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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 mm²), 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 coefficient; 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.

g	Range	Location/Village	Altitude (m)	A de in vears	Heioht (m)	DBH (cm)	Seed vield $(k \sigma V^{-1})$	Crown area (m ²)
	Burmu	Barhe	(11) (11) (11)	75	17	125	200	333.123
	Gumla	Indrakela Girijatoli	520	25	12	50	09	162.778
-	ohardaga	Chechra Nawadih	590	80	14	107	300	194.729
-	ohardaga	Kandra	570	85	10	103	250	296.967
	Simdega	Piosokra	370	55	13.6	92	150	193.495
	Kuru	Bather nawatana	640	50	13.7	128	100	312.432
~	tanka East	Vishrampur	410	20	10.3	35	50	150.581
D	hatra south	Ut:a sangra	640	60	15.5	92	250	260.023
-	Hazaribag	Nawakutar	610	100	17	114	160	289.382
	Barhi	Gramurwan	370	20	11.9	70	35	142.008
р	omchanch	Bariyadi	380	40	10.2	93	85	239.034
Ĩ	Ormanjhi	Chuttupallu	630	60	11.5	<i>LL</i>	100	198.456
	Saraikela	Hatnada Tal-tola	390	20	Ξ	55	40	122.656
	Chakulia	Dhalbumghar	350	20	8.0	50	45	69.363
2	anchi east	Pansakam	500	80	21	86	150	306.199
	Bero	Hutar	790	70	14.5	60	120	399.174
	Gumla	Bishrampur Jhatnitoli	800	80	12.7	140	140	331.507
	Gumla	Bombibary	500	50	12.4	105	100	323.491
	Songra	Murumbura	690	80	16	140	200	333.123
	Khunti	Itae dartoli	700	50	18.5	122	100	342.896
	Burmu	Jamun Tolli	650	60	16	158	140	289.382
-	Kurchutta	Bangabad	390	50	9.6	86	150	281.895
	Burmu	Chund	790	60	12.0	93	100	229.542
	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:

 $GA = K \cdot h^2 B \cdot \sqrt{Vp}$; 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 intercharacter relationships among seed and seedling traits following Varghese et al. (1976) as:

 $r_{p} = Cov_{p} (x_{1}, x_{2}) / [V_{p}(x_{1}) \cdot V_{p}(x_{2})]_{U}^{\frac{1}{2}}$

 $r_{g} = Cov_{g} (x_{1}, x_{2}) / [V_{g}(x_{1}) \cdot V_{g}(x_{2})]^{\frac{1}{2}}$

 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 mm²), 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 mm²), 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-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.

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Table 2. Me:	an performa	nce of selected	l genotypes for	pod and seed trait	ts in Pongamia pii	nnata.		Cand fra	Ę			
CPTs -	Length	Width	Thickness	100-pod weight	2D surface area	Length	Width	Aspect ratio	100-seed	Pod-Seed	Total oil	Germination
CBT 1	(IIIII)	(IIIII)	(IIIII)	231 00m		(IIII)	(IIII)	1961	weight (g)	2 A1Km	COLICER (70)	capacity
CPT-1	15.07	420-70 18-03h	9.02 11 7.6bode	00:167	10:07	21.85 2.4 g0 ^{cde}	47.01 1275h	1.38	982 CV1	2.01 ^c 2.40 ^{de}	32.27 20.60jk	00.0/ 61.33
CPT-3	55.88°	18.25 20.37 ^倍	11 98 ^{bcd}	358 13 ^{cf}	284 64 ^{eft}	23 30 ^{clg}	15.71°	1 5.4 ^{fbhi}	113.02	2 01 ⁸	34 20 ^{delg}	73.67 [©]
CPT-4	51.02 ^{de}	26.60	11.50 ^{defg}	407.50 ^d	346.09 ^{ab}	25.60 ^{bc}	17.55ª	1.46 ^{hij}	171.48°	2.38 ^{def}	34.87 ^{def}	86.00°
CPT-5	50.01 ^{defg}	20.34^{fg}	11.96bod	356.37 ^{cf}	326.06^{bc}	24.06 ^{def}	16.60^{bc}	1.45 ^{il}	168.15°	2.21 ^{fghi}	36.65 ^{od}	85.33°
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 ^{der}	91.33^{ab}
CPT-8	47.74 ^{gh}	19.78^{4h}	12.27^{ab}	284.57 ^{jk}	286.83 ^{efg}	23.47 ^{defg}	16.21 [°]	1.45 ^{hij}	135.29 th	2.10^{hlk}	29.65^{ik}	84.33 ^{cd}
CPT-9	49.95 ^{defg}	23.68^{de}	12.00 ^{bcd}	352.37 ^{efts}	315.81 ^{cd}	24.05 ^{def}	17.33ª	1.39	164.06°	2.29^{efg}	34.13 ^{defg}	92.00^{3}
CPT-10	65.73 ^a	23.64^{de}	10.96^{ghi}	451.77 ^c	332.27 ^{abc}	26.80^{ab}	15.19°	1.76^{bc}	124.83	2.58 ^{bc}	35.47 ^{ode}	93.67^{a}
CPT-11	57.72 ^{bc}	23.08°	12.12 ^{bc}	358.90^{ef}	297.42 ^{def}	25.60^{bc}	14.37^{B}	1.78^{b}	149.73 ^{def}	1.95 ^{khm}	34.00^{defg}	84.00^{cd}
CPT-12	58.51 ^b	25.95^{ab}	10.46^{ij}	337.33 ^{#h}	243.66^{kl}	24.86^{cd}	15.11°	1.65^{d}	129.46^{hi}	2.16^{3hi}	37.61^{bc}	79.00°
CPT-13	50.33 ^{def}	23.39^{dc}	9.66^{k}	274.77 ^k	270.91 ^{ghij}	23.96^{def}	14.62 ^{fg}	1.64^{dc}	142.22^{ig}	2.13 ^{ghij}	28.27^{k}	74.33^{fg}
CPT-14	51.46 ^d	24.90^{bc}	11.70 ^{bode}	423.13 ^d	305.49^{de}	24.36^{cde}	16.56^{bc}	1.47 ^{hij}	106.95	2.39 ^{def}	28.19^{k}	94.33 ^ª
CPT-15	48.50 ^{6h}	21.34 ^f	11.75 ^{bode}	303.10	$281.76^{(h)}$	23.67 ^{def}	15.24°	1.55 ^{efgh}	135.73^{th}	2.23 ^{elghi}	34.13 ^{defg}	84.00^{cd}
CPT-16	45.11 ⁱ	18.72^{h}	11.04^{fgh}	257.60^{1}	256.46 ^{jk}	23.61 ^{def}	14.44^{6}	1.64 ^{de}	114.91 ⁾	2.13 ^{ghij}	31.80^{shij}	$71.00^{$h}$
CPT-17	48.83 ^{etgh}	27.06^{3}	10.08^{ik}	329.22^{h}	287.80^{efg}	22.20^{8h}	17.46^{3}	1.27^{k}	151.83 ^{de}	2.24 ^{etgh}	34.73 ^{def}	86.67°
CPT-18	47.42 ^h	21.08^{f}	11.58 ^{adef}	366.52°	290.29^{chg}	25.59 ^{bc}	14.57^{g}	1.76^{bc}	147.15 ^{def}	2.67^{b}	31.07^{hij}	85.67°
CPT-19	65.64 ^a	23.69^{dc}	11.67 ^{cdc}	542.35*	351.18"	27.93*	17.40^{3}	1.61 ^{def}	202.89^{3}	2.49 ^{od}	44.33ª	87.67^{bc}
CPT-20	43.15	20.39^{l_8}	10.73^{hi}	333.27^{h}	258.39^{ijk}	23.67 ^{def}	14.24^{8}	1.66^{d}	185.01 ^b	1.80^{n}	39.33^{b}	84.33 ^{cd}
CPT-21	48.16 ^{@h}	22.83°	10.70^{hi}	343.45 ^{lgh}	284.73 ^{eft}	24.25 ^{cde}	14.53 ^g	1.67^{ol}	144.67 ^{cf}	2.38 ^{def}	33.33 ^{el@n}	80.00^{de}
CPT-22	44.69	18.73^{h}	9.96^{jk}	233.27^{m}	273.08 ^{ghij}	23.62 ^{def}	14.98 ^{ef}	1.58 ^{defg}	112.55	1.85 ^{mn}	34.40^{defg}	76.67 ^{ef}
CPT-23	44.40	24.26^{cd}	11.30^{elg}	296.72^{ij}	270.30^{2010}	22.74 ^{fbh}	15.25 ^e	1.49 ^{8hi}	181.39 ^b	2.05 ^{BKI}	35.53 ^{ode}	86.33°
CPT-24	49.14 ^{defgh}	23.16^{de}	9.83^{k}	276.27^{k}	260.64^{hijk}	20.32^{i}	16.24°	1.25 ^k	129.43 ^{hi}	1.89 ^{imn}	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	I by the same s	superscript lette	er and significantly	y different at $p = 0$).05.						

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	GV	PV	EV	GCV	PCV	ECV	Heritability (%)	GA (%) of mean
			F	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
			Se	ed 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	69.83	76.04	6.21	10.10	10.54	3.01	91.83	19.94

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

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 100pod 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, h²B 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 100seed 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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Germination **bercentage** 0.745*** 0.566*** 0.389 0.341 0.341 0.567** 0.588 0.404* 0.383 0.404* 0.383 0.248 0.248 0.408^{*} 0.369 0.451^{*} 0.416^{*} 0.418^{*} .365 678 Total oil content Pod-Seed 0.490° 0.475° 0.475° 0.114 0.124° 0.513° 0.519° 0.510° 0.510° 0.510° 0.510° 0.234 0.234 0.234 0.234 0.268° 0.183 0.268° 0.183 0.268° 0.183 0.268° 0.268° 0.268° 0.266° 0.2 ratio 100-seed weight 0.1310.1230.22470.2210.335 0.476° 0.476° 0.476° 0.472° 0.472° 0.465° 0.3530.3530.3530.3530.3530.3530.3530.3530.3530.3530.3600.3Aspect ratio 0.091 0.109 -0.462 -0.486 0.186 0.186 0.055 -0.187 0.0564 0.0602 0.602 0.564 -0.755 -0.755 -0.750 -0.750 -1.000 Seed width 0.359 0.351 0.607 0.581 0.581 0.202 0.180 0.515 0.515 0.515 0.744 0.77 0.076 0.077 0.077 0.070 0.070 0.070 Seed length 0.639** 0.612** 0.050 0.072 0.539** 0.539** 0.732** 0.732** 0.609** 0.578** 1.000 1.000 Seed 2D area 0.611 0.577 0.371 0.371 0.490 0.444 0.826 0.826 1.000 1.000 $\begin{array}{c} 0.739^{**}\\ 0.733^{**}\\ 0.368\\ 0.368\\ 0.365\\ 0.508^{*}\\ 0.490^{*}\\ 1.000\\ 1.000\end{array}$ 100-pod weight Pod thickness , significant at p = 0.05 and p = 0.01, respectively. 0.224 0.214 -0.188 -0.176 1.000 1.000 Pod width $\begin{array}{c} 0.441^{*}\\ 0.445^{*}\\ 1.000\\ 1.000\end{array}$ G <u>م</u> ن Total oil content 100-seed weight Pod-Seed ratio 100-pod weight Pod thickness Seed 2D area Aspect ratio Seed length Seed width Pod length Pod width

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

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tneiation co-efficient	0.408	0.451	0.418	0.717	0.745	0.389	0.667	-0.320	0.404	0.271	0.314	
Total oil content	-0.006	-0.003	-0.001	-0.007	-0.005	-0.003	-0.005	0.002	-0.008	0.000	-0.014	
Pod – Seed ratio	-0.176	-0.041	-0.196	-0.225	-0.186	-0.204	-0.084	-0.063	-0.029	-0.359	-0.007	
100-seed weight	-0.026	-0.049	-0.067	-0.097	-0.094	-0.081	-0.072	0.006	-0.199	-0.016	-0.122	
Aspect ratio	-0.142	0.718	-0.289	-0.101	0.369	-0.876	1.205	-1.554	0.048	-0.273	0.268	
Atbiw bee2	-0.454	-0.767	-0.255	-0.651	-0.940	-0.097	-1.264	0.980	-0.455	-0.295	-0.473	
Seed length	0.502	0.039	0.423	0.620	0.478	0.785	0.060	0.443	0.318	0.446	0.188	
Seed 2D સાલ્સ	0.185	0.119	0.148	0.250	0.303	0.184	0.225	-0.072	0.143	0.157	0.102	
thziow boq-001	0.672	0.334	0.462	0.909	0.751	0.718	0.468	0.059	0.443	0.571	0.454	
Pod thickness	0.075	-0.063	0.334	0.170	0.164	0.180	0.067	0.062	0.112	0.183	0.013	
dîbiw boq	0.143	0.324	-0.061	0.119	0.127	0.016	0.197	-0.150	0.080	0.037	0.063	
Pod length	-0.365	-0.161	-0.082	-0.270	-0.223	-0.233	-0.131	-0.033	-0.048	-0.179	-0.158	64987.
	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	Residual effect = 0.45

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

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