practices will have to be developed to increase the general flower production that will have direct bearing on the female flowers and fruit production.

The flowering and fruiting characters exhibited a significant influence of genotype, environment and their interaction. Hence selection of genotype, selection of site and matching of site are also essential to improve the flowering and fruiting in *Jatropha curcas.*

Acknowledgement

The authors thank the Department of Biotechnology, New Delhi, Govt. of India for extending financial assistance to carry out this research work.

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Table 1. Mean values for inflorescence and total flower production in *Jatropha curcas* across different years

Pheno types	Number of inflorescence/plant				Flowers / Inflorescence			
	2006 (Year 1)	2007 (Year 2)	2008 (Year 3)	Mean	2006 (Year 1)	2007 (Year 2)	2008 (Year 3)	Mean
1	1.00	2.67	2.67	2.11	32.33	79.00	50.24	53.86
2	2.00	2.00	3.00	2.33	70.67	35.33	51.51	52.50
3	2.33	2.67	3.00	2.67	94.33	41.00	60.93	65.42
4	2.33	3.67	4.00	3.33	101.33	78.00	84.80	88.04
5	5.33	2.67	7.33	5.11	239.33	73.33	148.95	153.87
6	2.00	3.67	2.67	2.78	47.33	63.67	48.75	53.25
7	2.33	2.33	1.33	2.00	67.00	30.67	44.97	47.55
8	2.33	3.67	5.33	3.78	83.33	48.00	59.58	63.64
9	3.67	5.33	7.00	5.33	139.00	80.00	103.04	107.35
10	2.00	5.33	7.33	4.89	180.00	101.00	136.40	139.13
11	2.67	2.33	4.00	3.00	90.67	31.33	56.05	59.35
12	2.00	1.00	2.00	1.67	68.33	4.67	31.42	34.81
13	2.33	2.00	4.67	3.00	91.00	45.00	64.37	66.79
14	2.00	3.67	5.00	3.56	79.00	69.67	69.53	72.73
15	1.00	4.33	4.33	3.22	20.67	85.00	48.16	51.28
16	1.00	4.67	3.00	2.89	43.67	104.00	70.25	72.64
17	2.00	5.67	4.33	4.00	91.00	139.00	111.80	113.93
Mean	**2.26**	**3.39**	**4.18**	**3.28**	**90.53**	**65.22**	**72.99**	**76.25**
	Year	**Phenotype**	**Y x P**		**Year**	**Phenotype**	**Y x P**	
S.e.d.	0.15	0.35	0.61		1.15	2.73	4.72	
C.D.	0.30	0.70	1.22		2.27	5.41	9.37	

S.e.d. – Standard error of deviation C.D. – Critical difference

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ISSN 0975-928X

Table 2. Mean values for male and female flower production in *Jatropha curcas* across different years

Pheno types	Female flowers / Inflorescence				Male flowers / Inflorescence				M/F ratio				Female flower (%)			
	2006	2007	2008	Mean	2006	2007	2008	Mean	2006	2007	2008	Mean	2006	2007	2008	Mean
1	1.33	2.67	1.67	1.89	30.67	77.00	48.57	52.08	30.67	28.84	29.08	29.53	3.09	3.38	3.32	3.27
2	6.00	1.33	2.33	3.22	65.00	34.00	49.18	49.39	10.83	25.56	21.11	19.17	8.49	3.76	4.52	5.59
3	4.33	1.00	5.33	3.55	90.33	40.33	55.60	62.09	20.86	40.33	10.43	23.87	4.59	2.44	8.75	5.26
4	4.00	1.00	4.33	3.11	98.00	77.00	80.47	85.16	24.50	77.00	18.58	40.03	3.95	1.28	5.11	3.45
5	9.33	2.00	6.33	5.89	232.67	71.00	142.62	148.76	24.94	35.50	22.53	27.66	3.90	2.73	4.25	3.63
6	4.67	3.33	4.67	4.22	41.67	61.33	44.09	49.03	8.92	18.42	9.44	12.26	9.87	5.23	9.58	8.23
7	5.00	1.33	3.00	3.11	62.00	30.00	41.97	44.66	12.40	22.56	13.99	16.32	7.46	4.34	6.67	6.16
8	0.00	0.00	0.00	0.00	83.00	48.00	59.58	63.53	-	-	-	-	0.00	0.00	0.00	0.00
9	13.33	1.33	9.00	7.89	126.00	78.67	94.04	99.57	9.45	59.15	10.45	26.35	9.59	1.66	8.73	6.66
10	11.67	3.00	11.33	8.67	173.67	98.00	125.06	132.24	14.88	32.67	11.04	19.53	6.48	2.97	8.31	5.92
11	5.33	1.00	2.33	2.89	84.33	30.67	53.71	56.24	15.82	30.67	23.05	23.18	5.88	3.19	4.16	4.41
12	0.00	0.00	0.00	0.00	66.67	5.00	31.42	34.36	-	-	-	-	0.00	0.00	0.00	0.00
13	5.33	1.33	2.00	2.89	85.67	43.67	62.37	63.90	16.07	32.83	31.19	26.70	5.86	2.96	3.11	3.97
14	3.67	0.00	2.00	1.89	75.00	70.00	67.53	70.84	20.44	-	33.77	27.10	4.65	0.00	2.88	2.51
15	1.00	0.00	2.00	1.00	19.67	85.00	46.16	50.28	19.67	-	23.08	21.38	4.84	0.00	4.15	3.00
16	0.00	1.00	0.67	0.56	43.67	103.00	69.58	72.08	-	103.00	103.85	103.43	0.00	0.96	0.95	0.64
17	8.00	4.00	4.33	5.44	84.00	135.00	107.47	108.82	10.50	33.75	24.82	23.02	8.79	2.88	3.87	5.18
Mean	4.86	1.43	3.61	3.30	86.00	63.98	69.38	73.12	17.70	44.74	19.22	27.22	5.37	2.19	4.95	4.17

	Year	Pheno type	Y x P	Year	Pheno type	Y x P	Year	Pheno type	Y x P	Year	Pheno type	Y x P
S.e.d.	0.24	0.57	0.98	1.16	2.77	4.79	2.40	5.70	9.87	0.46	1.08	1.88
C.D.	0.47	1.12	1.95	2.31	5.50	9.51	4.77	11.34	19.65	0.90	2.15	3.72

S.e.d. – Standard error of deviation C.D. – Critical difference

Electronic Journal of Plant Breeding, 6(3): 813-825 (Sep 2015)
ISSN 0975-928X

Table 3. Mean values for fruit production in *Jatropha curcas* across different years

Pheno types	Fruits / Inflorescence				Fruits (%)				Fruiting success %				Number of fruits / plant			
	2006	**2007**	**2008**	**Mean**	**2006**	**2007**	**2008**	**Mean**	**2006**	**2007**	**2008**	**Mean**	**2006**	**2007**	**2008**	**Mean**
1	1.33	2.33	1.67	1.78	4.11	2.95	3.32	3.46	100.00	87.27	100.00	95.76	1.3	6.2	4.5	4.00
2	5.00	1.33	1.33	2.55	7.08	3.76	2.58	4.47	83.33	100.00	57.08	80.14	10.0	2.7	4.0	5.57
3	4.00	1.00	4.33	3.11	4.24	2.44	7.11	4.60	92.38	100.00	81.24	91.21	9.3	2.7	13.0	8.33
4	2.33	1.00	3.67	2.33	2.30	1.71	4.33	2.78	58.25	100.00	84.76	81.00	5.4	4.9	14.7	8.33
5	9.00	2.00	5.33	5.44	3.76	2.73	3.58	3.36	96.46	100.00	84.20	93.56	48.0	5.3	39.1	30.80
6	4.67	3.33	4.67	4.22	11.26	5.23	9.58	8.69	100.00	100.00	100.00	100.00	10.7	12.2	12.5	11.80
7	4.00	1.00	2.00	2.33	5.97	3.26	4.45	4.56	80.00	75.19	66.67	73.95	9.3	2.3	2.7	4.77
8	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	0.0	0.0	0.0	0.00
9	5.00	1.00	7.00	4.33	3.60	1.25	6.79	3.88	37.51	75.19	77.78	63.49	18.4	5.3	49.0	24.23
10	8.00	3.00	10.00	7.00	4.44	2.97	7.33	4.92	68.55	100.00	88.26	85.60	16.0	16.0	73.3	35.10
11	3.00	1.00	2.00	2.00	3.31	3.19	3.57	3.36	56.29	100.00	85.84	80.71	8.0	2.3	8.0	6.10
12	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	0.0	0.0	0.0	0.00
13	4.67	1.00	1.00	2.22	5.13	2.22	1.55	2.97	87.62	75.19	50.00	70.94	10.9	2.0	4.7	5.87
14	3.67	0.00	1.00	1.56	5.48	0.00	1.44	2.31	100.00	-	50.00	75.00	8.7	0.0	5.0	4.57
15	0.00	0.00	1.33	0.44	0.00	0.00	2.76	0.92	0.00	-	66.50	33.25	0.0	0.0	5.8	1.93
16	0.00	1.00	0.33	0.44	0.00	0.96	0.47	0.48		100.00	49.25	74.63	0.0	4.7	1.0	1.90
17	4.00	4.00	3.00	3.67	4.40	2.88	2.68	3.32	50.00	100.00	69.28	73.09	8.0	22.7	13.0	14.57
Mean	3.53	1.37	2.86	2.59	3.90	2.10	3.92	3.31	72.63	95.80	79.22	82.55	**9.6**	**5.3**	**14.7**	**9.87**

	Year	**Pheno type**	**Y x P**	**Year**	**Pheno type**	**Y x P**	**Year**	**Pheno type**	**Y x P**	**Year**	**Pheno type**	**Y x P**
S.e.d.	0.26	0.63	1.09	0.60	1.43	2.47	4.68	11.13	19.28	0.52	0.97	1.49
C.D.	0.52	1.25	2.16	1.19	2.83	4.90	9.28	22.09	38.26	1.04	1.94	2.98

S.e.d. – Standard error of deviation C.D. – Critical difference

Table 4. Correlation coefficient of flowering and fruiting characters across different years

	No. inflo./ plant	Flowers per inflo. (year	Female flowe	Male flowers per	Fruits per inflo.	No of fruits per	No. inflo./ plant	Flowers per inflo.	Female flowe	Male flowers per	Fruits per inflo.	No of fruits per	No. inflo./ plant	Flowers per inflo.	Female flowe	Male flowers per	Fruits per inflo.	No of fruits per
No. inflo./ plant (year1)	1.000	0.840**	0.611**	0.838**	0.662**	0.885**	-0.102	-0.133	0.091	-0.139	0.091	-0.014	0.570*	0.598*	0.424	0.596*	0.403	0.466
Flowers/inflo. (year1)		1.000	0.723**	0.999**	0.785**	0.869**	0.147	0.146	0.297	0.138	0.297	0.253	0.774**	0.869**	0.674**	0.863**	0.661**	0.779**
Female flowers/ inflo. (year1)			1.000	0.687**	0.851**	0.689**	0.402	0.307	0.523*	0.294	0.523*	0.513*	0.638**	0.736**	0.865**	0.699**	0.810**	0.817**
Male flowers/ inflo. (year1)				1.000	0.763**	0.863**	0.125	0.131	0.274	0.124	0.274	0.228	0.768**	0.860**	0.645**	0.856**	0.635**	0.760**
Fruits/inflo. (year1)					1.000	0.853**	0.125	0.146	0.539*	0.130	0.539*	0.425	0.539*	0.705**	0.757**	0.677**	0.729**	0.716**
No of fruits/ plant (year1)						1.000	0.007	0.097	0.332	0.087	0.332	0.185	0.606**	0.738**	0.573*	0.733**	0.540*	0.602*
No. inflo./ plant (year2)							1.000	0.876**	0.429	0.879**	0.429	0.611**	0.509*	0.551*	0.526*	0.538*	0.482	0.501*
Flowers/ inflo. (year2)								1.000	0.595*	1.000**	0.595*	0.709**	0.420	0.614**	0.403	0.619**	0.368	0.386
Female flowers/ inflo. (year2)									1.000	0.572*	1.000	0.950**	0.163	0.536*	0.549*	0.518*	0.587*	0.453
Male flowers/ inflo. (year2)										1.000	0.572*	0.690**	0.423	0.608**	0.392	0.614**	0.355	0.378
Fruits/ inflo. (year2)											1.000	0.950**	0.163	0.536*	0.549*	0.518*	0.587*	0.453
No of fruits/ plant (year2)												1.000	0.220	0.559*	0.550*	0.542*	0.576*	0.477
No. inflo./ plant (year3)													1.000	0.823**	0.618**	0.821**	0.581*	0.764**
Flowers/ inflo. (year3)														1.000	0.730**	0.998**	0.700**	0.808**
Female flowers/ inflo. (year3)															1.000	0.684**	0.982**	0.945**
Male flowers/ inflo. (year3)																1.000	0.653**	0.773**
Fruits/ inflo. (year3)																	1.000	0.933**
No of fruits/plar (year3)																		1.000

**-Correlation is significant at the 0.01 level (2-tailed) *-Correlation is significant at the 0.05 level (2-tailed)

Table 5. Mean squares of flowering and fruiting characters for three years

Source	df	Number of inflorescence / plant	Flowers per inflorescence	Female flowers per inflorescence	Male flowers per inflorescence	Fruits per inflorescence	Number of fruits per plant
Environment	2	16.52**	2871.78**	53.09**	2,209.56**	20.53**	388.48**
Genotype	16	3.26**	3382.38**	18.23**	3,015.05**	11.27**	331.43**
Genotype x Environment	32	1.35**	879.37**	3.63**	825.95**	2.34**	117.15**
Pooled error	102	0.17	11.53	0.49	11.83	0.63	4.10
Total	50	2.57	1074.1	10.28	1581.80	5.925	196.66

**Significance at p> 0.01 df- degrees of freedom

Electronic Journal of Plant Breeding, 6(3): 813-825 (Sep 2015)
ISSN 0975-928X

Table 6. Mean values for vegetative characters in *J. curcas* across different years and the correlation coeffecient values

Pheno types	Plant height (m)				Collar diameter (mm)				No. of branches			
	2006	**2007**	**2008**	**Mean**	**2006**	**2007**	**2008**	**Mean**	**2006**	**2007**	**2008**	**Mean**
1	3.7	4.5	5.5	4.6	85.0	98.0	112.0	98.3	5.0	6.0	8.0	6.3
2	3.5	4.3	5.5	4.4	80.3	100.0	117.0	99.1	4.0	6.0	9.0	6.3
3	4.4	5.2	6.3	5.3	82.0	106.0	118.0	102.0	4.0	5.0	10.0	6.3
4	4.5	5.7	6.5	5.6	81.0	97.0	107.0	95.0	3.0	5.0	7.0	5.0
5	3.5	4.1	4.9	4.2	86.7	97.0	110.0	97.9	4.0	4.0	7.0	5.0
6	3.4	4.3	5.5	4.4	99.0	115.0	120.0	111.3	4.0	7.3	11.0	7.4
7	4.1	5	6.1	5.1	79.0	90.0	100.0	89.7	3.0	5.0	8.0	5.3
8	4.2	5.3	6.5	5.3	88.0	91.0	105.0	94.7	3.3	5.0	9.0	5.8
9	4.0	4.7	5.8	4.8	90.0	98.0	108.0	98.7	3.0	6.0	8.7	5.9
10	3.7	4.2	5.7	4.5	76.0	88.0	100.0	88.0	3.0	4.0	6.0	4.3
11	4.2	5.1	6.3	5.2	75.0	89.3	98.0	87.4	4.7	7.0	12.0	7.9
12	4.1	5.2	6.2	5.2	91.0	101.0	113.0	101.7	4.0	7.0	10.0	7.0
13	4.3	5.1	6.4	5.3	85.0	95.0	111.0	97.0	4.0	6.0	10.0	6.7
14	4.1	5	5.8	5.0	90.0	97.0	105.0	97.3	5.0	6.0	11.0	7.3
15	3.9	4.2	5.4	4.5	91.0	99.0	106.0	98.7	3.0	5.0	8.0	5.3
16	3.8	4.4	5.7	4.6	89.0	100.0	117.0	102.0	4.0	6.0	9.3	6.4
17	3.9	4.4	5.3	4.5	89.7	101.0	112.0	100.9	3.0	5.0	9.0	5.7
Mean	4.0	4.7	5.8	4.9	85.7	97.8	109.4	97.6	3.8	5.6	9.0	6.1
	Year	**Pheno type**	**Y x P**		**Year**	**Pheno type**	**Y x P**		**Year**	**Pheno type**	**Y x P**	
S.e.d.	0.00358	0.00852	0.01476		0.032	0.0762	0.132		0.0392	0.0934	0.1617	
C.D.	0.0071	0.0169	0.02928		0.0635	0.1512	0.2619		0.0778	0.1852	0.3207	

	Plant height	Collar diameter	No. of branches	No. of fruits/plant
Plant height	1	0.102	0.033	0.205
Collar diameter		1	0.113	0.028
No. of branches			1	0.271*
No. of fruits/plant				1

*Correlation coefficient is significant at p<0.0