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Genetic variability and relationship of pod and seed traits in *Pongamia Pinnata* (L.) Pierre., a potential agroforestry tree

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Abstract

Screening of twenty-four candidate plus trees from naturally available *Pongamia pinnata* genetic resources was carried out to elucidate the genetic variation and relationship of pod and seed traits on germination capacity to select the best planting material for higher productivity. The experiment conducted at Forest Research Centre, Institute of Forest Productivity Mandar, Ranchi during 2005-2006. Variability studies reveled that, genotype CPT-19 recorded maximum values for six traits viz. pod length (65.64 mm), 100-pod weight (542.35 g), 2D surface area (351.18 mm^2), seed length (27.93 mm), 100-seed weight (202.89 g) and total oil content (44.33%). However, maximum pod thickness (12.72 mm), seed length (17.49 mm), pod-seed ratio (2.89) germination capacity (94.67%) was recorded by the genotype CPT-6. The phenotypic and genotypic coefficients of variations were also close to each other for all traits, but 100-pod weight and 100-seed weight exhibited higher phenotypic coefficients of variation and genotypic coefficients of variation than the other traits. Estimates of broad sense heritability ranged from 0.82 (for seed length) to 0.98 (for 100-pod weight), genetic advance as percent of the mean ranged between 12.30% and 46.04% with seed length giving the lowest value and 100-pod weight giving the highest value. Germination capacity exhibited positive significant correlation with pod width, 100-pod weight, 2D surface area and seed width at both genotypic and phenotypic level. However, pod length, pod thickness and 100-seed weight expressed positive significant correlation only at genotypic level. Path analysis of pod and seed traits revealed that, the 100-pod weight (0.909) is the most pronounced character contributing directly to germination capacity followed by seed length (0.785) and pod length (0.324). In conclusion, the results revealed the existence of substantial genetic variation, which can be utilized for genetic resources conservation in gene bank and further tree improvement programmers of the species.

Keywords: Correlation; Genetic advance; Heritability; Image analyzer; *Pongamia pinnata*; Path co-efficient; Variability.

Introduction

Pongamia pinnata (L.) Pierre, an arboreal legume, commonly known as Indian-beech, poonga-oil-tree, pongam tree, karanja tree, karum and kanji is a member of the subfamily Papilionoideae, more specifically the tribe Millettieae. This plant has been synonymously known as *P. pinnata* Merr., *Pongamia glabra* Vent., *Derris indica* (Lam) Bennett and *Millettia novo-guineensis* Kane & Hat. This medium-size tree is indigenous to the Indian subcontinent and south-east Asia (Malaysia and Indonesia), and has been successfully introduced to humid tropical regions of the world as well as parts of Australia, New Zealand, China and the USA (Scott et al., 2008). It is drought resistant, nitrogen-fixing leguminous tree known to withstand water logging and mild frost, with high tolerance to salinity. It is grown as shade tree and wind break in tea plantation (Duke, 1983).

P. pinnata is an excellent multipurpose tree with each and every part of the tree having specific use. Leaves are used as lactagogue fodder, especially in arid regions and also as green manure. Dried leaves are used in stored grains to repel insects. Leaves are active against *Micrococcus*; their juice is used for cold, cough, diarrhea, dyspepsia, flatulence, gonorrhea, and leprosy (Muthu et al., 2006). Flowers are used to treat diabetes; roots for cleaning gums, teeth, ulcers and bark for bleeding piles (Duke, 1983). The wood is not durable, hence limited to cabinetmaking, cartwheels, posts, and fuel. The ash of the wood is used in dyeing (Allen and Allen, 1981). The seedcake is used as cattle and poultry feed and biogas production. Furthermore, the waste pulp is used as an organic fertilizer (Shrinivasa, 2001). It is valued for its seeds consisting of 30-40% oil rich in triglycerides. The oil is also used as a lubricant, water paint binder, pesticide, and in soap and tanning industries. The oil is also valued as a folk medicine in enhancing the pigmentation of skin affected by leucoderma and used as a liniment to treat scabies, herpes, and rheumatism (Burkill, 1966). Besides these advantages, pongamia seed oil because of similar properties to that of diesel (Heller, 1996), has gained the importance as bio-diesel and is fast emerging as a viable alternative to fossil fuel.

In meeting the future demands for bio-diesel it will be important to establish extensive commercial-scale pongamia plantations. However, the progress will be hampered by several factors viz. shortage of elite planting material, low viability of the seeds and insufficient seed germination due to fungal contamination during their storage, seedling susceptibility to *Rhizoctonia hiemalis* leading to premature defoliation, blight and retarded growth, and presence of a hard seed coat that reduces germination capability (Edwards and Naithani, 1999). Moreover, the constraint of plants established by vegetative propagation through stump cuttings are not deep rooted, and are easily uprooted (Azam et al., 2005).

Hence, the challenging task, as of today is to screen the naturally available *P. pinnata* genetic resources to select the best planting material for higher productivity. Seeds from proven source or plus trees form the backbone of any successful tree improvement and afforestation programme. Seed parameter and germination behaviour are most important for afforestation programme and these characters are interdependent and polygenically controlled. To exploit the potentiality of available resource base, variability and genetic analysis of twenty-four Pongamia genotypes selected from various locations in Jharkhand were assessed for pod and seed traits as a scope for further breeding program. Interrelationship among direct and indirect influence of component traits of seed/seedlings is important in predicting the correlated response to directional selection and in the detection of traits as useful markers. The knowledge of genetic variability and association between pod and seed traits linked with germination percentage is considered to provide considerable help in genetic improvement of the species. Keeping all this in view, an effort has been made to evaluate the extent of variation and relationship of pod and seed traits on germination behaviour of Candidate Plus trees (CPTs) collected from various zones of Jharkhand, India.

Materials and Methods

An extensive wild germplasm exploration survey was conducted to identify the high yielding CPTs of *Pongamia pinnata* at fruiting stage from different predominant naturalized locations in Jharkhand, India (Table 1). The selection was made on phenotypic assessment of economic interest characters *viz* yield potential, crown spread, total height, girth at breast height, age of the tree, free from pest and diseases etc. A total of 24 CPTs (morphologically superior trees) covering a latitude and longitudinal range between 22° N to 24° 50' N and 83° 30' E to 87° E respectively. From each CPTs 2 Kg mature capsules were collected during April-June, 2005. The observations for twelve quantitative characters (4 pods and 8 seeds) were recorded at Forest Research Centre, Institute of Forest Productivity Mandar, Ranchi district [latitude: 23 27 40 N, longitude: 85 05 56 E, altitude 2320 ft msl] during 2005-06 as follows.

Pod characters

The pods were cleaned and stored in muslin bags at ambient conditions. All lots were dried under similar temperature and humidity conditions to reach constant weight. A total of 300 healthy pods were collected from each CPTs to make three replications containing 100 pods per replication. Observation on four pod characters viz. length, width, thickness and 100-pod weight were record. Pod length was measured from the tip of the pod to the point of attachment of the pod to the stalk and expressed in mm. Pod width was measured with the help of vernier caliper and expressed in mm. Pod thickness was measured with the help of vernier caliper and expressed in mm. The weight of the 100-pods was recorded by weighing in electrical balance and average value was calculated and expressed in grams.

Seed characters

Samples of 300 seeds were collected from each CPTs to make three replications containing 100 seeds per replication. Measurement of morphometric character viz. 2D surface area, seed length, seed width, and aspect ratio (length/width ratio) was carried out using Image analyzer (leica Quantimet 500+) by spreading seeds on a glass platform of macro-viewer in replication wise and capturing images. Further captured images were sent to the software called Quantimet 500+ or Qwin and calibrated to actual scale. The Qwin identifies the object based on our specification for seed colour and the measurements carried out were 2 dimensional. 100-seed weight was obtained by weighting 100 pure seed and was expressed in grams. Pod-seed ratio is obtained as Ratio of 100-pod weight divided by 100-seed weight. Total oil content was estimated following the procedure of Sadasivam and Manickam, (1992). Germination Capacity (GC) was computed as the portion of number of germinated seeds to that of sown seeds and expressed in percentage.

Table 1. Details of *Pongamia pinnata* Candidate Plus trees (CPTs).

CPTs	Division	Range	Location/Village	Altitude (m)	Age in years	Height (m)	DBH (cm)	Seed yield (kg Y^{-1})	Crown area (m^2)
CPT-1	Ranchi east	Burmu	Barhe	610	75	17	125	200	333.123
CPT-2	Gumla	Gumla	Indrakela Girijatoli	520	25	12	50	60	162.778
CPT-3	Ranchi west	Lohardaga	Chechra Nawadih	590	80	14	107	300	194.729
CPT-4	Ranchi west	Lohardaga	Kandra	570	85	10	103	250	296.967
CPT-5	Simdega	Simdega	Piosokra	370	55	13.6	92	150	193.495
CPT-6	Lohardaga	Kuru	Bather nawatana	640	50	13.7	128	100	312.432
CPT-7	Garhwa south	Ranka East	Vishrampur	410	20	10.3	35	50	150.581
CPT-8	Chatra south	Chatra south	Utta sangra	640	60	15.5	92	250	260.023
CPT-9	Hazaribag west	Hazaribag	Nawakutar	610	100	17	114	160	289.382
CPT-10	Hazaribag north	Barhi	Gramurwan	370	20	11.9	70	35	142.008
CPT-11	Koderma	Domchanch	Bariyadi	380	40	10.2	93	85	239.034
CPT-12	Ranchi east	Ormanjhi	Chuttupallu	630	60	11.5	77	100	198.456
CPT-13	Saraikela	Saraikela	Hatnada Tal-tola	390	20	11	55	40	122.656
CPT-14	Dhalbum	Chakulia	Dhalbumghar	350	20	8.0	50	45	69.363
CPT-15	Ranchi east	Ranchi east	Pansakam	500	80	21	98	150	306.199
CPT-16	Ranchi	Bero	Hutar	790	70	14.5	90	120	399.174
CPT-17	Gumla	Gumla	Bishrampur Jhatnitoli	800	80	12.7	140	140	331.507
CPT-18	Gumla	Gumla	Bombibary	500	50	12.4	105	100	323.491
CPT-19	Porahat	Songra	Murumbura	690	80	16	140	200	333.123
CPT-20	Khunti	Khunti	Itae dartoli	700	50	18.5	122	100	342.896
CPT-21	Ranchi east	Burmu	Jamun Tolli	650	60	16	158	140	289.382
CPT-22	Giridih	Kurchutta	Bangabad	390	50	9.9	86	150	281.895
CPT-23	Ranchi	Burmu	Chund	790	60	12.0	93	100	229.542
CPT-24	Ranchi east	Bero	Pandu	810	65	10.3	102	130	248.719

Data analysis

The pod and seed parameters and progeny measurements were analysed for Analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) to understand the significance of differences between the pods, seeds and progenies of CPTs (Gomez and Gomez, 1984). Prior to ANOVA, the percentage data set (GC) was arcsine-transformed to meet the normality assumption (Zar, 1996). The phenotypic variation for each trait was partitioned into components due to genetic (hereditary) and non-genetic (environmental) factors and estimated using the following formula (Johanson et al., 1955):

V_p = MSG/r; V_g = (MSG-MSE)/r; V_e = MSE

where MSG, MSE and r are the mean squares of CPTs, mean squares of error and number of replications, respectively.

The phenotypic variance (V_p) is the total variance among phenotypes when grown over the range of environments of interest, the genotypic variance (V_g) is the part of the phenotypic variance that can be attributed to genotypic differences among the phenotypes, and the error variance (V_e) is part of the phenotypic variance due to environmental effects. To be able to compare the variation among traits, phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were computed according to the method suggested by Burton, (1952):

$PCV = (\sqrt{V_p}/X) \times 100$; $GCV = (\sqrt{V_g}/X) \times 100$

V_p, V_g and X are the phenotypic variance, genotypic variance and grand mean for each pod and seed-related trait, respectively.

Broad sense heritability (h^2B) was calculated according to Allard (1999) as the ratio of the genotypic variance (V_g) to the phenotypic variance (V_p). Genetic advance (GA) expected and GA as per cent of the mean assuming selection of the superior 5% of the genotypes were estimated in accordance with Johanson et al. (1955) as:

$GA = K \cdot h^2B \cdot \sqrt{Vp}$; GA (as % of the mean) = (GA/X) × 100

K is the selection differential (2.06 for selecting 5% of the genotypes).

Phenotypic (r_p) and genotypic (r_g) correlations were further computed to examine inter-character relationships among seed and seedling traits following Varghese et al. (1976) as:

$r_p = Cov_p\ (x_{1,}\ x_2)/[V_p(x_1) \cdot V_p(x_2)]^{½}$
$r_g = Cov_g\ (x_{1,}\ x_2)/[V_g(x_1) \cdot V_g(x_2)]^{½}$

Cov_p and Cov_g are phenotypic and genotypic covariances for any two traits x_1 and x_2, respectively, and Vp and Vg are the respective phenotypic and genotypic variances for those traits. Path coefficient analysis was done using genotypic correlation coefficients following Dewey and Lu, (1959).

Results and Discussion

Pod and seed traits

The ANOVA and mean performance of pod traits (pod length, pod width, pod thickness and 100-pod weight) and seed traits (2D surface area, seed length, seed width, length/width ratio, 100-seed weight, pod-seed ratio, total oil content and germination capacity) from 24

CPT's of *Pongamia pinnata* revealed significant difference among CPT's (Table 2). Variability studies for pod and seed traits reveled that, genotype CPT-19 recorded maximum values for six traits viz. pod length (65.64 mm), 100-pod weight (542.35 g), 2D surface area (351.18 mm^2), seed length (27.93 mm), 100-seed weight (202.89 g) and total oil content (44.33%). However, maximum pod thickness (12.72 mm), seed length (17.49 mm), pod-seed ratio (2.89) and germination capacity (94.67%) was recorded by the genotype CPT-6. Genotype CPT-2 exhibited lowest for five traits viz. pod length (45.07 mm) pod width (18.93 mm), 2D surface area (235.54 mm^2), seed width (12.75 mm) and germination percentage (61.33%). However, lowest pod thickness (9.62 mm), 100-pod weight (231.0 g), seed length (20.32 mm), seed length/width ratio (1.25), 100-seed weight (113.03 g) pod-seed ratio (1.8) and total oil content (28.19%) was recorded by genotype CPT-1, CPT-1, CPT-24, CPT-24, CPT-3, CPT-20 and CPT-14 respectively.

Seed weight, depends on reserve food material, which is produced as a result of double fertilization (endosperm) and is dominated by the maternal traits, also influenced by the nutrient availability at the time of seed setting and environmental factors (Allen, 1960; Johnsen et al., 1989). Embryo development and its physiological function are contributed by the maternal as well as by paternal (pollen grain) traits in the species. The occurrence of *Pongamia pinnata* over a wide range of habitats with diverse geo-climatic conditions was expected to be reflected in the genetic constitution of its populations. In the present study, the seeds from various CPTs exhibited significant variability in pod and seed traits could be attributed to isolations that inturn influence gene flow. Significant variability of seed characters like; seed size and weight was observed in selected plus trees (Bagchi and Sharma, 1989) and among various provenances of *S. album* (Veerendra et al., 1999). This type of variability in seed morphology and germination is attributed to the out-breeding nature of sandalwood. Genetic control of seed size traits has been observed in several tree species like *Faidherbia albida* (Ibrahim et al., 1997), *Tectona grandis* (Jayasankar et al., 1999), *Dalbergia sissoo* (Gera et al., 2000), *Tectona grandis* (Sivakumar et al., 2002), *Strychnos cocculoides* (Mkonda et al., 2003), *Juniperus procera* (Mamo et al., 2006), and *Cordia africana* (Loha et al., 2006).

Assessment of Genetic variability

The phenotypic and genotypic coefficients of variations were also close to each other for all traits, but 100-pod weight and 100-seed weight exhibited higher phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) than the other traits (Table 3). The magnitude of the error variance was relatively lower than the genotypic variance for all traits. Estimates of broad sense heritability ranged from 0.82 (for seed length) to 0.98 (for 100-pod weight), genetic advance as percent of the mean ranged between 12.30% and 46.04% with seed length giving the lowest value and 100-pod weight giving the highest value.

The magnitude of genotypic variance was higher than the error variance in the one hand, while the phenotypic and genotypic variances were close to each other on the other hand. It indicates that the genotypic component was the major contributor to the total variance for these traits (100-pod weight, 100-seed weight and total oil content); i.e., most of the variability observed in the phenotype for these traits has more of a genetic than a non-genetic basis. This variability due to genotypic variance further indicates considerable scope for selection.

Table 2. Mean performance of selected genotypes for pod and seed traits in *Pongamia pinnata*.

CPTs	Pod traits					Seed traits						
	Length (mm)	Width (mm)	Thickness (mm)	100-pod weight (g)	2D surface area (mm^2)	Length (mm)	Width (mm)	Aspect ratio	100-seed weight (g)	Pod-Seed ratio	Total oil content (%)	Germination capacity
CPT-1	51.33^{d}	26.26^{a}	9.62^{k}	231.00^{m}	278.36^{fghi}	21.83^{h}	15.79^{d}	1.38^{j}	125.04^{i}	2.01^{jklm}	32.27^{fghi}	68.67^{h}
CPT-2	45.07^{i}	18.93^{h}	11.76^{bcde}	254.20^{l}	235.54^{l}	24.80^{cde}	12.75^{h}	1.95^{a}	142.78^{fg}	2.40^{de}	30.60^{ijk}	61.33^{i}
CPT-3	55.88^{c}	20.37^{fg}	11.98^{bcd}	358.13^{ef}	284.64^{efg}	23.39^{efg}	15.21^{e}	1.54^{fghi}	113.03^{j}	2.91^{a}	34.20^{defg}	73.67^{fg}
CPT-4	51.02^{de}	26.60^{a}	11.50^{defg}	407.50^{d}	346.09^{ab}	25.60^{bc}	17.55^{a}	1.46^{hij}	171.48^{c}	2.38^{def}	34.87^{def}	86.00^{c}
CPT-5	50.01^{defg}	20.34^{fg}	11.96^{bcd}	356.37^{ef}	326.06^{bc}	24.06^{def}	16.60^{bc}	1.45^{il}	168.15^{c}	2.21^{fghi}	36.65^{cd}	85.33^{c}
CPT-6	58.20^{b}	24.96^{bc}	12.72^{a}	474.40^{a}	344.58^{ab}	26.57^{b}	17.49^{a}	1.52^{fghi}	185.80^{b}	2.86^{a}	39.21^{b}	94.67^{a}
CPT-7	56.65^{bc}	26.35^{a}	11.49^{defg}	357.77^{ef}	314.64^{cd}	24.48^{cde}	16.94^{b}	1.45^{hij}	154.88^{d}	2.36^{def}	34.81^{def}	91.33^{ab}
CPT-8	47.74^{gh}	19.78^{gh}	12.27^{ab}	284.57^{jk}	286.83^{efg}	23.47^{defg}	16.21^{c}	1.45^{hij}	135.29^{gh}	2.10^{hijk}	29.65^{jk}	84.33^{cd}
CPT-9	49.95^{defg}	23.68^{de}	12.00^{bcd}	352.37^{efg}	315.81^{cd}	24.05^{def}	17.33^{a}	1.39^{j}	164.06^{c}	2.29^{efg}	34.13^{defg}	92.00^{a}
CPT-10	65.73^{a}	23.64^{de}	10.96^{ghi}	451.77^{c}	332.27^{abc}	26.80^{ab}	15.19^{e}	1.76^{bc}	124.83^{i}	2.58^{bc}	35.47^{cde}	93.67^{a}
CPT-11	57.72^{bc}	23.08^{e}	12.12^{bc}	358.90^{ef}	297.42^{def}	25.60^{bc}	14.37^{g}	1.78^{b}	149.73^{def}	1.95^{klmn}	34.00^{defg}	84.00^{cd}
CPT-12	58.51^{b}	25.95^{ab}	10.46^{ij}	337.33^{gh}	243.66^{kl}	24.86^{cd}	15.11^{c}	1.65^{d}	129.46^{hi}	2.16^{ghij}	37.61^{bc}	79.00^{e}
CPT-13	50.33^{def}	23.39^{de}	9.66^{k}	274.77^{k}	270.91^{ghij}	23.96^{def}	14.62^{fg}	1.64^{de}	142.22^{fg}	2.13^{ghij}	28.27^{k}	74.33^{fg}
CPT-14	51.46^{d}	24.90^{bc}	11.70^{bcde}	423.13^{d}	305.49^{de}	24.36^{cde}	16.56^{bc}	1.47^{hij}	106.95^{j}	2.39^{def}	28.19^{k}	94.33^{a}
CPT-15	48.50^{fgh}	21.34^{f}	11.75^{bcde}	303.10^{i}	281.76^{fgh}	23.67^{def}	15.24^{e}	1.55^{efgh}	135.73^{gh}	2.23^{efghi}	34.13^{defg}	84.00^{cd}
CPT-16	45.11^{i}	18.72^{h}	11.04^{fgh}	257.60^{l}	256.46^{jk}	23.61^{def}	14.44^{g}	1.64^{de}	114.91^{j}	2.13^{ghij}	31.80^{ghij}	71.00^{gh}
CPT-17	48.83^{efgh}	27.06^{a}	10.08^{jk}	329.22^{h}	287.80^{efg}	22.20^{gh}	17.46^{a}	1.27^{k}	151.83^{de}	2.24^{efgh}	34.73^{def}	86.67^{c}
CPT-18	47.42^{h}	21.08^{f}	11.58^{cdef}	366.52^{e}	290.29^{efg}	25.59^{bc}	14.57^{g}	1.76^{bc}	147.15^{def}	2.67^{b}	31.07^{hij}	85.67^{c}
CPT-19	65.64^{a}	23.69^{de}	11.67^{cde}	542.35^{a}	351.18^{a}	27.93^{a}	17.40^{a}	1.61^{def}	202.89^{a}	2.49^{cd}	44.33^{a}	87.67^{bc}
CPT-20	43.15^{i}	20.39^{fg}	10.73^{hi}	333.27^{h}	258.39^{ijk}	23.67^{def}	14.24^{g}	1.66^{d}	185.01^{b}	1.80^{n}	39.33^{b}	84.33^{cd}
CPT-21	48.16^{fgh}	22.83^{e}	10.70^{hi}	343.45^{fgh}	284.73^{efg}	24.25^{cde}	14.53^{g}	1.67^{cd}	144.67^{ef}	2.38^{def}	33.33^{efgh}	80.00^{de}
CPT-22	44.69^{i}	18.73^{h}	9.96^{jk}	233.27^{m}	273.08^{ghij}	23.62^{def}	14.98^{ef}	1.58^{defg}	112.55^{j}	1.85^{mn}	34.40^{defg}	76.67^{ef}
CPT-23	44.40^{i}	24.26^{cd}	11.30^{efg}	296.72^{ij}	270.30^{ghij}	22.74^{fgh}	15.25^{e}	1.49^{ghi}	181.39^{b}	2.05^{ijkl}	35.53^{cde}	86.33^{c}
CPT-24	49.14^{defgh}	23.16^{de}	9.83^{k}	276.27^{k}	260.64^{hijk}	20.32^{i}	16.24^{c}	1.25^{k}	129.43^{hi}	1.89^{lmn}	39.53^{b}	80.33^{de}
Mean	51.44	22.90	11.20	341.83	291.54	24.23	15.67	1.56	146.64	2.27	34.51	82.72
SEM	0.72	0.36	0.17	5.73	6.61	0.42	0.14	0.03	2.61	0.06	0.82	1.44
CD 5%	2.08	1.05	0.50	16.66	19.24	1.22	0.39	0.08	7.57	0.174	0.58	4.18

Trait means not followed by the same superscript letter and significantly different at $p = 0.05$.

Table 3. Genetic estimates of parent tree pod and seed traits of *Pongamia pinnata*.

	GV	PV	EV	GCV	PCV	ECV	Heritability (%)	GA (%) of mean
Pod traits								
Pod length	38.57	40.11	1.54	12.07	12.31	2.41	96.20	24.39
Pod width	6.87	7.26	0.39	11.45	11.77	2.74	94.60	22.93
pod thickness	0.76	0.85	0.09	7.78	8.23	2.67	89.40	15.16
100-pod weight	5934.30	6032.66	98.36	22.54	22.72	2.90	98.40	46.04
Seed traits								
2D area	994.50	1125.59	131.09	10.82	11.51	3.93	88.40	20.95
Length	2.53	3.07	0.53	6.57	7.23	3.01	82.60	12.30
Width	1.66	1.72	0.05	8.23	8.36	1.49	96.80	16.68
Aspect ratio	0.03	0.03	0.00	10.41	10.95	3.40	90.40	20.38
100-seed weight	669.60	690.07	20.48	17.65	17.92	3.09	97.03	35.81
Pod-Seed ratio	0.08	0.01	0.01	12.66	13.36	4.26	89.90	24.73
Total oil content (%)	13.58	15.58	2.01	10.68	11.44	4.10	87.13	20.53
Germination percentage	69.83	76.04	6.21	10.10	10.54	3.01	91.83	19.94

The characters 100-pod weight and germination capacity exhibited significant variation among CPT's of *P. pinnata*. In most plant species, seeds vary in their degree of germinability between and within populations and between and within individuals (Gera et al., 2000; Benowicz et al., 2000, 2001; Thomsen and Kjær, 2002; Sivakumar et al., 2002; Mkonda et al., 2003) due to maternal and/or environmental factors (Wulff, 1995; Gutterman, 2000).

In the present study the genotypic coefficient of variation and the genetic advance as percent of the mean were found to be high for 100-pod weight. Higher GCV indicates that worthwhile improvement could be achieved for this trait through simple selection while higher genetic advance value suggests that population means for 100-pod weight may be changed considerably by selecting the superior 5% of the genotypes.

Correlation studies

Genotypic and phenotypic association of pod and seed traits was in the same direction and that the genotypic estimates were higher than the phenotypic ones (Table 4). Germination capacity exhibited positive significant correlation with pod width, 100-pod weight, 2D surface area and seed width both at genotypic and phenotypic level. However, pod length, pod thickness and 100-seed weight expressed positive significant correlation only at genotypic level. Total oil content trait showed strong correlation with 100-seed weight.

In general, the genotypic correlation coefficient values were higher than corresponding phenotypic values (Table 4). The genotypic correlation is an estimated value, whereas, phenotypic correlation is a derived value from the genotype and environmental interaction. The genotypic correlation is, therefore, a more reliable estimate for examining the degree of relationship between characters. Both phenotypic and genotypic correlations between 100-pod weight, 2D surface area and germination capacity and between 100-seed weight and total oil content were strong. This offers an opportunity to select phenotypes based on these traits. Correlated quantitative traits are major interest in an improvement program, as the improvement of one character may cause simultaneous changes in the other character. Here 100-pod weight and 100-seed weight are under strong genetic control [with high GCV, PCV, h^2B and GA (as % of the mean)], hence improvement in these character can lead to improve germination capacity and total oil content respectively. The results agree with the findings in *Grewia optiva* (Chauhan, 1989; Tyagi et al., 1999) and *Santalum album* (Bagchi and Sharma, 1989), which also exhibited positive correlation between 100-seed weight and germination percentage.

Path analysis

Measure of correlation does not consider the dependence of one variable on the other. The direct contribution of each component to the yield and the indirect effect which it has through its association with other components cannot be differentiated from mere correlation studies. A statistical method called path coefficient analysis developed by Wright, (1921) fulfills this lacuna. Path coefficient analysis is further helpful in knowing the relative contribution of different traits to the trait of major interest.

Path analysis of pod and seed traits revealed that, the 100-pod weight (0.909) is the most pronounced character contributing directly to germination capacity followed by seed length (0.785) and pod length (0.324) and most other traits associated to germination capacity are contributing indirectly through 100 pod weight (Table 5). This suggests that, 100-pod weight should invariably be given the most attention in the selection for seeds with high germination capacity in *P. pinnata*. The traits such as pod length, seed width and 100-seed weight which have a significant positive correlation, showed negative direct effects on germination and this is due to a higher negative value of the individual effects of other traits. In the same way, pod width and 2D surface area had significant correlation (0.745) with germination capacity, but its direct effect was about less than half of the correlation value (0.303) and this is due to negative indirect effect of pod length and seed width. A usual trend in majority of the tree species is that, more vigorous the seeds, the better will be the germination. Vigour is a measure of weight (100 seed weight) and size (length and width). These results are in confirmation with the studies conducted by Arun Prasad (1996) in *Tectona grandis* and Radhakrishnan (2001) in *Albizia lebbeck*. The correlation coefficient and path analysis only analyses the relationship and dependence of variables and can not measure the effect of genotypes/provenances on dependent variable.

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Table 4. Correlation matrix of pod and seed traits of *Pongamia pinnata*.

		Pod width	Pod thickness	100-pod weight	Seed 2D area	Seed length	Seed width	Aspect ratio	100-seed weight	Pod-Seed ratio	Total oil content	Germination percentage
Pod length	G	0.441^{*}	0.224	0.739^{**}	0.611^{**}	0.639^{**}	0.359	0.091	0.131	0.490^{*}	0.434^{*}	0.408^{*}
	P	0.445^{*}	0.214	0.733^{**}	0.577^{**}	0.612^{**}	0.351	0.109	0.123	0.475^{*}	0.398	0.369
Pod width	G	1.000	-0.188	0.368	0.392	0.050	0.607^{**}	-0.462^{*}	0.247	0.114	0.194	0.451^{*}
	P	1.000	-0.176	0.365	0.371	0.072	0.581^{**}	-0.408^{*}	0.221	0.123	0.171	0.416^{*}
Pod thickness	G		1.000	0.508^{*}	0.490^{*}	0.539^{**}	0.202	0.186	0.335	0.546^{**}	0.037	0.418^{*}
	P		1.000	0.490^{*}	0.444^{*}	0.497^{*}	0.180	0.193	0.308	0.513^{*}	0.040	0.365
100-pod weight	G			1.000	0.826^{**}	0.789^{**}	0.515^{**}	0.065	0.487^{*}	0.628^{**}	0.500^{*}	0.717^{**}
	P			1.000	0.769^{**}	0.732^{**}	0.502^{*}	0.075	0.476^{*}	0.617^{**}	0.457^{*}	0.678^{**}
Seed 2D area	G				1.000	0.609^{**}	0.744^{**}	-0.238	0.472^{*}	0.519^{**}	0.337	0.745^{**}
	P				1.000	0.578^{**}	0.706^{**}	-0.187	0.426^{*}	0.460^{*}	0.299	0.656^{**}
Seed length	G					1.000	0.077	0.564^{**}	0.405^{*}	0.568^{**}	0.239	0.389
	P					1.000	0.070	0.602^{**}	0.353	0.510^{*}	0.203	0.341
Seed width	G						1.000	-0.775^{**}	0.360	0.234	0.374	0.667^{**}
	P						1.000	-0.750^{**}	0.352	0.200	0.340	0.628^{**}
Aspect ratio	G							1.000	-0.031	0.176	-0.173	-0.320
	P							1.000	-0.038	0.183	-0.148	-0.288
100-seed weight	G								1.000	0.088	0.613^{**}	0.404^{*}
	P								1.000	0.064	0.569^{**}	0.383
Pod-Seed ratio	G									1.000	0.018	0.271
	P									1.000	0.002	0.220
Total oil content	G										1.000	0.314
	P										1.000	0.248

*, ** significant at $p = 0.05$ and $p = 0.01$, respectively.

Table 5. Path analysis of *Pongamia pinnata* pod and seed traits with germination percentage.

	Pod length	Pod width	Pod thickness	100-pod weight	Seed 2D area	Seed length	Seed width	Aspect ratio	100-seed weight	Pod – Seed ratio	Total oil content	Correlation co-efficient
Pod length	-0.365	0.143	0.075	0.672	0.185	0.502	-0.454	-0.142	-0.026	-0.176	-0.006	0.408
Pod width	-0.161	0.324	-0.063	0.334	0.119	0.039	-0.767	0.718	-0.049	-0.041	-0.003	0.451
Pod thickness	-0.082	-0.061	0.334	0.462	0.148	0.423	-0.255	-0.289	-0.067	-0.196	-0.001	0.418
100-pod weight	-0.270	0.119	0.170	0.909	0.250	0.620	-0.651	-0.101	-0.097	-0.225	-0.007	0.717
Seed 2D area	-0.223	0.127	0.164	0.751	0.303	0.478	-0.940	0.369	-0.094	-0.186	-0.005	0.745
Seed length	-0.233	0.016	0.180	0.718	0.184	0.785	-0.097	-0.876	-0.081	-0.204	-0.003	0.389
Seed width	-0.131	0.197	0.067	0.468	0.225	0.060	-1.264	1.205	-0.072	-0.084	-0.005	0.667
Aspect ratio	-0.033	-0.150	0.062	0.059	-0.072	0.443	0.980	-1.554	0.006	-0.063	0.002	-0.320
100-seed weight	-0.048	0.080	0.112	0.443	0.143	0.318	-0.455	0.048	-0.199	-0.029	-0.008	0.404
Pod-Seed ratio	-0.179	0.037	0.183	0.571	0.157	0.446	-0.295	-0.273	-0.016	-0.359	0.000	0.271
Total oil content	-0.158	0.063	0.013	0.454	0.102	0.188	-0.473	0.268	-0.122	-0.007	-0.014	0.314

Residual effect = 0.4564987.

References

Allard, R.W., 1999. Principles of plant breeding, 2nd edt. John Wiley & Sons, New York.
Allen, G.S., 1960. Factors affecting the viability and germination behaviour of coniferous seed. IV. Stratification period and incubation temperature, *Pseudostuga menziesii* (Mirb.) Franco. For. Chron. 36: 18-19.
Allen, O.N., Allen, E.K., 1981. The Leguminosae. The University of Wisconsin Press, USA.
Arun Prasad, K.C.A., 1996. Variability studies in teak (*Tectona grandis* Linn. F.) M.Sc. (For) Thesis, Tamil Nadu Agricultural University, Coimbatore.
Azam, M.M., Waris, A., Nahar, N.M., 2005. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. Biomass and Bioenergy, 29: 293-302.
Bagchi, S.K., Sharma, V.P. 1989., Biometrical studies on seed characters of *Santalum album* L. Silvae. Genet. 38: 152-153.
Benowicz, A., El-Kassaby, Y.A., Guy, R.D., Ying, C.C., 2000. Sitka Alder (*Alnus sinuate* RYDB.) Genetic diversity in germination, frost hardiness and growth attributes. Silvae. Genet. 49: 206-212.
Benowicz, A., Guy, R., Carlson, M.R., El-Kassaby, Y.A., 2001. Genetic variation among paper birch (*Betula papyrifera* MARSH.) populations in germination, frost hardiness, gas exchange and growth. Silvae. Genet. 50: 7-13.
Burkill, J.H., 1966. A dictionary of economic products of Malay peninsula L. 2 vols. Art Printing Works, Kuala Lumpur.
Burton, G.W., 1952. Quantitative inheritance of grass. Proc. 6th, Int. Grassland Cong. Held at Pennsylvania State College. Pa. U.S. 1: 74-83.
Chauhan, V., 1989. Germination ecology of seeds of *Grewia optiva* Drummond I. Seed polymorphism and germination response. J. Tree Sci. 8: 42-44.
Dewey, D.R., Lu, K.H., 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agron. J. 51: 515-518.
Duke, J.A., 1983. Handbook of Energy Crops, unpublished, Excerpt from the Internet.<http:// www. hort. purdue. edu/newcrop/duke_energy/Pongamia_pinnata.html>.
Edwards, D.G.W., Naithani, S.C., 1999. Seed and Nursery Technology of Forest Trees. New Age International, New Delhi.
Gera, M., Gera, N., Ginwal, H.S., 2000. Seed trait variations in *Dalbergia sissoo* Roxb. Seed Sci. Technol. 28: 467-475.
Gomez, A.K., Gomez, A.A., 1984. Statistical procedure for agricultural research. John Wiley and sons, Inc.
Gutterman, Y., 2000. Maternal effects on seeds during development. In: Fenner, M. (ed.), Seeds: The Ecology of Regeneration in Plant Communities. 2nd ed. CABI Publishing, Wallingford, Pp: 59-84.
Heller, J., 1996. Physic nut. Jatropha curcas L. Promoting the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute (IPGRI), Rome.
Ibrahim, A.M., Fagg, C.W., Harris, S.A., 1997. Seed and seedling variations amongst provenances in *Faidherbia albida*. For. Ecol. Manage. 97: 197-205.
Jayasankar, S., Babu, L.C., Sudhakar, K., Unnithan, V.K.G., 1999. Provenance variation in seed and germination characteristics of teak (*Tectona grandis* L.F.). Seed Sci Technol. 27: 131-139.
Johanson, H.W., Robinson, H.F., Comstock, R.E., 1955. Estimate of Genetic and environmental variability in soyabeans. Agron. J. 47: 314-318.
Johnsen, O., Dietrichson, J., Skaret, G., 1989. Phenotypic changes in progenies of northern clones of *Picea abies* (L.) Karst. grown in a southern seed orchard. III. Climate changes and growth in a progeny trial. Scand. J. For. Res. 4: 343-350.
Loha, A., Tigabu, M., Teketay, D., Lundkvist, K., Fries, A., 2006. Provenance variation in seed morphometric traits, germination and seedling growth of *Cordia africana* Lam. New Forests, 32: 71-86.
Mamo, N., Mihretu, M., Fekadu, M., Tigabu, M., Teketay, D., 2006. Variation in seed and germination characteristics among *Juniperus procera* populations in Ethiopia. For. Ecol. Manage. 225: 320-327.
Mkonda, A., Lungu, S., Maghembe, J.A., Mafongoya, P.L., 2003. Fruit-and seed-germination characteristics of *Strychnos cocculoides* an indigenous fruit tree from natural populations in Zambia. Agrofor. Sys. 58: 25-31.
Muthu, C., Ayyanar, M., Raja, N., Ignacimuthu, S., 2006. Medicinal plants used by traditional healers in Kancheepuram District of Tamil Nadu, India. J. Ethnobiol. Ethnomed. 2: 43.
Radhakrishnan, 2001. Seed source variation and molecular characterization of *Albizia lebbeck*. Ph.D. (For) Thesis, Tamil Nadu Agricultural University, Coimbatore.
Sadashivam, S., Manikam, A., 1992. Biochemical Methods for Agricultural Sciences, Wiley Eastern Ltd, New Delhi.

Scott, P.T., Pregelj, L., Chen, N., Hadler, J.S., Djordjevic, M.A., Gresshoff, P.M., 2008. *Pongamia pinnata*: An untapped resource for the biofuels industry of the future. Bioenerg. Res. 1: 2-11.

Shrinivasa, U., 2001. A viable substitute for diesel in rural India. Curr. Sci. 80: 1483-1484.

Sivakumar, V., Parthiban, K.T., Singh, B.G., Gnanambal, V.S., Anandalakshmi, R., Geetha, S., 2002. Variability in drupe characters and their relationship on seed germination in teak (*Tectona grandis* L.F.). Silvae. Genet. 51: 232-237.

Thomsen, K.A., Kjaer, E.D., 2002. Variation between single tree progenies of *Fagus sylvatica* in seed traits, and its implications for effective population numbers. Silvae. Genet. 51: 183-190.

Tyagi, P.C., Agarwal, M.C., Kumar, N., 1999. Provenance variation in seed parameters and germination of *Grewia optiva* Drummond. Ind. For. 5: 517-521.

Varghese, T.M., Singh, R.K., Choudhary, B.D., 1976. Biometrical techniques in genetics and breeding. International Bioscience Publishers, Hissar, India.

Veerendra, H.C.S., Ramalakshmi, S., Mallesha, B.B., 1999. Variation in seed characterstics in provenances of sandal (*Santalum album* L.). Ind. For. 125: 308-312.

Wright, S., 1921. Correlation and causation. J. Agrial. Res. 20: 557-585.

Wulff, R.D., 1995. Environmental maternal effects on seed quality and germination. In: Kigel, J., and Galili, G. (eds), Seed Development and Germination. Marcel Dekker, Inc., New York/Basel/ Hong Kong, Pp: 491-505.

Zar, J., 1996. Biostatistical Analysis. Prentice-Hall Inc., New Jersey, 662p.

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