academicJournals

Vol. 8(37), pp. 1759-1771, 4 October, 2013
DOI 10.5897/SRE11.2145
ISSN 1992-2248 © 2013 Academic Journals
http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Combining ability and heterosis in diallel analysis of *Jatropha curcas* L. in nursery stage

Alireza Biabanikhanehkahdani[1], Mohd Rafii Yusop[1]* Ghizan Saleh[1], Mahmoodreza Shabanimofrad[1] and M. A. Latif[1,2]

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

Accepted 31 May, 2013

Out of 384 *Jatropha curcas* plants evaluated, ten superior plants were selected based on seed yield and oil content, and were crossed among them in a 10 × 10 half-diallel mating design to produced 45 F_1-hybrids. The experiment was conducted in nursery stage using a randomized complete block experimental design (RCBD) with three replications. Analysis of variance for the combining ability indicated that general combining ability (GCA) and specific combining ability (SCA) variance were significant at 1% probability for 3 traits in nursery stage. The low ratio of GCA/SCA exhibited the non-additive effects and played a more important role than additive effects. Estimates for broad sense heritability of the studied genotypes were high for plant height, collar diameter and number of leaves after 15, 30, 60 and 90 days after planting. While, estimates for narrow sense heritability of the studied genotypes were low for plant height, collar diameter and number of leaves after 15, 30, 60 and 90 days after planting. Percentages of heterosis and heterobeltiosis values for the 45 hybrids ranged from negative to positive and some hybrids performed better than the average for studied traits of their parents. This showed that the existence of dominance or non-additive gene actions might be present in the hybrids. On the basis GCA and SCA effects, parents, Ph1.2 and In2.1 and hybrids 3×8, 9×10 and 1×10 could be used for future breeding program.

Key words: *Jatropha curcas*, diallel crosses, general combining ability (GCA), specific combining ability (SCA), heterosis, heritability.

INTRODUCTION

The employment of energy crops as a source of renewable fuels is a concept with great relevance to current ecological and economic issues at both national and global scales. Biodiesel, an alternative diesel fuel, is produced from renewable biological sources such as vegetable oils and animal fats (Fangrui and Milford, 1999; Kumar and Sharma, 2008).

Oil yielding crops produce different types of oil, called vegetable oils. Recently, biofuels extracted from plant species has been a major renewable source of energy such as *J. curcas* L. (Mukherjee et al., 2011; Sharma et al., 2011a).

J. curcas, also known in Peninsular Malaysia area as "*Jarak Pagar*" is a euphorbiaceous plant with number of uses around the world and a great potential in many areas (Basha and Sujatha, 2007; Fangrui and Milford,

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

1999; Ganesh Ram et al., 2008; Ghosh and Singh, 2011; Gohil and Pandya, 2008; Shah et al., 2004; Singh et al., 2010). However, *Jatropha* is native to Central America, and it exists as a crop with good adjustment in both the Old and the New World. Many advantages exist for *J. curcas* more than other oily species, due to its speedy growing, tolerates drought and easily adapts to marginal lands (Achten et al., 2008; Basha et al., 2009; Divakara et al., 2010; Ovando-Medina et al., 2011; Rao et al., 2008; Sharama et al., 2011).

So far, oily plant breeding has made the great strides in improving oil yield and quality characters in relation to oil and meal. However, in Malaysia, its properties such as oil content, seed yield and other traits still needs to be improved (Divakara et al., 2010; Heller, 1996; Kaushi and Kumar, 2004; Shabanimofrad et al., 2011).

The early views that hybridization would be an elixir for all crop improvement problems are strongly driven. Heterosis is rare far from a common phenomenon in hybrids (Rameeh, 2011a); and the more favorable and beneficial contribution of hybridization is in transferring desirable genes from one to another accession (Amiri et al., 2007; Marinkovic, 1984). Similar to other trees, *Jatropha* breeding is a time consuming process due to perenniality.

Diallel mating designs provide useful genetic information for breeding programs, such as general combining ability (GCA) and specific combining ability (SCA) to help them design appropriate breeding and selection strategies (Johnson and King, 1998). Diallel mating design was used in all too many crops including rapeseed and oleaginous and Griffing's approaches were employed more frequently (Banumathy and Patil, 2000; Machikowa et al., 2011; Rameeh, 2011b; Sharma et al., 2011b). Utilizing diallel mating with different parents, oil content, some agronomic traits, seed yield, and seed oil yield of *Jatropha* were investigated for gene effects, combining ability (GCA and SCA), heritability and heterosis.

Better understanding and realizing of the mode of inheritance of the traits leads to improvement in breeding programs. This current study was managed to estimate the genetic parameters and the mode of inheritance for some morphological traits of *J. curcas* in a set of half diallel crosses. From this study, better parents and hybrids could be selected for future breeding program also.

MATERIALS AND METHODS

The study was conducted in the experimental field of Universiti Putra Malaysia in 2010. The experimental site is located at 101.71655° N, 3.0059° E and at an altitude of 88 m above sea level. The area receives 2429 mm rainfall per year. The monthly average minimum and maximum temperature of UPM, ranged between 21 to 23°C and 31 to 33°C, respectively.

Ten superior plants were selected based on seed yield and oil content for a half diallel cross from six *J. curcas* populations after one year evaluation in farm (Table). The superior plants were crossed in a half-diallel mating design (10 × 10) with the half diallel cross producing 45 hybrids. The pollinations were carried out shortly after emasculation by using fresh pollen collected from male parents and then the pollinated female flower were covered for protection from other pollens. Two inflorescences with about five female flowers each were employed for making cross.

All nine hundred and ninety seeds of parental accessions and hybrids (Eighteen seeds from each parental accessions and hybrids) were planted in polyethylene bags to produce seedlings. Polyethylene bags were filled with soil mixture (clay, sand and organic matter in a 1:1:1 ratio). After planting, the seedbed was prepared carefully and a small amount of N, P and K fertilizers were applied in the soil. Also, the seedbed was watered to ensure germination of seeds.

Experiment was conducted using a randomized complete block experimental design with three replications. For morphological traits, analysis of variance was conducted to determine significance of variability among the parents and hybrids. Mean, range, standard deviation and coefficient of variation for each characteristic were determined using Statistical Analysis System (SAS) version 9.1 (SAS Institute Inc. 2005).

Parental accessions were selected from different *Jatropha* populations. Diallel analysis was performed to calculate general combining ability (GCA) and specific combining ability (SCA) according to the Griffing's (1956) method 2, model 1, using SAS program (Zhang et al., 2005).

The below model was considered for statistical analysis in this experiment:

$$Y_{ijk} = \mu + G_i + G_j + S_{ij} + R_k + E_{ijk}$$

Where: Y_{ijk} = observed value for a hybrid between the *i*th and *j*th parents in the *k*th replication; μ = population mean; G_i and G_j= GCA effect of the *i*th and *j*th parents; S_{ij} = SCA effect for the hybrid between the *i*th and the *j*th parents; R_k= effect of the *k*th replication; E_{ijk} = the error associated with the *ijk*th hybrid (the residual) (Johnson and King, 1998). The expected mean squares and genetic interpretations of a half diallel design are presented in Table .

Estimation of the additive and dominance genetic variance is simple after estimating the GCA variance (σ^2_{GCA}) and SCA variance (σ^2_{SCA}) (Zhang et al., 2005). The relationships are as follows:

When inbreeding coefficient (F) of parents = 0 (no inbreeding)

$$\sigma^2_A = 4\sigma^2_{GCA}$$
$$\sigma^2_D = 4\sigma^2_{SCA}$$

Heterosis and heterobeltiosis were computed as the percentage of superiority of the hybrid over its mid parent value (MP%) or better parent value (BP%) respectively.

Heritability expresses the proportion of the total variance that is attributable to the average effects of genes. Broad and narrow sense heritability was estimated based on the variance components in the ANOVA table.

Broad sense heritability values were obtained using GCA and SCA values.

$$H^2_B= \sigma^2_g / \sigma^2_p$$

Where: H^2_B = Heritability; σ^2_g = total genetic variance = $4\sigma^2_{GCA} + 4\sigma^2_{SCA;}$ and σ^2_p = phenotypic variance = $4\sigma^2_{GCA} + 4\sigma^2_{SCA} + \sigma^2_E$.

Narrow sense heritability was computed from the variance components in the ANOVA table (Table) for analysis of combining ability.

$$h^2_N = 4\sigma^2_{GCA} / 4\sigma^2_{GCA} + 4\sigma^2_{SCA} + \sigma^2_E$$

Table 1. Internet code and origin of ten superior plants accession.

Parents No.	Parents name	Parents origin
1	My2.1	Malaysia
2	In2.1	Indonesia
3	Ph1.2	Philippines
4	Id1.1	India
5	Id1.2	India
6	My1.1	Malaysia
7	In1.1	Indonesia
8	In1.2	Indonesia
9	Ph1.1	Philippines
10	My2.2	Malaysia

Table 2. Expected mean square and genetic interpretation of a half diallel.

S.O.V	df	EMS
Replications	(r-1)	$\sigma^2_e + g\sigma^2_r$
Genotypes	{[n(n-1)/2]+ n}-1	$\sigma^2_e + r\sigma^2_g$
GCA	n-1	$\sigma^2_e + r\sigma^2_{SCA} + r(n+2)\sigma^2_{GCA}$
SCA	n(n-1)/2	$\sigma^2_e + r\sigma^2_{SCA}$
Error	(r-1) {{[n(n-1)/2]+ n}-1}	σ^2_e

Where: r and n refer to number of replications and parents per diallel respectively.

Where: h^2_N = narrow sense heritability; $4\sigma^2_{GCA}$ = variance due to GCA; $4\sigma^2_{SCA}$ = variance due to SCA and σ^2_E = variance due to residual error.

Correlation mentioned refers to a change in one trait that is accompanied by a change in another. Phenotypic correlation was obtained from the following formula:

$$r_p = cov_p / (\sigma_{p(x)}\ \sigma_{p(y)})$$

Where: r_p = phenotypic correlation between traits x and y; cov_p = phenotypic covariance and $\sigma_{p(x)}\ \sigma_{p(y)}$ = the root of the genetic variance of x and y respectively.

Phenotypic correlation was computed from the combined analysis data based on genotype values over environment and replications.

RESULTS

Plant height

The average performance of parents and hybrids regarding plant height is shown in Table 3.. Among parents and hybrids, the highest plant height after 15, 30, 60 and 90 days planting were recorded in 1×10 (19 cm), 1×10 (20.7 cm), 2×9 (44.7 cm) and In2.1 (80.7 cm) respectively. While, the shortest plant height after 15, 30, 60 and 90 days planting were recorded in 1×5 (9.7 cm), 7×8 (11.7 cm), 7×8 (21.7 cm) and 7×9 (29.7 cm) respectively.

The highest positive GCA effects were for parents Ph1.2, Ph1.2, In2.1 and In2.1 for plant height after 15, 30, 60 and 90 days after planting, respectively. The highest negative GCA effects were for parent In1.1 for plant height at 15, 30, 60 and 90 days after planting (Table 5). The results showed that parents Ph1.2 and In2.1 could provide good plant height.

Estimates of SCA effects for plant height were significantly positive in some hybrids as shown in Table 6. The large size of SCA values suggested that parents used in these hybrids were more diverse in plant height than other hybrids, and is designed to be candidate hybrid varieties. Hybrids 1×10, 7×10, 3×8 and 3×8 gave the highest positive significant SCA effects for plant height while hybrids 1×5, 2×5, 2×3 and 2×10 had the highest negative significant effect after 15, 30, 60 and 90 days after planting respectively.

Broad and narrow sense heritability is presented in Table 7. Estimates for broad sense heritability of the studied genotypes, high heritability values for plant height were shown after 15, 30, 60 and 90 days after planting, ranging from 76.24 to 95.71%. Even, narrow sense heritability was low for plant height after 15, 30, 60 and 90 days after planting and ranged from 2.31 to 13.45%. Broad sense heritability was higher than narrow sense ones for plant height. This difference presented the influence of non-additive gene actions.

Percentage heterosis and heterobeltiosis values for the 45 hybrids ranged from negative to positive and

Table 3. Means of plant height, collar diameter and number of leaves of parents and their hybrids in *Jatropha curcas.*

Genotypes	Plant height				Collar diameter				No. of leaves			
	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP
My2.1 (1)	17.0	20.7	43.3	60.3	6.1	9.0	13.8	19.4	3.7	5.3	9.3	15.3
In2.1 (2)	15.0	20.7	49.7	80.7	4.9	7.8	16.9	23.6	4.0	6.3	13.3	20.3
Ph1.2(3)	17.3	19.7	30.3	45.3	6.4	9.6	13.6	18.7	4.0	6.0	11.7	8.3
Id1.1 (4)	14.3	19.3	39.3	40.7	6.7	9.5	15.7	18.7	4.0	6.0	9.0	7.7
Id1.2(5)	18.7	18.3	27.3	50.0	6.4	9.7	12.8	23.6	4.0	5.7	8.0	11.3
My1.1 (6)	17.3	19.3	35.0	51.0	7.2	9.7	15.2	24.1	4.0	6.0	9.0	11.7
In1.1 (7)	10.7	14.0	27.3	55.0	3.9	6.8	10.6	18.4	2.7	5.0	7.0	12.0
In1.2 (8)	13.0	16.0	34.7	57.0	5.9	8.1	14.6	20.0	3.0	5.0	10.0	14.0
Ph1.1 (9)	15.3	16.7	42.7	57.0	6.1	8.7	15.9	23.1	4.0	6.0	9.7	15.3
My2.2(10)	16.7	19.0	34.0	57.0	6.3	9.6	16.1	24.0	4.0	7.0	11.7	13.7
1*2	15.7	19.7	39.7	56.3	6.5	9.2	13.2	20.5	4.0	5.7	8.7	14.7
1*3	17.3	20.7	36.7	50.3	6.8	9.5	14.3	20.5	3.7	6.0	8.7	15.3
1*4	14.7	17.3	27.7	45.0	6.9	9.1	12.7	18.9	4.0	5.0	7.0	11.7
1*5	9.7	14.3	37.0	55.3	4.5	7.1	14.9	23.2	2.7	4.7	11.0	13.7
1*6	15.0	16.3	35.7	59.0	7.6	9.6	13.8	20.5	4.0	5.7	11.0	18.7
1*7	12.7	15.3	25.0	36.7	5.0	7.7	11.9	14.8	4.0	4.3	8.7	10.3
1*8	14.0	16.7	38.3	55.0	5.5	8.2	29.2	15.8	4.0	4.0	8.0	10.7
1*9	13.7	18.0	30.7	38.0	5.7	8.5	14.4	14.6	4.0	4.7	9.0	9.0
1*10	19.0	20.7	39.7	69.3	6.5	9.8	15.8	22.1	4.0	5.7	10.7	20.3
2*3	16.4	17.2	29.4	43.7	6.4	9.8	14.4	17.3	4.0	6.0	7.6	10.0
2*4	16.1	18.5	32.2	44.6	7.0	10.7	14.6	16.5	3.9	6.0	7.9	9.9
2*5	10.7	13.3	29.3	46.7	4.8	9.0	12.9	19.5	3.7	4.0	8.7	9.7
2*6	12.7	15.7	35.3	61.7	6.3	9.1	15.5	23.9	4.0	6.0	11.0	16.7
2*7	14.3	16.3	42.0	73.0	6.4	8.8	13.6	22.4	3.7	5.3	10.3	17.3
2*8	14.3	15.7	42.3	71.7	5.5	8.2	13.1	20.1	3.0	5.7	9.3	16.7
2*9	16.0	19.0	44.7	50.0	6.1	9.5	14.9	16.4	4.0	6.0	11.7	10.7
2*10	18.0	19.7	29.7	38.0	6.5	9.5	14.3	15.8	4.0	5.3	6.3	8.0
3*4	15.3	18.7	42.3	50.7	5.9	9.3	18.6	25.3	4.0	6.0	11.7	11.0
3*5	14.7	18.7	33.0	41.7	5.7	9.0	13.2	17.2	4.0	6.0	7.3	7.7
3*6	16.0	20.0	29.0	30.0	6.6	10.1	14.1	17.0	4.0	5.3	6.0	5.7
3*7	15.7	18.7	40.0	61.3	6.4	9.8	14.2	21.0	3.3	5.3	8.3	14.0
3*8	13.3	17.0	43.0	76.7	4.6	7.9	16.2	25.0	4.0	5.7	11.0	16.0
3*9	14.0	19.0	31.7	57.7	5.3	8.9	14.6	23.9	3.7	6.0	10.3	12.7
3*10	15.3	18.0	30.3	51.7	6.2	9.8	13.4	21.2	4.0	6.0	7.7	12.3
4*5	16.0	19.0	30.0	31.0	6.3	9.1	13.5	15.8	4.0	6.0	6.0	6.7
4*6	13.7	17.7	37.0	49.0	5.2	8.4	15.6	21.8	4.0	6.0	9.3	10.7
4*7	15.3	17.0	37.3	54.0	6.0	8.1	15.2	22.2	3.3	5.7	10.0	13.7
4*8	16.0	17.0	32.0	42.7	6.2	8.6	13.4	18.6	4.0	5.0	7.3	9.3
4*9	16.7	19.3	39.3	55.0	6.9	9.4	15.5	22.5	4.0	6.0	8.7	12.0
4*10	15.0	17.0	26.3	38.3	5.9	9.0	13.4	20.9	4.0	4.7	7.3	10.7
5*6	12.0	14.3	30.0	53.7	5.1	7.4	14.7	23.7	4.0	5.0	7.7	12.0
5*7	15.0	17.7	25.7	36.7	6.0	8.7	12.4	17.7	4.0	5.0	6.3	8.7
5*8	15.3	17.7	28.3	36.7	6.5	9.7	14.1	17.4	4.0	6.0	6.7	8.7
5*9	15.7	16.3	39.0	43.7	5.6	7.9	15.1	20.9	3.7	5.7	9.7	11.0
5*10	11.7	16.0	28.7	36.7	4.6	8.2	14.8	22.8	3.3	5.7	8.0	8.7
6*7	14.7	15.7	30.0	35.7	5.6	8.3	13.3	19.5	3.3	5.0	7.0	8.3
6*8	16.3	19.0	27.7	47.3	5.8	9.8	13.9	18.6	4.0	6.0	6.7	9.3
6*9	13.3	18.7	23.3	36.7	6.0	9.3	13.6	20.6	4.0	6.0	8.0	6.7
6*10	14.0	16.3	26.3	47.7	5.7	8.7	14.9	23.5	3.7	5.0	8.0	10.0

Table 3. Contd.

7*8	10.0	11.7	21.7	35.0	4.0	6.2	11.1	17.6	3.0	4.3	6.3	7.7
7*9	13.7	15.0	24.0	29.7	5.4	7.7	10.7	16.7	3.3	5.0	5.7	7.0
7*10	16.7	20.0	29.3	42.7	6.1	9.2	13.1	17.6	4.0	6.0	6.3	14.0
8*9	14.7	16.3	32.7	44.0	5.4	8.4	14.1	21.3	4.0	5.0	9.0	11.3
8*10	14.3	16.3	28.0	38.3	6.0	8.7	11.1	18.8	4.0	5.3	6.3	11.0
9*10	17.3	20.0	35.3	63.3	6.7	10.6	17.9	27.7	3.7	6.7	12.3	16.0
Max	19.0	20.7	49.7	80.7	7.6	10.7	29.2	25.3	4.0	7.0	13.3	20.3
Min	9.7	13.3	25.0	30.0	3.9	6.8	10.6	14.6	2.7	4.0	6.0	5.7
Mean	15.0	17.8	34.8	51.5	6.0	9.0	14.7	20.2	3.8	5.5	9.0	12.2
C.V.	12.7	9.7	10.3	9.8	14.1	10.1	8.5	9.3	13.2	11.6	15.2	21.5
LSD 5%	1.4	1.3	2.7	4.3	0.7	0.7	8.2	1.5	0.6	0.7	1.1	2.3
LSD 1%	1.9	1.8	3.6	5.7	1.0	1.0	10.8	2.0	0.8	1.0	1.5	3.0

LSD, Least significant difference.

Table 4. Mean squares from analysis of variance, general combining ability (GCA) and specific combining ability (SCA) for three characters of diallel cross involving 10 parents of *Jatropha curcas.*

S.O.V.	d.f	Mean square											
		Plant height				Collar diameter				No. of leaves			
		15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP
Blocks	2	16.06**	16.61**	62.52**	143.13**	1.64^{ns}	0.54^{ns}	5.52*	13.16**	2.01^{ns}	1.32*	13.17**	5.01^{ns}
Genotypes	54	12.31**	11.86**	120.59**	430.07**	1.47**	2.28**	8.38**	25.96**	0.40**	0.91**	10.75**	37.67**
GCA	9	14.90**	2511**	223.04**	594.69**	2.59**	4.71**	21.09**	29.10**	0.85**	1.89**	17.3**	56.41**
SCA	45	11.80**	9.24**	100.25**	397.24**	1.25**	1.81**	5.83**	25.36**	0.30$^{n.s}$	0.75**	9.45**	33.93**
EMS	108	3.54**	2.91**	11.96**	23.33**	0.70**	0.81**	1.50**	3.58**	0.25**	0.41**	1.75**	6.35**

DAP, Day after planting; ^{ns}, * and **: non-significant, significant at the 0.05 and 0.01 levels respectively.

presented in Table . Some hybrids did better than the average plant height of their parents. This showed the existence of dominance or non-additive gene actions. The heterosis for plant height at 15, 30, 60 and 90 days after planting ranged from -45.79 to 22.67, 21.21 to -31.62, 38.73 to -39.91 and 49.84 to -47.02% respectively (Table). The highest heterosis for plant height at 15, 30, 60 and 90 days after planting were found in the hybrids 4×7, 7×10, 3×7 and 3×8 respectively. The heterobeltiosis of plant height at 15, 30, 60 and 90 days after planting ranged from -48.21 to 11.76, -35.48 to 5.26, -45.31 to 31.87 and -52.89 to 34.50% respectively. The highest value was obtained in the heterobeltiosis cross between parents 1×10, 7×10, 3×7 and 3×8 for plant height at 15, 30, 60 and 90 days after planting respectively.

The percentages for heterosis and heterobeltiosis for plant height at 15, 30, 60 and 90 days after planting in some hybrids were significantly higher indicating the high degree of genetic diversity that existed among the parents. The cross of parents 7×10, 3×7 and 3×8 gave both the highest heterosis and heterobeltiosis.

Collar diameter

Among genotypes, the highest collar diameter after 15, 30, 60 and 90 days planting were recorded in 1×6 (7.6 mm), 2×4 (10.7 mm), 3×4 (18.6 mm) and 9×10 (27.7 mm) respectively. While, the shortest collar diameter after 15, 30, 60 and 90 days planting were recorded in In1.1 (3.9 mm), 7×8 (6.2 mm), In1.1 (10.6 mm) and 1×9 (14.6 mm) respectively.

Significant differences ($p \leq 0.01$) were observed among collar diameter after 15, 30, 60, and 90 days (Table 4). Analysis of variance for the combining ability indicated that GCA and SCA variance were significant at 1% probability for collar diameter in nursery stage. The low ratio of GCA/SCA exhibited the non-additive effects and played a more important role than additive effects. The ratio of GCA/SCA ranged from 0.01 to 016.

Parents Id1.1, Ph1.2, Id1.1 and My2.2 presented the highest positive GCA effects for collar diameter at 15, 30, 60 and 90 days after planting, respectively. While, parent In1.1 presented the highest negative GCA effect for collar

Table 5. Estimate of general combining ability effects (GCA) of ten *Jatropha* parents for measured traits in nursery stage.

Parents	Plant height				Collar diameter				No. of leaves			
	15DAP	30DAP	60DAP	90DAP	15DAP	30DAP	60DAP	90DAP	15DAP	30DAP	60DAP	90DAP
My2.1 (1)	0.18$^{n.s}$	0.6**	2.43**	3.55**	0.17**	-0.07$^{n.s}$	-0.43**	-1.08**	-0.36*	-0.37**	0.46**	2.12**
In2.1 (2)	0.07$^{n.s}$	0.24*	4.59**	8.63**	0.01$^{n.s}$	0.12*	0.41**	-0.24*	-0.31$^{n.s}$	0.16**	1.02**	2.10**
Ph1.2(3)	0.79**	1.16**	0.62**	0.88*	0.12*	0.45**	0.42**	0.28*	1.53**	0.30**	0.49**	-0.62**
Id1.1 (4)	0.32*	0.57**	1.23**	-4.26**	0.39**	0.26**	0.69**	-0.24*	-0.22$^{n.s}$	0.13*	-0.21*	-1.53**
Id1.2(5)	-0.46**	-0.76**	-2.68**	-5.08**	-0.27**	-0.17**	-0.35**	0.22$^{n.s}$	-0.38$^{n.s}$	-0.12*	-0.71**	-1.65**
My1.1 (6)	-0.09$^{n.s}$	-0.06$^{n.s}$	-1.96**	-1.7**	0.26**	0.21**	0.37**	1.22**	1.56**	0.11$^{n.s}$	-0.26*	-0.65**
In1.1 (7)	-1.18**	-1.48**	-3.18**	-2.36**	-0.52**	-0.79**	-1.57**	-1.37**	-0.72**	-0.39**	-1.07**	-0.34$^{n.s}$
In1.2 (8)	-0.76**	-1.15**	-0.38$^{n.s}$	1.52**	-0.31**	-0.47**	-0.62**	-0.79**	-0.5**	-0.31**	-0.43**	-0.04$^{n.s}$
Ph1.1 (9)	0.18$^{n.s}$	0.15$^{n.s}$	1.51**	-0.92**	0.01$^{n.s}$	0.01$^{n.s}$	0.61**	0.69**	-0.31$^{n.s}$	0.19**	0.66**	-0.18$^{n.s}$
My2.2 (10)	0.93**	0.74**	-2.18**	-0.25$^{n.s}$	0.15**	0.44**	0.45**	1.32**	-0.28$^{n.s}$	0.30**	0.04$^{n.s}$	0.77**
SE (g)	0.09**	0.07**	0.30**	0.58**	0.02**	0.02**	0.04**	0.09**	0.01**	0.01**	0.04**	0.16**
SE (gi-gj)	0.20**	0.16**	0.67**	1.30**	0.04**	0.05**	0.08**	0.20**	0.01**	0.02**	0.10**	0.35**

DAP, days after planting; ^{ns}, * and **: non-significant, significant at the 0.05 and 0.01 levels respectively.

Table 6. Estimate of specific combining ability effects (SCA) of 45 *Jatropha* hybrids for measured traits in nursery stage.

Hybrids	Plant height				Collar diameter				No. of leaves			
	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP
1*2	0.55^{ns}	1.27**	-0.8^{ns*}	-5.22**	0.44**	0.24^{ns*}	-2.13^{ns}	1.55**	0.88^{ns}	0.35^{ns}	-1.52**	-1.33**
1*3	1.49**	1.35**	0.17^{ns}	-3.47**	0.56**	0.25^{ns*}	-0.20^{ns}	1.03**	-1.68**	0.55**	1.99**	2.06**
1*4	0.70^{ns}	-1.40**	-9.44**	-3.66**	0.46**	0.07^{ns*}	-2.91^{ns}	0.65^{ns}	0.90^{ns}	-0.29^{ns}	-1.96**	-0.69^{ns}
1*5	-4.92**	-3.06**	3.81**	7.50**	-1.32**	-1.53**	0.39^{ns}	3.85**	0.77^{ns}	-0.37^{ns}	2.54**	1.42**
1*6	0.55^{ns}	-1.76**	1.76**	7.78**	1.22**	0.58**	-1.43^{ns}	1.62 **	-1.38*	0.41**	2.09**	5.42**
1*7	-1.20**	-1.34**	-7.69**	-13.89**	-0.56**	-0.32^{ns}	-1.42^{ns}	-2.96**	0.90^{ns}	-0.43**	1.56**	-2.22**
1*8	0.48^{ns}	0.34^{ns}	2.84**	0.56^{ns*}	-0.27^{ns}	-0.13^{ns}	13.45**	-2.57**	0.68^{ns}	-0.84**	-0.74**	-3.19**
1*9	-1.56**	0.31^{ns}	-6.71**	-14.00**	0.32^{ns*}	-0.40^{ns}	-1.10^{ns}	-5.29**	0.98^{ns}	-0.68**	-0.83**	-4.72**
1*10	3.02**	1.77**	5.98**	16.67**	0.23^{ns*}	0.59**	0.42^{ns}	1.62**	0.96^{ns}	0.21^{ns}	1.45**	5.67**
2*3	0.94**	-1.95**	-9.99**	-15.89**	0.22^{ns*}	0.16^{ns*}	-0.16^{ns}	2.61**	-1.40*	0.02^{ns}	-2.88**	-2.88**
2*4	0.74^{ns*}	-0.04^{ns}	-7.27**	-8.75**	0.65**	1.35**	-0.50^{ns}	-3.42**	0.85^{ns}	0.18^{ns}	-1.52**	-2.63**
2*5	-3.81**	-3.70**	-6.02**	-6.25**	-0.86**	0.14^{ns}	-1.03^{ns}	-0.69^{ns}	0.98^{ns}	-1.57**	-0.35^{ns}	-2.52**
2*6	-2.17**	-2.06**	-0.74^{ns}	5.36**	0.15^{ns*}	-0.11^{ns}	0.89^{ns}	2.69**	1.30^{ns}	0.21^{ns}	1.54**	3.48**
2*7	0.58^{ns*}	0.52^{ns}	7.15**	17.36**	1.04**	0.62**	0.86^{ns}	3.77**	0.91^{ns}	0.05^{ns}	1.67**	3.84**
2*8	0.16^{ns*}	-0.98**	4.67**	12.14**	-0.08^{ns}	-0.29^{ns}	-2.00^{ns}	0.89**	0.98^{ns}	0.30^{ns}	0.94 **	2.87**
2*9	0.88**	1.05**	5.12**	-7.08**	0.16^{ns*}	0.49**	-0.02^{ns}	-4.32**	0.93^{ns}	0.13^{ns}	1.29**	2.99**
2*10	2.13**	1.13**	-6.19**	-19.75**	0.42**	0.03^{ns}	-0.43^{ns}	-5.48**	0.90^{ns}	-0.65**	-3.44**	-6.61**
3*4	0.64^{ns*}	-0.62^{ns}	7.04**	4.67**	-0.53**	-0.31^{ns}	3.65^{ns}	4.99**	-1.49*	0.05^{ns}	2.67**	1.42**
3*5	0.53^{ns*}	0.71**	1.62**	-3.50**	-0.04^{ns}	-0.15^{ns}	-0.74^{ns}	-3.58**	-1.32*	0.30^{ns}	-1.16**	-1.80**
3*6	0.44^{ns*}	1.35**	-3.10**	-18.55**	0.30^{ns*}	0.53**	-0.56^{ns}	-4.74**	-1.65**	-0.59**	-2.94**	-4.80**
3*7	1.19**	1.44**	9.12**	13.45**	0.92**	1.23**	1.48^{ns}	1.85**	-1.65**	-0.09^{ns}	2.20**	3.23**
3*8	-1.56**	-0.56^{ns}	9.31**	24.89**	-1.12**	-0.98**	1.05^{ns}	5.24**	-1.21**	0.16^{ns}	2.23**	4.92**
3*9	-1.84**	0.13^{ns}	3.91**	9.34**	-0.71**	-0.40**	-0.26^{ns}	2.69**	-1.74**	-0.01^{ns}	2.48**	2.73**
3*10	-1.26**	-1.45**	-1.55**	2.67^{ns*}	-0.02^{ns}	0.07^{ns}	-1.34^{ns}	0.61^{ns}	-1.43**	-0.12^{ns}	-1.58**	0.45^{ns}
4*5	1.27**	1.63**	-1.99**	-9.03**	0.29^{ns}	0.18^{ns}	-0.75^{ns}	-4.45**	0.93^{ns}	0.46**	-1.80**	-1.88**
4*6	-1.42**	-0.40^{ns}	4.29**	5.59**	-1.37**	-0.94**	0.64^{ns}	0.62^{ns}	-1.52**	0.24^{ns}	1.09**	3.12 **
4*7	1.33**	0.35^{ns}	5.84**	11.25**	0.19^{ns}	-0.24^{ns}	2.24^{ns}	3.54**	0.90^{ns}	0.41**	2.56**	3.81**
4*8	1.58**	0.02^{ns}	-2.30**	-3.97**	0.21^{ns}	-0.02^{ns}	-1.95^{ns}	0.61^{ns}	0.94^{ns}	-0.34^{ns}	-0.74**	-0.83^{ns}
4*9	1.30**	1.05**	3.15**	11.81**	0.55**	0.23^{ns}	0.30^{ns}	1.84**	0.95^{ns}	0.16^{ns}	-0.49^{ns}	2.98**
4*10	-1.12**	-1.87**	-6.16**	-6.53**	-0.52**	-0.53**	-1.61^{ns}	-0.42^{ns}	0.82^{ns}	-1.29**	-1.21**	-0.30^{ns}

Table 6. Contd.

5*6	-2.31**	-2.40**	1.2 ns*	11.09**	-0.84**	-1.51**	0.77 ns	1.99**	1.35*	-0.51**	1.08**	2.56**
5*7	1.77**	2.35**	-1.91*	-5.25**	0.88**	0.82**	0.41 ns	-1.43**	0.93 ns	-0.01 ns	-0.60 ns	-0.08 ns
5*8	1.69**	2.02**	-2.05**	-9.14**	1.17**	1.44**	-0.21 ns	-2.27**	0.91 ns	0.91**	-0.91**	-1.38*
5*9	1.08**	-0.62 ns	6.73**	0.31 ns*	-0.09 ns	-0.81**	0.97 ns	-0.26 ns	0.98 ns	0.07 ns	2.01**	1.09 ns
5*10	-3.67**	-1.54**	0.09 ns	-7.36**	-1.16**	-0.97**	0.86 ns	1.02**	-0.18 ns	-0.04 ns	-0.05 ns	-2.19**
6*7	1.08**	-0.34 ns	1.70**	-9.64**	-0.05 ns	0.03 ns	0.66 ns	0.59 ns	-1.68**	-0.23 ns	-0.38 ns	-2.01**
6*8	2.33**	2.66**	-3.44**	-1.86 ns*	-0.09 ns	1.15**	-1.20 ns	-2.10**	-1.24*	0.68**	-1.35**	-1.72**
6*9	-1.62**	1.02**	-9.66**	-10.08**	-0.22 ns	0.24 ns	-1.22 ns	-1.52**	-1.43*	0.18 ns	-1.10**	-4.24**
6*10	-1.70**	-1.90**	-2.96**	0.25 ns*	-0.63**	-0.79**	0.21 ns	0.69 ns	-1.79**	-0.93**	-0.49ns	-1.86**
7*8	-2.92**	-3.26**	-8.21**	-13.53**	-1.11**	-1.45**	-2.03 ns	-0.52 ns	0.84 ns	-0.48*	-0.88**	-3.69**
7*9	0.20 ns*	1.23**	7.77**	16.41**	0.00 ns*	-0.40*	-2.18 ns	-2.83**	0.98 ns	-0.32 ns	-2.63**	-4.22**
7*10	2.05**	3.19**	1.26 ns	-4.08**	0.60**	0.71**	0.31 ns	-2.60**	0.82 ns	0.57**	-1.35**	1.84**
8*9	0.38 ns*	-0.23 ns	-1.91**	-5.97**	-0.21 ns	0.02 ns	-1.17 ns	1.19**	0.62 ns	-0.40*	1.06**	-0.19 ns
8*10	0.70 ns*	1.81**	2.88**	12.30**	0.22 ns*	-0.14 ns	-4.01 ns	-2.00**	0.60 ns	-0.18 ns	-1.99**	-1.47**
9*10	1.36**	1.55**	2.56**	15.14**	0.62**	1.28**	3.00 ns	5.48**	0.87 ns	0.66**	2.92**	3.67**
SE (sij)	1.00**	0.82**	3.39**	6.60**	0.20**	0.23**	0.42**	1.01**	0.07**	0.11**	0.49**	1.80**
SE (sij-sik)	2.16**	1.77**	7.32**	14.25**	0.43**	0.50**	0.92**	2.19**	0.15**	0.25**	1.06**	3.88**
SE (sij-skl)	1.97**	1.61**	6.65**	12.96**	0.39**	0.45**	0.83**	1.99**	0.14**	0.23**	0.96**	3.53**

DAP, Days after planting; ns, * and **: non-significant, significant at the 0.05 and 0.01 levels respectively.

Table 7. Quadratic components of GCA ability, SCA ability, narrow and broad sense heritability and ratio of GCA/SCA.

Quadratic components	Plant height				Collar diameter				No. of leaves			
	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP
σ^2_{SCA}	2.75	2.11	29.43	124.64	0.18	0.33	1.44	7.26	0.02	0.11	2.57	9.19
σ^2_{GCA}	0.09	0.44	3.41	5.48	0.04	0.08	0.42	0.10	0.02	0.03	0.22	0.62
σ^2_D	11.01	8.44	117.72	498.55	0.72	1.33	5.77	29.04	0.07	0.45	10.27	36.77
σ^2A	0.34	1.76	13.64	21.94	0.15	0.32	1.70	0.42	0.06	0.13	0.87	2.50
EMS	3.54	2.91	11.96	23.33	0.71	0.81	1.50	3.58	0.25	0.41	1.75	6.35
h^2_b	76.24	77.81	91.66	95.71	55.03	67.15	83.28	89.16	33.82	58.59	86.42	86.08
h^2_n	2.31	13.45	9.52	4.03	9.43	13.07	18.90	1.26	16.18	12.79	6.77	5.48
GCA/SCA	0.02	0.12	0.09	0.04	0.09	0.12	0.16	0.01	0.14	0.11	0.06	0.05

DAP, Days to flowering; σ^2_{SCA}: SCA variance, σ^2_{GCA}: GCA variance, σ^2_D: dominant variance, σ^2_A: additive variance, h^2_b: broad sense heritability, h^2_n: narrow sense heritability.

diameter at 15, 30, 60 and 90 days after planting (Table 5).

Estimates of SCA effects for collar diameter were significantly positive in some hybrids as shown in Table 6. The large size of SCA values suggested that parents for these hybrids were more diverse in collar diameter than the parents of other hybrids. So hybrids having large SCA values may be developed as candidate hybrid varieties. Hybrids 1×6, 5×8, 1×8 and 9×10 gave the highest positive significant SCA effects and hybrids 4×6, 1×5, 8×10 and 2×10 gave the highest negative significant SCA effects for collar diameter at 15, 30, 60 and 90 days after planting respectively (Table 6).

The estimates for broad sense heritability for the studied genotypes, high heritability values for collar diameter were found at 15, 30, 60 and 90 days after planting, ranging from 76.24 to 95.71%. The narrow sense heritability was low for plant height at 15, 30, 60 and 90 days after planting and ranged from 2.31 to 13.45% (Table 7). Broad sense heritability was higher than narrow sense ones for collar diameter. This difference indicated the influence of non-additive gene actions.

The heterosis for collar diameter at 15, 30, 60 and 90 days after planting ranged from -27.61 to 46.77, -24.33 to 23.80, -27.31 to 27.05 and -33.47 to 35.12% respectively

Table 8. Heterosis (MP) and heterobeltiosis (BP) for plant height in hybrids of *Jatropha* in nursery stage.

Hybrids	Plant height							
	15 DAP		30 DAP		60 DAP		90 DAP	
	%MP	%BP	%MP	%BP	%MP	%BP	%MP	%BP
1*2	-2.1	-7.8	-4.8	-4.8	-14.7	-20.1	-20.1	-30.2
1*3	1.0	0.0	2.5	0.0	-0.5	-15.4	-4.7	-16.6
1*4	-6.4	-13.7	-13.3	-16.1	-33.1	-36.2	-10.9	-25.4
1*5	-45.8	-48.2	-26.5	-30.7	4.7	-14.6	0.3	-8.3
1*6	-12.6	-13.5	-18.3	-21.0	-8.9	-17.7	6.0	-2.2
1*7	-8.4	-25.5	-11.5	-25.8	-29.3	-42.3	-36.4	-39.2
1*8	-6.7	-17.7	-9.1	-19.4	-1.7	-11.5	-6.3	-8.8
1*9	-15.5	-19.6	-3.6	-12.9	-28.7	-29.2	-35.2	-37.0
1*10	12.9	11.8	4.2	0.0	2.6	-8.5	18.2	14.9
2*3	1.7	-5.2	-14.5	-16.6	-26.5	-40.8	-30.6	-45.8
2*4	10.0	7.5	-7.5	-10.4	-27.6	-35.1	-26.5	-44.7
2*5	-36.6	-42.9	-31.6	-35.5	-23.8	-40.9	-28.6	-42.2
2*6	-21.7	-26.9	-21.7	-24.2	-16.5	-28.9	-6.3	-23.6
2*7	11.7	-4.4	-5.8	-21.0	9.1	-15.4	7.6	-9.5
2*8	2.4	-4.4	-14.6	-24.2	0.4	-14.8	4.1	-11.2
2*9	5.5	4.4	1.8	-8.1	-3.3	-10.1	-27.4	-38.0
2*10	13.7	8.0	-0.8	-4.8	-29.1	-40.3	-44.8	-52.9
3*4	-3.2	-11.5	-4.3	-5.1	21.5	7.6	17.8	11.8
3*5	-18.5	-21.4	-1.8	-5.1	14.5	8.8	-12.6	-16.7
3*6	-7.7	-7.7	2.6	1.7	-11.2	-17.1	-37.7	-41.2
3*7	11.9	-9.6	10.9	-5.1	38.7	31.9	22.3	11.5
3*8	-12.1	-23.1	-4.7	-13.6	32.3	24.0	49.8	34.5
3*9	-14.3	-19.2	4.6	-3.4	-13.2	-25.8	12.7	1.2
3*10	-9.8	-11.5	-6.9	-8.5	-5.7	-10.8	1.0	-9.4
4*5	-3.0	-14.3	0.9	-1.7	-10.0	-23.7	-31.6	-38.0
4*6	-13.7	-21.2	-8.6	-8.6	-0.5	-5.9	6.9	-3.9
4*7	22.7	7.0	2.0	-12.1	12.0	-5.1	12.9	-1.8
4*8	17.1	11.6	-3.8	-12.1	-13.5	-18.6	-12.6	-25.2
4*9	12.4	8.7	7.4	0.0	-4.1	-7.8	12.6	-3.5
4*10	-3.2	-10.0	-11.3	-12.1	-28.2	-33.1	-21.5	-32.8
5*6	-33.3	-35.7	-23.9	-25.9	-3.7	-14.3	6.3	5.2
5*7	2.3	-19.6	9.3	-3.6	-6.1	-6.1	-30.2	-33.3
5*8	-3.2	-17.9	2.9	-3.6	-8.6	-18.3	-31.5	-35.7
5*9	-7.8	-16.1	-6.7	-10.9	11.4	-8.6	-18.4	-23.4
5*10	-34.0	-37.5	-14.3	-15.8	-6.5	-15.7	-31.5	-35.7
6*7	4.8	-15.4	-6.0	-19.0	-3.7	-14.3	-32.7	-35.2
6*8	7.7	-5.8	7.6	-1.7	-20.6	-21.0	-12.4	-17.0
6*9	-18.4	-23.1	3.7	-3.5	-39.9	-45.3	-32.1	-35.7
6*10	-17.7	-19.2	-14.8	-15.5	-23.7	-24.8	-11.7	-16.4
7*8	-15.5	-23.1	-22.2	-27.1	-30.1	-37.5	-37.5	-38.6
7*9	5.1	-10.9	-2.2	-10.0	-31.4	-43.8	-47.0	-48.0
7*10	22.0	0.0	21.2	5.3	-4.4	-13.7	-23.8	-25.2
8*9	3.5	-4.4	0.0	-2.0	-15.5	-23.4	-22.8	-22.8
8*10	-3.4	-14.0	-6.7	-14.0	-18.5	-19.2	-32.8	-32.8
9*10	8.3	4.0	12.2	5.3	-7.8	-17.2	11.1	11.1
MIN	-45.8	-48.2	-31.6	-35.5	-39.9	-45.3	-47.0	-52.9
MAX	22.7	11.8	21.2	5.3	38.7	31.9	49.8	34.5

DAP, Days to flowering.

(Table). The highest heterosis for collar diameter at 15, 30, 60 and 90 days after planting were found in hybrids 1×5, 1×5, 8×10 and 2×10 respectively. Some hybrids did better than the average plant height of their parents. This showed that the existence of dominance or non-additive gene actions might be present.

The heterobeltiosis of collar diameter at 15, 30, 60 and 90 days after planting ranged from -33.15 to 32.19, -27.05 to 13.25, -32.64 to 18.68 and -37.03 to 34.88% respectively. The highest heterobeltiosis value was obtained in the cross between parents 7×8, 1×5, 7×9 and 1×9 for collar diameter at 15, 30, 60 and 90 days after planting respectively (Table). The percentages of heterosis and heterobeltiosis for plant height at 15, 30, 60 and 90 days after planting in some hybrids were significantly higher indicating that the high genetic diversity existed among the parents. The cross of parents 2×7 and 3×4 gave both highest heterosis and heterobeltiosis.

Number of leaves

Significant differences between genotypes with respect to the number of leaves at 15, 30, 60 and 90 days after planting were observed. Among parents the highest number of leaves was recorded in My2.2 (4.0), My2.2 (7.0), In2.1 (13.3) and Id1.1 (20.3) for after 15, 30, 60 and 90 days after planting respectively. Also, the lowest number of leaves was recorded in In1.1 (2.7), In1.1 (5.0), In1.1 (7.0) and Id1.1 (7.7) after 15, 30, 60 and 90 days after planting respectively. Among hybrids the highest number of leaves was recorded in 2×3 (4.0), 9×10 (6.7), 9×10 (12.3) and 1×10 (20.3) for after 15, 30, 60 and 90 days after planting respectively. The lowest number of leaves was recorded in 1×5 (2.7), 2×5 (4.0), 7×9 (5.7) and 3×6 (5.7) after 15, 30, 60 and 90 days after planting respectively (Table 3.).

Results of analysis of variance (ANOVA) on number of leaves at 15, 30, 60 and 90 days after planting indicated significant variation among parents and hybrids at $P \leq 0.01$ (Table 4). Variance of GCA and SCA were significant at 1% probability for number of leaves in nursery stage except SCA for number of leaves after 15 days after planting. The low ratio of GCA/SCA revealed the non-additive effects and played a more important role than additive effects (Table 4). The ratio of GCA/SCA ranged from 0.05 to 014.

Parents Ph1.2, Ph1.2, In2.1 and My2.1 had the highest positive GCA effects for number of leaves presented at 15, 30, 60 and 90 days after planting, respectively. While, parents In1.1, In1.1, In1.1 and Id1.1 presented the highest negative GCA effect for number of leaves at 15, 30, 60 and 90 days after planting respectively (Table 5).

Estimates of SCA effects for number of leaves were significantly positive in some hybrids as shown in Table 6. Hybrids 5×7, 5×8, 9×10 and 1×10 gave the highest positive significant SCA effects while hybrids 6×10, 2×5, 2×10 and 2×10 gave highest negative significant SCA effects for number of leaves at 15, 30, 60 and 90 days after planting respectively (Table 6).

Estimates for broad sense heritability of the studied genotypes displayed high heritability values for number of leaves at 15, 30, 60 and 90 days after planting, ranging from 33.82 to 86.08%. Also, narrow sense heritability was low for number of leaves at 15, 30, 60 and 90 days after planting and ranged from 5.45 to 16.18% (Table 7). Broad sense heritability were higher than narrow sense ones for number of leaves. This difference presented the influence of non-additive gene actions.

The heterosis for number of leaves at15, 30, 60 and 90 days after planting ranged from -30.43 to 26.32, -33.33 to 12.50, -49.33 to 26.92 and -52.49 to 43.8% respectively (Table 10). The highest heterosis for number of leaves at 15, 30, 60 and 90 days after planting were found in the cross between parents 1×7, 5×8, 1×5 and 3×8 respectively. The heterobeltiosis of number of leaves at 15, 30, 60 and 90 days after planting ranged from -33.33 to 9.09, -36.84 to 5.88, -52.50 to 17.86 and -60.66 to 32.61% respectively (Table 10). The highest heterobeltiosis value was obtained in hybrids 1×7, 5×8, 1×5 and 1×10 for number of leaves at 15, 30, 60 and 90 days after planting respectively.

Phenotypic correlation between characters

Phenotypic correlations between traits of hybrids are showed in Table 11. Phenotypic correlations between plant height (at 15, 30, 60 and 90 days after planting) were positive and highly significant with collar diameter (at 15, 30, 60 and 90 days after planting) and number of leaves (at 15, 30, 60 and 90 days after planting) in the same time; also collar diameter (at 15, 30, 60 and 90 days after planting) revealed highly significant positive relationship with number of leaves (at 15, 30, 60 and 90 days after planting) in the same time. Positive significant correlations were observed between all traits with one time difference in nursery stage.

DISCUSSION

Ten superior parents were crossed in a diallel manner to produce 45 hybrids. These hybrids and their parents were evaluated for combining abilities and heterosis in green house. Analyses of variance presented significant differences among parents and hybrids for plant height, collar diameter and number of leaves in nursery stage. Ramezanpour et al. (2010) reported that highly significant variation due to general combining ability (GCA) and also specific combining ability (SCA) indicated the importance of additive as well as non additive types of gene action in inheritance of characters.

Table 9. Heterosis (MP) and heterobeltiosis (BP) for collar diameter in hybrids of *Jatropha* in nursery stage.

Hybrids	Collar diameter							
	15 DAP		30 DAP		60 DAP		90 DAP	
	%MP	%BP	%MP	%BP	%MP	%BP	%MP	%BP
1*2	19.5	7.7	8.9	1.5	-14.2	-22.2	-4.8	-13.2
1*3	8.9	6.3	2.2	-0.7	4.6	4.1	7.4	5.3
1*4	8.3	3.0	-1.4	-3.9	-14.0	-19.3	-1.1	-2.9
1*5	-27.6	-29.3	-24.3	-27.1	12.3	8.5	8.0	-1.6
1*6	14.1	5.1	2.5	-1.0	-4.6	-9.2	-5.8	-14.9
1*7	0.3	-17.6	-2.7	-14.8	-2.2	-13.6	-21.6	-23.7
1*8	-8.3	-9.3	-4.5	-9.2	-17.2	-19.5	-19.9	-21.1
1*9	-5.5	-5.5	-4.3	-5.9	-3.0	-9.6	-31.6	-37.0
1*10	4.3	2.1	5.4	2.1	5.7	-1.9	1.7	-8.0
2*3	14.1	0.7	12.8	2.4	-5.5	-14.7	-18.2	-26.7
2*4	21.3	4.5	23.8	12.7	-10.5	-13.7	-22.2	-30.2
2*5	-14.5	-24.6	2.3	-7.9	-13.3	-23.8	-17.2	-17.2
2*6	5.0	-12.0	4.0	-6.2	-3.4	-8.3	0.3	-0.8
2*7	46.8	32.2	21.0	13.3	-1.3	-19.9	6.8	-5.0
2*8	2.5	-6.7	3.4	1.2	-16.8	-22.6	-7.8	-14.7
2*9	11.6	0.6	14.9	8.8	-9.5	-12.2	-29.9	-30.6
2*10	16.1	2.6	8.6	-1.7	-13.3	-15.6	-33.5	-34.1
3*4	-9.9	-12.4	-2.8	-3.1	27.1	18.7	35.1	34.9
3*5	-10.0	-10.0	-6.7	-7.5	-0.3	-3.2	-18.8	-27.3
3*6	-2.7	-8.3	4.5	3.8	-2.3	-7.4	-20.5	-29.5
3*7	25.3	1.1	19.4	2.1	17.4	4.2	13.3	12.5
3*8	-25.2	-27.8	-11.1	-17.8	14.7	11.0	29.0	24.6
3*9	-14.2	-16.2	-2.4	-6.6	-1.0	-8.2	14.4	3.3
3*10	-2.9	-3.1	2.4	2.1	-9.8	-16.6	-0.6	-11.7
4*5	-3.3	-5.9	-5.0	-6.2	-5.6	-14.2	-25.5	-33.2
4*6	-25.4	-27.8	-12.5	-13.4	0.7	-0.9	2.0	-9.4
4*7	12.2	-11.4	-0.6	-14.7	16.0	-3.0	19.4	18.3
4*8	-2.1	-7.9	-2.1	-9.1	-11.2	-14.4	-4.0	-7.2
4*9	7.3	2.0	2.7	-1.4	-2.2	-2.9	7.6	-2.6
4*10	-9.2	-11.9	-5.6	-6.2	-15.6	-16.6	-2.3	-13.0
5*6	-25.3	-29.6	-23.8	-24.0	4.5	-3.7	-0.8	-1.8
5*7	16.9	-5.8	5.7	-10.3	5.7	-3.6	-15.9	-25.1
5*8	5.7	2.1	8.2	-0.7	3.2	-3.0	-20.2	-26.3
5*9	-10.5	-12.6	-14.4	-18.8	5.0	-5.2	-10.6	-11.4
5*10	-27.0	-27.2	-15.7	-16.1	2.7	-7.7	-4.3	-5.1
6*7	0.9	-22.2	1.0	-14.1	3.4	-12.5	-8.2	-19.1
6*8	-12.2	-19.9	9.5	0.7	-6.9	-9.0	-15.9	-23.0
6*9	-10.1	-17.1	1.3	-3.8	-12.5	-14.4	-12.6	-14.4
6*10	-15.8	-20.8	-9.7	-10.0	-4.8	-7.3	-2.5	-2.6
7*8	-19.3	-33.2	-17.4	-24.2	-11.7	-23.8	-8.6	-12.3
7*9	8.4	-11.0	-0.9	-11.8	-19.0	-32.6	-19.4	-27.7
7*10	19.9	-3.2	12.4	-4.2	-1.9	-18.7	-17.1	-26.8
8*9	-10.0	-11.0	0.0	-3.4	-7.3	-11.3	-1.2	-7.8
8*10	-2.7	-5.8	-2.1	-9.7	-27.3	-30.7	-14.8	-21.9
9*10	8.1	5.8	15.4	10.0	12.1	11.6	17.6	15.4
MIN	-27.6	-33.2	-24.3	-27.1	-27.3	-32.6	-33.5	-37.0
MAX	46.8	32.2	23.8	13.3	27.1	18.7	35.1	34.9

DAP, Days to flowering.

Table 10. Heterosis (MP) and heterobeltiosis (BP) for number of leaves in hybrids of *Jatropha* in nursery stage.

Hybrids	Number of leaves							
	15 DAP		30 DAP		60 DAP		90 DAP	
	%MP	%BP	%MP	%BP	%MP	%BP	%MP	%BP
1*2	4.4	0.0	-2.9	-10.5	-23.5	-35.0	-17.8	-27.9
1*3	-4.4	-8.3	5.9	0.0	-17.5	-25.7	29.6	0.0
1*4	4.4	0.0	-11.8	-16.7	-23.6	-25.0	1.5	-23.9
1*5	-30.4	-33.3	-15.2	-17.7	26.9	17.9	2.5	-10.9
1*6	4.4	0.0	0.0	-5.6	20.0	17.9	38.3	21.7
1*7	26.3	9.1	-16.1	-18.8	6.1	-7.1	-24.4	-32.6
1*8	20.0	9.1	-22.6	-25.0	-17.2	-20.0	-27.3	-30.4
1*9	4.4	0.0	-17.7	-22.2	-5.3	-6.9	-41.3	-41.3
1*10	4.4	0.0	-8.1	-19.1	1.6	-8.6	40.2	32.6
2*3	0.7	0.7	-2.4	-4.9	-39.4	-43.2	-30.0	-50.7
2*4	-1.4	-1.4	-3.4	-5.9	-29.7	-41.1	-29.1	-51.2
2*5	-8.3	-8.3	-33.3	-36.8	-18.8	-35.0	-39.0	-52.5
2*6	0.0	0.0	-2.7	-5.3	-1.5	-17.5	4.2	-18.0
2*7	10.0	-8.3	-5.9	-15.8	1.6	-22.5	7.2	-14.8
2*8	-14.3	-25.0	0.0	-10.5	-20.0	-30.0	-2.9	-18.0
2*9	0.0	0.0	-2.7	-5.3	1.5	-12.5	-40.2	-47.5
2*10	0.0	0.0	-20.0	-23.8	-49.3	-52.5	-52.9	-60.7
3*4	0.0	0.0	0.0	0.0	12.9	0.0	37.5	32.0
3*5	0.0	0.0	2.9	0.0	-25.4	-37.1	-22.0	-32.4
3*6	0.0	0.0	-11.1	-11.1	-41.9	-48.6	-43.3	-51.4
3*7	0.0	-16.7	-3.0	-11.1	-10.7	-28.6	37.7	16.7
3*8	14.3	0.0	3.0	-5.6	1.5	-5.7	43.3	14.3
3*9	-8.3	-8.3	0.0	0.0	-3.1	-11.4	7.0	-17.4
3*10	0.0	0.0	-7.7	-14.3	-34.3	-34.3	12.1	-9.8
4*5	0.0	0.0	2.9	0.0	-29.4	-33.3	-29.8	-41.2
4*6	0.0	0.0	0.0	0.0	3.7	3.7	10.3	-8.6
4*7	0.0	-16.7	3.0	-5.6	25.0	11.1	39.0	13.9
4*8	14.3	0.0	-9.1	-16.7	-22.8	-26.7	-13.9	-33.3
4*9	0.0	0.0	0.0	0.0	-7.1	-10.3	4.4	-21.7
4*10	0.0	0.0	-28.2	-33.3	-29.0	-37.1	0.0	-22.0
5*6	0.0	0.0	-14.3	-16.7	-9.8	-14.8	4.4	2.9
5*7	20.0	0.0	-6.3	-11.8	-15.6	-20.8	-25.7	-27.8
5*8	14.3	0.0	12.5	5.9	-25.9	-33.3	-31.6	-38.1
5*9	-8.3	-8.3	-2.9	-5.6	9.4	0.0	-17.5	-28.3
5*10	-16.7	-16.7	-10.5	-19.1	-18.6	-31.4	-30.7	-36.6
6*7	0.0	-16.7	-9.1	-16.7	-12.5	-22.2	-29.6	-30.6
6*8	14.3	0.0	9.1	0.0	-29.8	-33.3	-27.3	-33.3
6*9	0.0	0.0	0.0	0.0	-14.3	-17.2	-50.6	-56.5
6*10	-8.3	-8.3	-23.1	-28.6	-22.6	-31.4	-21.1	-26.8
7*8	5.9	0.0	-13.3	-13.3	-25.5	-36.7	-41.0	-45.2
7*9	0.0	-16.7	-9.1	-16.7	-32.0	-41.4	-48.8	-54.4
7*10	20.0	0.0	0.0	-14.3	-32.1	-45.7	9.1	2.4
8*9	14.3	0.0	-9.1	-16.7	-8.5	-10.0	-22.7	-26.1
8*10	14.3	0.0	-11.1	-23.8	-41.5	-45.7	-20.5	-21.4
9*10	-8.3	-8.3	2.6	-4.8	15.6	5.7	10.3	4.4
MIN	-30.4	-33.3	-33.3	-36.8	-49.3	-52.5	-52.9	-60.7
MAX	26.3	9.1	12.5	5.9	26.9	17.9	43.3	32.6

DAP, Days to flowering.

Table 11. Coefficients of phenotypic correlation between traits of Jatropha in diallel crosses involving ten parents in nursery stage.

Traits		Plant height			Collar diameter				No. of leaves			
		30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP	15 DAP	30 DAP	60 DAP	90 DAP
Plant height	15 DAP	0.81**	0.23^{ns}	0.07^{ns}	0.75**	0.74**	0.13^{ns}	0.03^{ns}	0.53**	0.55**	0.07^{ns}	0.14^{ns}
	30 DAP		0.35**	0.14^{ns}	0.61**	0.71**	0.22^{ns}	0.06^{ns}	0.53**	0.64**	0.2^{ns}	0.15^{ns}
	60 DAP			0.75**	0.14^{ns}	0.08^{ns}	0.47**	0.38**	0.04^{ns}	0.35**	0.70**	0.66**
	90 DAP				-0.01^{ns}	-0.01^{ns}	0.34**	0.61**	-0.1^{ns}	0.27*	0.72**	0.89**
Collar diameter	15 DAP					0.83**	0.08^{ns}	-0.01^{ns}	0.52**	0.45**	0.03^{ns}	0.11^{ns}
	30 DAP						0.12^{ns}	0.04^{ns}	0.57**	0.56**	0.06^{ns}	0.01^{ns}
	60 DAP							0.22^{ns}	0.22^{ns}	0.07^{ns}	0.38**	0.19^{ns}
	90 DAP								-0.06	0.40**	0.60**	0.55**
No. of leaves	15 DAP									0.32*	0.02^{ns}	-0.07^{ns}
	30 DAP										0.39**	0.25^{ns}
	60 DAP											0.65**

DAP, Days after planting; ^{ns}, * and **: non-significant, significant at 0.05 and 0.01 levels respectively.

Estimates of GCA effects indicated that only one parent, namely Ph1.2 showed significant positive GCA effects for plant height, collar diameter and number of leaves at 15, 30, 60 and 90 days after planting except number of leaves after 90 days. Also Id1.1 gave significant GCA effects for plant height, collar diameter and number of leaves, indicating that it is a good general combiner for these traits and should be used in breeding program.

Analysis of specific combining ability in this study exhibited that some hybrids presented significant SCA effects for each trait, but none presented the best SCA effect simultaneously. According to Sprague and Tatum (1942) the SCA is controlled by non additive gene action. The SCA effect is an important criterion for the evaluation of crosses. Machikowa et al*.* (2011) reported that SCA were highly significant for plant height in sunflower and revealed that non additive effects were important for plant height. This report shows a similar trend with our study.

In our study the low ratio of GCA/SCA were observed for plant height, collar diameter and number of leaves. Also, Vaghela et al. (2011) and Sabaghnia et al. (2010) reported the variance due to SCA was higher than that of variance due to GCA for some characters. This revealed the role of non additive gene action in the inheritance of traits. This is in agreement with our study. Rêgo et al*.* (2009) and reported low GCA/SCA ratio for pepper plant canopy width and show non additive effects is more important than additive effects. Also, Tchiagam et al. (2011) reported that the values of GCA /SCA ratios and the variance components showing the preponderance of SCA for studied traits, demonstrated the higher influence of non additive gene effects in cowpea.

High broad sense heritability was observed for plant height, collar diameter and number of leaves in present study. Ginwal et al*.* (2005) presented high broad sense heritability for height (89%) in plants evaluated at six months of age, and heritability of 97% for 24-month old plants. Ginwal et al*.* (2004) observed an increase in heritability related to height of the same plants from one year to another. Also, Rao et al*.* (2008) showed high broad sense heritability (88%) for plant height in 34 month old plants. The high size values of broad sense heritability were associated with higher selective precision, revealing the possibility of high accuracy in the selection.

Cilas et al. (1998) reported that broad sense heritability values for caller diameter is significantly greater than zero and greater than the narrow sense heritability which is not significantly greater than zero for coffee tree (*Coffea Arabica*). Genotypic variance was observed very close to phenotypic variance accompanied by very high broad sense heritability in collar diameter of *J. curcas* under nursery condition (Ginwal et al., 2005). High broad sense heritability was computed by Tenkouano et al. (2010) in *Musa*. This indicated that phenotypic selection may be effective and that there may be little or no cropping system effect.

In the present study, low narrow sense heritability were observed for plant height, collar diameter and number of leaves. The low narrow sense heritability of some traits was also reported in other crops. On the other hand, high estimates of broad sense heritability for these traits revealed that other types of genetic effects such as dominance or epitasis might be involved in their variation (Bolanos-Aguilar et al., 2001; Pahlavani et al., 2007).

High heterosis and heterobeltiosis value were observed in our study. Sabaghnia et al. (2010) observed significant positive heterosis effects involving mid-parent and high parent heterosis for studied traits but for different number of hybrids. Parental genotypes with best GCA and its utilization as one of the parents produced superior hybrid combinations having valuable SCA determination for seed oil yield. The result of this study could be an excellent indicator to recognize the most promising genotypes to be exploited either as F1 hybrids or as a resource population for further selection in *J. curcas* L. improvement.

Parents Ph1.2 and In2.1 showed positive GCA effect for three characters. Finally, the hybrids 3×8, 9×10 and 1×10 showed positive SCA effects for plant height, collar diameter and number of leaves. Heterosis and heterobeltiosis were found higher for those characters. Therefore, these parents and hybrids could be used for future breeding program. To our knowledge, this is the first report about dialle mating design in *Jatropha.* Therefore, the outcome of this part of the study could not compare to any other source in the *Jatropha*.

REFERENCES

Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008). *Jatropha* bio-diesel production and use. Biomass Bioenerg. 32(12):1063-1084

Amiri OH, Shariati F, Asadi M, Tusi F, Kamyab F (2007). Study of heterosis and combining ability of yield and yield components in spring rapeseed.

Banumathy S, Patil S (2000). Diallel analysis for seed cotton yield and its components in cotton. Ann. Plant Phys. 14(1):56-61

Basha S, Francis G, Makkar H, Becker K, Sujatha M (2009). A comparative study of biochemical traits and molecular markers for assessment of genetic relationships between *Jatropha curcas* L. germplasm from different countries. Plant Sci. 176(6):812-823.

Basha S, Sujatha M (2007). Inter and intra-population variability of *Jatropha curcas* (L.) characterized by RAPD and ISSR markers and development of population-specific SCAR markers. Euphytica 156(3):375-386.

Bolanos-Aguilar E, Huyghe C, Djukic D, Julier B, Ecalle C (2001). Genetic control of alfalfa seed yield and its components. Plant Breed. 120(1):67-72.

Cilas C, Bouharmont P, Boccara M, Eskes A, Baradat P (1998). Prediction of genetic value for coffee production in *Coffea arabica* from a half-diallel with lines and hybrids. Euphytica 104(1):49-59.

Divakara B, Upadhyaya H, Wani S, Gowda C (2010). Biology and genetic improvement of *Jatropha curcas* L.: A review. Appl. Energy 87(3):732-742.

Fangrui M, Milford AH (1999). Biodiesel production: a review. Bioresour. Technol. 70(1):1-15.

Ganesh RS, Parthiban K, Senthil Kumar R, Thiruvengadam V, Paramathma M (2008). Genetic diversity among *Jatropha* species as revealed by RAPD markers. Genet. Resour. Crop Evol. 55(6):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(1):113-122.

Ginwal H, Phartyal S, Rawat P, Srivastava R (2005) Seed source variation in morphology, germination and seedling growth of *Jatropha curcas* Linn. in central India. Silvae Genetica 54(2):76-79.

Ginwal H, Rawat P, Srivastava R (2004). Seed source variation in growth performance and oil yield of *Jatropha curcas* Linn. in central India. Silvae Genetica 53(4):186-191

Gohil R, Pandya J (2008). Genetic diversity assessment in physic nut (*Jatropha curcas* L.). Int. J. Plant Prod. 2(4):321-326.

Griffing B (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9(4):463-493.

Heller J (1996). Physic nut Jatropha curcas L. Promoting the conservation and use of underutilized and neglected crops, 1. Rome: Institute of Plant Genetics and Crop Plant Research.

Johnson G, King J (1998). Analysis of half diallel mating designs. Silvae Genet. 47:74-79

Kaushi K, Kumar S (2004). *Jatropha curcas* L. Silviculture and Uses. Agrobios (India), Jodhpur.

Kumar A, Sharma S (2008). An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): A review. Ind. Crops Prod. 28(1):1-10.

Machikowa T, Saetang C, Funpeng K (2011). General and Specific Combining Ability for Quantitative Characters in Sunflower. J. Agric. Sci. 3(1):91.

Marinkovic R (1984). The manner of inheriting the grain yield and some yield components in crossing various inbred sunflower lines. 127 p.

Mukherjee P, Varshney A, Johnson TS, Jha TB (2011). *Jatropha curcas*: A review on biotechnological status and challenges. Plant Biotechnol. Rep. 1-19.

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

Pahlavani M, Saeidi G, Mirlohi A (2007). Genetic analysis of seed yield and oil content in safflower using F1 and F2 progenies of diallel crosses. Int. J. Plant Prod. 1:129-140.

Rameeh V (2011a). Heritability and other genetic parameters assessment for flowering associated stress indices in oil seed rape varieties. Int. J. Plant Breed. Genet. 5(3):268-276

Rameeh V (2011b) Heterosis and Combining Ability Assessment for Phenological Traits, Plant Height and Grain Yield in Winter Spring Combinations of Rapeseed Varieties. Int. J. Plant Breed. Genet. 5(4):349-357.

Ramezanpour SS, Bastam SV, Soltanloo H, Kia S, Kalate M (2010). Estimation of Combining Abilities and Heterosis of'Septoria tritici'Blotch Resistance in Wheat Genotypes. Aust. J. Crop Sci. 4(7):480.

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(5):697-709.

Rêgo ER, do Rêgo MM, Finger FL, Cruz CD, Casali VWD (2009). A diallel study of yield components and fruit quality in chilli pepper (*Capsicum baccatum*). Euphytica. 168(2):275-287

Sabaghnia N, Dehghani H, Alizadeh B, Mohghaddam M (2010). Heterosis and combining ability analysis for oil yield and its components in rapeseed. Aust. J. Crop Sci. 4(6):390.

SAS S, Guide S (2005). Version 9.1. SAS Institute, Cary, NC.

Shabanimofrad M, Yusop MR, Saad MS, Megat PE, Wahab AB, Latif M (2011). Diversity of physic nut (*Jatropha curcas*) in Malaysia: Application of DIVA-geographic information system and cluster analysis. Aust. J. Crop Sci. 5(4):361-368.

Shah S, Sharma A, Gupta M (2004). Extraction of oil from *Jatropha curcas* L. seed kernels by enzyme assisted three phase partitioning. Ind. Crops Prod. 20(3):275-279.

Sharama S, Kumar N, Reddy MP (2011). Regeneration in *Jatropha curcas*: Factors affecting the efficiency of *in vitro* regeneration. Ind. Crops Prod. 1(34):943–951.

Sharma K, Kumhar J, Sastry E, Jakhar M (2011b). Diallel Analysis in Taramira (*Eruca sativa*). J. Oilseed Brassica 2(1):29-34.

Sharma, Sudheer Pamidimarri DVN, Vijay Anand KG, Reddy MP (2011a). Assessment of genetic stability in micropropagules of *Jatropha curcas* genotypes by RAPD and AFLP analysis. Ind. Crops Prod. 34(1):1003-1009.

Singh A, Reddy MP, Chikara J, Singh S (2010). A simple regeneration protocol from stem explants of *Jatropha curcas*--A biodiesel plant. Ind. Crops Prod. 31(2):209-213.

Sprague G, Tatum LA (1942). General vs. specific combining ability in single crosses of corn. J. Am. Soc. Agron. 34(10):923-932.

Tchiagam JBN, Bell JM, Nassourou AM, Njintang NY, Youmbi E (2011). Genetic analysis of seed proteins contents in cowpea (*Vigna unguiculata* L. Walp.). Afr. J. Biotechnol. 10(16):3077-3086

Tenkouano A, Oselebe HO, Ortiz R (2010) Selection Efficiency in'Musa L.'under Different Cropping Systems. Aust. J. Crop Sci. 4(2):74

Vaghela P, Thakkar D, Bhadauria H, Sutariya D, Parmar S, Prajapati D (2011). Heterosis and combining ability for yield and its component traits in Indian mustard [*Brassica juncea* (L.)]. J. Oilseed Brassica. 2(1):39-43.

Zhang Y, Kang MS, Lamkey KR (2005) Diallel-SAS05: A comprehensive program for griffing's and gardner-eberhart analyses. Agron. J. 97(4):1097.