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Variation in seed and seedling characters of *Jatropha curcas* L. with varying zones and provenances

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Abstract: This study describes the variation in seed and seedling characters of *Jatropha curcas* L.. Seeds of *J. curcas* were collected from 6 zones (geographical regions) within India and 4 - 6 provenances within each zone. Significant variation was found among zones and among different provenances within zones, for all traits of seed and seedlings of *J. curcas*. Among six zones, sub-humid to humid eastern, south eastern uplands, semi arid lava plateaus and central highlands showed maximum seed length, seed weight, oil content and plant height. All seed and seedling characters were lowest for humid western Himalayan zone. Among 32 provenances, Danikundi, Pendra road, Nainpur and Indore-1 provenances showed better seed and seedling characters. This study has implications for identifying potential seed sources of *J. curcas* for exploiting for higher oil content.

Resumen: El presente estudio describe la variación en caracteres de las semillas y las plántulas de *Jatropha curcas* L.. Las semillas de *J. curcas* fueron recolectadas en seis zonas diferentes (regiones geográficas) dentro de la India y de 4 a 6 procedencias dentro de cada zona. Hubo variación significativa entre zonas y entre diferentes procedencias dentro de las zonas, para todos los rasgos de las semillas y las plántulas de *J. curcas*. Entre las seis zonas, las tierras altas subhúmedas y húmedas del este y sureste, las planicies de lava semiáridas y las planicies altas centrales mostraron los valores máximos de longitud de la semilla, peso de la semilla, contenido de aceite y altura de la planta. Todos los caracteres de las semillas y las plántulas tuvieron sus valores más bajos para la zona occidental del Himalaya. Entre las 32 procedencias, las correspondientes a Danikundi, camino Pendra, Nainpur e Indore-1 mostraron los mejores caracteres de la semilla y las plántulas. Este estudio tiene implicaciones para la identificación de fuentes potenciales de semillas de *J. curcas* que permitan la explotación de mayores contenidos de aceite.

Resumo: Este estudo descreve a variação de caracteres nas sementes e plântulas de *Jatropha curcas* L.. As sementes de *J. curcas* foram colhidas em 6 zonas (regiões geográficas) na Índia e de 4-6 proveniências dentro cada zona. Encontraram-sevariações significativas entre zonas e entre proveniências dentro de cada zona, para todas as características das sementes e plântulas de *J. curcas*. Entre as seis zonas, as regiões sub-húmidas a húmidasno Leste, planaltos do Sudeste, planaltos semi-áridos de lava e planalto central, apresentaram valores máximos para ocomprimento das sementes, peso das sementes, teor de valores em óleo e altura da planta. Todos os caracteres para as sementes e plântulas foram os mais baixos para a zona húmida ocidental do Himalaia. Entre as 32 proveniências, as de Danikundi, estrada de Pendra, Nainpur e Indore apresentaram as melhores semente e melhores caracteres para as plântulas. Este estudo tem implicações para a identificação das fontes potenciais de sementes de *J. curcaspara* exploração do maior teor em óleo.

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Key words: Oil per cent, provenance, seedlings, seed length, seed source, seed weight.

Introduction

Jatropha curcas L. is considered to have originated in Latin America, and is presently grown throughout the arid and semi-arid tropical and subtropical regions of the world. Success in the establishment and productivity of tree plantations is determined largely by species used and the source of seed within species (Lacaze 1978). Growth and management of *J. curcas*, be it on private, public or community lands, have been poorly documented, with little field experience being shared amongst researchers and farmers (Saika *et al*. 2009). For reducing the dependence on crude oil and to achieve energy independence by the year 2012, jatropha has been promoted under the National Biodiesel Mission in India. Forson (2004) reported that the 'jatropha seed oil' can be easily processed to partially or fully replace petroleum-based diesel fuel. Therefore, the use of this plant for large-scale biodiesel production is of great importance in order to solve the energy shortage, mitigating atmospheric CO_2 and enhancing the income of farmers (Banerji *et al*. 1985; Gubitz *et al.* 1999; Keith 2000).

Most tree species, with a few exceptions, have a high degree of fecundity and their wild pollinated out crossing mating system, ensures large amount of heterozygosity and considerable genetic variability (Libby 1987). Studies on provenance and seed sources have been made for many tree species indicating the usefulness of better quality, genetically improved seeds for plantations (Burley & Nikles 1973; Lacaze 1977; Wells & Wakeley 1970). However, such studies on *Jatropha curcas* are lacking. Research conducted across the world showed that *Jatropha* oil is an important emerging, low-cost and smokeless alternative of petrodiesel. *Jatropha* is viewed with a mixture of optimism and prudence. The cultivation of *Jatropha* has begun world over for biodiesel production, but unfortunately there is a lack of availability of quality planting material. In order to translate effective breeding programs, it is necessary to know each and every aspect of the plant, and for this purpose study of provenance variation and initial growth performance of seedlings are considered to be important. The objective of the study was to evaluate the variation in seed morphology and growth performance of seedlings from different provenances of *Jatropha curcas*.

Materials and methods

The study was conducted at Indira Gandhi Krishi Vishwavidyalaya, Raipur (21° 16' N lat.; 81° 36' E long.) in Chhattisgarh region of central India. The elevation above mean sea level is 289 m. The climate of the study site is sub-humid tropical with an average rainfall of 1250 mm. Almost 80 % of rainfall occurs during rainy season, from second week of June to second week of September. May is the hottest month and December is the coldest month of the year. The maximum temperature (44.4 °C) is recorded in the third week of May and minimum (9.6 °C) in the third week of January.

Seeds were collected from different agro-climatic zones of India. Details of zones and provenances (original geographical area from where seeds were collected) are given in Table 1. The morphological parameters of seeds obtained from different provenances, *viz.* seed length, seed width, thickness and seed weight (100 seeds) of different seed lots were measured. Seed length, seed width and seed thick-

Table 1. List of zones and provenances from where *Jatropha* seeds were collected.

S.N.	Zones	Provenances
1.	Humid western Himalayan region	Udhampur, Kathua, Jammu, PJ Set-1, PJ Set-2 and Chandrabani
2.	Sub-humid Sutlej Ganga alluvial plains	Gorakhpur, NRCAF-15, NRCAF-18, NRCAF-14 and NRCAF-13
3.	Sub humid to humid eastern and south eastern uplands	Mancheswar, Hyderabad, Pendra road, Surajpur, Taraiyapara and Danikundi
4.	Arid western plain	Bawal, Udaipur-1 and Udaipur-2
5.	Semi arid lava plateaus and central highlands	AMOS-201, APOS-201, PKVJSJ-1, PKVJMKU-1, Nainpur and Indore-1
6.	Humid to semi arid Western Ghats and Karnataka plateaus	TNMC-3, TNMC-2, TNMC-22, TNMC-7, TNMC-5 and TNMC-4

ness were measured using digital Vernier caliper. Weight of 100 seeds was measured using an electronic balance. Separate weight of seed coat and that for kernels, after removing the seed coat, was measured, to calculate kernel/seed coat ratio.

Four to five sample seeds, corresponding to different seed lots were oven dried at 80 °C for 4-5 h, hard seed coat was removed and kernel was crushed into powder. Oil was extracted with the help of Socs plus solvent exractor (Pelican Equipments, Chennai) using acetone as the solvent in the laboratory at the Department of Forestry, IGKV, Raipur. One gram crushed kernel was placed in the cellulose thimble. Initial weight of the beaker was taken before placing it in the extractor. Further, 80 ml of solvent (acetone) was added in the beaker. The cellulose thimble containing the sample was dipped into the beaker containing solvent. Later, the beaker containing crushed kernel sample along with cellulose thimble was placed on the extractor and boiled for 40 - 45 minutes at 90 °C. After boiling at 90 °C the temperature was increased to 150 °C and the stopper knob was opened for proper rinsing. Thereafter, the stopper knob was closed and solvent was emptied, which was collected in the extractor. Beakers containing oil were removed and kept in oven maintained at 150 °C for 1 h. After an hour these beakers were removed, cooled and weighed. The per cent of oil present in each sample was calculated as:

$$\% \text{ of oil} = \frac{W_2 - W_1}{W} \times 100$$

where, W_1 = Initial weight of beaker, W_2 = Final weight of beaker (beaker + oil), W = Weight of powdered sample (1 g).

Seeds were sown in polythene bags (arranged in the nursery beds) filled with soil, sand and farmyard manure in the ratio 1:1:1, in nursery during November 2004. One seed was sown in each polythene bag. Germinated seeds were counted when seeds stopped germinating in all the replications. After 180 days of sowing, height, collar diameter at the base of the stem and number of leaves were recorded for each seedling.

Analysis of variance was performed under completely randomized design with factors of provenances nested within different agro-climatic zones of India.

Results

Our investigation revealed that seed and seedling characters varied among zones, and provenances within those zones. Initially, zonal variation for different characters was explored; then within those particular zones (in which variations were observed), provenance variation for different characters was studied. Number of provenances within zones was unequal, so, LSD for various zonal pairs was different. Zonal means were compared with appropriate LSD, and it was found that seed and seedling characters differed significantly among zones. Seed length was highest for zone 3 while it was minimum for zone 1 (Fig. 1a). Seed width was maximum for zone 3, followed by zone 5, zone 2, zone 6 and zone 4. It was minimum for zone 1 (Fig. 1b). Seed thickness was the highest for zone 3 while it was minimum for zone 1 (Fig. 1c). Maximum seed weight was recorded for zone 3 and minimum for zone 1 (Fig. 1d). Oil per cent was maximum for zone 3 followed by zone 5, zone 2, zone 4 and zone 1, while it was minimum for zone 6 (Fig. 1e). The highest seed germination per cent was recorded for zone 3 and minimum for zone 1 (Fig. 1f). The highest seedling height was observed for zone 3 and minimum for zone 1 (Fig. 1g). Collar diameter was maximum for zone 3 (Fig. 1h). Maximum number of leaves were found for zone 3 and minimum for zone 1 (Fig. 1i).

Seed characters

Seed length

Seeds collected from various zones varied significantly for seed length. The maximum seed length (19.06 mm) was found in seeds from Nainpur provenance, while Udaipur - 2 provenance (Table 2) recorded the lowest seed length (16.40 mm) followed by Jammu provenance (Table 2).

Seed width

In the entire study, seed width varied between 10.17 mm (provenance - Udhampur, zone humid western Himalayan region) to 11.97 mm (provenances - Pendra road, zone sub-humid to humid eastern and south eastern uplands).

Seed thickness

Differences in seed thickness between provenances within zones 1, 3, 4, 5 and 6 were statistically significant (Table 2). Seed thickness varied between 7.79 to 9.15 mm within zone humid western Himalayan region, 8.77 - 9.07 mm within zone sub-humid Sutlej Ganga alluvial plains, 8.79 - 10.11 mm within zone sub-humid to humid eastern and south eastern uplands, 8.42 - 8.77 mm Arid western plain, 8.83 - 9.47 mm within semi arid lava plateaus and central highlands and 8.55 - 9.27 mm within humid to semi arid Western Ghats and Karnataka plateaus.

Table 2. Provenance variation in seed characters of *Jatropha curcas*, collected from different zones (Mean ± SD).

Zones	Provenances	Seed length (mm)	Seed width (mm)	100 Seed thickness (mm)	Seed weight (g)	Kernel/Seed coat ratio	Oil (%)	Germination (%)
Zone 1	Udhampur	16.61 ± 0.32	10.17 ± 0.28	7.90 ± 0.06	65.91 ± 0.10	1.32 ± 0.003	36.27 (35.00 ± 0.21)	38.06 (38.00 ± 0.48)
	Kathua	16.47 ± 0.74	10.37 ± 0.36	7.79 ± 0.02	65.62 ± 0.10	1.24 ± 0.009	36.87 (36.00±0.15)	36.26 (35.00 ± 1.76)
	Jammu	16.41 ± 0.23	10.23 ± 0.52	7.80 ± 0.03	62.22 ± 0.05	1.29 ± 0.003	38.05 (38.00 ± 0.39)	35.65 (34.00 ± 1.79)
	PJ Set-1	16.84 ± 0.27	11.26 ± 0.09	9.15 ± 0.42	66.43 ± 0.08	1.24 ± 0.006	36.87 (36.00 ± 0.20)	69.43 (86.50 ± 1.14)
	PJ Set-2	16.73 ± 0.16	10.95 ± 0.21	8.85 ± 0.36	66.27 ± 0.04	1.28 ± 0.001	36.27 (35.00 ± 0.22)	66.27 (83.80 ± 1.55)
	Chandrabani	16.77 ± 0.28	10.89 ± 0.08	8.80 ± 0.24	66.01 ± 0.12	1.29 ± 0.001	35.06 (33.00 ± 0.12)	53.58 (64.70 ± 1.65)
	LSD	NS	0.30	0.23	0.61	NS	0.43	4.05
Zone 2	Gorakhpur	17.30 ± 0.08	11.29 ± 0.14	8.77 ± 0.38	62.25 ± 0.81	1.31 ± 0.001	35.66 (34.00 ± 0.27)	51.94 (62.00 ± 1.28)
	NRCAF- 15	17.59 ± 0.28	11.05 ± 0.26	8.83 ± 0.28	73.66 ± 0.50	1.31 ± 0.001	39.23 (40.00 ± 0.34)	60.95 (76.40 ± 1.69)
	NRCAF- 18	17.56 ± 0.06	10.23 ± 0.07	8.86 ± 0.35	72.49 ± 0.54	1.25 ± 0.003	36.87 (36.00 ± 0.10)	53.13 (64.00 ± 1.09)
	NRCAF- 14	17.72 ± 0.07	11.39 ± 0.16	8.96 ± 0.27	73.73 ± 0.07	1.24 ± 0.001	38.64 (39.00 ± 0.19)	67.05 (84.80 ± 1.24)
	NRCAF- 13	17.80 ± 0.34	11.50 ± 0.12	9.07 ± 0.27	74.77 ± 0.14	1.37 ± 0.071	39.81 (39.30 ± 0.24)	63.47 (80.10 ± 1.29)
	LSD	0.32	0.30	NS	0.61	NS	0.43	4.05
Zone 3	Mancheswar	18.07 ± 0.20	11.12 ± 0.23	8.79±0.05	66.26 ± 0.26	1.21 ± 0.002	39.81 (41.00 ± 0.21)	64.19 (81.00 ± 1.18)
	Hyderabad	17.96 ± 0.11	11.02 ± 0.31	8.63 ± 0.23	72.33 ± 0.27	1.26 ± 0.008	42.13 (45.00 ± 0.15)	44.99 (50.00 ± 1.14)
	Pendra road	18.16 ± 0.44	11.97 ± 0.98	9.85 ± 0.11	76.91 ± 0.18	1.21 ± 0.001	43.85 (48.00 ± 0.15)	68.05 (86.11 ± 1.51)
	Surajpur	18.07 ± 0.22	11.01 ± 0.23	9.35 ± 0.27	73.70 ± 0.13	1.27 ± 0.002	38.05 (38.00 ± 0.10)	66.43 (84.00 ± 1.08)
	Taraipara	18.11 ± 0.18	11.14 ± 0.12	9.27 ± 0.17	76.01 ± 0.29	1.25 ± 0.001	40.39 (42.00 ± 0.10)	72.58 (91.10 ± 1.46)

contd....

Table 2. Continued.

Zones	Provenances	Seed length (mm)	Seed width (mm)	100 Seed thickness (mm)	Seed weight (g)	Kernel/Seed coat ratio	Oil (%)	Germination (%)
	Danikundi	18.54 ± 0.18	11.29 ± 0.13	10.11 ± 0.10	77.01 ± 0.24	1.24 ± 0.002	39.81 (41.00 ± 0.12)	75.94 (94.10 ± 1.22)
	LSD	NS	0.30	0.23	0.61	NS	0.43	4.05
Zone 4	Bawal	17.57 ± 0.01	11.01 ± 0.03	8.68 ± 0.15	68.19 ± 0.40	1.25 ± 0.001	34.45 (32.00 ± 0.04)	65.66 (83.00 ± 1.06)
	Udaipur- 1	16.42 ± 0.09	10.96 ± 0.35	8.77 ± 0.06	66.56 ± 0.23	1.26 ± 0.002	37.46 (37.00 ± 0.21)	39.94 (41.20 ± 0.18)
	Udaipur- 2	16.40 ± 0.04	10.62 ± 0.30	8.42 ± 0.22	67.39 ± 0.19	1.28 ± 0.005	38.64 (39.00 ± 0.10)	44.41 (49.00 ± 1.05)
	LSD	0.32	0.30	0.23	NS	NS	0.43	4.05
Zone 5	AMOS- 201	17.10 ± 0.60	10.77 ± 0.19	8.83 ± 0.21	66.12 ± 0.54	1.24 ± 0.002	37.46 (37.00 ± 0.28)	49.80 (58.30 ± 1.68)
	APOS- 201	17.38 ± 0.15	10.88 ± 0.38	9.13 ± 0.11	67.59 ± 0.01	1.26 ± 0.003	38.64 (39.00 ± 0.10)	51.83 (65.10 ± 1.13)
	PKVJSJ1	17.90 ± 0.37	11.14 ± 0.15	9.29 ± 0.24	69.18 ± 0.74	1.24 ± 0.001	38.05 (38.00 ± 0.23)	62.91 (79.30 ± 0.82)
	PKVJMKU1	17.78 ± 0.25	10.83 ± 0.07	8.88 ± 0.13	72.60 ± 0.53	1.31 ± 0.001	37.46 (37.00 ± 0.10)	58.13 (73.60 ± 1.52)
	Nainpur	19.06 ± 0.51	11.91 ± 0.38	9.37 ± 0.14	77.04 ± 0.16	1.22 ± 0.003	40.25 (41.80 ± 0.22)	70.79 (89.20 ± 1.56)
	Indore- 1	18.56 ±0.26	11.69 ± 0.22	9.47 ± 0.34	76.23 ± 0.56	1.21 ± 0.001	40.39 (42.00 ± 0.24)	68.17 (86.20 ± 1.09)
	LSD	0.32	0.30	0.23	0.61	NS	0.43	4.05
Zone 6	TNMC- 3	17.72 ± 0.13	10.50 ± 0.26	9.27 ± 0.07	67.41 ± 0.19	1.31 ± 0.012	36.27 (35.00 ± 0.18)	60.68 (76.00 ± 1.43)
	TNMC- 2	16.98 ± 0.24	10.52 ± 0.19	8.55 ± 0.15	66.02 ± 0.34	1.24 ± 0.004	36.97 (36.20 ± 0.57)	56.17 (69.00 ± 1.13)
	TNMC- 22	17.69 ± 0.37	11.41 ± 0.09	8.96 ± 0.18	66.15 ± 0.19	1.28 ± 0.001	36.87 (36.00 ± 0.53)	57.42 (71.00 ± 1.15)
	TNMC- 7	17.68 ± 0.05	10.66 ± 0.15	8.78 ± 0.52	67.25 ± 0.37	1.28 ± 0.001	35.67 (34.00 ± 0.25)	57.40 (70.90 ± 0.51)
	TNMC- 5	17.09 ± 0.15	10.56 ± 0.80	8.69 ± 0.04	66.11 ± 0.16	1.26 ± 0.002	36.27 (35.00 ± 0.10)	56.79 (70.00 ± 1.14)
	TNMC- 4	17.04 ± 0.09	11.76 ± 0.31	8.72 ± 0.15	65.17 ± 0.28	1.28 ± 0.001	35.17 (33.20 ± 0.08)	56.05 (68.80 ± 0.35)
	LSD	0.32	0.30	0.23	0.61	NS	0.43	4.05

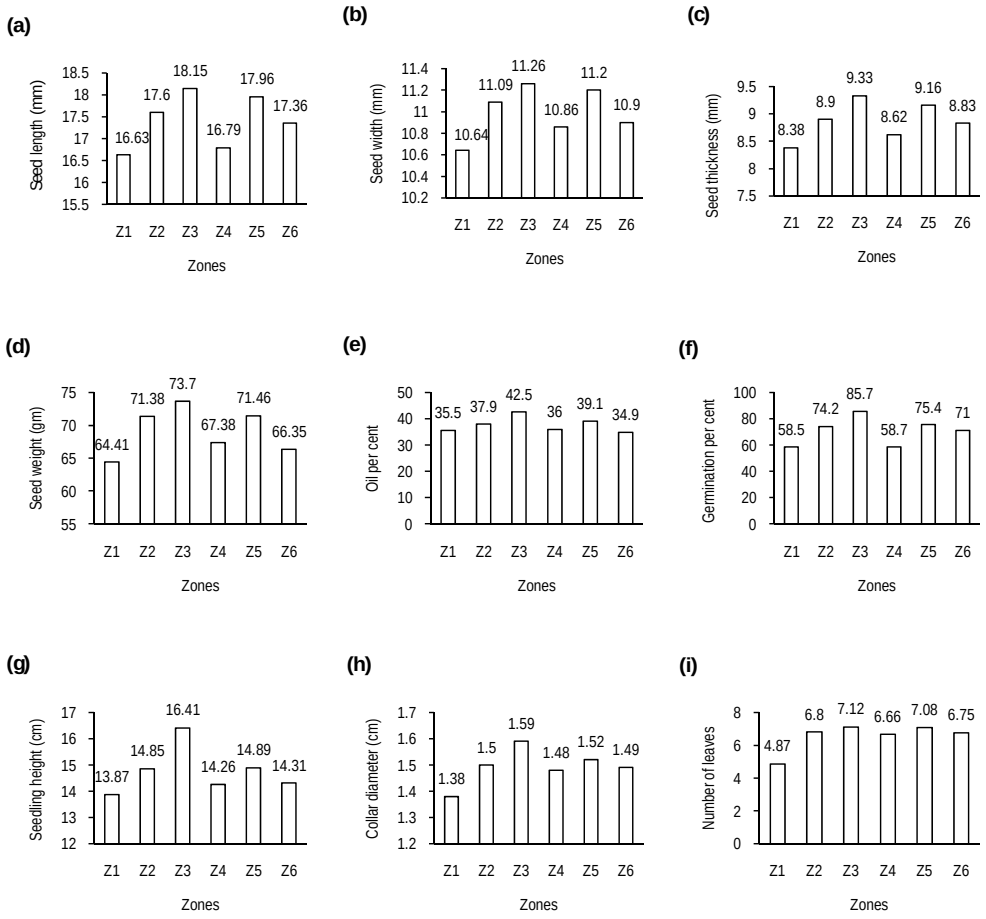

Fig. 1. Zonal variation for seed length (a), seed width (b), seed thickness (c), seed weight (d), oil % (e), germination % (f), seedling height (g), collar diameter (h) and number of leaves (i). Note: Z1 (Humid western Himalayan region), Z2 (Sub-humid Sutlej Ganga alluvial plains), Z3 (Sub humid to humid eastern and south eastern uplands), Z4 (Arid western plain), Z5 (Semi arid lava plateaus), Z6 (Humid to semi arid western ghats and Karnataka plateaus).

Seed weight

Within the zone humid western Himalayan region, PJ Set-1 had the highest seed weight (Table 2). Within sub-humid Sutlej Ganga alluvial plains NRCAF-13 had the maximum seed weight (Table 2), while Gorakhpur provenance had the minimum seed weight. Provenances, within the zone sub-humid to humid eastern and south eastern uplands, differed significantly for seed weight (Table 2). Within zone semi-arid lava plateaus and central highlands, Nainpur provenance had the maximum seed weight and AMOS-201 the minimum. At the same time, within zone humid to semi-arid Western Ghats and Karnataka plateaus, various provenances, differed significantly in seed weight (Table 2).

Kernel/seed coat ratio

Analysis of variance indicated that different zones had no significant effect on kernel/seed coat ratio.

Oil per cent

Provenances within zones 1, 2, 3, 4, 5 and 6 varied significantly (LSD = 0.43) in oil content (Table 2). Among provenances, seeds collected from humid western Himalayan region's Jammu provenance showed the highest oil content (38 %) while the Chandrabani provenance had the lowest oil content (33 %). Provenances such as NRCAF-13 (39.3 %), Pendra road (48.09 %), Udaipur-2 (39 %), Indore-1 (42 %) and TNMC-2 (36.2 %) had highest oil content, whereas NRCAF-18 (36 %), Surajpur (38 %), Bawal (32 %), AMOS-201 (37 %) and TNMC-4 (33.2 %) had the lowest oil per cent within their respective zones (Table 2). In the entire study, highest oil per cent was found in Pendra road provenance, whereas lowest in Bawal.

Per cent germination

While comparing means with LSD (4.05), differences in per cent germination in all the provenances, from different zones of India, were statistically significant (Table 2). Per cent germination varied from 34.00 to 86.50 %, 62.00 to 84.80 %, 50.00 to 94.10 %, 41.20 to 83.00 %, 58.30 to 89.20 % and 68.80 to 76.00 % in different provenances within zones, humid western Himalayan region, sub-humid Sutlej Ganga alluvial plains, sub-humid to humid eastern and south eastern uplands, arid western plain, semi arid lava plateaus and central highlands and humid to semi arid Western ghats and Karnataka plateaus, respectively.

Seedling characters

Seedling height

Seedling height ranged from 14.45 cm to 15.36 cm in different provenances within sub-humid Sutlej Ganga alluvial plains (Table 3). In Zone 2, it was significantly higher in NRCAF- 13, and significantly lower in NRCAF- 15 (LSD 0.35). It varied from 14.12 cm to 17.90 cm in different provenances within sub-humid to humid eastern and south eastern uplands. Within arid western plain it varied between 14.03 cm to 14.55 cm and 14.45 cm to 15.24 cm within semi arid lava plateaus and central highlands. At the same time provenances NRCAF-13, Danikundi, Bawal, Nainpur and TNMC-22 had the tallest seedlings and provenances NRCAF-18, Hyderabad, Udaipur-2 and AMOS-201 had the lowest seedling height. In the entire study, highest (17.9 cm) seedling height was found in Danikundi provenance (sub-humid to humid eastern and south eastern uplands) (Table 3).

Collar diameter

The analysis of variance indicated that provenances within zones sub - humid to humid eastern and south eastern uplands and semi arid lava plateaus and central highlands had significantly different impact on collar diameter. It ranged from 1.45 to 1.7 cm, 1.42 to 1.65 cm and 1.4 to 1.57 cm in zones sub-humid to humid eastern south eastern uplands, semi arid lava plateaus and central highlands and humid to semi arid Western Ghats and Karnataka plateaus, respectively.

Number of leaves

All zones had significantly different effect. The number of leaves varied between 4.25 to 5.50 across the provenances (Table 3). Danikundi provenance had the highest number of leaves, whereas Kathua provenance had the lowest. Number of leaves ranged from 4.3 to 5.5, 5.8 to 7.8, 5.2 to 9.5, 5.8 to 7.8, 6.3 to 7.8 and 5.8 to 7.5 among different provenances within zones 1, 2, 3, 4, 5 and 6 respectively.

Discussion

ANOVA revealed that seed and seedling characters of *J. curcas* differed significantly among different zones and provenances. Zonal differences showed that environmental factors play a vital role in changing seed and seedling characters. Each provenance represented a particular locality, soil and climatic condition. The provenances possessed genotypic characters according to their locality, but when grown in Chhattisgarh (zone sub-humid to humid eastern and south eastern uplands), they were adjusted by local climatic conditions and this adjustment affected their performance. On an average, provenances from the zone sub-humid to humid eastern and south eastern uplands performed best whereas provenances from the zone humid western Himalayan region proved poorest. Because this study was conducted in Chhattisgarh (zone sub-humid to humid eastern and south eastern uplands), the provenances belonging to this particular zone experienced less stress, whereas other provenances faced totally different climate.

The highest 100 seed weight and germination per cent of Danikundi provenance is due to the fact that it belongs to the zone sub-humid to humid eastern and south eastern uplands, where annual rainfall is 75-150 cm and temperature range is 16-28 °C (Jan), 27-36 °C (July). The lowest 100 seed weight and germination per cent of Jammu provenance could be attributed to the origin of seeds from an area experiencing low temperature ranges.

Within zone differences might be due to local variations in bioclimate, soil fertility and topographic conditions, as zones are themselves characterized by well distinguished annual rainfall, temperature range and major soil groups. Various climatic factors influence the vegetation collectively but not individually. Thus the vegetation of a place is the result of various climatic factors acting together. While affecting vegetation collectively, these factors modify the influence of each other to certain extent. Total rainfall of a place influences vegetation, but the effect of total rainfall is modified by the number of rainy days. Considering these facts, provenances may possess climatic and edaphic features different than their zones. These factors ultimately caused provenance variation within zones.

Manga & Sen (1995) observed that germination per cent in *Prosopis cineraria* can be improved

Table 3. Provenance variation in seedling characters of *Jatropha curcas* (raised from seeds collected from different Zones) (Mean ± SD).

Seedling characters	Humid western Himalayan region (Zone 1)						LSD for provenances
	Udhampur	Kathua	Jammu	PJSet-1	PJSet-2	Chandrabani	
Seedling height (cm)	13.76 ± 0.34	13.70 ± 0.30	13.83 ± 0.08	13.99 ± 0.46	13.84 ± 0.33	14.11 ± 0.09	NS
Collar diameter (cm)	1.35 ± 0.05	1.37 ± 0.05	1.42 ± 0.05	1.40 ± 0.01	1.45 ± 0.06	1.32 ± 0.05	NS
Number of leaves	4.50 ± 0.57	4.25 ± 0.50	4.75 ± 0.50	5.25 ± 0.50	5.00 ± 0.81	5.50 ± 0.57	0.75
	Sub-humid Sutlej Ganga alluvial plains (Zone 2)						
	Gorakhpur	NRCAF- 15	NRCAF- 18	NRCAF- 14	NRCAF- 13		
Seedling height (cm)	14.75 ± 0.14	14.45 ± 0.10	14.54 ± 0.16	15.19 ± 0.15	15.36 ± 0.37		0.35
Collar diameter (cm)	1.42 ± 0.12	1.50 ± 0.08	1.47 ± 0.09	1.57 ± 0.09	1.52 ± 0.09		NS
Number of leaves	7.50 ± 0.57	6.25 ± 0.50	5.75 ± 0.50	6.75 ± 0.50	7.75 ± 0.50		0.75
	Sub humid to humid eastern and south eastern uplands (Zone 3)						
	Mancheswar	Hyderabad	Pendra road	Surajpur	Taraiyapara	Danikundi	
Seedling height (cm)	14.29 ± 0.22	14.12 ± 0.09	17.84 ± 0.09	16.73 ± 0.35	17.58 ± 0.21	17.90 ± 0.16	0.35
Collar diameter (cm)	1.45 ± 0.05	1.50 ± 0.01	1.70 ± 0.14	1.65 ± 0.06	1.67 ± 0.05	1.60 ± 0.08	0.11
Number of leaves	5.50 ± 0.57	5.25 ± 0.50	8.00 ± 0.01	7.00 ± 0.81	7.50 ± 0.57	9.50 ± 0.57	0.75
	Arid western plain (Zone 4)						
	Bawal	Udaipur- 1	Udaipur- 2				
Seedling height (cm)	14.55 ± 0.22	14.19 ± 0.23	14.03 ± 0.25				0.35
Collar diameter (cm)	1.47 ± 0.05	1.42 ± 0.05	1.55 ± 0.10				NS
Number of leaves	7.75 ± 0.50	5.75 ± 0.50	6.50 ± 0.57				0.75
	Semi arid lava plateaus and central highlands (Zone 5)						
	AMOS- 201	APOS- 201	PKVJSJ1	PKVJMKU1	Nainpur	Indore- 1	
Seedling height (cm)	14.45 ± 0.24	14.76 ± 0.27	14.84 ± 0.24	14.93 ± 0.27	15.24 ± 0.14	15.12 ±0.55	0.35
Collar diameter (cm)	1.50 ± 0.08	1.42 ± 0.05	1.47 ± 0.09	1.52 ± 0.05	1.55 ± 0.05	1.65 ± 0.05	0.11
Number of leaves	6.25 ± 0.50	7.25 ± 0.95	7.00 ± 0.10	7.50 ± 0.57	7.75 ± 0.50	6.75 ± 0.50	0.75
	Humid to semi arid western ghats and Karnataka plateaus (Zone 6)						
	TNMC- 3	TNMC- 2	TNMC- 22	TNMC- 7	TNMC- 7	TNMC- 4	
Seedling height (cm)	14.23 ± 0.18	14.37 ± 0.35	14.45 ± 0.21	14.32 ± 0.03	14.24 ± 0.12	14.22 ± 0.06	NS
Collar diameter (cm)	1.50 ± 0.08	1.42 ± 0.09	1.40 ± 0.08	1.52 ± 0.05	1.57 ± 0.09	1.55 ± 0.05	NS
Number of leaves	6.25 ± 0.50	7.50 ± 0.57	7.25 ± 0.50	7.00 ± 0.01	6.75 ± 0.50	5.75 ± 0.50	0.75

by selecting large and heavy seeds. The performance of seed immediately after germination is governed by seed size (Willan 1985). Heavy and large seeds contain more food reserves than smaller ones, which is helpful in germination by providing more energy (Lusk 1995). Similar findings were also reported by Ponnamal *et al*. (1993). For example, within the zone humid western Himalayan region, seeds from PJSet-1 had maximum seed weight and the highest germination percent.

Seed size and weight are two important characters for improving seedling productivity and reducing nursery cost through selection of quality seeds, apart from selecting and delineating provenances (Armstrong & Westoby 1993; Isik 1986; Uniyal *et al*. 2002). The purpose for provenance testing is to measure the pattern of genetic variation and to aid in selection of well-adapted and highly productive seed sources for silvicultural practices.

Within the zone sub-humid to humid eastern and south eastern uplands and arid western plain, highest seed weight was observed for Danikundi and Bawal provenances respectively, at the same time both provenances produced highest seedling length in their respective zones. Hence, it is clear that seeds with greater seed weight produced seedlings with higher shoot length. This may be due to greater nutrient reserves in larger seeds (Kathju *et al*. 1978). Similar trend was also reported for *Virola koschyni* (Gonzales 1993), *Hardwickia binata* (Ponnamal *et al*. 1993) and *Albizia lebbek* (Roy 1985). Thus it can be concluded that seed size has operational importance.

Provenances with higher seed weight also possessed higher length and vice versa. Provenances PJ Set-1, within humid western Himalayan region, Bawal, within arid western plain, Danikundi, within sub-humid to humid eastern and south eastern uplands, NRCAF-13, within sub-humid Sutlej Ganga alluvial plain, Nainpur, within semi-arid lava plateaus and central highlands and TNMC-3, within humid to semi-arid Western Ghats and Karnataka plateaus, had the highest seed length along with highest seed weight. Similar results were also reported in *Albizia lebbeck* (Bhat & Chauhan 2002; Luna *et al*. 2006). Seed weight is also related to oil content. Zones with higher seed weight also had higher oil per cent.

The significant difference in various seed morphological and seedling characters of *J. curcas* provenances is indicative of the possibility of selecting large and heavier seeds for further improvement work. Significant zonal impact revealed that environmental factors contribute in changing external appearance as the species grows in a wide range of ecological conditions and hence population can be expected to experience markedly selective pressure on seed characters. The zonal and provenance variation could partly arise from genetic diversity which needs to be studied in detail.

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