PROVENANCE VARIATIONS IN *GMELINA ARBOREA* WITH PARTICULAR REFERENCE TO TREE FORM

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INDIRA, E. P. 2006. Provenance variations in *Gmelina arborea* with particular reference to tree form. Provenance trials of *Gmelina arborea* were conducted to examine the extent of genetic variation in various traits and to estimate the genetic gain by choosing the best provenances for raising plantations. Fourteen provenances were collected from the main *Gmelina* growing areas in India. Growth performance, tree form and the characters controlling them were studied. With respect to tree form, the provenances varied significantly for clear bole percentage and tapering. Axis persistence, straightness and mode of branching also had significant variation between provenances at one of the sites. The provenance, Khasi Hills, showed the best performance at both sites for tree form as well as growth in the early years. The provenances Baramura and Begur also showed good tree form.

Keywords: Genetic variability, selection, seed source, genetic improvement

INDIRA, E. P. 2006. Variasi provenans *Gmelina arborea* dari segi bentuk pokok. Ujian provenans *Gmelina arborea* dijalankan untuk mengkaji takat variasi genetik beberapa ciri dan untuk menganggar keuntungan genetik provenans terbaik untuk penubuhan ladang. Empat belas provenans diperoleh daripada kawasan penanaman *Gmelina* utama di India. Prestasi pertumbuhan, bentuk pokok dan ciri-ciri yang mengawalnya dikaji. Dari segi bentuk pokok, provenans menunjukkan perbezaan bererti untuk peratusan batang bersih dan penirusan. Provenans juga menunjukkan perbezaan untuk keterusan paksi, kelurusan dan cara percabangan di salah satu tapak. Provenans Bukit Khasi menunjukkan prestasi terbaik di kedua-dua tapak untuk bentuk pokok dan pertumbuhan pada peringkat muda. Provenans-provenans Baramura dan Begur juga menunjukkan bentuk pokok yang baik.

Introduction

Gmelina arborea is a fast growing tree species of South-East Asia, occurring naturally almost throughout India, Nepal, Sikkim, Bangladesh, Sri Lanka, Myanmar, Thailand, Laos, Cambodia, Vietnam and the southern provinces of China. It has been planted extensively in Malaysia and has been established successfully along the west coast of Africa, Brazil, Malawi and other tropical countries.

The tree yields excellent timber, is well appreciated for its durability (if not kept in contact with soil), lack of shrinkage and distortion, smooth finish and ease with which it can be worked. It has a wide variety of uses in general construction, and in making furniture, plywood and veneer. Moreover, it is a potentially important source of pulp (Doat 1976). This species received international support for its genetic improvement programmes.

Tree breeders consider the use of proper seed source as crucial since this leads to the largest, cheapest and fastest gains in most tree improvement programmes, no matter how sophisticated the other breeding methods are (Zobel & Talbert 1984). Theoretically the vast distribution range of *G. arborea* in India alone, from 8° to 27° N and 72° to 96° E, should have given rise to significant genetic variation (Lauridsen 1977).

Seeds of this species were collected from various states of India in connection with the International Provenance Trial Programme co-ordinated through an Indo-Danish Project. From these seed lots, Indian provenances were tested by Kerala Forest Research Institute through establishment of provenance trials at Nilambur Range, Kerala to study the extent of genetic variation and adaptability of seed sources to the environment there. The field observations for the present study were taken from these plots.

Growth performance and tree form are the main factors considered for most of the tree improvement programmes. Hence, height, girth, clear bole percentage and tapering were measured, as these characters influence productivity. Clear bole percentage, tapering, straightness, persistence of axis, mode of branching and branch thickness were taken into consideration since these characters affect tree form. Based on those characters for which the seed sources vary significantly, the provenances were clustered into best, moderate and poor performers. The inter-relationship between these characters was studied through correlation coefficients.

Materials and methods

Provenance

Seeds of *G. arborea* from different geographic areas in India designated as different provenances were obtained from the seed lots collected through the Indo-Danish Seed Procurement project. The seed lots collected were from the semi-evergreen, moist deciduous, semi moist deciduous and dry deciduous forests of the northeastern, northern, central and southern parts of India.

A *G. arborea* provenance trial was established from 1977 till 1978 at Chempankolly area (latitude 11° 22' N and longitude 76° 17' E), with eight provenances (Table 1). In this trial, seed sources from Kerala were not included. Hence, in 1978 a second trial was established at Kariamuriam area (latitude 11° 23' N and longitude 76° 16' E), Nilambur Range, Kerala with nine provenances including one provenance from Kerala (Table 2). Both the areas are in Nilambur Range, Kerala, receiving around 2600 mm rainfall and having a temperature range of 17–37 °C.

Table 1 Geo-climatic factors of the provenances planted at Chempankolly

Provenance	State	Latitude	Longitude	Altitude (m)	Rainfall (mm)	Type of forest
Agarthala 1	Tripura	23° 50' N	91° 25' E	150	2400	Moist deciduous
Agarthala 2	Tripura	23° 50' N	91° 25' E	140	2400	Moist deciduous
Baramura	Tripura	23° 49' N	91° 33' E	130	2403	Moist deciduous
Cachar	Assam	24° 00' N	92° 15' E	200	1675	Moist deciduous
Ghottil	Maharashtra	17° 14' N	73° 57' E	1000	1000	Semi moist deciduous
Khasi Hills	Meghalaya	25° 46' N	91° 46' E	550	2509	Moist deciduous to semi-evergreen
Kundrukutu	Bihar	22° 30' N	85° 50' E	600	1400	Dry deciduous
Shikaribari	Tripura	23° 58' N	91° 54' E	300	2245	Moist deciduous

Table 2 Geo-climatic factors of the provenances planted at Kariamuriam

Provenance	State	Latitude	Longitude	Altitude (m)	Rainfall (mm)	Type of forest
Begur	Kerala	11° 55' N	76° 05' E	700	2500	Moist deciduous
Lambasingi	Andhra	17° 52' N	82° 30' E	900	505	Dry deciduous
Sankos	W. Bengal	26° 40' N	89° 50' E	50	4800	Moist deciduous
Baramura	Tripura	23° 49' N	91° 33' E	130	2403	Moist deciduous
Sewanthiwadi	Maharashtra	15° 54' N	73° 46' E	100	3000	Moist deciduous
Kundrukutu	Bihar	22° 30' N	85° 50' E	600	1400	Dry deciduous
Herrur	Karnataka	12° 27' N	75° 25' E	1000	1025	Semi moist deciduous
Sitabai Valley	Maharashtra	18° 22' N	73° 49' E	1000	1000	Dry deciduous
Khasi Hills	Meghalaya	25° 46' N	91° 46' E	550	2509	Moist deciduous to semi-evergreen

The field trial at Chempankolly is 100–120 m above msl and the trial at Kariamuriam is on the slope of a hill at 80–100 m above msl. Three provenances were common to both trials. The seedlings were planted in randomised block design with treatments replicated three times. In each block, 72 plants (6 × 12) of each of the eight provenances were planted at Chempankolly and 49 plants (7 × 7) of each of the nine provenances were planted at Kariamuriam with a 2 × 2 m spacing.

Observations on growth and tree form were taken at 15 years of age. In addition to height and girth, characters such as clear bole percentage and tapering are also factors which determine the final volume of wood. Height, girth at breast height (at 1.37 m height), girth at 2.37 m height and clear bole height were measured. Characters such as persistence of axis, straightness, branch thickness and mode of branching were scored following Lauridsen *et al.* (1987). Spacing between trees influences growth and tree form characters. To avoid this, 10 randomly selected trees with equal spacing were considered for measurement and other studies in each provenance per block. Hence, a total of 30 trees (10 × 3) were measured for each provenance in each trial.

Clear bole percentage

Clear bole length corresponds to the height where the main axis is forking. This height was measured using a multimeter. The percentage of clear bole length to the total height was then estimated.

Tapering

It gives an indication of the intensity of tapering. It was estimated as

$$\text{Tapering} = \frac{\text{Girth at 2.37 m height}}{\text{Girth at 1.37 m height}}$$

Characters such as persistence of axis and bole straightness were scored. These score values are useful for studying variations in individual characters. To compare the provenances, the percentage of trees with good axis persistence, straight trees and light branched trees were estimated as described below.

Persistence of axis

Total height of the tree was divided into four quarters and the following visual scoring system was used to assess the persistence of axis.

Score 1 – Tree is multiple stemmed at the ground level
Score 2 – When the main stem branched out in the lowest quarter
Score 3 – Main stem branched out in lower second quarter
Score 4 – Main stem forked in the third quarter
Score 5 – Main stem forked in the fourth quarter
Score 6 – Complete persistence of axis

Trees with scores 4 to 6 were considered to have good axis persistence.

Straightness

Five classes were given for scoring straightness.

Score 1 – Trees with crooked and more than three serious bends
Score 2 – Trees crooked and with 1 to 2 serious bends
Score 3 – Trees slightly crooked with many bends
Score 4 – Trees slightly crooked and with few bends
Score 5 – Straight trees

The number of trees from each plot qualifying for score 4 and 5 were pooled to find out the proportion of straight trees.

Branch thickness

Five classes were identified.
Score 1 – Heavy branches of more than half the size of the main stem
Score 2 – Trees with heavy branches of half the size of the main stem
Score 3 – Trees with medium branches with one fourth to half the size
Score 4 – Light branched trees with one fourth size of the main stem
Score 5 – Light branched trees with very light branches with less than one fourth size of the main stem

Trees with light branches scoring values 4 or 5 were pooled together to estimate the proportion of light branched trees.

Mode of branching

Five classes were allotted for scoring of the mode of branching.
Score 1 – Trees with double limbs
Score 2 – Trees with scattered but pronounced branching
Score 3 – Trees with light forking
Score 4 – Trees with scattered but light branching
Score 5 – Trees with very light branching

All the values including score values measured or estimated for tree form characters have been arranged in such a way that a high value would correspond to a positive characteristic.

Statistical analysis

The data were subjected to analysis of variance as follows.

Source	Df	Mean sum of squares	E (MS)
Replication	(r-1)	MS_{repl}	
Provenance	(t-1)	MS_{prov}	$\sigma_e^2 + r\,\sigma_g^2$
Error	(r-1) (t-1)	MS_e	σ_e^2

Statistical analysis was done using the computer software packages SPSS/PC+ advanced statistics V 2.0. The ANOVA provides the basic information for the calculation of provenance heritability and other genetic estimates. σ^2_{Prov} is the variance component for provenance. This variance component provides an estimate of genetic variance between provenances, which accordingly is obtained as $\frac{MS_{prov} - MS_e}{r}$ (Lauridsen *et al.* 1987) . Phenotypic and genotypic coefficients of variation (Pcv and Gcv) and heritability were computed following Singh and Chaudhary (1985) as well as Burley and Wood (1976).

Genotypic variance (σ_g^2) = $\frac{MS_{prov} - MS_e}{r}$ and phenotypic variance (σ_P^2) = $\sigma_g^2 + \sigma_e^2$

Genotypic coefficient of variation (Gcv) = $\frac{\sqrt{\sigma_g^2}}{\bar{x}} \times 100$, where $\bar{x}$ is the mean.

Phenotypic coefficient of variation (Pcv) = $\frac{\sqrt{\sigma_P^2}}{\bar{x}} \times 100$

$$\text{Heritability } (H^2) = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} = \frac{\sigma_g^2}{\sigma_P^2} \times 100 = \frac{\sigma_g^2}{\sigma_e^2 + \sigma_g^2} \times 100$$

Correlation coefficients between different parameters were estimated after Goulden (1952). The values of genetic parameters were classified as below.

Genetic parameter	Low	Moderate	High
Gcv and Pcv	0–10%	10–20%	More than 20%
Heritability	0–30%	30–60%	More than 60%

Euclidean clustering

Where only one or very few characters were considered for clustering depending upon their significance, clustering was done using average linkage between group algorithms. This corresponds to the group average method reported by Everitt (1974). The distance measure used was squared Euclidean distance. The analysis was carried out using the statistical package SPSS/PC+ advanced statistics V2.0. The provenances were then clustered into three groups as best, moderate and poor performers.

Results and discussion

Performance of provenances

The mean performance of the provenances are given in Tables 3 and 4 with respect to Chempankolly and Kariamuriam respectively and the results of the ANOVA in Tables 5 and 6.

There were no significant differences between provenances for height or girth at breast height at either locality at 15 years (Tables 3 and 4). However, there were significant differences between provenances for clear bole percentage and tapering. At both localities, Khasi Hills showed outstanding performance.

With regard to axis persistence, there were no significant differences between provenances at both localities. Only at Kariamuriam, percentage of trees with good axis persistence showed significant difference between provenances. Local provenance, Begur, showed 73% of trees with good axis persistence.

In *G. arborea*, the general criticism is that the trees frequently have undesirable stem form with forking, bending and basal sweep. This study showed that more than 80% of the trees were not straight, thereby confirming the disadvantage.

There were no significant differences between provenances for stem straightness as well as for percentage of straight trees at Chempankolly but at Kariamuriam there were significant differences. The provenance Khasi Hills had the highest score for straightness followed by Kundrukutu and Sitabai Valley. With regard to the percentage of straight trees, provenances Begur, Sitabai Valley and Khasi Hills had the greatest percentage.

There were no significant differences between provenances for branch thickness as well as for percentage of light branched trees at both localities. Generally more light branched trees were seen at Chempankolly including the three provenances common to both localities. When the growth during the early years (Indira 1999) and tree form were considered together, the provenance Khasi Hills outperformed others at both the localities. At Chempankolly, the provenance Ghottil showed

Table 3 Performance of 15-year-old provenances at Chempankolly

Provenance	Ht (m)	Gbh (cm)	Clear bole (%)	Taper	Axis persistence	Trees with good axis persistence (%)	Straight-ness	Straight trees (%)	Branch size	Light branched trees (%)	Mode of branching
Agarthala 1	18.67	74.21	49.31	0.59	4.00	53.33	1.67	3.40	3.67	50.00	3.33
Agarthala 2	18.00	64.01	53.06	0.67	3.67	50.00	1.33	3.40	3.67	53.33	3.00
Baramura	21.00	66.26	58.68	0.66	3.67	70.00	2.33	16.67	3.67	50.00	3.33
Cachar	20.67	64.89	55.05	0.62	4.00	70.00	2.33	20.00	4.00	83.33	4.00
Ghottil	18.33	55.50	53.18	0.50	3.33	50.00	1.67	13.37	4.00	60.00	3.00
Khasi Hills	19.67	66.83	60.98	0.62	4.00	76.67	2.00	10.00	4.00	63.33	3.67
Kundrukutu	21.00	62.33	48.03	0.61	3.33	40.00	2.00	16.67	4.00	70.00	3.00
Shikaribari	20.00	63.69	55.06	0.65	3.33	53.33	2.00	13.37	3.67	50.00	3.00
Grand mean	19.67	64.71	54.17	0.61	3.67	57.92	1.92	12.11	3.83	60.00	3.29

Table 4 Performance of 15-year-old provenances at Kariamuriam

Provenance	Ht (m)	Gbh (cm)	Clear bole (%)	Taper	Axis persistence	Trees with good axis persistence (%)	Straight-ness	Straight trees (%)	Branch thickness	Light branched trees (%)	Mode of branching
Begur	20.33	54.01	60.63	0.59	4.00	73.33	2.33	26.67	3.67	56.67	3.33
Lumbasinghi	19.67	54.01	48.70	0.52	3.67	43.33	2.00	0.10	3.33	46.67	3.00
Sankos	18.67	65.35	53.80	0.65	4.00	63.33	2.00	16.67	3.00	36.67	3.00
Baramura	18.33	53.87	50.90	0.64	3.33	43.33	2.00	10.03	3.67	46.67	3.00
Sewanthiwadi	18.33	56.63	51.10	0.58	3.67	50.00	2.33	13.33	3.67	46.67	3.33
Kundrukutu	18.67	52.83	54.40	0.61	4.00	63.33	2.67	20.00	4.00	53.33	3.00
Herrur	20.00	56.82	51.97	0.63	3.33	50.00	2.00	13.33	4.00	56.17	2.67
Sitabai Valley	20.67	54.81	59.60	0.64	3.67	66.67	2.67	26.67	3.33	43.33	3.67
Khasi Hills	17.67	55.28	58.97	0.62	4.00	63.33	3.00	26.67	3.33	53.33	3.67
Grand mean	19.19	56.26	54.45	0.61	3.74	57.41	2.33	17.05	3.56	48.89	3.19

Table 5 Analysis of variance for different characters at Chempankolly

Character	Mean sum of squares		
	Provenance (Df = 7)	Replication (Df = 2)	Error (Df = 14)
Height	4.3809	6.7915	3.7917
Gbh	81.0690	322.7600*	49.9590
Clear bole%	56.5037*	35.7109	12.2777
Tapering	0.0080**	0.0039*	0.0009
Axis persistence	0.2857	0.2917	0.1964
% of trees with good axis persistence	485.1200	379.1700	245.8300
Straightness	0.3571	0.0417	0.2321
% of straight trees	112.7600	53.6700	91.7600
Branch thickness	0.0952	0.6667**	0.0952
% of light branched trees	428.5900	1400.0000**	185.7100
Mode of branching	0.4226*	0.2917	0.1012

** Significant at p = 0.01, * significant at p = 0.05

Table 6 Analysis of variance for different characters at Kariamuriam

Character	Mean sum of squares		
	Provenance (Df = 8)	Replication (Df = 2)	Error (Df = 16)
Height	3.092	6.2590**	1.8010
Gbh	40.587	75.1990	23.8280
Clear bole%	55.738**	1.7500	9.5020
Tapering	0.005*	0.0030	0.0020
Axis persistence	0.231	0.7040*	0.1200
% of trees with good axis persistence	356.480*	137.0400	124.5400
Straightness	0.417*	0.1110	0.1530
% of straight trees	243.920*	48.3330	93.8330
Branch thickness	0.333	0.1110	0.2360
% of light branched trees	133.333	11.1110	161.1110
Mode of branching	0.343	0.0370	0.3290

** Significant at p = 0.01, * significant at p = 0.05

very poor performance in both growth and tree form. At Kariamuriam, the provenance Lumbasingi was the most undesirable.

At Chempankolly, the provenance Cachar showed good growth, moderate clear bole percentage and tapering, high percentage of trees with good axis persistence, highest percentage of straight trees and highest percentage of light branched trees. At Kariamuriam though Begur was not preferred for its growth rate during the early years, it had the best tree form such as clear bole percentage, highest percentage of trees with good axis persistence, highest percentage of straight trees and light branched trees.

Across site performance

The performance of the three provenances, common to both localities is given in Table 7. The characters such as clear bole percentage, tapering and mode of branching did not vary much. These were the characters which showed significant difference between provenances. Percentage

Table 7 Mean performance of three provenances common to both sites

Provenance	Height (m)	Gbh (cm)	Clear bole %	Taper	Axis persistence	Trees with good axis persistence (%)	Straight-ness	Straight trees (%)	Branch size	Light branched trees %)	Mode of branching
Baramura											
Site 1	21.00	66.26	58.68	0.66	3.67	70.00	2.33	16.67	3.67	50.00	3.33
Site 2	18.33	53.87	50.90	0.64	3.33	43.33	2.00	10.03	3.67	46.67	3.00
Khasi Hills											
Site 1	19.67	66.83	60.98	0.62	4.00	76.67	2.00	10.00	4.00	63.33	3.67
Site 2	17.67	55.28	58.97	0.62	4.00	63.33	3.00	26.67	3.33	53.33	3.67
Kundrukutu											
Site 1	21.00	62.33	48.03	0.61	3.33	40.00	2.00	16.67	4.00	70.00	3.00
Site 2	18.67	52.83	54.40	0.61	4.00	63.33	2.67	20.00	4.00	53.33	3.00

Site 1 at Chempankolly, Site 2 at Kariamuriam of trees with good axis persistence, percentage of straight trees and percentage of light branched trees showed wide variation between sites. While Kundrukutu had good score for axis persistence at Kariamuriam it had low value at Chempankolly. At Chempankolly, Kundrukutu was having only 40% of the total trees with good axis persistence whereas at Kariamuriam the same provenance was having 63% with good axis persistence. Likewise, Baramura was having 70% of their trees with good axis persistence at Chempankolly while it had only 43% with good axis persistence at Kariamuriam. Hence, it could be inferred that this character is highly environmentally controlled. Sandiford (1990) reported that a serious obstacle which existed when making comparisons between populations was the marked sensitivity of *G. arborea* to site. Greaves (1981) also noted the extreme site sensitivity of this species. Provenance × site interactions were reported to be high in other species too. Lebot and Ranaivoson (1994) noted this type of interaction in many species of *Eucalyptus*.

Genetic parameters

Estimates for coefficient of variation and heritability are given in Table 8 with regard to provenances at Chempankolly and in Table 9 for provenances at Kariamuriam. Among the tree form characters, provenances planted at Chempankolly varied significantly for clear bole percentage, tapering and for mode of branching. Clear bole percentage, tapering, mode of branching, persistence of axis and branch thickness showed their phenotypic coefficient of variation (Pcv) around 10%. Among these, branch thickness had the lowest genotypic coefficient of variation (Gcv). Hence, this character must be strongly controlled by the environment. Generally, more light branched trees were seen at Chempankolly including the three provenances common to both localities. Heritability was moderate for clear bole percentage and mode of branching and high for tapering. Straightness had a Pcv of 27.30 but Gcv was low with a value of 10.65. For all the other characters heritability was low.

In provenances planted at Kariamuriam significant differences were seen between provenances for characters such as straightness, percentage of straight trees, percentage of trees with good axis persistence, clear bole percentage and tapering. Among these, percentage of straight trees showed the highest Pcv and Gcv with values 70.34 and 41.48 respectively followed by percentage of trees with good axis persistence with Pcv and Gcv of 24.75 and 15.32 respectively. Clear bole percentage had high heritability of 62% and percentage of straight trees had moderate heritability.

The Pcv, Gcv and heritability for each character were quite variable from one site to another. The two possible reasons are that (i) the provenances planted at these two sites were different and (ii) site factors were different. This finding is in accordance with those of Lauridsen *et al.* (1987) in *G. arborea* and Garcia-Cuevas *et al.* (1992) in *E. camaldulensis* in Mexico. Lauridsen *et al.* (1987) estimated heritability of nine characters, namely, survival, health, diameter at breast height, basal area, axis dominance, forking height, number of branches, straightness and wood density while evaluating provenance trials in *G. arborea* at 27 localities with 36 provenances and found that the heritability of each character differed widely from one experiment to another. Garcia-Cuevas *et al.* (1992) indicated that heritability and genetic gain for height, diameter and volume varied in *E. camaldulensis* depending on localities. Bouvet and Vigneron (1995) also found the same in many *Eucalyptus* species, where the variances and heritabilities were strongly influenced by the experimental processes such as nursery, planting and environmental effects. Romero (1995) also found that growth variables in *E. saligna* and *E. grandis* provenances were significantly affected by environmental variables.

Correlation

The correlation coefficients estimated for growth and tree form with respect to provenances at Chempankolly are given in Table 10. Height had significant positive correlation with straightness. Clear bole percentage was significantly correlated with percentage of trees with good axis persistence. Axis persistence had significant correlation with mode of branching. Tapering had no significant positive correlation with any character. This shows that it is an independent character.

At Kariamuriam, height and girth at breast height had no significant positive correlations with any character (Table 11). Clear bole percentage showed highly significant positive correlations with percentage of trees with good axis persistence and percentage of straight trees. Persistence of axis had a significant positive correlation with mode of branching. Percentage of trees with good axis persistence showed highly significant positive correlation with percentage of straight trees.

The fact that clear bole percentage showed significant positive correlation with percentage of trees with good axis persistence at both sites indicates that trees with good axis persistence will generally have good clear bole percentage. Axis persistence was significantly and positively correlated with mode of branching at both sites, inferring that if forking is less in the branches, it will also be less in the main stem.

Clustering

Significant variations were seen between provenances only for clear bole percentage and tapering out of the various tree form characters. Hence, the provenances at both localities were grouped through Euclidean clustering based on these two characters.

At Chempankolly cluster I comprised the best provenances—Baramura and Khasi Hills. These two provenances also excelled in growth during the early years (Indira 1999). Cluster II included four moderate provenances—Agarthala 2, Cachar, Ghottil and Shikaribari. The third cluster had provenances with poor tree form, i.e. Agarthala 1 and Kundrukutu (Table 12).

At Kariamuriam, three clusters (Table 13) were also formed where cluster I was having the three best provenances—Begur, Sitabai Valley and Khasi Hills. The second cluster had five provenances—Sankos, Baramura, Sewanthiwadi, Kundrukutu and Herrur. The third cluster comprised only one provenance—Lambasingi, with poor characters.

Table 8 Variability and heritability in provenances at Chempankolly

Character	Pcv	Gcv	H^2
Height	10.15	2.25	
Gbh	12.00	4.98	
Clear bole %	9.60	7.09	54.60
Tapering	9.33	7.91	72.00
Axis persistence	12.97	4.71	
% of trees with good axis persistence	31.16	15.42	
Straightness	27.30	10.65	
% of straight trees	82.08	21.85	
Branch thickness	8.05	0.02	
% of light branched trees	27.22	15.00	
Mode of branching	13.87	9.94	51.40

Table 9 Variability and heritability in provenances at Kariamuriam

Character	Pcv	Gcv	H^2
Height	7.79	3.42	
Gbh	9.64	4.20	
Clear bole %	9.17	7.21	61.90
Tapering	8.50	5.32	39.20
Axis persistence	10.61	5.14	
% of trees with good axis persistence	24.75	15.32	38.30
Straightness	21.03	12.71	36.50
% of straight trees	70.34	41.48	34.80
Branch thickness	14.57	5.06	
% of light branched trees	25.96	0.06	
Mode of branching	18.13	2.14	

Table 10 Correlation between different characters in 15-year-old provenances planted at Chempankolly

Character	Gbh	Clear bole %	Tapering	Axis persistence	% of trees with good axis persistence	Straight-ness	% of straight trees	Branch thickness	% of light branched trees	Mode of branching
Height	0.161	0.064	0.084	-0.182	-0.055	0.427*	0.299	0.116	0.299	0.189
Gbh		-0.025	0.272	0.191	-0.007	0.119	-0.070	-0.378	-0.073	0.316
Clear bole %			0.310		0.525**		0.051		-0.029	
Tapering					0.240		-0.135		-0.018	
Axis persistence						0.263		-0.162		0.411*
% of trees with good axis persistence							0.092		0.048	
Straightness								0.000		0.349
% of straight trees									0.219	
Branch thickness										0.169

** Significant at $p = 0.01$, * significant at $p = 0.05$

Table 11 Correlation between different characters in 15-year-old provenances planted at Kariamuriam

Character	Gbh	Clear bole %	Tapering	Axis persistence	% of trees with good axis persistence	Straight-ness	% of straight trees	Branch thickness	% of light branched trees	Mode of branching
Height	-0.236	0.079	-0.106	0.008	0.149	-0.080	0.050	0.169	-0.048	0.016
Gbh		-0.020	0.238	-0.124	0.117	-0.259	-0.125	-0.177	-0.064	-0.091
Clear bole %			0.125		0.595**		0.791**		0.234	
Tapering					0.043		0.156		-0.188	
Axis persistence						0.143		0.068		0.424*
% of trees with good axis persistence							0.577**		0.370	
Straightness								-0.146		0.033
% of straight trees									0.176	
Branch thickness										0.031

** Significant at $p = 0.01$, * significant at $p = 0.05$

Table 12 Clusters based on tree form in provenances at Chempankolly

Cluster	No. of provenances	Name of provenances
I	2	Baramura, Khasi Hills
II	4	Agarthala 2, Cachar, Ghottil, Shikaribari
III	2	Agarthala 1, Kundrukutu

Table 13 Clusters based on tree form in provenances at Kariamuriam

Cluster	No. of provenances	Name of provenances
I	3	Begur, Sitabai Valley, Khasi Hills
II	5	Sankos, Baramura, Sewanthiwadi, Kundrukutu, Herrur
III	1	Lumbasingi

When growth in early years and tree form were considered together, Khasi Hills and Baramura showed very good performance. Although provenance Begur was not preferred for its growth rate in the early years, it had the best tree form. Provenance Sankos had very good growth but the tree form was not that good. Hence, desirable characters from provenances having better tree form can be incorporated into the provenances with faster growth rate through inter provenance hybridization. Combinational hybridization can be an important method of breeding for multiple characteristics (Nikles 1970, Wright 1976).

The international series of *Gmelina* provenance trials have shown that land races from Oceania and Africa appear to perform better than natural sources when stem quality is taken into consideration. A few provenances selected for good tree form within natural provenance regions are Sholayar and Baramura from India (Lauridsen *et al.* 1995). In these trials, Baramura had shown very good performance. Although Khasi Hills had shown very good performance here, it was not a preferred provenance in international trials.

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