Variation in seed traits and oil content in 24 *Jatropha curcas* L. seed sources from Asia, Africa and Papua New Guinea

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Abstract

This study was carried out to determine the extent of variation in seed traits and oil content among 24 seeds sources of *Jatropha curcas* from 8 countries in Asia, Africa and Papua New Guinea. There were marked differences in the length (range 15.88–19 mm), breadth (10.20–11.71 mm), thickness (7.95–9.37 mm) and volume index of seed (1337–2000 mm^3), weight of seed (42.67–80.20 g) and kernel (18.44–51.04 g), kernel/seed ratio (0.43–0.66), and oil content in seed (18.08–37.89%) and kernel (34.02–59.09%). In general, seeds from Laos, Mali, Papua New Guinea, Philippines and Thailand were larger and heavier than sources from China and India, but contained lower oil content in seed and kernel. Principal component analysis revealed that seed and kernel weight and oil content in whole seed and in kernel were useful characteristics in explaining the variation pattern among seed sources. Seven out of the 24 seed sources investigated in this study are considered promising for planting for oil-seed production. This study underpins the importance of selecting suitable seed sources for commercial plantation establishment of *J. curcas*.

Key words: Jatropha curcas L., biofuel, seed size parameters, seed oil content, principal component analysis.

Introduction

Jatropha curcas L. (Euphorbiaceae) commonly known as physic nut is a deciduous, multipurpose shrub or small tree up to 5 m in height. It is native to Mexico and Central America, from where it has been introduced and become naturalized in many parts of the semiarid, tropical and subtropical world (HELLER, 1996). Portuguese traders are believed to have distributed the species from the Caribbean via the Cape Verde islands to countries in Africa and Asia in the 19th century (HELLER, 1996). *J. curcas* plants have medicinal values and are commonly grown as hedges to protect gardens and fields from animals. The oil extracted from *J. curcas* seeds is not edible and is traditionally used for manufacturing soap and medicinal application (JONGSCHAAP et al., 2007). The overall ranges of oil content are 27–40% of seed weight and 55–60% of kernel weight (ACHTEN et al., 2007; MAKKAR et al., 2008). In recent years the species has gained great significance as a potential producer of biodiesel, an alternative to petro-diesel. *J. curcas* is very adaptable to a wide range of soils and climates, and grows well with moderate requirements for applied fertilizer (PATIL and SINGH, 1991). However, the species should not be planted on soils at risk of even temporary water logging (ACHTEN et al., 2008). It can be propagated readily from seed and stem or branch cuttings, and produces large quantities of oil-seed commencing 2–3 years after planting. Optimal fertilization and irrigation increase growth and seed yield (ACHTEN et al., 2008; MOHAPATA and PANDA, 2011).

The economic importance of *J. curcas* has generated wide interest in understanding the genetic diversity of the species as an initial step towards selection and breeding of superior genotypes. There have been numerous reports on genetic diversity of *J. curcas* using various molecular techniques (BASHA and SUJATHA, 2007; SUN et al., 2008; SUDHEER et al., 2009; GRATIVOL et al., 2011; MACHUA et al., 2011; SHEN et al., 2010; SHEN et al., 2012). However, evidence of quantitative variation in traits of economic importance such as seed parameters and oil yields is scarce and appears to be limited to studies using genetic material from one or two countries. GINWAL et al. (2004) examined *J. curcas* seeds among ten sources from central India and found oil contents ranged from 33% to 39% in whole seed, and from 47% to 58% in the kernel. KAUSHIK et al. (2007) reported variation in seed size and weight and seed oil content (28–39%) of 24 accessions of *J. curcas* from within Haryana state in India. SANTOSO (2011), in contrast, found little variation in seed size (1.78–1.82 mm in length and 0.80–0.86 mm in breadth), seed weight (0.60–0.74 g) and oil content (38.8–42.3%) among five wild populations of *J. curcas* in West Nusa Tenggara, Indonesia. Most studies, however, suggest there is potential for selection and breeding for high oil-yielding varieties, despite using plant material from limited genetic diversity,

A recent assembly of *J. curcas* seeds from many countries in Asia, Africa and Papua New Guinea by the Australian Tree Seed Centre (ATSC), Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Institute of Forest Tree Improvement and Biotechnology (IFTIB), Vietnamese Academy of Forest Sciences made it possible to examine variation in the physical characteristics of the seed and oil content from a wider range of seed sources. The objective of the present study was to determine the extent of variation in seed traits and oil content, and to identify superior varieties with high oil content suitable for planting for production of oil seed.

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Materials and Methods

Seed materials

Seeds from 24 sources were included in the study. These seeds came from eight countries: China (6 sources), India (8), Laos (2), Mali (2), Papua New Guinea (1), Philippines (1), Thailand (1) and Vietnam (3). Details of the seed origins are given in *Table 1*. Seed collection method followed the standard practice of the Australian Tree Seed Centre (GUNN, 2001). For each source 5 to 20 healthy parent trees, depending on population size, at least 300 m apart were randomly selected for seed collection. In order to have sufficient quantity from each tree, seeds (fruits) were collected from primary and secondary branches of mature trees. The collected fruits were air-dried to extract the seeds which were then air-freighted to Vietnam for assembly at the IFTIB seed laboratory. Seed moisture contents were examined for all seedlots, using oven-drying method, before cool room storage at 4 °C, and found to be within the range 8–10 %. Equal amounts of seed from each tree were bulked up to represent the seed source.

Measurement of seed traits

For each seedlot, 45 seeds were drawn from the seed store and randomly divided into 3 replicates of 15 each. Length, breadth and thickness of each seed were measured with a digital caliper to the nearest 0.01 mm. Volume index of each individual seed was estimated as the product of length, breadth and thickness.

Weight of individual seed was determined using an electronic balance to the nearest 0.01 g. Weight of kernel was measured after removing the seed coat. To facilitate

Table 1. – Location and climate (mean annual rainfall and temperature) of 24 seed sources of *Jatropha curcas* used in the study.

No.	Code	Seed source location	Country	Lat (° ′)	Long (° ′)	Alt (m)	Rain (mm)	Temp (°C)
1	HN1	Wenchang, Hainan	China	19 32 N	110 47 E	38	2361	23.9
2	HN2	Ledong, Hainan	China	18 41 N	108 48 E	80	1600	24.0
3	HN3	Lingao, Hainan	China	19 54 N	109 40 E	30	1418	23.5
4	YN1	Dayao, Yunnan	China	25 43 N	101 19 E	1,860	796	15.6
5	YN2	Shuangbai, Yunnan	China	24 41 N	101 38 E	1,964	920	15.0
6	YN3	Yongren, Yunnan	China	26 03 N	101 40 E	1,536	840	17.8
7	IN1	Ongole, Andhra Pradesh	India	15 50 N	80 50 E	8	1250	27.0
8	IN2	Jodhpur, Rajasthan	India	26 45 N	72 45 E	600	445	26.8
9	IN3	Cumbum, Tamil Nadu	India	10 04 N	77 45 E	350	943	28.9
10	IN4	Vellore, Tamil Nadu	India	12 55 N	79 07 E	200	997	28.7
11	IN5	Madurai, Tamil Nadu	India	09 34 N	77 57 E	350	843	28.9
12	IN6	Coimbatore, Tamil Nadu	India	10 55 N	76 44 E	450	647	26.7
13	IN7	Coimbatore, Tamil Nadu	India	10 55 N	76 44 E	451	647	26.7
14	IN8	Coimbatore, Tamil Nadu	India	10 55 N	76 44 E	452	647	26.7
15	LA1	Phieng district, Xayyabury	Laos	19 12 N	101 46 E	377	1700	27.5
16	LA2	Nakathong Xathany, Nakhonluang	Laos	18 33 N	102 44 E	200	1800	28.0
17	ML1	Keleya, Bougouni	Mali	11 49 N	07 47 W	393	1000	26.0
18	ML2	Diallaya, Kita	Mali	13 00 N	09 25 W	370	750	30.0
19	PG1	Ramu, Morobe	Papua New Guinea	05 35 S	145 27 E	180	4500	26.3
20	PH1	Candelaria, Quezon	Philippines	13 34 N	122 33 E	20	1570	26.9
21	TH1	Nakhon Pathom	Thailand	13 50 N	100 01 E	3	1235	28.8
22	VN1	Muong La, Son La	Vietnam	21 15 N	103 45 E	500	1440	21.7
23	VN2	Ham Thuan Nam, Binh Thuan	Vietnam	11 13 N	108 08 E	238	1150	26.5
24	VN3	Gia Lai	Vietnam	13 46 N	108 15 E	504	2270	21.8

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comparison with other studies, weight data was expressed as 100-seed weight and 100-kernel weight by conversion of data from 15 seeds and 15 kernels. Kernel/seed weight ratio was calculated in order to determine the proportion of seed coat.

Oil extraction

Oil extraction was carried out by solvent (n-Hexane, boiling range 68–69 °C) with the 3 replicates described above using a Twisselman extraction apparatus (BARTHET and DAUN, 2004). Kernel was crushed into powder and placed in 100 ml flasks. The solvent (80 ml of n-Hexane) was then added to each flask containing crushed kernel. The mixture in solvent was heated at 50 °C for 6 h, and evaporated by a vacuum rotary evaporator at 40 °C. After one hour the weight of oil was measured. The percent of oil present in each sample was calculated as:

% of seed oil = oil weight/seed weight x 100

% of kernel oil = oil weight/kernel weight x 100

Table 2. – Mean values for 9 seed characteristics of 24 *J. curcas* seed sources.

No.	Code	SL (mm)	SB (mm)	ST (mm)	SV (mm^3)	SW (g)	KW (g)	K/S ratio	SO (%)	KO (%)
1	HN1	18.18	11.25	9.00	1852	69.60	43.09	0.62	34.84	53.70
2	HN2	17.40	11.20	8.63	1688	65.22	39.87	0.61	21.84	34.02
3	HN3	17.17	10.65	8.44	1548	62.20	38.62	0.62	31.61	50.63
4	YN1	17.63	10.77	8.32	1583	70.60	45.18	0.64	37.20	53.83
5	YN2	17.24	10.57	8.28	1514	64.89	40.84	0.63	37.89	59.09
6	YN3	17.10	10.01	7.95	1368	50.78	30.64	0.60	35.22	57.27
7	IN1	17.13	11.36	8.82	1724	44.96	20.80	0.46	18.08	35.91
8	IN2	16.79	10.84	8.47	1525	59.93	35.56	0.59	32.16	52.47
9	IN3	17.17	10.97	8.41	1595	57.91	33.93	0.58	22.35	48.75
10	IN4	16.58	10.98	8.64	1576	42.67	18.44	0.43	19.67	50.28
11	IN5	17.06	10.90	8.56	1600	63.76	40.27	0.63	29.78	46.09
12	IN6	17.61	11.04	8.60	1686	65.49	40.71	0.62	32.52	49.73
13	IN7	17.47	11.01	8.30	1599	48.87	24.73	0.51	20.81	43.30
14	IN8	15.88	10.20	8.18	1337	45.56	28.58	0.63	20.95	39.12
15	LA1	18.74	11.11	9.02	1877	75.29	46.27	.061	34.78	55.36
16	LA2	18.49	11.52	9.02	1922	69.11	41.96	0.61	29.65	36.06
17	ML1	18.44	11.16	8.78	1811	77.27	51.04	0.66	32.14	50.30
18	ML2	18.65	11.22	8.96	1879	74.49	46.16	0.62	29.38	45.83
19	PG1	19.00	11.26	9.28	1987	79.69	50.13	0.63	29.79	46.94
20	PH1	18.52	11.52	9.37	2000	80.20	50.44	0.63	29.64	47.54
21	TH1	18.59	11.71	9.13	1988	69.31	40.13	0.58	29.46	47.70
22	VN1	17.62	10.76	8.48	1614	65.53	41.49	0.63	32.48	58.84
23	VN2	17.84	11.15	8.82	1764	73.29	46.53	0.64	28.99	44.12
24	VN3	18.30	11.10	8.68	1768	66.91	41.56	0.62	34.97	50.93
Overall mean		17.69	11.01	8.67	1700	64.31	39.04	0.60	29.43	48.24
l.s.d. (5%)		0.40	0.22	0.26	106	5.21	4.75	0.04	1.11	0.95

SL = seed length, SB = seed breadth, ST = seed thickness, SV = seed volume index, SW = 100 seed weight, KW = 100 kernel weight, K/S = kernel/seed weight ratio, SO = % oil content in seed, KO = % oil content in kernel. Differences between means were significant at $P < 0.001$ for all characteristics.

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Data analysis

Analysis of variance (ANOVA) was performed at replicate mean level using the statistical package Genstat 12th Edition (Payne et al., 2009). Least significant differences (l.s.d.) were used to compare the differences between seedlot means. The estimated seedlot means were subjected to a principal component analysis (PCA) to investigate the combination of the characteristics which would help to elucidate the differences between seed sources from different countries. Seed volume was not included in the PCA analysis because of its correlation with the seed size parameters from which the volume was derived.

Results

Seed size characteristics

There were highly significant differences ($P < 0.001$) among seed sources in seed length (range 15.88–19.0 mm), seed breadth (10.20–11.71 mm), seed thickness (7.95–9.37 mm) and volume index of seed (1337–2000 mm^3) (*Table 2*). Seeds from Papua New Guinea (PG1) recorded maximum length while those from Thailand (TH1) and Philippines (PH1) had maximum breadth and thickness, respectively. Overall, the length, breadth, thickness and volume index of seeds from Laos, Mali, Papua New Guinea, Philippines and Thailand were greater than those from other countries. Seed volume index appeared to be a good characteristic to generalize differences in seed size among the seed sources. In this regard, seeds from China and India, with a few exceptions, were generally smaller than the seedlots from other countries while those from Vietnam were intermediate.

Seed length, breadth, thickness and volume index were all positively correlated with each other, though to a varying extent (*Table 3*). For example, the largest volume (2000 mm^3) of PG1 was due primarily to thicker seeds, while the smallest volume (1337 mm^3) of IN8 seeds from Coimbatore India was a combination of short, narrow and thin seed attributes.

Seed and kernel weight

Whole seed and kernel weight varied considerably among seed sources, ranging from 42.67 g (IN4) to 80.20 g (PH1) for 100 seed weight, and 18.44 g (IN4) to 51.04 g (ML1) for 100 kernel weight (*Table 2*). With a few exceptions, large and heavy seed translated to heavy kernel. Larger seeds from Laos, Mali, Papua New Guinea, Philippines and Thailand had significantly greater 100 seed weight (69.11–80.20 g) while smaller seeds from India were lighter (42.67–65.49 g). Three Indian seed sources (IN1, IN4 and IN7) had significantly low kernel/seed weight ratio (0.43–0.51) indicating thick seed coats in these Indian seeds. Most seed sources in this study had a kernel/seed weight ratio between 0.60 and 0.66.

Seed and kernel weight were found to be significantly correlated with seed size parameters ($r^2 = 0.294–0.786$) but kernel/seed ratio was correlated with seed length only ($r^2 = 0.298$) (*Table 3*).

Oil content

Seed sources varied markedly in oil content in whole seed and in kernel (*Table 2*). The highest oil contents in seed (37.89%) and in kernel (59.09%) were recorded for YN2 from Shuangbai, China. The lowest oil content in seed (18.08%) belonged to IN1 from Ongole, Andhra Pradesh, India while the lowest oil content in kernel (34.02%) belonged to HN2 from Jianfeng Mountain in Hainan, China. Large and heavy seeds such as those from Mali, Papua New Guinea, Philippines and Thai-

Table 3. – Correlation matrix for 9 *J. curcas* seed characteristics.

	SL	SB	ST	SV	SW	KW	K/S	SO	KO
SL	1								
SB	0.670**	1							
ST	0.752**	0.842**	1						
SV	0.896**	0.892**	0.946**	1					
SW	0.786**	0.447**	0.592**	0.679**	1				
KW	0.687**	0.294*	0.469**	0.549**	0.969**	1			
K/S	0.298*	-0.130	0.007	0.121	0.668**	0.824**	1		
SO	0.385**	-0.164	-0.001	0.010	0.577**	0.634**	0.631**	1	
KO	0.063	-0.379**	-0.230	-0.188	0.181	0.220	0.245*	0.723**	1

SL = seed length, SB = seed breadth, ST = seed thickness, SV = seed volume index, SW = 100 seed weight, KW = 100 kernel weight, K/S = kernel/seed weight ratio, SO = % oil content in seed, KO = % oil content in kernel.

* and ** indicate significance at $P < 0.05$ and $P < 0.01$ level respectively.

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Table 4. – The first two component loadings of *J. curcas* seed characteristics.

Characteristic	Loadings	
	PCP 1	PCP 2
Seed length	0.041	0.024
Seed breadth	0.009	0.031
Seed thickness	0.013	0.024
Seed weight	0.731	0.250
Kernel weight	0.596	0.134
Kernel/seed weight ratio	0.003	-0.001
Seed oil content	0.287	-0.450
Kernel oil content	0.160	-0.846

Table 5. – Percentage of total variation contributed by important *J. curcas* seed characteristics.

PCP	Latent roots	Percentage of total variation	Cumulative percentage of variation	Characteristics contributing
1	4984	76.84	76.84	Seed weight and kernel weight
2	1316	20.29	97.13	Seed oil and kernel oil content

land did not contain higher percentage of oil content than sources with smaller and lighter seeds. An exception was LA1 seed source from Laos which had large and heavy seed as well as high oil content. Three Chinese sources from Yunnan (YN1, YN2 and YN3) had relatively small seed volume (1368–1583 mm^3) but ranked in the top four for seed and kernel oil contents.

Within-country variation in the oil content, irrespective of seed size and weight, was observed (*Table 2*). Of the 2 seed sources from Laos, the oil content in seed and kernel recorded for LA1 was 34.78 and 55.36% respectively compared to 29.65 and 36.06% respectively for LA2. For the 3 Vietnamese seedlots, VN2 has significantly lower oil content in the seed and kernel (28.99 and 44.12% respectively) than VN1 (32.48 and 58.84% respectively) and VN3 (34.97 and 50.93% respectively). Likewise among the 6 seed sources from China, HN2 had considerably lower oil content (21.84% in seed and 34.02% in kernel) than the other 5 sources (>31% in seed and >50% in kernel). For the 8 Indian seed sources which were generally low in seed and kernel oil content, IN2 and IN6 had higher oil content in seed (32.16–32.52%) and/or in kernel (49.73–52.47%) than the other 6 seed sources (18.08–22.35% in seed and 35.91–50.28% in kernel).

Oil content in whole seed was positively correlated with seed length and seed and kernel weight (r^2 = 0.385, 0.577 and 0.634), while oil content in kernel was negatively correlated with seed breadth (r^2 = –0.379) (*Table 3*).

Multivariate analysis

The first two principal component loadings are given in *Table 4*. A large absolute value for a variate (characteristic) loading indicates importance of the variate in the formation of the principal component variates. The percentage of total variation contributed by each characteristic, or combination of characteristics, is shown in *Table 5*. The first component, which explained 77% of the total variation, is based largely on the seed weight and kernel weight while the second relates to seed oil and kernel oil contents. These first two components accounted for 97% of the total variation.

A plot of the scores of the first and second principal components is shown in *Fig. 1*. The 24 seed sources formed two distinct clusters. Cluster I consisted of 4 Indian seed sources (IN1, IN4, IN7 and IN8) which were characterized by light seed and kernel weight. Cluster II comprised the remaining 20 seed sources where seed and kernel were all heavier than those in Cluster I. Further perusal of the position of the 20 seed sources in Cluster II revealed a gradient in seed and kernel oil contents. The dotted line in *Fig. 1* divided these seed sources into two groups. The first group consisted of 10 seed sources from China (HN1, HN3, YN1, YN2, YN3), India (IN2, IN6), Laos (LA1) and Vietnam (VN1, VN3) which were predominantly higher in oil content in whole seed and/or in kernel than the other 10 seed sources in the second group from China (HN2), India (IN3, IN5), Laos, (LA2), Mali (ML1, ML2), Papua New Guinea (PG1), Philippines (PH1), Thailand (TH1) and Vietnam

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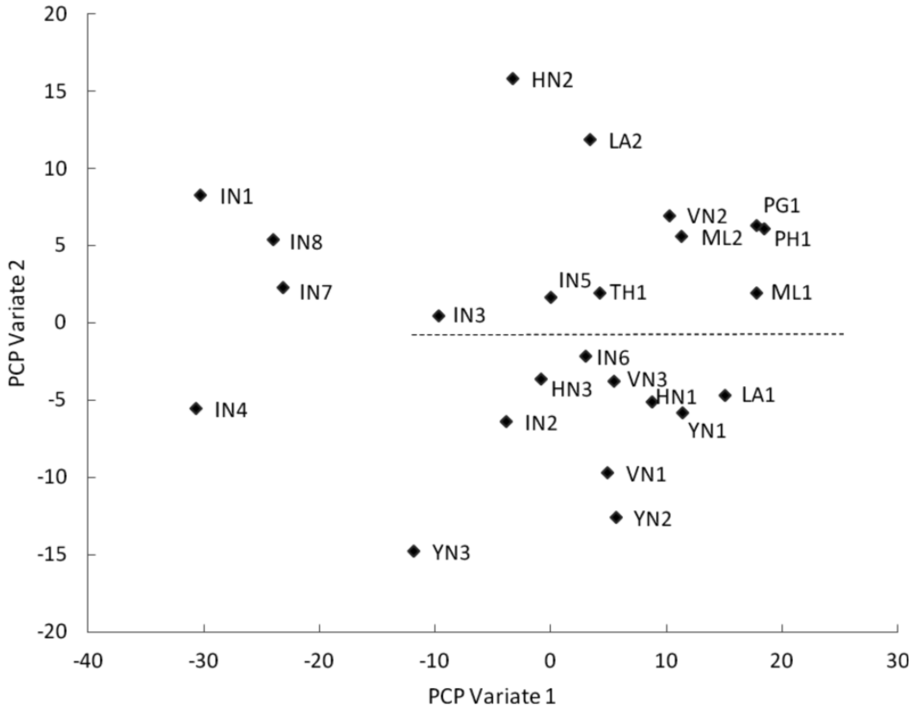

Figure 1. – Plot of scores for principal components 1 and 2 from the principal component analysis of 8 seed size parameters and oil content of 24 J. curcas seed sources, forming 2 distinct clusters based on seed and kernel weight. Dotted line divides low and high oil-content seed sources.

(VN2). Seed sources from the same country viz. China, Laos, India and Vietnam were present in both groups corresponding to their high or low oil content characteristics as described in the previous section.

Discussion

It has been well documented that seed-related traits can be used to examine variability within a plant species (GILES, 1990; SUJATHA et al., 2002; HATHURUSINGHA et al., 2011; RAWAT and BAKSHI, 2011; DIVAKARA et al., 2010). Variation in seed size is common in vascular plants. Seed size within an individual plant varies in response to changing environmental conditions. The environmental conditions prevailing during flowering and fruiting can exert a strong maternal effect on the size of seeds produced (VALENCIA-DIAZ and MONTANA, 2005). Large variation in average seed weight (0.46–0.83 g seed^{-1}) has been reported among 18 natural provenances of *J. carcus* in Mexico (MARTINEZ-HERRERA et al., 2010). In the present study, we demonstrated considerable variation in physical parameters of *J. curcas* seeds. For instance, the difference between the largest and smallest seed volume was more than 33%, and the difference between the heaviest and the lightest 100-seed weight was 47%. In general, seeds from China and India were smaller and lighter than those from Laos, Mali, Papua New Guinea, Philippines and Thailand. Such variation is to be expected for plant materials from a wide range of growing environments in Africa and Asia. As shown in *Table 1*, the locations from which seed was collected for this study varied greatly in altitude, mean annual rainfall and mean annual temperature. Although their genetic origins from the natural range are unknown, it is reasonable to expect that these populations have become adapted to the local environments in which they are grown.

There was evidence of within-country differences in seed traits for China, India and Vietnam. Among the seeds from China for instance, HN1 seeds from Hainan were >1 mm longer, wider and thicker than YN3 seeds from Yunnan. Likewise in India, IN1 seeds from Andhra Pradesh were >1 mm longer and wider than IN8 seeds from Tamil Nadu. These differences could be due to local variations in bioclimate and soil fertility. GHOSH and SINGH (2011) found provenance differences in seed traits of *J. curcas* within zone or region in India and summed up that various climatic factors influence vegetation collectively but not individually. The vegetation of a place is the result of various climatic factors acting together. While affecting vegetation collectively, these factors also modify each other to a certain extent. For example total rainfall of a place influences vegetation but the effect of total rainfall is modified by the number of rainy days. Thus, local seed sources or land races may possess unique climatic and edaphic adaptations that set them apart from the general population for that zone or region.

Data obtained for kernel/seed ratio indicated that seed contained 60–65% of kernel, which is in agreement with results obtained by studies in China (YAN et al., 2011; LIU et al., 2010), India (KAUSHIK et al., 2007; GHOSH and SINGH, 2011; GINWAL et al., 2004; RAO et al., 2008; MOHA-

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PATA and PANDA, 2010), Indonesia (SANTOSO, 2011) and MEXICO (MAKKAR et al., 2008). Some Indian sources (e.g. IN1, IN4 and IN7) had significantly small kernel/seed ratio indicating thicker seed coat characteristic. Seeds evolve to have thicker seed coats as protection, a defense strategy, until they germinate (WESTOBY et al., 1997). In hot climates a thicker seed coat helps avoid or reduce desiccation and resistance to fire damage. In cold climates a thicker seed coat helps insulate a seed from frost damage. It is plausible that some *J. curcas* seeds in India might have adapted to extreme summer temperature conditions by developing a thicker seed coat.

Seed sources in this study varied considerably in oil content in whole seed (18.08–37.89%) and in kernel (34.02–59.09%). Despite large and heavy seeds, populations from Laos (LA2), Mali, Papua New Guinea, Philippines and Thailand gave a lower percentage of oil content in seed and kernel compared to smaller seeds from China and a few sources from India and Vietnam. The top five seed sources in oil content percentage (HN1, YN1, YN2, YN3 and VN1) contained levels of seed and kernel oil comparable to those reported for Mexican materials (MAKKAR et al., 2008; SUJATHA et al., 2002), and were substantially higher in oil percentage than seed materials from Indonesia (SANTOSO, 2011), and on par with or higher than the best sources in China (LIU et al., 2010) and India (KAUSHIK et al., 2007; GHOSH and SINGH, 2011; GINWAL et al., 2004; SRIVASTAVA et al., 2008).

Results of principal component analysis indicate that seed and kernel weight and oil content in whole seed and kernel are useful characteristics in explaining the variation pattern among the 24 seed sources used in this study. The results suggest that a successful hybrid breeding program can be initiated by selection of genotypes from PC1 and PC2. Two distinct clusters were observed based largely on seed and kernel weight. While Cluster I consisted of 4 Indian seed sources with light seed and kernel weight, Cluster II was a mixture of the remaining 20 seed sources from different countries, and it was possible to observe a gradient in the seed and kernel oil contents among these seed sources. Seven seed sources, viz. HN1, YN1, YN2, YN3 from China; IN2 from India; LA1 from Laos and VN1 from Vietnam were exceptionally high in seed and/or kernel oil contents, and considered promising for establishment of plantations for seed oil production. Thus, despite earlier findings from a molecular study by SHEN et al. (2012) that Asian populations of *J. curcas* including the seedlots used in this study were generally low in genetic diversity, it is feasible to select for desirable quantitative traits such as high oil content among introduced populations in Asia.

Since the seeds in this study originated from collections in the different growing environments, there is a potential effect of environment on the development of seed traits, such as size, shape and oil yield. Fruit yield and oil concentration are the most important factors when determining the best provenances of jatropha for biofuel production. This can only be determined by growing the provenances in a single environment. A follow-up study on seeds of the different populations from trees grown in a common environment is a logical next step.

Conclusion

This study revealed considerable variation in seed size, seed weight and oil content in seed and kernel among *J. curcas* seed sources from different environments in Africa and Asia. In general, seeds from Laos, Mali, Papua New Guinea, Philippines and Thailand were larger and heavier than sources from China and India. The latter, however, were found to contain higher oil content in seed and kernel. Results from this study underpin the importance of selecting suitable seed sources for large-scale commercial plantation establishment of *J. curcas* for production of oil seed.

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