Study of accession source variation in morpho-physiological parameters and growth performance of *Jatropha curcas* Linn.

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Jatropha (*Jatropha curcas* Linn.) is a non-edible oilseed plant with adaptability to marginal semi-arid lands and wastelands. The Indian Government is promoting jatropha to reduce dependence on the crude oil and to achieve energy independence by the year 2012, under the National Biodiesel Mission. Adaptive trials on *J. curcas* were undertaken at the North East Institute of Science and Technology, Jorhat, Assam. The aim of the study was to determine source variation in *J. curcas* accessions collected from 17 states (34 locations) of India and to identify the best sources to be utilized for reforestation and future genetic improvement work. The evaluation of 34 cultivars revealed a good degree of variation for plant height, stem girth, branches per plant and 100 seed weight. The accessions have shown measurable growth responses, which were sufficient for a conclusive remark. Hence the present study was carried out with the respective first and second year growth performances. Variation in the physiological parameters of different sources was also studied. The pattern of variation exhibited for different characters was found to be different and varied with age. Such variation among different populations may be due to different intensities of natural selection acting upon the traits in their natural habitat. High 100 seed weight (142 g) was observed in one cultivar. The performance of Naharlagun (Arunachal Pradesh), Lamphelpat (Manipur), Dergaon (Assam) and Namsa (Nagaland) sources was satisfactory. The results indicate that genetic differences exist among accessions of *J. curcas*. The relative performance of these sources was fairly consistent throughout the observation period.

Keywords: Accession source, genetic improvement, *Jatropha curcas*, morpho-physiological parameters.

JATROPHA CURCAS Linn. is a deciduous shrub that grows up to a height of 3–5 m, and has a productive life of 50 years. It is a multipurpose shrub and is considered to have originated in Latin America, but presently it grows throughout the arid, semi-arid, tropical and subtropical regions of the world[1–3]. In India, the 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. To reduce dependence on crude oil and to achieve energy independence by the year 2012, jatropha has been promoted under the National Biodiesel Mission in India. The seed oil ‘jatropha oil’ can be easily processed to partially or fully replace petroleum-based diesel fuel[4]. Thus, the use of this plant for large-scale biodiesel production is of great interest with regard to solving the energy shortage, reducing carbon emission and increasing the income of farmers[5–9]. Recently, the high yield of seeds from the tree (~5 t/ha/yr) and the high oil content of the seeds (~66.4%) attracted global attention for the development of *J. curcas* as a source of bio-fuel[8,10–12]. The plant can be propagated on a massive scale by direct seedling, planting stem cuttings, stumps and root cuttings. Hot and humid weather is preferred for good germination of seeds and plant growth. A seedling starts yielding seeds at the end of the first year in North East India. Its yield is limited by some abiotic stresses, especially cold and drought[11].

Utilization of *J. curcas* oil as a new source for diesel engine has tremendous scope in contributing to the growing needs of energy resources in the country. However, many specific questions about its production, commercialization and genetic improvement work are still in their infancy. No work on genetic improvement aspects of this species has been taken up so far in India. Systematic provenance trails at different locations have not yet been carried out with *J. curcas* in India and to the necessary extent in the world. The material from the centre of origin has not been sufficiently screened[13]. At the global level, information on genetic improvement of *J. curcas* is restricted to a few publications. Among these reports, no morphological differences among 42 clones originating from different locations was observed in Thailand[14]. A significant difference in vegetative development among the 13 provenances of *J. curcas* in multi-location field trials in two countries, viz. Senegal and Cape Verde, and a significant genotype–environment interaction in Senegal was reported[13]. Owing to its importance, the species has gained popularity and is being scaled up in different parts of India on a large scale. There is a good reason for developing *J. curcas* as a new energy crop, as it does not compete with conventional food crops for land, water and manpower resources and it also has the ability to make a significant contribution to the nation’s growing needs for energy through large-scale cultivation with ease[15]. In the present study, a total of 34 sources of *J. curcas* representing the promising jatropha-growing belt of India, were screened and evaluated. The objective of the study was to understand the magnitude of genetic variation in growth, behaviour and adaptability in North East India to identify the best sources to be utilized for reforestation and future genetic improvement work.

The experiment was conducted at North East Institute of Science and Technology (NEIST), Jorhat which falls

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Table 1. Accession sources of *Jatropha curcas* and their geographical locations

Accession code	State	Locality	Latitude (°N)	Longitude (°E)	Altitude (m)	Rainfall (mm)	Mean temperature (°C) (minimum–maximum)
S1	Gujarat	Panchmahal	23.00	74.00	1000.00	750	14.0–45.0
S2	Gujarat	Bhavnagar	21.45	72.10	24.00	454	21.4–33.6
S3	Gujarat	Junagarh	21.52	70.47	107.00	680	15.0–45.0
S4	Gujarat	Banaskantha	23.05	72.09	36.50	472	24.3–43.9
S5	Orissa	Ganjam	19.40	84.70	45.00	1187	16.0–35.0
S6	Andhra Pradesh	Rangareddy	16.55	77.30	560.84	750	13.4–27.8
S7	Uttarakhand	Dehradun	30.19	78.04	2200.00	2137	14.6–27.7
S8	Manipur	Lamphelpat	24.44	93.65	790.00	2027	8.0–34.0
S9	Haryana	Hisar	29.17	75.73	215.00	400	5.1–44.9
S10	Haryana	Mahendragarh	27.47	75.56	3800.00	455	6.0–41.0
S11	Arunachal Pradesh	Naharlagun	27.00	93.42	200.00	2688	8.0–32.0
S12	Arunachal Pradesh	Roing	28.05	95.89	300.00	2800	5.0–29.0
S13	Nagaland	Tuli	26.44	94.65	1325.00	2330	9.0–25.0
S14	Nagaland	Namsa	26.78	94.77	897.64	1644	13.3–24.8
S15	Tripura	Baramura	23.82	91.65	904.00	2800	12.5–33.0
S16	Tripura	Kamalasagar	23.63	91.25	1000.00	2700	10.1–34.3
S17	Meghalaya	Watrigithim	25.98	90.68	1496.00	3350	10.0–37.0
S18	West Bengal	Durgapur	25.31	88.7	68.90	1500	29.4–46.1
S19	West Bengal	Sonamukhi	23.00	87.41	65.00	1820	10.0–45.0
S20	West Bengal	Purulia	23.19	86.22	229.00	1300	7.0–46.8
S21	West Bengal	Bankura	23.15	87.04	76.80	1350	20.8–32.9
S22	West Bengal	Midnapur	22.15	87.39	159.00	1450	24.5–40.1
S23	Tamil Nadu	Coimbatore	11.00	76.97	426.00	557	20.7–39.4
S24	Kerala	Palakkad	10.46	76.28	80.00	2414	15.0–35.0
S25	Uttarakhand	Nainital	29.24	79.28	1938.00	2794	7.6–18.0
S26	Uttarakhand	Latehar	23.45	84.30	1140.00	1500	12.0–15.0
S27	Uttarakhand	Ranchi	23.28	85.32	625.00	1530	37.2–10.3
S28	Uttarakhand	Garhwal	30.50	77.65	1700.00	2180	1.0–45.0
S29	Jharkhand	Palamau	23.50	84.30	1140.00	1036	20.6–37.2
S30	Mizoram	Kolasib	24.13	92.40	660.54	2860	7.0–32.0
S31 (Local)	Assam	Dergaon	26.73	94.01	86.00	2052	10.8–31.9
S32 (Local)	Assam	Khakarpur	26.55	90.58	53.31	1614	12.9–31.7
S33 (Local)	Assam	Sengeliati	26.45	97.30	26.70	2072	10.8–31.9
S34 (Local)	Assam	Lakhimpur	27.65	96.25	87.00	2635	8.0–31.5

between 27.35–26.30°N latitude and 93.45–94.30°E longitude. The area enjoys moderate type of climate, with mean annual rainfall 2244 mm. Accessions of *J. curcas* were collected through surveys from parent plants chosen randomly from each population, which were about 100 m apart from each other. Accessions from each plant were collected and labelled to maintain their identities. The accessions were put in polythene bags (one accession per bag) containing potting mixture of sand, soil and farmyard manure in the ratio of 1 : 1 : 1 (by volume) in four replicates each using randomized complete block design[16]. Accessions were maintained in polythene bags for 30 days for rooting. One-month-old rooted accessions were planted in the field (pit size 50 × 50 × 50 cm) in a randomized complete block design with three replications, and the spacing between plants was 2.5 × 2.5 m. Observations were recorded on the trail periodically for plant height (cm), stem girth (cm), number of branches per plant and physiological parameters, viz. photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) and stomatal conductance (cm s^{-1}). The first assessment was carried out 12 months after field planting and subsequently after 24 months. Photosynthetic rate and stomatal conductance were measured using Portable Photosynthesis System, TPS-2 (PP Systems). Leaf area was measured with a Leaf Area Meter 211 (Systronics) for five leaves chosen randomly from each tree and expressed as average leaf area per leaf. The leaf area was multiplied by the number of leaves occurring in the plant and was expressed as total leaf area per plant. Statistical analysis was done according to the standard procedure[16]. All the percentage data were suitably transformed and analysed in a completely randomized design (CRD).

Accession sources of *J. curcas* are given in Table 1. *J. curcas* is being explored for its oil-yield potential throughout the world. The sources used in this study had mean annual rainfall range from 400 to 3350 mm. The accessions collected from 34 sources were evaluated for growth and survival at ages 12 and 24 months of field planting. The corresponding mean performance values are presented in Tables 2 and 3. Root formation of *J. curcas* cuttings of different diameters (1, 2 and 3 cm) and

Table 2. Growth performance of various accessions after transplantation to the field

Accession code	Plant height (cm)		Stem girth (cm)		Number of branches/plant		100 seed wt (g)	
	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr
S1	81.50	161.31	2.70	13.96	4.02	6.12	0.00	81.00
S2	39.00	122.00	3.20	7.33	0.00	4.33	0.00	0.00
S3	39.33	72.67	9.87	10.97	2.33	3.67	0.00	0.00
S4	33.00	103.22	2.70	10.50	1.81	3.33	0.00	69.60
S5	126.00	177.00	2.60	13.24	3.20	5.93	0.00	77.60
S6	33.40	104.00	3.30	12.10	0.00	5.00	0.00	0.00
S7	28.00	106.67	2.10	9.32	2.50	3.25	0.00	72.90
S8	97.75	199.50	9.23	15.11	5.01	6.06	0.00	139.20
S9	25.00	119.81	2.30	9.90	2.02	4.41	0.00	87.17
S10	27.00	83.67	2.31	6.00	0.00	3.67	0.00	0.00
S11	96.25	280.00	4.75	27.50	3.25	7.44	0.00	142.00
S12	53.00	151.00	3.25	9.50	0.00	7.00	0.00	52.28
S13	44.00	109.50	2.20	7.50	0.00	4.00	0.00	50.93
S14	46.50	114.33	2.00	9.00	0.00	5.00	0.00	86.07
S15	61.00	157.33	2.50	8.67	0.00	5.33	0.00	65.64
S16	42.00	126.00	2.55	8.00	0.00	3.50	0.00	44.54
S17	35.00	154.33	2.20	12.50	0.00	5.00	0.00	62.78
S18	129.00	176.00	4.30	15.22	0.00	11.00	0.00	0.00
S19	100.00	179.00	4.00	18.00	0.00	5.00	0.00	67.93
S20	38.50	88.00	1.40	8.00	0.00	2.00	0.00	38.00
S21	30.00	93.50	1.20	5.50	0.00	3.00	0.00	0.00
S22	110.00	180.00	3.70	26.00	0.00	5.00	0.00	0.00
S23	86.00	154.00	2.50	6.00	0.00	8.00	0.00	40.00
S24	38.00	121.00	1.80	7.00	0.00	3.00	0.00	53.33
S25	26.00	88.67	2.31	6.00	0.00	3.67	0.00	0.00
S26	28.00	74.50	2.50	7.50	0.00	4.50	0.00	62.22
S27	28.00	74.50	2.50	7.50	0.00	4.50	0.00	62.22
S28	58.00	106.50	2.60	12.50	0.00	3.50	0.00	0.00
S29	46.30	134.00	2.30	11.00	0.00	3.00	0.00	74.18
S30	59.54	256.00	3.25	14.00	2.50	6.00	0.00	54.00
S31	114.50	179.87	8.95	16.11	7.18	8.75	0.00	126.40
S32	63.50	125.00	4.50	14.00	0.00	4.67	0.00	68.41
S33	56.00	131.00	2.90	9.75	0.00	3.00	0.00	47.55
S34	51.00	143.00	2.00	10.00	0.00	6.33	0.00	55.71
CD (5%)	8.97	3.64	1.98	2.67	NS	0.63	0.00	NS

NS, Non-significant; CD, Critical difference; 1st yr = 12 months growth; 2nd yr = 24 months growth.

lengths (5 and 7 cm) in the polythene bags was observed. Thicker cuttings formed more roots than the thinner ones. Cuttings of 30 cm length developed more roots and their survival rate was higher than cuttings of 15 cm length. The following two factors are generally responsible for rooting: age of the plant from which cuttings are taken and position of the cutting within the plant[17]. The height growth after one year of planting was higher in S18 followed by S5, S31 and S22, which were statistically at par with each other. The lowest value was recorded in S9 followed by S25 and S10. Stem girth was maximum in S3 followed by S8 and S32, which were statistically at par. Maximum number of branches was found in S31 followed by S8, S1, S11 and S5 (Table 2). The sources were statistically at par with respect to the number of branches. Photosynthetic rate, stomatal conductance and leaf area were also measured, which showed significant variability. 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.

After 24 months of field planting, significant differences ($P < 0.05$) were noticed among accession sources in height, stem girth, number of branches, leaf area, photosynthesis rate, stomatal conductance and survival per cent. The growth followed a more or less similar trend as was observed at age 12 months. A clear-cut distinction in the performance of the accession sources was observed at this age, in which the S11 source outranked the remaining ones with regard to height (280 cm), stem girth (27.5 cm), 100 seed weight (142 g) and field survival (100%). The number of branches was maximum in S31 followed by S11, S14 and S34, and they were statistically at par with each other. The percentage of survival recorded was 100 in 15 out of 34 sources. However, the lowest survival was recorded in S26 (Table 3). The average leaf area, photosynthesis rate and stomatal conductance ranged between 91.9

and 127.6 cm^2, 2.51 and 14.98 µmol CO_2 m^{-2} s^{-1}, and 0.08 and 0.98 cm s^{-1} respectively. The total leaf area per plant was maximum in S11, and S4 depicted the minimum value (Table 4). Variation in leaf area reflects the extent or seasonal integral of light interception, which may be directly correlated with yield. Similarly, the photosynthetic rate and stomatal conductance was maximum in S11 and S2 depicted the minimum values (Table 5). The seed weight of *J. curcas* also varied significantly with respect of 100 seed weight. The 100 seed weight was highest in the case of S11, which was at par with S8 and S31 (Table 2). The extent of variation in seed weight was large compared to the other traits. The consideration of seed weight in selecting and understanding the geographical variation has been advocated because of the least plasticity in this character[18].

The 100 seed weight was found to have higher significant positive relationship with height (12 and 24 months field growth), stem girth (12 and 24 months field growth) and number of branches (12 and 24 months field growth). Growth traits, viz. height, stem girth, 100 seed weight and field survival were found to have significant inter-correlation with each other. It was found that heavier seeds have better seedling growth in the field[19]. The correlation suggests that following the complection of germination, seedlings allocate much of their energies for root and shoot development. Such relationship can be explored for screening of genotypes to have an early indication about their oil yield and growth performance. It is interesting to note that none of the characters showed negative correlation with each other. Thus these characters may be used to the advantage of the breeder for easily bringing simultaneous improvement of these traits. The inter-correlation found among seed weight and seedling characters in *J. curcas* is consistent with that of earlier studies[20–23]. The patterns of variation exhibited for various characters were substantially different and varied with age. The presence of such difference among popula-

Table 3. Survival rate of various accessions after transplantation to the field

Accession code	Field survival (%) 2nd yr
S1	100.00
S2	90.00
S3	20.00
S4	45.83
S5	100.00
S6	44.00
S7	81.25
S8	100.00
S9	33.33
S10	55.55
S11	100.00
S12	100.00
S13	100.00
S14	100.00
S15	100.00
S16	100.00
S17	100.00
S18	88.88
S19	44.44
S20	44.44
S21	100.00
S22	55.55
S23	66.66
S24	66.66
S25	22.22
S26	10.00
S27	66.66
S28	66.66
S29	66.66
S30	66.66
S31	100.00
S32	100.00
S33	100.00
S34	100.00
CD (5%)	10.45

2nd yr = 24 months growth.

Table 4. Total leaf area of various accessions after transplantation to the field

Accession code	Area of single leaf (cm^2) 2nd yr	Total leaf area (cm^2 $plant^{-1}$) 2nd yr
S1	93.2	3914.4
S2	97.8	3814.2
S3	111.5	4348.5
S4	91.9	3492.2
S5	94.8	3886.8
S6	98.2	4026.2
S7	92.1	3868.2
S8	126.8	5198.8
S9	114.8	4560.0
S10	108.7	4348.0
S11	127.6	5231.6
S12	106.9	4062.2
S13	121.6	4742.4
S14	124.5	4980.0
S15	101.6	4242.0
S16	94.7	3693.3
S17	98.3	4030.3
S18	121.0	4719.0
S19	124.1	4964.0
S20	96.9	3779.1
S21	99.0	4059.0
S22	97.3	3989.3
S23	111.1	4332.9
S24	108.2	4003.4
S25	106.6	3837.6
S26	112.9	4290.2
S27	115.1	4143.6
S28	98.8	3853.2
S29	94.2	3485.4
S30	92.6	3796.6
S31	124.8	5116.8
S32	121.9	4510.3
S33	122.3	4280.5
S34	119.3	4533.4
CD (5%)	4.32	11.37

2nd yr = 24 months growth.

Table 5. Photosynthetic rate and stomatal conductance of various accessions after transplantation to the field

Accession code	Photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) 1st yr	Photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) 2nd yr	Stomatal conductance (cm s^{-1}) 1st yr	Stomatal conductance (cm s^{-1}) 2nd yr
S1	1.15	3.11	0.06	0.16
S2	1.02	2.51	0.03	0.08
S3	2.32	3.65	0.07	0.19
S4	1.28	2.70	0.07	0.18
S5	2.69	3.96	0.12	0.32
S6	1.35	2.97	0.14	0.32
S7	3.70	5.40	0.04	0.47
S8	12.32	14.89	0.91	0.97
S9	4.46	6.21	0.06	0.86
S10	4.04	5.79	0.07	0.12
S11	12.98	14.98	0.93	0.98
S12	10.75	12.56	0.16	0.32
S13	3.70	11.17	0.22	0.36
S14	11.75	13.98	0.87	0.95
S15	6.90	4.28	0.06	0.38
S16	1.57	2.89	0.08	0.12
S17	1.32	2.87	0.09	0.34
S18	2.35	3.12	0.12	0.45
S19	3.27	4.89	0.26	0.65
S20	4.13	4.76	0.21	0.31
S21	1.35	2.67	0.11	0.23
S22	1.24	2.89	0.13	0.43
S23	2.48	3.92	0.34	0.53
S24	1.57	3.91	0.33	0.64
S25	2.98	3.33	0.12	0.21
S26	1.76	4.98	0.56	0.67
S27	3.97	5.98	0.67	0.89
S28	2.59	4.97	0.56	0.76
S29	1.76	12.98	0.46	0.95
S30	5.40	3.10	0.04	0.94
S31	11.76	14.28	0.89	0.78
S32	2.46	3.46	0.08	0.21
S33	10.76	13.56	0.76	0.87
S34	9.38	13.21	0.67	0.76
CD (5%)	1.75	0.67	0.02	0.08

1st yr = 12 months growth; 2nd yr = 24 months growth.

tions is probably due to different intensities of natural selection acting upon these traits in their natural habitat. Some of the variation found may be associated with the discrete populations from which accession was collected. Variation in accessions of *J. curcas* with respect to morpho-physiological characters and growth performance could be mainly due to the fact that this species grows over a wide range of rainfall, temperature and soil types. Populations might have also experienced marked differences in selective pressure. Crown exposure and genotype of mother tree, and soil and climate of the place of origin of the accession are important factors affecting the morpho-physiological characters and growth performance.

The present study shows that considerable amount of genetic variability exists in this species with respect to growth performance, which offers scope for selection and breeding to the breeder. It is clear that the Naharlagun source is good in growth performance, particularly in the prevailing conditions at Jorhat. High seed weight observed in this source has been attributed to higher photosynthetic rate, stomatal conductance and leaf area. Further, clay and sandy texture of the soil having level topography and collar height of >60 cm (data not shown) might have provided better aeration, facilitating good exchange of gases and aiding in increased photosynthetic activity. The Lamphelpat, Dergaon and Namsa sources also performed satisfactorily with respect to growth and 100 seed weight. These sources can safely be used for large-scale reforestation programmes in the region for high seed yield and vegetative growth. Germplasm used in afforestation programmes in India and other countries, generally utilizes only locally available material. Thus opportunities for using materials with higher yield potential or with more desirable characteristics might have been missed. This work will facilitate selection of promising accessions for multi-location evaluation and will also hasten the process of utilization of germplasm. It further gives a direction to the effect and practice studies for genetic improvement of this species.

1. Hikwa, D., *Jatropha curcas* L. Agronomy Research Institute, Department of Research and Specialist Services, Harare, Zimbabwe, 1995, p. 4.
2. Henning, R., Combating desertification. In Arid Lands Newsletter No. 40, The Jatropha Project of Mali, West Africa, 1996; http://aq.arizona.edu/OALS/ALN/aln40/jatropha.html
3. Makkar, H. P. S., Becker, K. and Schmook, B., Edible provenances of *Jatropha curcas* from Quintna Roo State of Mexico and effect of roasting on anti-nutrient and toxic factors in seeds. Institute for Animal Production in the Tropics and Subtropics, University of Hohenheim, Germany, 1997, p. 6.
4. Forson, F. K., Performance of Jatropha oil blends in a diesel engine. *Renewable Energy*, 2004, **29**, 1135–1145.
5. Banerji, R., Chowdhury, A. R., Misra, G., Sudarsanam, G., Verma, S. C. and Srivastava, G. S., *Jatropha curcas* seed oils for energy. *Biomass*, 1985, **8**, 277–282.
6. Martin, G. and Mayeux, A., Curcas oil (*Jatropha curcas* L.): a possible fuel. *Agric. Troop*., 1985, **9**, 73–75.
7. Gubitz, G. M., Mittelbach, M. and Trabi, M., Exploitation of the tropical seed plant *Jatropha curcas* L. *Bioresour. Technol*., 1999, **67**, 73–82.
8. Keith, O., A review of *Jatropha curcas*: an oil plant of unfulfilled promise. *Biomass Bioenergy*, 2000, **19**, 1–15.
9. Zhou, H., Lu, H. and Liang, B., Solubility of multi component systems in the biodiesel production by transesterification of *Jatropha curcas* L. oil with methanol. *J. Chem. Eng. Data*, 2006, **51**, 1130–1135.
10. Chen, Y. X., Mao, Z. Q., Wu, Z. B., Zhu, H. P. and Tang, Z. Y., Comprehensive exploitation and utilization of Jatropha oil plants. *China Oils Fats*, 2006, **31**, 63–65.
11. Adebowale, K. O. and Adedire, C. O., Chemical composition and insecticidal properties of the underutilized *Jatropha curcas* seed oil. *Afr. J. Biotechnol*., 2006, **10**, 901–906.
12. Li, K., Yang, W. Y., Li, L., Zhang, C. H., Cui, Y. Z. and Sun, Y. Y., Distribution and development strategy for *Jatropha curcas* L. *For. Stud. China*, 2007, **9**, 120–126.
13. Heller, J., Physic nut. *Jatropha curcas* L. Promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetics and Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy, 1996, p. 44.
14. Sukarin, W., Yamada, Y. and Sakaguchi, S., Characteristics of physic nut, *Jatropha curcas* L. as a new biomass crop in the tropics. *Jpn. Agric. Res. Q*., 1987, **20**, 302–303.
15. Srivastava, R., Study in variation in morpho-physiological parameters with reference to oil yield and quality in *Jatropha curcas* Linn. Ph D thesis, Forest Research Institute, Dehradun, 1999.
16. Panse, V. G. and Shukhatme, P. V., *Statistical Procedures for Agricultural Workers*, ICAR Publication, New Delhi, 1967.
17. Hartmann, H. T. and Kester, D. E., *Plant Propagation. Principles and Practices*, Prentice-Hall Inc., Englewood Cliffs, 1983, 4th edn.
18. Harper, J. L., Lovell, P. H. and Moore, K. G., The shape and size of seeds. *Annu. Rev. Ecol. Spet*., 1970, **1**, 327–356.
19. Aslan, S., Relationship between seed dimensions and seedling percentage and seedling quality in *Pinus brutia*. *Orm. Aras. Enst. Tek. Bult*., 1975, **64**, 39.
20. Palmberg, C., Geographic variation and early growth in southeastern semi-arid Australia of *Pinus halepensis* Mill. and the *Pinus brutia* Ten. species complex. *Silvae Genet*., 1975, **24**, 150–159.
21. Iktueren, S., Provenance experiments on *Pinus brutia* and *Pinus pinea* in Turkey. In Seed and Nursery Results. Proceedings of the Tubitak VIth Science Congress. Agriculture and Forestry Section, Ankara, 1977, pp. 11–19.
22. Isik, K., Altitudinal variation in *Pinus brutia* Ten.: Seed and seedling characteristics. *Silvae Genet*., 1986, **35**, 2–3.
23. Ginwal, H. S., Rawat, P. S. and Srivastava, R. L., Seed source variation in growth performance and oil yield of *Jatropha curcas* Linn. in Central India. *Silvae Genet*., 2004, **53**, 186–192.

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Mesoproterozoic coiled megascopic fossil *Grypania spiralis* from the Rohtas Formation, Semri Group, Bihar, India

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The present communication records rare megascopic coiled impressions present on a shale slab collected during the recent field work on the Early Mesoproterozoic Rohtas Formation of the Semri Group, Vindhyan Supergroup exposed in the Rohtas District, Bihar. The fossil *Grypania* is considered as an important evidence in understanding the evolution of oxygen in the early atmosphere and early experimentation in the biosphere. The present paper also traces the appearance of *Grypania* to the lower part of the Rohtas Formation and adds to our knowledge about the distribution of *Grypania* in the Rohtas Formation.

Keywords: Early atmosphere, *Grypania spiralis*, Rohtas Formation, Semri Group, Vindhyan Supergroup.

THE coiled megascopic fossil, *Grypania spiralis*, is one of the most important members of the carbonaceous remains reported from Late Palaeoproterozoic to Mesoproterozoic successions of America, China and India. This report adds to a meagre record of *Grypania* in the world, in comparison to the other types of mega-remains, viz. *Chuaria*, *Tawuia*, Elipsophysid and Moranid remains mostly found worldwide in Mesoproterozoic to Neoproterozoic successions. Coiled fossils were first described by Walcott[1] more than a century ago and subsequently reported by different workers. They are interpreted vari-

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