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Genetic diversity and trait association between growth, yield and seed component of *Jatropha curcas* (L.) source collection from Indian sub-continent

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Seventy-two *Jatropha curcas* clonal accessions, collected from different parts of India, were grown in randomized block design and evaluated for 13 characters. These showed significant differences in growth, yield and seed characteristics, except for number of primary branches per plant. The accessions AFRI-35, AFRI-52 and AFRI-56 showed above mean value for 12 growth, fruit and seed yield characters except for number of primary branches, seed width and seed thickness. Accessions AFRI-12, AFRI-20, AFRI-21 and AFRI-39 showed above mean value for 11 traits. All the growth traits except for number of primary branches were positively correlated with fruit and seed yield. The magnitude of genotypic correlation coefficient (r_g) was higher than their corresponding phenotypic coefficient of correlations (r_p) for almost all the growth and yield characters, indicating the strong genetic linkage among all the characters. Kernel oil percentage was positively correlated with 20-seed weight and seed/kernel ratio. Seed/kernel ratio and oil percentage were negatively and non-significantly correlated with seed length and width. Principal component analysis revealed that plant height, collar diameter, number of secondary branches, crown diameter, fruit yield, seed yield, 20-seed weight, seed length, seed width, seed thickness, S/K ratio and oil percentage could be used as characters to distinguish the germplasm entries. *K*-means clustering revealed that trees from different geographic regions were grouped together in a cluster as well as trees from the same geographical area were placed in different clusters, suggesting that geographical diversity did not go hand in hand with genetic diversity. In addition, clustering identified promising accessions with favourable traits for future establishment of elite Seedling Seed Orchard (SSO) and Clonal Seed Orchard (CSO) for varietal and hybridization programmes.

Key words: Biodiesel, clustering, genetic variation, growth performance, principal component analysis

INTRODUCTION

The increased prices of petroleum products coupled with depletion of fossil fuel reserves and compulsion to reduce greenhouse gas emission, have evoked worldwide interest in searching for alternative sources of raw material for fuels (Mohapatra and Pande, 2010). Biodiesel, bio-ethanol and biomass gasification are the three major bio-energy and fast developing options which have huge potential in India to develop as renewable energy sources, where investment made would be economical (Parikh and Walia, 2002; Mishra, 2009). Bio-energy generated from bio-fuels constitute a suitable renewable energy source that may help to cope up with rising energy prices and offer new livelihood opportunities to farmers and rural communities around the world (Hazell and Pachauri, 2006; Rao et al., 2009). In recent years *Jatropha curcas* L., a perennial plant belonging to the family Euphorbiaceae has received considerable attention from researchers as a non-edible tree-born oil-seed crop (Tiwari et al*.,* 2007; Das et al., 2010). It is a native of tropical Central America and is domesticated widely in Africa and Asia due to its ability to grow in varied climatic zones of tropical and subtropical regions particularly in marginal lands (Rao et al., 2008). *J. curcas* is a prominent species with a wide variety of uses: seeds, leaves and bark used in traditional medicine and for veterinary purpose (Heller, 1996) and oil as an insecticidal agent, in preparation of soap, candle, by-product glycerine and as germination promoter (Ginwal et al., 2005; Nabil and Yasser, 2012; Sharma et al., 2012). It is a highly promising species as bio-diesel crop of short gestation period, hardy nature, high quality oil contents and wide adaptability compared to most other non-edible oil yielding species. The seeds of *J. curcas* contain about 35 to 40% of non-edible oil (Keith, 2000). The magnitude of genetic variability present in base population of any crop species is pivotal to crop improvement; however, no species simultaneously performs best in respect to its all attribute (Vongadow and Bredenkamp, 1992; Raje and Rao, 2000; Idahosa et al., 2010). Considering the vast semi-wild distribution of *J. curcas* in different parts of India, there exists considerable genetic variability which can be exploited for potential economic yield (Pant et al., 2006; Rao. et al., 2008). Detection and exploitation of natural genetic variability in *J. curcas* is the need of the hour to deliver the best genotypes from the working germplasm collections to meet the immediate requirement of the growers. The first step in this process is selection criteria, which is, the retention of desired genotypes and elimination of undesirable ones. Once the selection criterias are clarified, the next is to choose a proper system of selection. Selection index maximizes genetic gain in a desired direction and is usefully applied to develop better cultivars with target traits (Ceron-Rojas et al., 2006). In a population under selection for quantitative characters, gene frequencies are altered and these are further modified by the mating systems that may be utilized to advance the selected individuals to the next generation (Chopra, 2000). Ginwal et al. (2005) reported variability of *J. curcas* from central India limited to seed source, morphology, germination and seedlings growth. Kaushik et al*.* (2007) reported divergence in seed oil traits of *J. curcas* in 24 locally collected accessions Srivastava et al. (2011) mentioned the paucity of date on growth performance and yield of *J. curcas*.

One important limitation for selection for improvement is the extent of diversity present in the germplasm. Quantitative characters such as yield and its determinants exhibit substantial degree of interaction with the environment thus it is imperative to analyse the variability present in the germplasm and partition it into genotypic, phenotypic nature. Release of high yielding cultivars is impossible without ascertaining the magnitude of variation present in the available germplasm, interdependence of growth pattern with yield, extent of environmental influence on these factors, heritability and genetic gain of the materials (Rao et al., 2008). The potentiality of plants for optimum yield (seed yield and oil percentage) is dependent both on environmental and genotypic factor. The knowledge of genetic variation/diversity would be useful for selection especially when the desired ideo type is yet to be defined due to its wide adaptability. Knowledge of genetic variation for attributes viz: branching pattern, female to male flower ratio, pest resistance, drought hardiness and yield attributes in germplasm of *Jatropha* is of great significance in tree improvement programmes and particularly for selection of genotypes having more seed yield and oil content (Burely et al*.,* 1984; Voncarlowitz, 1986, Wen et al., 2012; Ndir et al., 2013). Basha and Sujatha (2007) indicated modest levels of genetic variation in the Indian germplasm based on random amplified polymorphic DNA (RAPD) and inter simple sequence repeat (ISSR) markers. Reddy et al*.* (2007) reported 8 to 10% (AFLP; Amplified Fragment Length polymorphism; genetic fingerprinting technique) and 14 to 16% (RAPD) polymorphism in 23-selected provenances from 300 collections. Randae et al*.* (2008) reported a wide diversity in 12 germplasm of *J. curcas* through molecular markers. Sakaguchi and Somabi (1987) studied 40 genotypes of *J. curcas* from different places in Thailand. Mahajen et al*.* (2009) reported significant variation in oil content of *J. curcas* for Uttarakhand States of India.

In the present investigation the magnitude of genetic variability is quantified in terms of morphological traits present in the existing base population (72 *J. curcas* clonal accessions) collected from different regions of India (Map 1) and to identify important yield attributing characters to provide useful information for developing improved high yielding *J. curcas* genotypes for establishment of elite seedling seed orchard (SSO) and clonal seed orchard (CSO) with favorable traits for future

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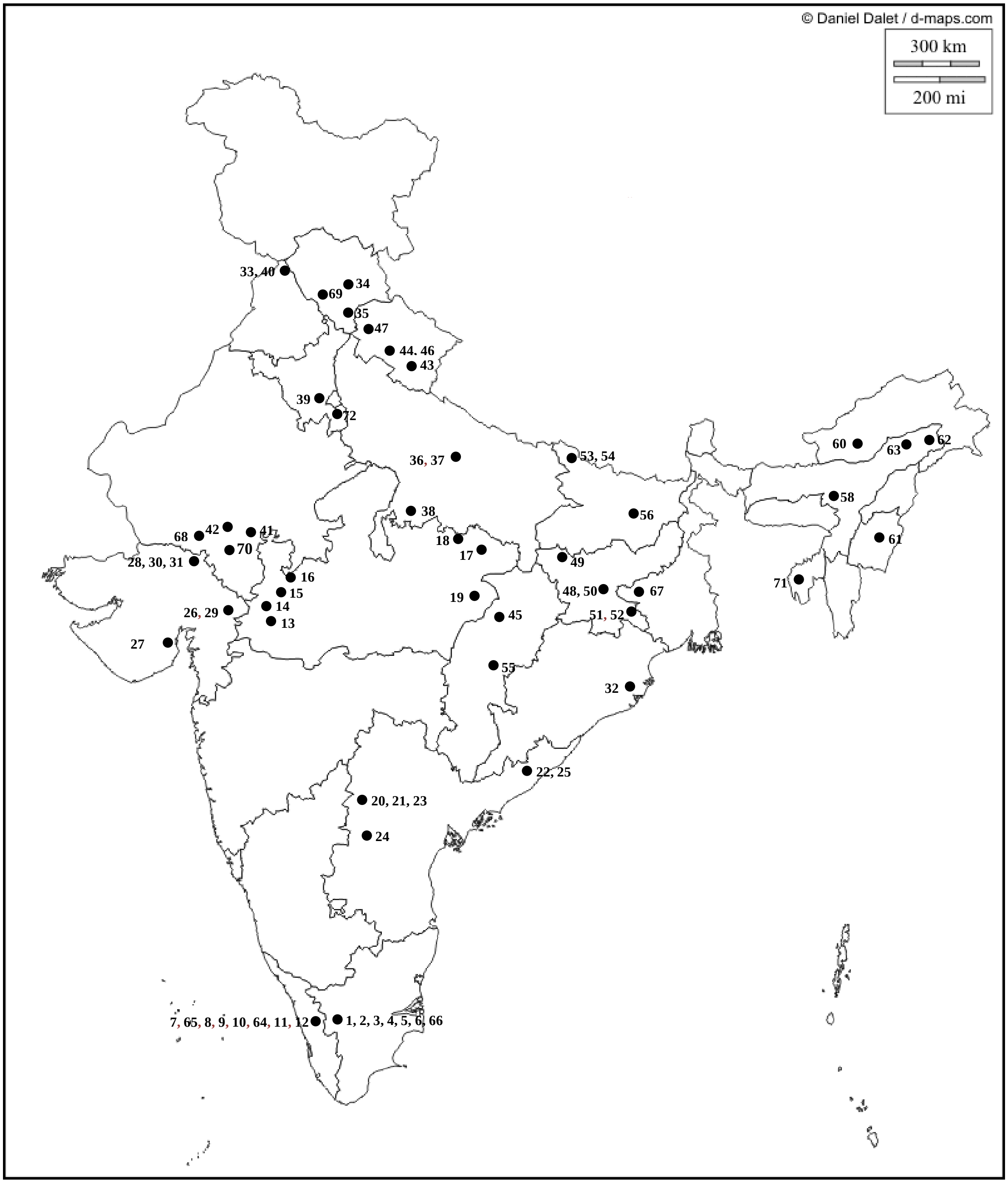

Map 1. Showing the location of collected *Jatropha curcas* clonal accessions.

plantation and breeding programmes.

MATERIALS AND METHODS

Experimental site

Experiment was conducted at the experimental site of Arid Forest Research Institute, Jodhpur (AFRI) (24° 40´ N and longitude 71° 15´ E), India. The experimental site was flat, had loamy sand soil. The soil pH was 7.8 (recorded by digital pH meter) and organic matter content in the soil was about 0.25% (analyzed at laboratory level). The average annual rainfall of the region during the study period from 2007 to 2010 ranged between 139.2 mm in 2010 to 321.2 mm in 2007. Average number of rainy days annually is 10 to 15 and maximum temperature goes as high as 49°C in summer and drops to 0°C in winter (source: metrological database of CAZRI (Central Arid Zone Research Institute, Jodhpur).

Collection of plantation material

In the present study a representative set of clonal material in the form of stem cuttings of 72 accessions of *J. curcas* from different geographical regions of India were evaluate for genetic variation and cluster analysis. The collection of the clonal material in the form of stem cutting ranged from latitude 10.0°46' to 32°02'N and longitude 72.0° 45' to 95.0° 1'E (Table 1). The selection were made on phenotypic assessment of characters of economic interest, that is, plant height, number of primary and secondary branch, branching pattern, crown spread, girth, fruit and seed yield. Clonal material in the form of stem cuttings was raised to saplings under nursery conditions and when plants were 4-months old were used for planting. Care was taken to avoid trees infested with pests and diseases.

Plantation at experimental site

The plants were planted in the pits of 45 cm^3 filled with mixture of FYM (farm yard manure): sand: soil in 1:1:1 ratio at 3 x 3 m spacing in randomized block design (RBD) having three replicates. Each replicate consisted of one plant propagated by stem cuttings of single mother plant. The plantation was done in July to August 2007. Plants were irrigated immediately after planting. Further, the irrigation was done at 15-days interval in summer and 30-days interval in winter. Mortality was replaced with new plants up to six month.

Data measurements

Measurements were taken in August 2010 for plant height (cm), collar diameter (cm), number of primary branches, number of secondary branch, crown diameter (cm). Fruit were collected and seed were harvested from five to eight picking of dried black fruits at 15 to 20 days interval from July to November in 2010; these were weighed and expressed as yield (g) per plant. Seed characteristics were analysed after separating seeds from the fruit, cleaned and stored in muslin cloth bags at ambient conditions (26°C and 55% RH). All seed lots were dried in hot air oven at 60°C till constant weight. The 20-seeds weight (g) were determined by using calibrated electronic balance to the nearest 0.01 g), seed/kernel ratio (S/K ratio) was calculated in order to determine the proportion of seed coat and length (mm), width (mm) and thickness (mm) of seed was recorded with digital calliper to the nearest 0.01 mm as per ISTA, (1976). For estimate oil content three replicates for each seed lot were used, 20 g of kernel were ground and powdered before placing in Soxhlet apparatus and were extracted with petroleum ether (60°C) for six hours without interruption by heating it at 60±5°C over water bath. Oil content was calculated on percentage basis. In the present investigation the data of 2010 have been analysed.

Statistical analysis

Data were subjected to analysis of variance by using SPSS (version 8.0; SPSS Inc.). Linear correlation coefficients were calculated at both genotypic (r_g) and phenotypic (r_p) levels among the studied traits, as described by Mode and Robinson (1959). The estimated studied traits mean were subjected to a principal component analysis (PCA) to investigate the dimensionality of studied data sets in test population and to identify new meaningful underlying variables under particular growth environment. Non-hierarchical (*K*-means) Euclidian cluster analysis was done for growth and yield traits and seed characters in planted *J. curcas* accessions separately.

RESULTS

Variability in growth and yield attributes

Significant variation at p<0.01 in the mean value was observed in plant height, collar diameter, number of secondary branches, crown diameter, fruit yield and seed yield. Number of primary branch showed non-significant variation among all the tested accessions of *J. curcas* (Table 2). Maximum mean plant height 272.50 cm was recorded in AFRI-39 followed by 267.50 cm in AFRI-35, while minimum was 90.00 cm in accession AFRI-16. The maximum collar diameter 11.49 cm was in AFRI-35 closely followed by 11.15 cm in AFRI-9. The high degree of variability with regard to the number of secondary branch was observed as AFRI-7 had 22.00 secondary branches followed by 21.00 in (AFRI-9, AFRI-12 and AFRI-43), which were almost five times compared to the lowest rank series 4.00 in (AFRI-16, AFRI-28 and AFRI-63). Crown diameter ranged from 62.50 cm in AFRI-23 to 260.00 cm in AFRI-35. The recorded data pertaining to fruit and seed yielding parameters showed significant variation among the accessions. Out of 72 tested accessions only 65 seeded after a period of 36 month. Among the seeded plants fruit and seed yield was minimum 30.00 and 22.00 g in accessions AFRI-50 and varied up-to 1586.00 and 812.50 g in AFRI-32, respectively. Out of 72 accessions only 21 and 23 accessions expressed significant higher fruit and seed yield per plant, respectively over general mean.

Variability in seed characters

Table 2 revealed that from 72 studied accessions only 65 were seeded so the seed characteristic study was restricted to these seed yielded accessions only. Analysis of components of total variability in the germplasm indicated significant difference among the accessions for all the seed characteristic traits. Highest 20 seed weight was noticed 12.80 g in AFRI-3 nearly followed by 12.72 and 12.65 g in AFRI-31 and AFRI-30, respectively. Whereas lowest 20 seed weight was observed 5.87 g in AFRI-63 closely followed by 5.88 g in AFRI-64 accession. The highest seed/kernel ratio and oil % was shown by accession AFRI-30 which had 0.81 and 57.32%, respectively while the lowest was showed by AFRI-6 with the value of 0.31 and 27.43%, respectively. Thirty accessions expressed significantly higher values over general mean of oil percent. Maximum seed length was observed 17.63 mm in AFRI-32 closely followed by 17.53 mm in AFRI-51 and minimum was 13.11 mm in AFRI-48. Seed width ranged from 9.24 mm in AFRI-22 to 11.51 mm in AFRI-30 accession which was closely followed by 11.46 mm in AFRI-40. Maximum seed thickness was

Table 1. Source detail of *J. curcas* and their geographical locations.

Source code	Locality	Rainfall	Mean temperature	
			Minimum (°C)	Maximum (°C)
AFRI 1	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 2	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 3	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 4	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 5	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 6	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 7	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 8	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 9	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 10	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 11	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 12	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 13	Dhar, Madhya Pradesh	1083.4	19.5°	34.0°
AFRI 14	Indore, Madhya Pradesh	890.0	10.0°	40.0°
AFRI 15	Ujjain, Madhya Pradesh	1768.4	9.0°	48.0°
AFRI 16	Shahjahanpur, Madhya Pradesh	NA	NA	NA
AFRI 17	Sidhi, Madhya Pradesh	NA	8.1°	42°
AFRI 18	Satna, Madhya Pradesh	NA	8.8°	42.3°
AFRI 19	Sahadol, Madhya Pradesh	1065.2	8.4°	41.4°
AFRI 20	Rangareddy, Andhra Pradesh	776.8	14.2°	38.7°
AFRI 21	Rangareddy, Andhra Pradesh	776.8	14.2°	38.7°
AFRI 22	Vishakhpatnam, Andhra Pradesh	1279.8	21.0°	32.6°
AFRI 23	Rangareddy, Andhra Pradesh	776.8	14.2°	38.7°
AFRI 24	Mahaboobnagar, Andhra Pradesh	596.3	25°	40.9°
AFRI 25	Vishakhpatnam, Andhra Pradesh	1279.8	21.0°	32.6°
AFRI 26	Panchmahal, Gujarat	1418.2	14°	45°
AFRI 27	Bhavnagar, Gujarat	732.1	15°	44°
AFRI 28	Banaskantha, Gujarat	1375.1	5°	45°
AFRI 29	Panchmahal, Gujarat	1418.2	14°	45°
AFRI 30	Banaskantha, Gujarat	1375.1	5°	45°
AFRI 31	Banaskantha, Gujarat	1375.1	5°	45°
AFRI 32	Pulbhani, Orissa	943.0	NA	NA
AFRI 33	Gurdaspur, Punjab	1032.4	6.0°	41.0°
AFRI 34	Mandi, Himachal Pradesh	1265.2	3.0°	35.0°
AFRI 35	Shimla, Himachal Pradesh	1200.6	NA	NA
AFRI 36	Lucknow, Uttar Pradesh	914.4	11.0°	48.0°
AFRI 37	Lucknow, Uttar Pradesh	914.4	11.0°	48.0°
AFRI 38	Mahoba, Uttar Pradesh	NA	4.1°	48.2°
AFRI 39	Jhajjar, Haryana	444.0	7.0°	40.5°
AFRI 40	Gurdaspur, Punjab	1032.4	6.0°	41.0°
AFRI 41	Chittorgarh, Rajasthan	1121.8	11°	44°
AFRI 42	Rajsamand, Rajasthan	666.6	7.8°	38.6°
AFRI 43	Nainital, Uttrakhand	1022.9	3.0°	27.0°
AFRI 44	Pauri Gharwal, Uttarkhand	1857.1	NA	NA
AFRI 45	Bilaspur, Chhatisgarh	1091.7	NA	NA
AFRI 46	Pauri Gharwal, Uttarkhand	1857.1	NA	NA
AFRI 47	Dehradun, Uttrakhand	1735.0	13.3°	27.8°
AFRI 48	Ranchi, Jharkhand	1555.9	10.3°	37.2°
AFRI 49	Plamau, Jharkhand	1163.4	5.6°	46.7°
AFRI 50	Ranchi, Jharkhand	1555.9	10.3°	37.2°

Table 1. Contd.

AFRI 51	E. Singhbhum, Jharkhand	1500.0	6.0°	44.0°
AFRI 52	E. Singhbhum, Jharkhand	1500.0	6.0°	44.0°
AFRI 53	W. Champaran, Bihar	1422.0	5.0°	46.0°
AFRI 54	W. Champaran, Bihar	1422.0	5.0°	46.0°
AFRI 55	Raipur, Chhatisgarh	1206.7	13°	42°
AFRI 56	Begusarai, Bihar	1384.0	6.0°	34.0°
AFRI 57	Durg, Chhatisgarh	886.4	11.0°	42.2°
AFRI 58	Karbi Anglong, Assam	925.0	6.0°	32.0°
AFRI 59	Lakhimpur, Assam	NA	10.0°	31.0°
AFRI 60	Papumpare, Arunachal Pradesh	2148.1	5.5°	29.0°
AFRI 61	Imphal, Manipur	846.2	3.5°	36.0°
AFRI 62	Mon, Nagaland	2600.0	5.0°	32.0°
AFRI 63	Mokokchung, Nagaland	2500.0	8.0°	24.0°
AFRI 64	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 65	Palakkad, Kerala	2658.7	19.0°	36.0°
AFRI 66	Coimbatore, Tamil Nadu	765.6	18.7°	35.3°
AFRI 67	Purulia, West Bengal	NA	NA	NA
AFRI 68	Sirohi, Rajasthan	1545.5	8.0°	47.0°
AFRI 69	Bilaspur, Himachal Pradesh	1348.0	5.0°	42.0°
AFRI 70	Udaipur, Rajasthan	1092.0	11.6°	38.3°
AFRI 71	West Tripura, Tripura	1954.8	10.0°	33.0°
AFRI 72	Guragaon, Haryana	340.5	5.1°	40.0°

observed 8.74 mm in AFRI-3 and minimum 7.10 mm in AFRI-28 accessions.

Table 3 showed positive association of correlation coefficient among different growth and yield traits. For growth and yield traits phenotypic correlation and genotypic correlation ranged from 0.087 to 0.978 (r_p) and 0.100 to 1.00 (r_g). Plant height and collar diameter exhibited significant correlation with all growth and yield traits at both phenotypic level and genotypic level. Number of primary branch exhibit higher r value for genotypic correlation (r_g) than phenotypic correlation (r_p) with number of secondary branch, crown diameter, fruit yield and seed yield. At phenotypic level its exhibited positive significant correlation only with number of secondary branch and crown diameter (it was 0.335 and 0.268, respectively). Number of secondary branch exhibited positive significant correlation with crown diameter, fruit yield and seed yield at both level. Crown diameter showed positive significant correlation with fruit and seed yield at both level. The maximum correlation coefficient for both r_p and r_g was observed between fruit and seed yield at both level with 0.978(r_p) and 1.002(r_g). Data in Table 3 revealed that seed yield showed higher values of genotypic correlation for all parameters (that is, plant height, collar diameter, number of primary branch, number of secondary branch, crown diameter and fruit yield) compared to phenotypic correlation.

Table 4 showed the correlation coefficient between various seed characteristics here it ranged from -0.048 (seed length with oil % on kernel basis) to 0.682 (Seed width with seed length) of r_p and -0.039 (Seed length with seed/kernel ratio) to 0.715 (Seed kernel ratio with 20-seed weight) of r_g. 20 seed weight exhibited a significant positive correlation at $p<0.01$ with seed/kernel ratio, oil %, seed length and seed thickness at both phenotypic and genotypic level whereas there was no significant positive correlation between seed width and 20-seed weight. High r_g value of 20 seed weight with seed/kernel ratio and oil % observed than $r_{p.}$ Seed/kernel ratio showed positive significant correlation only with oil percent at phenotypic and genotypic level. Positive value of r was registered between seed/kernel ratio and seed thickness without any significance at phenotypic and genotypic level. There was non-significant negative correlation between seed/kernel ratio and seed length and width. Non significant negative correlation was also observed between oil % and seed length, width and thickness at phenotypic and genotypic levels. Seed length exhibited highly significant positive correlation value of r_p with seed width and seed thickness but also exhibited low level of genotypic correlation between them. Seed width showed significant positively correlation with seed thickness at r_p level but poorly associated at r_g level.

Principal component analysis

Table 5 revealed that the first principal component

Table 2. Mean values for growth characteristics of different *J. curcas* accessions.

Accession	Height (cm)	Collar diameter (cm)	Number of primary branch	Number of secondary branch	Crown diameter (cm)	Fruit yield (g)	Seed yield (g)	20-seed weight (g)	Seed/kernel ratio	Oil % on kernel basis	Length (mm)	Width (mm)	Thickness (mm)
AFRI 1	205.00	8.44	2.00	11.50	207.50	720.00	340.00	7.53	.48	42.92	15.89	10.13	7.70
AFRI 2	232.50	8.27	2.50	13.00	172.50	135.00	87.50	8.61	.45	40.90	16.53	10.61	8.28
AFRI 3	193.33	7.10	2.67	10.67	173.33	440.00	279.25	12.80	.78	48.82	16.90	11.24	8.74
AFRI 4	240.00	9.57	1.50	17.00	170.00	392.50	231.95	9.24	.62	42.91	16.35	11.13	8.40
AFRI 5	215.00	7.14	2.00	10.50	192.50	-	-	-	-	-	-	-	-
AFRI 6	182.50	7.09	2.00	10.00	137.50	62.50	27.50	5.98	.31	27.43	15.29	10.11	7.71
AFRI 7	207.50	7.42	2.50	22.00	170.00	1122.50	647.50	9.17	.62	45.81	15.75	10.30	8.05
AFRI 8	230.00	7.02	2.50	18.50	182.50	305.00	187.50	11.42	.69	51.36	16.40	10.94	8.09
AFRI 9	247.50	11.15	3.00	21.00	241.25	777.50	450.00	7.43	.60	46.56	15.34	10.28	7.62
AFRI 10	165.00	5.96	2.00	8.00	98.75	387.50	212.50	9.38	.63	48.77	15.90	10.95	8.05
AFRI 11	232.50	10.86	2.50	19.00	232.50	1270.00	790.00	7.40	.53	44.58	15.69	11.00	7.84
AFRI 12	220.00	9.89	3.00	21.00	167.50	60.00	32.50	9.91	.71	51.22	16.15	10.75	8.44
AFRI 13	145.00	5.61	2.00	6.00	80.00	255.00	155.00	10.11	.64	48.60	16.19	10.70	8.03
AFRI 14	172.50	6.59	3.00	15.00	140.00	-	-	-	-	-	-	-	-
AFRI 15	130.00	5.10	2.00	6.00	71.25	182.50	95.70	7.85	.58	42.57	16.67	10.63	8.43
AFRI 16	90.00	4.30	2.00	4.00	92.50	-	-	-	-	-	-	-	-
AFRI 17	160.00	4.24	2.50	6.50	105.00	240.00	147.50	9.73	.63	48.42	16.55	10.83	8.25
AFRI 18	125.00	3.79	2.00	5.00	88.75	-	-	-	-	-	-	-	-
AFRI 19	182.50	6.38	1.50	6.50	78.75	315.00	190.00	10.03	.66	52.78	16.47	11.04	7.89
AFRI 20	215.00	8.44	2.50	12.50	190.00	210.00	137.50	10.60	.65	48.31	16.69	10.84	8.41
AFRI 21	247.50	9.49	3.50	11.00	172.50	980.00	580.00	9.85	.64	50.56	16.34	10.70	7.78
AFRI 22	255.00	6.07	1.50	14.00	117.50	125.00	35.00	6.96	.56	40.90	15.13	9.24	7.15
AFRI 23	115.00	3.83	1.50	4.50	62.50	222.31	84.81	10.06	.63	45.34	16.51	10.47	7.76
AFRI 24	165.00	5.96	2.00	10.00	113.75	182.50	107.50	9.18	.53	39.60	15.87	10.30	7.47
AFRI 25	205.00	7.21	2.00	13.00	127.50	-	-	-	-	-	-	-	-
AFRI 26	212.50	7.30	2.00	19.00	178.75	52.50	26.00	8.48	.52	38.62	15.42	10.10	7.77
AFRI 27	200.00	7.25	2.50	12.00	141.25	850.00	460.00	8.70	.62	54.66	14.87	10.56	7.88
AFRI 28	105.00	3.75	2.00	4.00	90.00	50.00	25.00	5.35	.46	32.48	14.50	9.78	7.10
AFRI 29	240.00	7.81	2.00	14.00	207.50	570.00	310.00	8.77	.54	41.03	16.60	10.94	7.99
AFRI 30	210.00	6.98	3.00	11.00	185.00	277.00	225.00	12.65	.81	57.32	17.00	11.51	8.35
AFRI 31	215.00	6.89	2.00	14.00	202.50	204.00	138.20	12.72	.64	51.72	16.70	11.10	8.49
AFRI 32	250.00	9.16	1.50	16.50	245.00	1586.00	812.50	7.85	.47	35.29	17.63	11.26	8.68
AFRI 33	207.50	7.48	3.00	20.00	205.00	322.50	157.50	9.14	.54	36.25	16.99	11.25	8.40
AFRI 34	162.50	8.26	1.50	11.00	137.50	370.00	250.00	11.72	.67	55.82	16.72	10.93	8.30
AFRI 35	267.50	11.49	2.00	17.00	260.00	1285.00	810.00	9.74	.63	48.25	16.71	11.04	8.39
AFRI 36	247.50	6.81	2.00	13.50	207.50	200.00	117.50	10.27	.69	47.11	16.43	10.72	7.78

Table 2. Contd.

AFRI 37	212.50	6.57	2.50	10.50	193.75	360.00	167.50	7.01	.51	41.56	15.75	11.01	8.02
AFRI 38	145.00	5.33	2.00	5.50	90.00	92.50	46.00	7.62	.57	41.22	15.88	10.79	8.06
AFRI 39	272.50	8.48	2.50	16.00	230.00	687.50	363.50	9.29	.58	50.91	15.59	10.88	8.18
AFRI 40	155.00	4.39	1.00	7.00	92.50	487.50	257.50	10.90	.55	54.20	17.33	11.46	8.24
AFRI 41	265.00	8.77	2.50	12.00	182.50	790.00	365.50	8.11	.48	42.16	17.38	11.13	8.52
AFRI 42	235.00	7.67	2.50	19.50	211.25	407.50	199.50	9.31	.61	47.39	16.31	10.59	7.73
AFRI 43	240.00	7.86	2.00	21.00	193.75	190.00	112.75	7.07	.62	59.51	15.20	10.75	7.51
AFRI 44	160.00	6.91	3.00	6.00	92.50	-	-	-	-	-	-	-	-
AFRI 45	260.00	7.88	1.50	7.50	222.50	405.00	200.00	9.56	.60	40.88	15.70	10.61	8.08
AFRI 46	227.50	8.08	2.50	4.50	160.00	55.00	29.00	9.57	.66	47.28	16.01	10.31	7.84
AFRI 47	235.00	8.17	2.50	11.50	160.00	140.00	87.50	9.96	.70	42.33	13.29	9.62	7.48
AFRI 48	210.00	7.49	2.00	7.00	100.00	268.50	148.50	6.08	.69	43.39	13.11	9.63	7.22
AFRI 49	200.00	7.71	2.00	4.50	187.50	70.00	34.70	9.38	.64	44.00	15.02	10.01	8.01
AFRI 50	192.50	6.82	3.00	13.50	96.25	30.00	22.00	9.07	.62	41.83	15.19	10.35	8.14
AFRI 51	252.50	10.00	2.50	14.00	187.50	408.50	212.50	11.31	.59	43.54	17.52	11.11	9.12
AFRI 52	265.00	9.74	2.50	15.00	177.50	1020.00	537.00	10.24	.63	52.33	16.16	10.58	8.10
AFRI 53	230.00	9.01	2.50	17.50	217.50	401.50	195.50	9.94	.64	51.23	16.32	11.03	8.25
AFRI 54	250.00	7.39	4.00	11.50	205.00	70.00	32.00	7.34	.57	41.60	15.08	9.70	7.35
AFRI 55	205.00	8.25	2.50	11.50	157.50	325.00	181.00	9.32	.64	51.22	15.41	10.57	8.26
AFRI 56	240.00	10.27	3.50	15.00	215.00	919.00	586.50	9.77	.64	54.64	16.16	10.89	8.02
AFRI 57	202.50	7.74	2.50	17.00	193.75	306.50	161.00	7.44	.52	42.11	16.03	10.66	7.86
AFRI 58	170.00	6.97	2.50	11.50	247.50	469.00	265.50	7.66	.62	45.75	14.99	10.69	7.84
AFRI 59	230.00	8.72	3.50	17.50	178.75	-	-	-	-	-	-	-	-
AFRI 60	185.00	8.62	2.00	7.50	96.25	226.00	126.50	10.00	.66	44.91	16.41	11.00	8.70
AFRI 61	193.33	8.28	2.00	11.67	135.83	102.50	51.30	11.03	.63	53.60	16.53	10.57	8.15
AFRI 62	197.50	6.86	1.50	14.00	108.75	197.50	126.00	7.60	.67	39.80	14.96	10.80	7.97
AFRI 63	110.00	5.14	1.00	4.00	88.75	151.50	53.50	5.87	.33	35.52	16.78	10.79	8.28
AFRI 64	265.00	9.13	2.00	17.50	245.00	840.00	475.00	5.88	.49	42.43	15.39	10.63	7.61
AFRI 65	190.00	9.00	2.00	10.50	132.50	180.00	120.00	9.51	.62	44.38	15.86	10.90	8.16
AFRI 66	215.00	5.66	2.50	14.50	157.50	1185.00	681.00	8.26	.47	40.50	16.30	10.75	8.00
AFRI 67	180.00	6.92	2.50	14.50	203.75	50.00	30.00	7.59	.49	47.29	14.84	10.19	7.44
AFRI 68	215.00	9.14	2.50	17.00	200.00	875.50	489.00	8.33	.61	43.69	16.21	10.95	7.88
AFRI 69	205.00	9.05	2.00	16.50	190.00	623.50	323.50	7.28	.52	37.99	15.73	10.80	8.32
AFRI 70	232.50	7.43	2.00	16.00	205.00	1214.50	685.75	9.06	.55	44.32	16.49	11.07	8.04
AFRI 71	215.00	9.30	2.00	17.50	191.25	288.00	150.00	11.98	.70	50.03	16.65	11.02	8.19
AFRI 72	225.00	7.73	2.00	14.50	190.00	813.50	463.50	9.31	.57	39.93	17.08	11.05	8.31
Mean±SD	205.03±45.2	7.54±1.8	2.25±.84	12.50±5.3	163.23±57.3	443.11	248.17	9.02±1.7	0.592±.09	45.40±6.2	16.01±1.4	10.68±.02	8.03±.02
SEM	1.9760	.0870	.0740	.2630	3.1300	35.80	20.72	.1100	.0050	.3860	.0390	.0220	.0200
CD 1%	41.92	1.61	NS	5.68	61.95	256.79	174.79	1.16	0.05	2.65	2.32	1.15	1.10

CD = critical difference, SE = standard error of mean.

Table 3. Genotypic (r_g) and phenotypic (r_p) correlation coefficients between plant growth traits for studied *J. curcas* accessions.

Trait		Collar diameter	Primary branches	Secondary branch	Crown diameter	Fruit yield	Seed yield
Height	r_p	0.750**	0.308**	0.619**	0.732**	0.451**	0.443*
	r_g	(0.742)	(0.389)	(0.613)	(0.793)	(0.100)	(0.480)
Collar diameter	r_p		0.290**	0.623**	0.708**	0.382**	0.395**
	r_g		(0.495)	(0.551)	(0.685)	(0.451)	(0.478)
Primary branch	r_p			0.335**	0.268**	0.087	0.098
	r_g			(0.592)	(0.672)	(0.329)	(0.373)
Secondary branch	r_p				0.661**	0.351**	0.358**
	r_g				(0.670)	(0.440)	(0.451)
Crown diameter	r_p					0.467**	0.473**
	r_g					(0.499)	(0.488)
Fruit yield	r_p						0.978**
	r_g						(1.002)

Table 4. Genotypic (r_g) and phenotypic (r_p) correlation coefficients between seed characteristics for studied *J. curcas* accessions.

Traits		Seed/Kernel ratio	Oil % on kernel basis	Seed length	Seed width	Seed thickness
20-seed weight	r_p	0.666**	0.582**	0.210**	0.1108	0.186**
	r_g	(0.715)	(0.635)	(0.147)	(0.070)	(0.136)
Seed/kernel ratio	r_p		0.656**	-0.0355	-0.0427	0.0281
	r_g		(0.705)	(-0.039)	(-0.032)	(0.022)
Oil% on kernal basis	r_p			-0.048	-0.0433	-0.0169
	r_g			(-0.007)	(-0.025)	(-0.002)
Seed length	r_p				0.682**	0.576**
	r_g				(0.080)	(0.070)
Seed width	r_p					0.548**
	r_g					(0.062)

explained 36.15% of the total variation and dominated by plant height (0.876), crown diameter (0.862), collar diameter (0.838) and number of secondary branches (0.831). The coefficient of the second PC revealed a positive relationship with seed size and weight and received large contribution from seed length, seed thickness, seed width (0.917, 0.914 and 0.859, respectively). The PC II explained an additional 24.62% of total variation. The coefficient of third PC explained large contribution from S/K ratio, oil % on kernel basis and 20-seed weight (0.926, 0.888 and 0.748, respectively) and contributes 15.43% of total variation. The fourth PC (8.36% of total variation) largely contributed by fruit (0.925) and seed yield (0.922).

Genetic divergence in growth characteristics

Six clusters were delineated by *K*-mean clustering for the 72 accessions of *Jatropha* shown in Table 6. Cluster VI had highest 30 members in it and cluster IV had lowest 2 members in it. Cluster I and II had 13 and 10 members

Table 5. Results of principal component analysis (PCA) of growth, yield and seed traits of *Jatropha curcas* collection.

Variables	Component			
	PC I	PC II	PC III	PC IV
Initial eigenvalues	4.34	2.95	1.85	1.00
% of variance	36.15	24.62	15.43	8.36
Cumulative %	36.15	60.77	76.20	84.56
Eigenvector				
Pl ant height	0.876	-0.031	0.104	0.159
Collar diameter	0.838	0.098	0.122	0.188
Secondary branch	0.831	0.021	0.014	0.129
Crown diameter	0.862	0.074	-0.050	0.237
Fruit yield	0.328	0.154	-0.065	0.922
Seed yield	0.331	0.147	-0.003	0.925
20 seed weight	0.033	0.529	0.748	-0.120
Seed/kernel ratio	0.063	0.030	0.926	-0.104
Oil% on kernel basis	0.063	0.089	0.888	0.113
Seed length	-0.008	0.917	0.028	0.128
Seed width	0.057	0.859	0.196	0.239
Seed thickness	0.089	0.914	0.117	-0.005

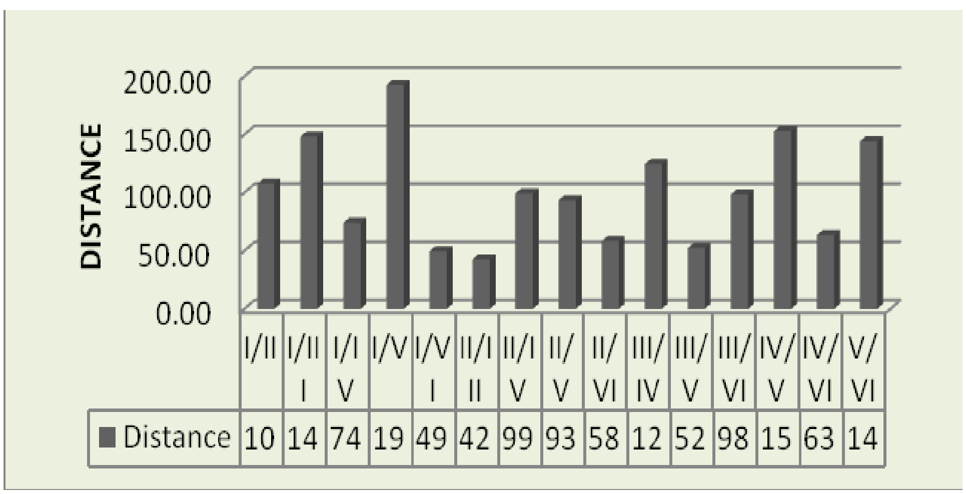

Figure 1. Estimates of inter-cluster (six clusters) by K-means non-hierarchical clustering in growth traits in *Jatropha curcas* accessions.

and cluster III and V had 9 and 8 members, respectively. Cluster I consisted of high mean value of height (267.50 cm), collar diameter (11.49 cm), number of secondary branches (17.00) and crown diameter (260.00 cm). Cluster IV consisted of highest mean of number of primary branches which had mean value of 2.50. The minimum inter-cluster distance seen between II and III (42.58) followed by I and VI (49.65). While maximum inter-cluster distance was seen between I and V with value of 192.69 depicted in Figure 1.

Genetic divergence in yield and seed characteristics

Sixty-five accessions of *Jatropha* were grouped in six clusters on the basis of *K*-mean clustering shown in Table 7. Minimum one accession was separated in cluster III and maximum 25 were placed in cluster V followed by 20 in cluster IV. Accession AFRI-32 which is placed in cluster III showed highest mean value for fruit and seed yield, seed length, seed width and seed thickness and this showed lowest mean value for 3

Table 6. Composition of Euclidean clusters and cluster mean values obtained by K-means Non-hierarchical clustering for growth traits in *Jatropha curcas* accessions.

Cluster	No. of accession	Accession name and number	Height	Collar diameter	Number of primary branch	Number of secondary branch	Crown diameter
I	13	AFRI-9, AFRI-11, AFRI-29, AFRI-32, AFRI-35, AFRI-36, AFRI-39, AFRI-42, AFRI-45, AFRI-53, AFRI-54, AFRI-56, AFRI-64	267.50	11.49	2.00	17.00	260.00
II	10	AFRI-6, AFRI-14, AFRI-22, AFRI-25, AFRI-27, AFRI-48, AFRI-55, AFRI-61, AFRI-62, AFRI-65	255.00	6.07	1.50	14.00	117.50
III	9	AFRI-10, AFRI-17, AFRI-19, AFRI-24, AFRI-34, AFRI-40, AFRI-44, AFRI-50, AFRI-60	182.50	6.38	1.50	6.50	78.75
IV	2	AFRI-58, AFRI-67	170.00	6.97	2.50	11.50	247.50
V	8	AFRI-13, AFRI-15, AFRI-16, AFRI-18, AFRI-23, AFRI-28, AFRI-38, AFRI-63	90.00	6.56	2.00	4.00	92.50
VI	30	AFRI-1, AFRI-2, AFRI-3, AFRI-4, AFRI-5, AFRI-7, AFRI-8, AFRI-12, AFRI-20, AFRI-21, AFRI-26, AFRI-30, AFRI-31, AFRI-33, AFRI-37, AFRI-41, AFRI-43, AFRI-46, AFRI-47, AFRI-49, AFRI-51, AFRI-52, AFRI-57, AFRI-59, AFRI-66, AFRI-68, AFRI-69, AFRI-70, AFRI-71, AFRI-72	225.00	7.73	2.00	14.50	190.00

Plant height, collar diameter and crown diameter in cm.

Table 7. Composition of Euclidean clusters and cluster mean values obtained by K-means Non-hierarchical clustering for yield and seed characteristics traits in *Jatropha curcas* accessions.

Cluster	No. of accession	Accession name and number	Fruit yield	Seed yield	20-seed weight	Seed/Kernel ratio	Oil %	Length	Width	Thickness
I	9	AFRI-1, AFRI-9, AFRI-27, AFRI-29, AFRI-39, AFRI-41, AFRI-64, AFRI-69, AFRI-72	741.33	394.56	8.03	0.54	44.29	15.98	10.71	8.01
II	5	AFRI-7, AFRI-11, AFRI-35, AFRI-66, AFRI-70	1215.40	722.85	8.72	0.56	44.69	16.19	10.83	8.06
III	1	AFRI-32	1586.00	812.50	7.85	0.47	35.29	17.63	11.26	8.68
IV	21	AFRI-3, AFRI-4, AFRI-8, AFRI-10, AFRI-13, AFRI-17, AFRI-19, AFRI-30, AFRI-33, AFRI-34, AFRI-37, AFRI-40, AFRI-42, AFRI-45, AFRI-48, AFRI-51, AFRI-53, AFRI-55, AFRI-57, AFRI-58, AFRI-71	353.88	198.80	9.84	0.63	47.73	16.22	10.90	8.16
V	25	AFRI-2, AFRI-6, AFRI-12, AFRI-15, AFRI-20, AFRI-22, AFRI-23, AFRI-24, AFRI-26, AFRI-28, AFRI-31, AFRI-36, AFRI-38, AFRI-43, AFRI-46, AFRI-47, AFRI-49, AFRI-50, AFRI-54, AFRI-60, AFRI-61, AFRI-62, AFRI-63, AFRI-65, AFRI-67	129.65	71.44	8.70	0.58	43.58	15.76	10.45	7.92
VI	4	AFRI-21, AFRI-52, AFRI-56, AFRI-68	948.63	548.13	9.54	0.63	50.30	16.22	10.78	7.94

Fruit and seed yield in (g) plant^{-1} , 20-seed weight in (g), oil content in % on kernel basis, seed length, seed width and seed thickness in mm.

characters viz. (20 seed weight, seed/kernel ratio and oil % on the basis of kernel).

Lowest mean value for fruit and seed yield, seed length, seed width and seed thickness was showed by cluster V which had 25 members in it. Highest mean of seed/kernel ratio and oil % was

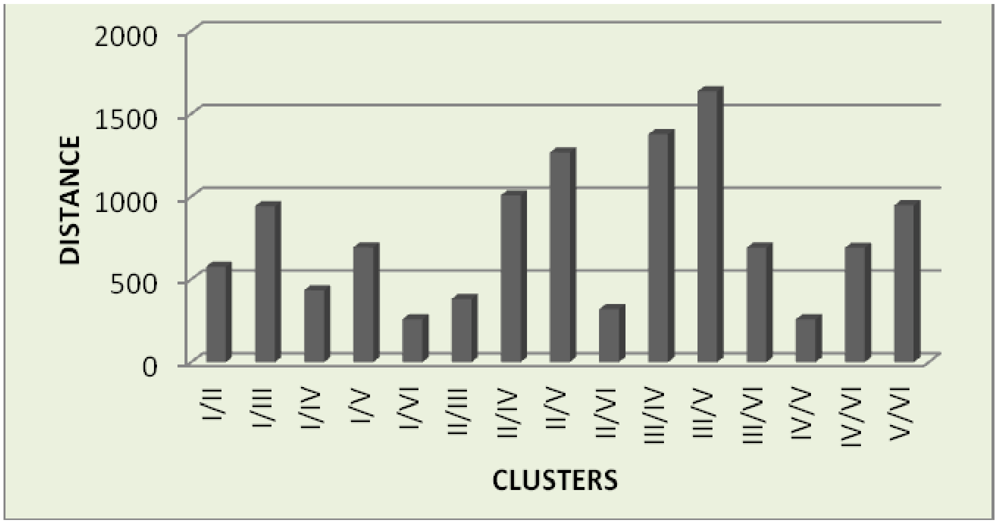

Figure 2. Estimates of inter-cluster (six clusters) by K-means non-hierarchical clustering in yield traits in *Jatropha curcas* accessions.

seen in cluster VI with the value of 0.63 and 50.30%, respectively. Inter-cluster distance between cluster III and IV was the maximum at 1634. Minimum inter-cluster distance was seen between cluster IV and V followed by cluster I and VI with the distance value of 257.91 and 258.05, respectively (Figure 2).

DISCUSSION

Study revealed that different accessions of *J. curcas* exhibited considerable amount of morphological variability. The sources were statistically at par with respect to the plant height, collar diameter, numbers of secondary branches, crown diameter, fruit yield, seed yield, 20-seed weight, seed/kernel ratio, oil percent, seed length, seed width and seed thickness but the number of primary branches did not differ significantly as this favours the finding of Pant et al. (2006) and Vijayanand et al. (2009). The variability in growth performance of accessed accession significantly differs and the finding agreed with Saikia et al. (2009) in which they got considerable amount of variation in plant height, stem girth and 100-seed weight in 34 accessed *J. curcas* accession collected from 17 States of India. The apparent variability in growth performance indicates that economic benefits may be obtained. The results of the present study will be valuable for the conservation of genetic variation, prospects of improvement and assessment of the potential of the locally adapted accession source. In present study fruit and seed yield significantly differ and agree with the finding of Francis et al. (2005) but in contrast with genetic variability, which is rather small in Indian germplasm (Basha and Sujatha, 2007). Seed oil content variation is more widely reported not only in annual crops but also in a wide variety of trees borne oil seed (Kaura et al., 1998). The variation found in oil content in the present study along with other seed morphological attributes presents us with a viable selection alternative at a very early stage (collection of germplasm) from base seed material. This could be of use in improvement programmes of *J. curcas*. The variation in *J. curcas* population has been recorded earlier by Wani et al. (2006) for oil content (27.8 to 39% on kernel basis) and 100-seed weight (44 to 77 g), in India accessions and by Kaushik et al. (2007) in 100 seed weight (49 to 69 g) and oil content (28 to 39%) in Haryana-India accessions. Similarly Rao et al. (2008) found wide variation in 100 seed weight (57 to 79 g) and oil content (30 to 37%) for Andhra Pradesh, India, accessions. Srivastava et al. (2011) reported 17 to 34% oil yield in ten restricted accessions screened on the basis of growth performance and biomass characterization. Large variation in average seed weight (0.46 to 0.83 g/seed) has been reported among 18 natural provenances of *J. curcas* in Mexico (Martinez-Herrera et al., 2010). Ouattara et al. (2013) reported high variability in *J. curcas* seed traits with 100 seed weight ranging from 63.68 to 77.83 g among the 19 accessions collected from Senegal. In the present investigation, the 20 seed weight ranged from 5.87 to 12.80 g whereas oil % on kernel basis ranged from 27.43 to 57.32% in 65 seeded accession out of 72 collected accessions. Variation in characters could be due the fact that the species had been collected over a wide range of rainfall, temperature and soil type. Wen et al. (2012) observed that seed weight and oil content of *J. curcas* were positively correlated with the mean annual sunshine duration, mean annual temperature, mean minimum daily temperature of the coldest month, mean maximum daily temperature of the warmest month and the mean annual evaporation, but negatively correlated with altitude and the mean annual precipitation. Ndir et al. (2013) observed that seed oil content and seed thickness were correlated to rainfall; however, seed length, breadth and 20 seed-weight were not correlated to rainfall. Moreover, genetic diversity was not correlated to geographic position in *J. curcas* (Ndir et al., 2013). However, one part of variability is under genetic control. Kaushik et al. (2007) envisaged that environment has comparatively low influence on the seed traits and oil content. High heritability and high genetic advance for 100 seed weight have been reported by Kaushik et al. (2007) in *J. curcas*. Hence these characters can be considered as best gain characteristics for *J. curcas* improvement program because of its strong genetic control and the wide variability. Plant height and number of branches are also important characters that can be-looked upon as major selection indices when the objective is to incorporate *J. curcas* in an agro-forestry system. Variation observed in yield characters can be useful in selecting plant types for block plantations with high yield and higher % of oil in seed as the primary objective. The fruit and seed yield as expected is positively associated (r_p and r_g) with plant height and number of secondary branches suggesting that phenotypic and genotypic relation is reliable and in turn offer good scope for selection of CPP (Candidate plus plant) at primary level. Knowledge of genetic diversity within natural population in and outside the centre of origin is required to know the potentially valuable genetic material. Here the growth and yield attributes in these *J. curcas* accessions can be of great potential in improvement programs.

Correlation analysis is an important tool to bring information about relationship between growth and yield attributes, however lack of relationship between traits and environment makes selection of CPP poorly predictable for improvement program. The degree of correlation depends upon the gene causing such variation and their developmental relation. Correlation matrix revealed interesting relationship in the growth traits, yield traits and seed characters studied. The magnitude of genotypic correlation coefficient (r_g) was higher than their corresponding phenotypic coefficient of correlations (r_p) for almost all the growth and yield characters indicating the strong genetic inherent association ship or gene linkage among all the characters and suggests that their phenotype are more regulated with gene and less influenced by environmental effect. Such positive and significant correlation was registered in *J. curcas* and these characters are an advantage to the breeder for bringing improvement of traits (Ginwal et al*.,* 2004; Das et al., 2010). It has been well known that seed related characteristics can also be used to examine variability with in plant species (Rawat and Bakshi, 2011). Ouattara et al. (2013) observed that seed length was significantly correlated to all seed traits excepted Seed/fruit ratio in *J. curcas*. In the present investigation positive significant correlation of 20-seed weight existed with seed/kernel ratio, oil %, seed length and seed thickness at both r_g and r_p level from these result it is evident that these traits are interrelated at their gene level or these are QTL (Quantitative Trait Loci) therefore, seed weight is important trait for early selection of seed sources. This is further in agreement with the finding of Rao et al. (2008) in *J. curcas* and Kaura et al. (1998) in *Azadirachta indica*. 20-seed weight exhibited positive relationship with seed width at both r_g and r_p level but it's not at significant level. Very high degree of direct relationship observed between fruit yield and seed yield per plant at both r_p (0.978) and r_g (1.002) level indicate that both are in same and strong genetic control. Here, seed/kernel ratio exhibited high r_p and r_g value with oil % indicated that both characters are in strong genetic control and suggested the effectiveness of indirect selection for kernel oil content through 20-seed weight. The estimation of 20-seed weight being less expensive and laborious compared to kernel oil content, the former can be used as a tool during selection process. The existence of negative correlation at both phenotypic and genotypic level between oil % and seed length, seed width and seed thickness indicated that both characters are independent on each other at both level and these traits variation in response to changing environmental condition (Valencia-Diaz and Montana, 2005). Significant correlations between fruit and seed yield with plant height, collar diameter, number of secondary branches and crown diameter also indicates that plant with good height and branching tend to develop more crown and flower subsequently fruit and seed. It indicates that the selection in any one of these yield attributing traits will lead to increase in the other traits, thereby finally enhancing the yield. Selection from early plantations of *J. curcas* can be made on the basis of these characters because of the difficulty in selecting plants solely based on yield as the full potential of yield is reached only after several years of growth in *J. curcas*. Similar relations have been reported in *Pennisetum typhoedes* by Van Osteroma et al. (2006) as well and in *Chenopodiem quinoa* by Bhargava et al. (2007).

The results from principal component analysis indicate that among all the 12 studied variable, variation is contributed by plant height, collar diameter, number of secondary branch, crown diameter, fruit yield, seed yield, 20-seed weight, seed length, width, thickness, S/K ratio and oil %. The first four components in the collection with eigen values were able to explain 84.56% of the total variance for morphological traits. According to Mardia et al. (1979), the total variance accumulated by principal component close to 80% explains satisfactorily the variability manifested between individuals. It is concluded that the above variables could be used as characters to distinguish the germplasm entries and might also be taken into consideration for effective selection of parents during hybridization program of this use full plant.

Genetic diversity

Analysis of genetic diversity in collections facilitated reliable classification of accessions and identification of core subsets of the accessions for future utility in specific breeding purposes. K-means clusters clustering pattern in this study revealed that trees from different geographic regions were grouped together in a cluster and also trees from the same geographical area placed in different clusters, suggesting that geographical diversity did not go hand in hand with genetic diversity. K-means clustering is done to understand the trend of evolution and choose genetically diverse parents for obtaining desirable recombination (Tams et al*.,* 2006). By clustering of growth attributes the maximum inter-cluster distance (192.69) was observed between I/V cluster while in yield and seed characters the distance was (1634.1) observed between III/V cluster indicating substantial segregation.

Existence of substantial variation and diversity can be utilized for further tree improvement programmers of the species. Selection of parent material from such cluster for hybridization programme will develop elite plant with desirable characters. The minimum inter-cluster distance observed in growth attributes (42.58) between II/III and in yield and seed attributes (257.91) between IV/V indicates that accessions in these groups are closely related. Therefore, the selection of parent plant from these clusters should be avoided. Finally the cluster that are having more inter-cluster distance and high mean will produce divergent candidate.

Conclusion

In the study, most of the accessions are growing well in arid climate region of, Rajasthan, India. However, accession AFRI-35, AFRI-52, AFRI-56, AFRI-12, AFRI-20, AFRI-21 and AFRI-39 performing better among studied 72 accessions. Significant positive association of kernel oil content (percent) with 20-seed weight suggested the effectiveness of indirect selection for kernel oil content through 20-seed weight. Principal component analysis stated that plant height, collar diameter, number of secondary branch, crown diameter, fruit yield, seed yield, 20-seed weight, seed length, width, thickness, S/K ratio and oil percent could be used as morphological marker to distinguish the germplasm. On the bases of observations recorded here on a divergent group of *J. curcas* accessions, it is concluded that hybridization between the accessions of variable clusters may help to produce wide spectrum of variation in the segregating progeny and thus may be helpful in hybridization program to cope up the fore coming limitations pertaining to improvement of bio-fuels species for biodiesel industry. It is also suggested that for creating variability and developing the best selection a large number of divergent lines, instead of few should be used in the hybridization.

Conflict of Interest

The authors have not declared any conflict of interests.

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