VARIATION IN FRUIT MORPHOLOGICAL TRAITS OF *JATROPHA CURCAS* AT STAND AND TREE LEVEL

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Introduction

The term "Jatropha" is usually used to refer the species *Jatropha curcas*, although there are over 200 known species of this plant in the world but in India only twenty-six species have been reported in literature. However, some of those are synonyms and only 12 species are documented in India, which have internationally accepted botanical names (Malhotra *et al*., 2011).

A fossil discovery in Belen (Peru) puts the existence of *J. curcas* in the early tertiary era which began about 70 million years ago. It may, therefore, be presumed that this plant has been exposed to the most varied environmental influence so that only the hardiest specimen could survive. Because of its hardiness and high degree of adaptability to a wide range of edaphic and climatic factors, it is found all over the tropics and parts of the sub-tropical regions (Patil and Singh, 1991).

J. curcas is a fast growing perennial crop able to grow in a wide range of soils, especially gravelly and sandy soils. It can reach a height of about 3 to 8 metres. It can produce seeds up to 50 years (Gaur, 2010). The seeds can be harvested for oil extraction after 2 to 5 years of plantation depending on the soil quality and rainfall. The annual yield of seeds is in the range of 0.5 to 12 tonnes per hectare (Heller, 1996). The cultivation of *J. curcas* is successful in the tropics with annual rainfall of 250 to 3,000 mm. It can also grow at low altitude areas that have an average annual temperature above 20°C and experience slight frost (Tewari, 1994; Gaur, 2010). The plant is monoecious, bearing unisexual, occasionally hermaphrodite flowers. Fruits of *J. curcas* are trilocular capsules which are ellipsoid in shape, initially green in colour and after maturation they turn yellow and finally develop dull dark brown or black exterior when ripe, breaking up into 3 cocci (Dehgan and Webster, 1979).

J. curcas has tremendous potential to provide us an environmentally safe, cost-effective and renewable source of biodiesel. Seed oil can be utilised as a biodiesel (after transesterification), and in making of soap, candles, varnish and lubricant. Its by-product glycerin can be used in the pharmaceutical. The oil cake can be used as an organic fertilizer due to high nitrogen content (3.2 to 3.8%) (Makkar *et al.*, 2001). The plant possesses several medicinal properties (Henning, 2002; Thomas, 1989). In recent years, utilization of *J. curcas* oil as a source of fuel for aeroplane engine was successfully carried out.

In first decade of 21st century, *J. curcas* has been planted on millions of hectares in India, but superior variety is still awaited (Dhyani *et al*., 2011). The superior material can be obtained by tree improvement programme, which basically seeks to exploit variability existing in the species. Variation studies on fruit and seed morphological traits have been conducted in this species in the past, at stand (provenance) level (Ginwal *et al*., 2005) or at tree level (Pandey and Mandal, 2006), but simultaneous assessment of variation at both levels is not attempted so far. Khalil (1984), Kumar *et al*. (2007) and other researchers have analysed the pattern of variation at both these levels simultaneously in different species, showing that there exists tree-to-tree variation coupled with geographic variation in those species, but the relative magnitudes of these levels vary with species and traits. The present investigation is designed to understand the nature, extent and pattern of variation existing across stands as well as among trees within stand of *J. curcas* in respect of fruit morphology using nested analysis of variance for pure Model II (Sokal and Rohlf, 1969).

Material and Methods

A survey was carried out to identify stands of *J. curcas* throughout the state of Uttarakhand, in accordance with definition of stand given by Schmidt (1997). Ten representative stands namely Saknidhar (S1), Naithana (S2), Bamoth (S3), Kothagi Bhatwarhi (S4), Umrakot (S5), Tarigaon (S6), Kakkartala (S7), Belkhet (S8), Betalghat (S9) and Pili Parab and Indiranagar (S10), each having a minimum of 50 trees of *J. curcas*, were randomly selected in eight forest divisions of Uttarakhand. Randomly 8 to 10 representative trees were selected from each stand having a minimum distance of 50 m from one another on the basis of the following criteria: fully grown mature trees free from insects and diseases (minor infection was ignored), and well developed crown.

The selected trees were marked. Fruit collection was done from each tree during July to August, 2007

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except in Haridwar Forest Division, where fruit collection was done in the month of January, 2008 due to late fruit maturation. Only black and brownish black mature fruits were collected from individual plants in separate gunny bags. Fruits were dried and brought to laboratory.

Observations on morphological traits such as fruit length, fruit diameter with digital vernier calliper (Model: Mitutoyo's, Absolute digimatic) and fruit weight with digital electronic balance (Model: Sartorius, MA 40 Series) were recorded from randomly selected 10 fruits per selected tree per stand. Seeds were extracted separately from each fruit. The seed weight was taken for individual seeds of each fruit. The total seed weight per fruit was calculated by adding the weight of all seeds in a fruit (including immature seed, if any).

Kernels were manually extracted from the seeds and total kernel weight per fruit was recorded. Pericarp weight per fruit was obtained by subtraction of total seed weight per fruit from fruit weight. Finally seed: fruit weight ratio, kernel: fruit weight ratio and pericarp: fruit weight ratio, were calculated on weight basis.

Statistical analysis

Analysis of variance and variance components

The data were statistically analyzed using computer software SPSS version 16; Genstat 3.2 and Microsoft excel 2007, for variance and variance components by two level nested ANOVA with unequal sample size (i.e. unbalanced) for morphological fruit traits suggested by Sokal and Rohlf (1969). The structure of the analysis of variance is given in Table 1.

Estimation of repeatability

As genetic effects cannot be separated from environmental effects in natural populations where parental origin and environmental effects are not controlled, the genetic variance between populations and within populations cannot be estimated accurately and consequently the heritability at the population and individual tree level cannot be estimated. So repeatability, which can be considered as the upper limit of relation of genetic and phenotypic variance, was calculated with standard error for fruit morphological traits as suggested by Khalil (1984), Becker (1984), Basu (1996) and Falconer and Mackay (1996).

$$R = \frac{\sigma^2_d}{\sigma^2_d \ \sigma^2_e}$$

Where,

R = repeatability

σ^2_d = variance of difference among individuals

σ^2_e = variance of differences between measurement within the individuals

Results

Mean values of fruit traits among stands (i.e. at stand level)

The mean values of traits for various stands have been depicted in Table 2. Highly significant difference was found among stands for fruit length, fruit diameter, and pericarp weight per fruit (p = 0.01). The maximum fruit length was recorded in stand S10 (25.87 mm). The maximum diameter of fruit was also recorded in stand S10 (21.13 mm); however stands S2, S5, S7, S8 and S9 did not vary significantly from it. The maximum pericarp weight was recorded in stand S10 (0.844 g) which differed significantly from all other stands. The least pericarp weight was observed in stand S6 (0.478 g). Evidently, variation in fruit weight, total seed weight per fruit and total kernel weight per fruit were not significant (p =0.01).

Differences among stands were also significant for ratio traits (p =0.01) (Table 2). Seed: fruit weight ratio and kernel: fruit weight ratios were maximum (0.787 and 0.496 respectively) in stand S6. The stands S1, S3, S4, S7 and S8 were found to be consistently on par with stand S6 for both traits. The stand S9 was also found on par with stand S6 for kernel: fruit weight ratio while stand S10 showed least values (0.641 and 0.352) for these ratios. Pericarp: fruit weight ratio was greatest in stand S10 (i.e. 0.359) which differed significantly from all other stands.

Mean values of fruit traits among trees within stands (i.e. at tree level)

The morphological traits of fruit were also recorded among trees within stands (or at tree level) and the corresponding mean values have been presented in Table 3 to Table 9. All traits showed significant variation (p =0.01) among trees within stands.

The maximum fruit length (27.57 mm) and fruit diameter (22 mm) were recorded in tree T8 of stand S9 and tree T4 of stand S7, respectively (Table 3 and 4). Stand S2, S4, S7 and S8 did not have any tree, which could be on par with the maximum fruit length. Fruit weight was maximum in tree T4 of stand S7 (3.11 g) on par with twenty-three trees (Table 5).

The maximum total seed weight per fruit was found in tree T4 of stand S7 (2.26 g) which was on par with forty-four trees. The minimum value of this trait was found in tree T3 of stand S10 (1.12 g) (Fig.1). The maximum total kernel weight per fruit was recorded in tree T4 of stand S7 (1.45 g) on par with forty-five trees (Table 6) while minimum value was recorded in tree T3 of stand S10 (0.50 g). The least pericarp weight was in tree T8 of stand S3 (0.408 g) on par with forty-four trees.

The highest value of seed: fruit weight ratio was

Fig. 1

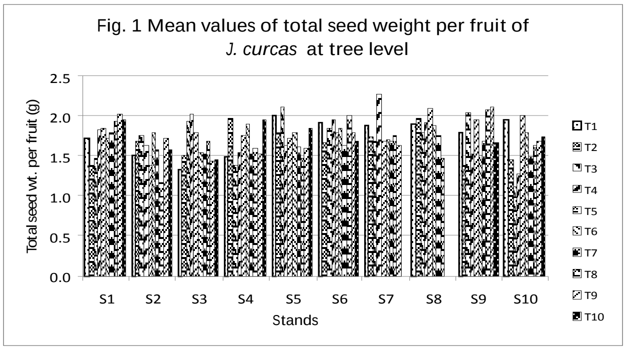
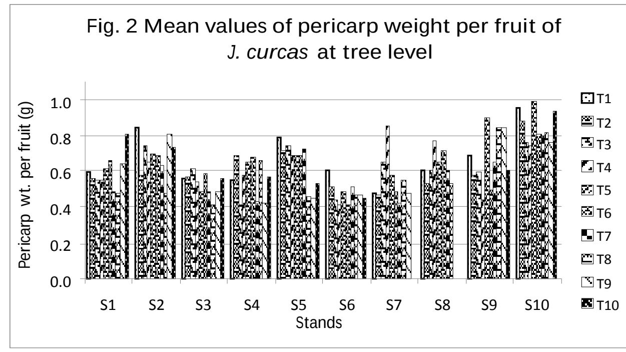


Fig. 2



observed in tree T4 of stand S6 (0.823) on par with thirty-six trees (Table 7). All trees of stand S6 had higher proportion of seed in fruits while no tree present in stand S2 and S10 for the same.

The maximum kernel: fruit weight ratio (0.532) and pericarp: fruit weight ratio (0.414) were found in tree T4 and T8 of stand S6 and tree T2 of stand S10, respectively.

Estimation of variance components of fruit traits

The maximum variance was contributed by fruits level in all fruit morphological traits in contrast with tree and stand levels (Fig. 3). Fruit size (i.e. length and diameter) recorded high proportion (about 75 per cent) of variation component due to fruits. It also contributed 81 per cent to 86 per cent of variation for fruit weight, total seed weight per fruit and total kernel weight per fruit which were the main traits of interest while tree contributed 13 to 17 per cent and stand contribute negligible amount of variation in these traits. Pericarp weight, which constituted approximately 27 per cent of fruit weight, contributed around 57 per cent proportion of variation at fruit level whereas stand and tree both contributed considerable variations i.e. approximately 21 per cent for this trait (Fig. 3).

Variance components for seed: fruit weight ratio, kernel: fruit weight ratio and pericarp: fruit weight ratio traits were 64, 72 and 64 per cent respectively at fruit level, while stand added 19 to 26 per cent for these ratio traits.

Estimation of repeatability of fruit traits

Fruit length, Fruit diameter, fruit weight, total seed weight per fruit, total kernel weight per fruit traits had negligible (below 0.085) repeatability at stand level while pericarp weight per fruit, seed: fruit weight ratio, kernel: fruit weight ratio and pericarp: fruit weight ratio traits had low to moderate repeatability (0.192 to 0.255) at stand level (Table 10). The repeatabilities of all fruit traits at tree level were also low to moderate (0.105 to 0.278).

Discussion

Variation in fruit traits among stands (i.e. stand level)

Fruit length and diameter had highly significant differences among stands (Table 1). The maximum length and maximum diameter of fruits were found in stand S10 while minimum values of these traits were found in stand S7 and stand S3, respectively. Singh *et al.* (2008) recorded 21.41 to 28.11 mm fruit length and 15.24 to 18.36 mm fruit diameter in Uttarakhand accessions of this species. It would be seen here that the range of fruit length in the present study was within the range of fruit length, however, fruit diameter in this study falls outside the range reported. This might have been caused by differences in the place of fruit collection and/or

Table 1

Two levels nested analysis of variance with unequal size of fruit traits

Source of variation	Mean sum of squares	Expected M.S. for a pure Model II
Among stands	MS_s	$\sigma^2_e + n_o'\sigma^2_{t\subset s} + (nt)_o\sigma^2_s$
Among trees within stands	MS_t	$\sigma^2_e + n_o\sigma^2_{t\subset s}$
Among fruits within trees or Error	MS_e	σ^2_e

Where,

σ^2_s = variance of among stands

$\sigma^2_{t\subset s}$ = variance of among trees within stands

σ^2_e = variance among fruits within trees or error

n_o' and nt = coefficient of variation for among stands

n_o = coefficient of variation for among trees within stands

Table 2

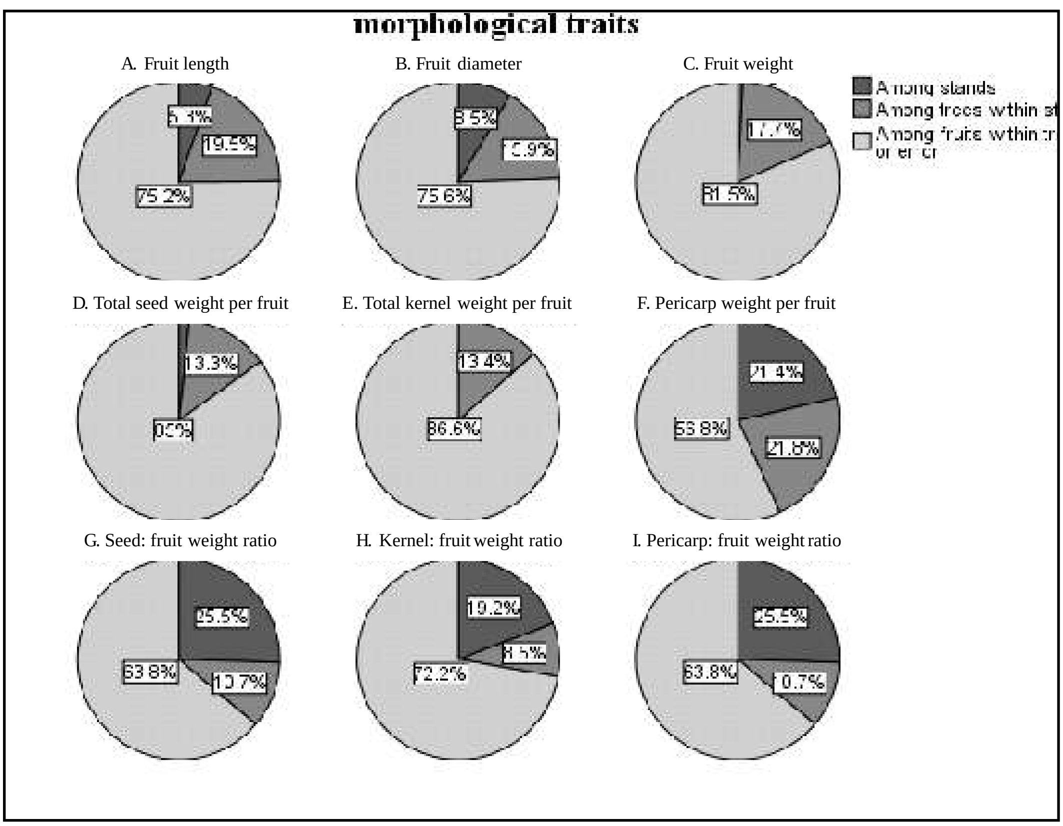
Mean values of fruit traits of Jatropha curcas at stand level

Stands	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	Total seed weight per fruit (g)	Total kernel weight per fruit (g)	Pericarp weight per fruit(g)	Seed: fruit weight ratio	Kernel: fruit weight ratio	Pericarp: fruit weight ratio
S1	24.85**	19.68	2.36	1.76	1.09	0.593	0.744**	0.452**	0.256
S2	24.21	20.41**	2.26	1.58	0.91	0.685	0.690	0.386	0.310
S3	24.67**	19.58	2.15	1.62	0.99	0.529	0.747**	0.455**	0.253
S4	24.32	19.79	2.22	1.66	1.03	0.563	0.744**	0.450**	0.256
S5	24.52**	20.40**	2.40	1.76	1.04	0.646	0.727	0.421	0.273
S6	24.79**	20.12	2.29	1.81	1.15	0.478	0.787**	0.496**	0.213
S7	23.65	20.25**	2.33	1.78	1.12	0.552	0.763**	0.476**	0.237
S8	24.86**	20.62**	2.47	1.85	1.17	0.626	0.743**	0.458**	0.257
S9	24.62**	20.47**	2.43	1.77	1.11	0.659	0.729	0.444**	0.271
S10	25.87**	21.13**	2.46	1.61	0.92	0.844**	0.641	0.352	0.359**
SE_d	0.45	0.30	0.13	0.10	0.07	0.048	0.014	0.016	0.014
$CD_{(a = 0.01)}$	1.46	0.98	ns	ns	ns	0.155	0.046	0.052	0.046
CV %	6.71	5.91	21.51	24.34	30.07	24.37	8.15	17.37	22.21

**Significant at p = 0.01.

ns: The effect of the trait was not significant.

Fig. 3



Variance components (%) at different levels for fruit morphological traits

different period of fruit collection. Luna *et al.* (2008) reported 10.64 and 11.66 per cent variation in different periods of harvesting (i.e. August and February) for fruit diameter among 24 seed sources of *J. curcas* from north Indian states of Himachal Pradesh, Jammu and Kashmir and Punjab. The range of these traits in the present study, however, overlaps with the range reported by Srivastava (1999).

Weight traits of fruits (i.e. fruit weight, total seed weight per fruit, total kernel weight per fruit) did not show significant differences among stands *per se* except for pericarp. Study on *Pinus roxburghii* did not reveal significant difference among populations *per se* of that species for cone dry weight while tree-to-tree differences within populations were significant (Kumar *et al.*, 2007). Among stands, the maximum pericarp weight per fruit was noticed in stand S10, which was significantly different from all other stands ($p = 0.01$), this suggests that the proportion of seed weight in a unit quantity (by weight) of fruit will be less in this stand.

Stand S6 had highest seed: fruit weight ratio and possessed maximum seed weight per fruit (i.e. 787 g seed per kg of fruit). This would result in more amount of oil from a given quantity (by weight) of fruit among stands having same seed oil content (per cent).

Variation in fruit traits among trees within stands (i.e. at tree level)

Studies on variation among trees within stands (i.e. at tree level) showed that trees of different stands had significant variation (Table 3 to Table 9). The maximum fruit diameter occurred in tree T4 of stand S7 (22.00 mm) which was on par with thirty trees (Table 4). These thirty-one higher value trees were spread over nine stands, except stand S3. However, study among stands depicted that only six stands had significantly different mean values for fruit diameter out of the ten stands.

Likewise, 24, 45 and 46 trees of different stands formed groups of good performer trees (i.e. those trees which did not have significantly different value vis-à-vis the highest value) with respect to maximum fruit weight, total seed weight per fruit and total kernel weight per fruit, respectively. This is in contrast to the inference one would draw from the study at stand level only, where stands were not found to be significantly different from one another on the basis of mean values. Parallel observations were also recorded for ratio traits of fruits.

The seed: fruit weight ratio is an important trait for improvement of tree-borne oil seed crops. Meagre information is available on seed: fruit weight ratio at tree level of this species, although values of stand averages are documented by different researchers (Pandey and

Table 3

Mean values of fruit length of Jatropha curcas at tree level

Fruit length (mm)	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	24.82	25.57	26.09**	22.66	26.19**	26.09**	24.22	25.16	25.04	27.37**
T2	24.76	24.52	26.43**	25.56	23.03	24.73	23.63	24.42	24.06	26.27**
T3	23.89	24.31	25.28	24.36	26.00**	24.87	23.66	25.12	24.78	24.31
T4	24.48	23.34	25.73**	23.98	24.85	24.18	25.07	25.59	22.97	24.98
T5	25.89**	24.01	23.91	24.57	23.88	23.71	23.03	25.40	24.93	26.03**
T6	23.83	25.14	23.55	24.77	24.63	24.28	22.69	25.31	22.31	25.56
T7	24.80	24.41	23.94	23.71	24.56	24.51	23.69	24.99	24.67	25.59
T8	25.49	22.30	24.57	25.03	23.44	25.39	23.86	22.88	27.57**	25.88**
T9	24.85	24.94	23.85	24.51	23.10	25.88**	22.98	-	26.56**	26.13**
T10	25.67**	23.54	23.34	23.99	25.50	24.30	-	-	23.30	26.56**

** Significant at p = 0.01, Standard error 0.74, Critical difference (∝ = 0.01) 1.97, Coefficient of variation % 6.71

Table 4

Mean values of fruit diameter of Jatropha curcas at tree level

Fruit diameter (mm)	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	19.46	21.15**	18.70	19.08	20.94**	20.76**	19.98	20.48	20.49	21.74**
T2	18.61	19.96	19.94	20.70**	20.21	20.31	19.74	20.43	19.39	20.85**
T3	18.82	21.46**	20.41	19.79	21.20**	19.79	20.66**	20.42	21.21**	21.03**
T4	19.64	19.81	20.22	19.49	20.11	19.83	22.00**	21.07**	18.80	21.01**
T5	19.63	20.35	19.87	20.13	20.62**	19.80	20.67**	21.39**	21.66**	21.85**
T6	19.87	21.04**	19.58	20.42	20.08	19.78	19.61	21.04**	19.61	21.12**
T7	20.38	20.34	18.85	18.85	19.91	20.39	19.88	20.41	19.88	20.38
T8	19.32	18.33	19.34	19.92	20.02	20.55	20.00	19.72	21.48**	21.03**
T9	20.28	21.00**	19.74	19.36	20.16	20.26	19.71	-	21.81**	21.07**
T10	20.81**	20.63**	19.10	20.20	20.79**	19.76	-	-	20.37	21.20**

** Significant at p = 0.01, Standard error 0.53, Critical difference (∝ = 0.01) 1.42, Coefficient of variation % 5.91

Table 5

Mean values of fruit weight of Jatropha curcas at tree level

Fruit weight (g)	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	2.32	2.34	1.87	2.04	2.80**	2.53**	2.35	2.50	2.49	2.90**
T2	1.94	2.27	2.07	2.65**	2.51**	2.17	2.20	2.50	1.96	2.33
T3	2.01	2.49	2.54**	1.79	2.84**	2.27	2.32	2.39	2.63**	1.88
T4	2.37	2.28	2.56**	2.12	2.33	2.36	3.11**	2.69**	1.96	2.03
T5	2.45	2.07	2.28	2.41	2.40	2.27	2.26	2.74**	2.86**	3.00**
T6	2.37	2.47	2.13	2.57**	2.47	2.27	2.19	2.60**	1.99	2.60**
T7	2.26	2.22	2.01	1.95	2.33	2.14	2.11	2.36	2.34	2.29
T8	2.41	1.65	2.10	2.25	1.93	2.47	2.31	2.01	2.92**	2.44
T9	2.66**	2.51**	1.91	1.95	2.06	2.26	2.11	-	2.95**	2.43
T10	2.76**	2.30	2.01	2.51**	2.36	2.12	-	-	2.26	2.67**

** Significant at p = 0.01, Standard error 0.22, Critical difference (∝ = 0.01) 0.60, Coefficient of variation % 21.54

Table 6

Mean values of total kernel weight per fruit of Jatropha curcas at tree level

Total kernel weight per fruit (g)	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	1.05	0.77	0.76	0.92	1.26**	1.23**	1.19**	1.24**	1.14**	1.16**
T2	0.85	0.99	0.89	1.24**	1.06	1.02	1.11**	1.29**	0.83	0.77
T3	0.96	1.02	1.19**	0.81	1.30**	1.16**	1.06	1.15**	1.23**	0.50
T4	1.16**	0.99	1.28**	0.93	0.98	1.26**	1.45**	1.15**	1.04	0.60
T5	1.16**	0.75	1.09**	1.08**	1.05	1.14**	1.04	1.30**	1.22**	1.26**
T6	1.03	1.10**	0.93	1.19**	1.10**	1.18**	1.11**	1.20**	0.93	1.08**
T7	1.07**	0.93	0.96	0.90	0.98	1.00	1.05	1.08**	1.02	0.86
T8	1.18**	0.60	1.08**	0.94	0.73	1.31**	1.12**	0.90	1.39**	1.00
T9	1.28**	1.00	0.93	1.06	0.87	1.12**	0.96	-	1.31**	0.97
T10	1.17**	0.92	0.84	1.24**	1.09**	1.06	-	-	1.00	0.98

** Significant at p = 0.01, Standard error 0.14, Critical difference (∝ = 0.01) 0.38, Coefficient of variation % 30.16

Table 7

Mean values of seed: fruit weight ratio of Jatropha curcas at tree level

Seed: fruit weight ratio	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	0.743	0.627	0.699	0.727	0.707	0.756**	0.800**	0.753**	0.719	0.667
T2	0.700	0.735	0.719	0.742	0.712	0.759**	0.787**	0.787**	0.698	0.586
T3	0.719	0.701	0.759**	0.764**	0.741	0.806**	0.714	0.743	0.775**	0.588
T4	0.768**	0.711	0.787**	0.721	0.691	0.823**	0.731	0.718	0.773**	0.623
T5	0.747	0.647	0.778**	0.727	0.710	0.784**	0.741	0.763**	0.686	0.670
T6	0.714	0.718	0.718	0.741	0.706	0.816**	0.779**	0.712	0.738	0.674
T7	0.780**	0.712	0.760**	0.768**	0.689	0.754**	0.792**	0.741	0.731	0.643
T8	0.799**	0.695	0.805**	0.702	0.762	0.813**	0.759**	0.725	0.718	0.653
T9	0.760**	0.673	0.739	0.769**	0.777	0.781**	0.766**	-	0.710	0.681
T10	0.710	0.678	0.709	0.776**	0.772	0.783**	-	-	0.728	0.625

** Significant at p = 0.01, Standard error 0.027, Critical difference (∝ = 0.01) 0.070, Coefficient of variation % 8.15

Mandal, 2006). Tree level values of seed: fruit weight ratio in the present study varied from 0.640 to 0.780. Tree T4 of stand S6 recorded a value of 0.823 for seed: fruit weight ratio. This is despite the fact that maximum total seed weight per fruit (i.e. 2.26 g) was recorded in tree T4 of stand S7.

The foregoing paragraphs reveal that even if a stand has a lower mean value of a fruit trait than the minimum desired value of that trait, it is possible to find one or more trees in that stand that would exceed the minimum desired value of that trait among trees within stands. Similar inference has been drawn by Kumar *et al*.

Table 8

Mean values of kernel: fruit weight ratio of Jatropha curcas at tree level

Kernel: fruit weight ratio	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	0.449**	0.309	0.402	0.447**	0.441	0.483**	0.505**	0.492**	0.450**	0.391
T2	0.438**	0.424	0.420	0.465**	0.417	0.457**	0.506**	0.516**	0.418	0.294
T3	0.399	0.402	0.465**	0.443**	0.452**	0.509**	0.450**	0.476**	0.468**	0.259
T4	0.487**	0.432	0.496**	0.431	0.401	0.532**	0.461**	0.421	0.443**	0.285
T5	0.472**	0.344	0.468**	0.440	0.436	0.494**	0.454**	0.474**	0.423	0.422
T6	0.420	0.441	0.426	0.466**	0.418	0.520**	0.504**	0.394	0.448**	0.391
T7	0.462**	0.413	0.473**	0.453**	0.414	0.457	0.488**	0.448**	0.435	0.360
T8	0.486**	0.324	0.515**	0.407	0.362	0.532**	0.482**	0.442**	0.476**	0.403
T9	0.481**	0.388	0.483**	0.457**	0.413	0.487**	0.435	-	0.443**	0.385
T10	0.424	0.387	0.399	0.495**	0.458**	0.493**	-	-	0.430	0.328

** Significant at p = 0.01, Standard error 0.03, Critical difference (∝ = 0.01) 0.09, Coefficient of variation % 17.39

(2007) for cone traits in *Pinus roxburghii.* This suggests that selection for fruit morphological traits should not be done merely at stand level (i.e. among stands) where fruit from trees would be bulked, but it should also be done at tree level (i.e. among trees within stands) where identities of different donor trees within stands would be maintained so as to determine the tree, and also the stand, with the best fruit characteristics.

Pandey and Mandal (2006) studied 150 trees of *J. curcas* belonging to 89 seed sources of Madhya Pradesh and found wide ranges for morphological traits i.e. fruit weight from 1.34 to 3.08 g. However, these authors did not study relative magnitude of variation among trees and among stands.

The behaviour of variation noticed in this study might be due to self incompatible and cross-pollination behaviour (Dehgan, 1984) which enhances the variation among trees within stand, which is basically dependent upon the extent of outcrossing (Singh, 2005).

Variance component and repeatability estimation

Sokal and Rohlf (1969) opine that the variance component estimation by nested or hierarchical analysis of variance is important as it helps in identifying the level of the experiment at which most of our efforts should be concentrated. This approach can be used in geographic variation studies in which variance among samples within one locality and among localities can be estimated which may lead to important conclusions about the population distribution pattern of an organism.

The estimation of the variance components of fruit traits showed that fruit weight, total seed weight per fruit and total kernel weight per fruit have negligible contribution from stands and small contribution from trees, which implies that these fruit traits are not much controlled by stands or by trees within stands *per se* (Fig. 3). Maximum variation was found among fruits within trees (i.e. at fruit level or error). Pericarp weight per fruit and fruit ratio traits were affected to small extent by stand *per se*.

Table 9

Mean values of pericarp: fruit weight ratio of Jatropha curcas at tree level

Pericarp: fruit weight ratio	Stands									
Trees	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1	0.257	0.373**	0.301	0.273	0.293	0.244	0.200	0.247	0.281	0.333
T2	0.300	0.265	0.281	0.258	0.288	0.241	0.213	0.213	0.302	0.414**
T3	0.281	0.299	0.241	0.236	0.259	0.194	0.286	0.257	0.225	0.412**
T4	0.232	0.289	0.213	0.279	0.309	0.177	0.269	0.282	0.227	0.377**
T5	0.253	0.353**	0.222	0.273	0.290	0.216	0.259	0.237	0.314	0.330
T6	0.286	0.282	0.282	0.259	0.294	0.184	0.221	0.288	0.262	0.326
T7	0.220	0.288	0.240	0.232	0.311	0.246	0.208	0.259	0.269	0.357**
T8	0.201	0.305	0.195	0.298	0.238	0.187	0.241	0.275	0.282	0.347**
T9	0.240	0.327	0.261	0.231	0.223	0.219	0.234	-	0.290	0.319
T10	0.290	0.322	0.291	0.224	0.228	0.217	-	-	0.270	0.375**

** Significant at p = 0.01, Standard error 0.027, Critical difference (∝ = 0.01) 0.071, Coefficient of variation % 22.20

Table 10
Estimated value of repeatability of fruit traits

Levels	Fruit traits								
	Fruit length	Fruit diameter	Fruit weight	Total seed weight per fruit	Total kernel weight per fruit	Pericarp weight per fruit	Seed: fruit weight ratio	Kernel: fruit weight ratio	Pericarp: fruit weight ratio
Stand	0.053 ±0.067	0.085 ±0.078	0.008 ±0.050	0.017 ±0.054	0.000 ±0.047	0.214 ±0.113	0.255 ±0.121	0.192 ±0.108	0.255 ± 0.121
Tree	0.206 ±0.114	0.174 ±0.106	0.179 ±0.108	0.135 ±0.096	0.134 ±0.096	0.278 ±0.128	0.144 ±0.099	0.105 ±0.087	0.144 ± 0.099

The study showed that fruits within trees possess the maximum proportion of variance for all the fruit traits (Fig. 3). It implies that there is much variation within a tree either due to sampling error or use of smaller sample size. This variation can be reduced by increment in sample size or increment in replication, but in this way, morphological trait, i.e. phenotype, of fruit or seed will not change, it will still exist in the samples. It is also quite possible that variability in fruit traits within a tree is inherent nature of the species as a result of which an average tree would not be expected to produce uniform fruit. In the absence of uniformity within a tree in respect of a fruit trait, such as fruit length, the only practical method of obtaining uniform fruit would be by grading the fruit by physical or mechanical methods to get a morphologically uniform fruit lot. Else, trees would need to be found that would have uniformity among fruits for fruit traits. However, the frequency of such trees would not be very high and that option would seem to be impractical.

The behaviour of *J. curcas*, as noted above, is different from *Vitelleria paradoxa*. In the latter species, Sanou *et al*. (2006) observed relatively lower variance due to fruits vis-à-vis trees and populations for fruit weight (i.e. 15.879 for among fruits within trees, 35.328 for among trees within populations and 18.649 for among populations).

Khalil (1984) noted that distribution pattern of variation for cone length and cone diameter in *Picea mariana*, had only a small contribution from the provenance component, and the variation was equally divided among trees within populations and among cones within trees. Higher contribution to variance from trees vis-à-vis error implied that there was pronounced uniformity among the cones collected from an average individual tree in respect of the studied characters.

The repeatability sets an upper limit to the heritability. The repeatability is usually much easier to determine than the heritability and it may often be known when heritability is not known (Falconer and Mackay, 1996). The repeatability value of fruit morphological traits fluctuated from zero to 0.28 for all the studied stands and trees (Table 10). Standard error of repeatability was high suggesting that these values of repeatability were not significant. It implies that if the selection of best material is made on the basis of fruit morphological traits then chances of getting similar trait values of various stands or trees will be low.

From this study it can be concluded that maximum stress should be laid on selection of individual trees within a stand rather than selection of stands *per se* for improvement of fruit morphololological traits. Further studies will be required to determine the variance components at fruit level for seed morphological traits.

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SUMMARY

Nine fruit morphological traits were studied in ten stands of *Jatropha curcas* spread in eight forest divisions of Uttarakhand. Variation was examined at stand level as well as at tree level. Significant differences were found among stands for fruit length, fruit diameter, pericarp weight per fruit, seed: fruit weight ratio, kernel: fruit weight ratio and pericarp: fruit weight ratio traits while all morphological traits showed significant differences among trees within stands. The estimation of the variance components, however, revealed that the fruit traits, especially weight traits viz. fruit weight, total seed weight per fruit and total kernel weight per fruit have negligible contribution from stands and small contribution from trees. Maximum variation was found among fruits within trees (i.e. at fruit level or error). Pericarp weight per fruit and fruit ratio traits (i.e. seed: fruit weight ratio, kernel: fruit weight ratio and pericarp: fruit weight ratio) were affected to small extent by stand *per se*. The repeatability of all fruit traits at tree level were also low to moderate (0.105 to 0.278).

Keywords: Jatropha curcas, fruit morphological traits, variance components, repeatability.

स्टैण्ड और वृक्ष स्तर पर *जट्रोफा करकश* के फल आकारिकीय विशेषकों में विभिन्नता

क्षितीज मल्होत्रा, दिनेश कुमार और विद्याधर पाण्डे

सारांश

उत्तराखण्ड के आठ वन प्रभागों में फैले *जट्रोफा करकश* के दस स्टैण्डों में नौ फल आकारिकीय विशेषकों का अध्ययन किया गया। स्टैण्ड स्तर साथ ही साथ वृक्ष स्तर पर विभिन्नता की जांच की गई। फल लम्बाई, फल व्यास, प्रतिफल फलावरण भार, बीजः फल भार अनुपात, गिरीः फल भार अनुपात और फलावरणः फल भार अनुपात विशेषकों के लिए स्टैण्डों में महत्वपूर्ण विभिन्नताएं पाई गई जबकि सभी आकारिकीय विशेषकों ने स्टैण्डों के भीतर वृक्षों में महत्वपूर्ण अन्तर दर्शाया। तथापि, विसंगति घटकों के आकलन ने दर्शाया कि फल विशेषकों विशेषकर भार विशेषकों उदा. – फल भार, प्रति फल कुल बीज भार और प्रति फल कुल गिरी भार का स्टैण्डों से नगण्य सहयोग है और वृक्षों से थोड़ा सहयेाग है। वृक्षों (उदा. फल स्तर पर अथवा त्रुटि) के भीतर फलों में अधिकतम विभिन्नता पाई गई। प्रतिफल फलावरण भार और फल अनुपात विशेषक (उदा.– बीज : फल भार अनुपात, गिरी : फल भार अनुपात और फलावरणः फल भार अनुपात) स्वतः स्टैण्ड द्वारा कुछ सीमा तक प्रभावित थे। वृक्ष स्तर पर सभी फल विशेषकों की बारम्बारता भी निम्न से मध्यम (0.105 से 0.278) थी।

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