VARIATIONS IN GROWTH AND MORPHOLOGICAL CHARACTERISTICS OF *CASUARINA JUNGHUHNIANA* PROVENANCES GROWN IN THAILAND

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PINYOPUSARERK, K., WILLIAMS, E. R. LUANGVIRIYASAENG, V. & PITPREECHA, K. 2005. Variations in growth and morphological characteristics of *Casuarina junghuhniana* provenances grown in Thailand. Variation in growth, stem form and branching characteristics was assessed in a 48-month-old provenance trial of *Casuarina junghuhniana* planted in Kanchanaburi, Thailand. The trial compared 28 seed sources from the natural distribution of the species in Indonesia, planted stands from Kenya, Tanzania and Australia and a local commercial hybrid clone of *C. junghuhniana* × *C. equisetifolia*. The following characteristics were assessed: height and diameter growth; axis persistence; stem straightness; density, thickness and angle of permanent branches; and length, thickness and stiffness of branchlets. There were significant differences between seed sources in most of the characteristics assessed. Principal component analysis suggested a pattern of geographic variation among natural provenances from Indonesia, with Java, Timor and Wetar forming a group separated from Lombok and most seedlots from Bali. In general seed sources from low altitudes grew faster than those from high altitudes. Natural provenances from Bali and land races from Kenya were very variable in growth rate with some being among the slowest growing and some among the fastest growing. Provenances from Bali also showed considerable variation within its group in stem form and branching habit. Selection of suitable provenances to optimize plantation productivity is feasible.

Key words: *C. junghuhniana* – provenance variation – height – diameter – stem form– branching habit

PINYOPUSARERK, K., WILLIAMS, E.R. & LUANGVIRIYASAENG, V. & PITPREECHA, K. 2005. Variasi ciri pertumbuhan serta morfologi provenans *Casuarina junghuhniana* yang ditanam di Thailand. Variasi ciri-ciri pertumbuhan, bentuk batang dan dahan dinilai dalam satu kajian provenans *Casuarina junghuhniana* berusia 48 tahun yang ditanam di Kanchanaburi, Thailand. Kajian ini membandingkan 28 sumber anak benih daripada taburan semula jadi spesies ini di Indonesia, dirian yang ditanam di Kenya, Tanzania dan Australia serta satu klon hibrid komersil tempatan *C. junghuhniana* × *C. equisetifolia*. Ciri-ciri yang dikaji adalah (1) pertumbuhan ketinggian dan diameter, (2) ulangan paksi, (3) kelurusan batang, (4) ketumpatan, besar dan sudut dahan kekal, dan (5) panjang, besar serta kekukuhan jejarum. Terdapat perbezaan ketara antara sumber biji benih dalam kebanyakan ciri yang dikaji. Analisis

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komponen utama mencadangkan corak variasi geografi antara provenans semula jadi dari Indonesia yakni provenans Jawa, Timor dan Wetar membentuk kumpulan berasingan daripada Lombok serta kebanyakan lot biji benih dari Bali. Secara umumnya, sumber anak benih dari altitud rendah tumbuh lebih cepat berbanding anak benih dari altitud tinggi. Provenans semula jadi dari Bali dan ras daratan dari Kenya sangat berbeza dari segi kadar pertumbuhan. Ada antaranya yang tumbuh paling lambat dan ada pula yang paling cepat. Provenans dari Bali menunjukkan variasi yang agak banyak dalam kumpulannya dari segi bentuk batang dan sifat bercabang. Pemilihan provenans yang sesuai untuk mengoptimumkan penghasilan ladang boleh dilaksanakan.

Introduction

Casuarina junghuhniana (syn. *C. montana*) of the Casuarinaceae family is a deciduous tree, 25–35 m tall and 50–80 cm in diameter. The natural distribution is restricted to the eastern part of the Indonesian Archipelago where it occurs on Java, Bali, Lombok, Sumbawa, Flores, Alor, Sumba, Wetar and Timor Islands (Pinyopusarerk & House 1993, Mile 1996). It grows in various habitats such as hard stony ground, steep slopes of water-ways, valley sides and mountains, and in crater valleys. It is a principal species on the slopes of volcanoes at altitudes of 1500–3100 m but also at lower altitudes in Wetar and Timor, where it occurs from near sea level to 800 m altitude. It is long-lived and well adapted to a monsoonal climate with a distinct dry season. Rainfall in the natural distribution ranges from 700 to 1500 mm, and up to 2500 mm in highland places in Java (Mile 1996). Mean annual minimum and maximum temperatures are 13 and 28 °C respectively. The species tolerates a variety of soil conditions, from compact clays to coastal volcanic soils and alkaline shales on Timor. When trees reach a few metres in height they are fire tolerant and sprout readily after being damaged by fire.

The crown of *C. junghuhniana* is reasonably open and comprises numerous long, deciduous branchlets bearing scale-like leaves reduced to tiny teeth in whorls of 9–11. The greyish green branchlets are formed by numerous segments of article, each 10–15 mm long. Trees are predominantly dioecious. Male inflorescence, 3–8 cm long, is borne on the apex of a deciduous branchlet. Female flowers are cone shaped and are borne in the axil of scale leaves on lateral permanent branches, 5–8 mm long.

Casuarina junghuhniana is a pioneer species of deforested lands, moderately to very drought tolerant and especially good as a pioneer of soils prone to landslides (Djogo 1992). It is planted to improve soil fertility and rehabilitate degraded soils and as a windbreak. Branches and foliage are burnt and the ash is spread on village gardens in Timor. The wood is heavy, its air dry density being 900–1000 kg m^{-3}, and makes good firewood and charcoal. The energy value of the charcoal is 34 500 kJ kg^{-1}, which is among the highest for firewood species (Pinyopusarerk 1997). *Casuarina junghuhniana* has been introduced successfully to some countries in eastern Africa including Kenya, Uganda and Tanzania and is increasingly being planted as an agroforestry tree (Okorio *et al.* 1994, Mwihomeke *et al.* 2002). It has shown potential in early species introduction trials in southern China (Zhong & Bai 1996). A hybrid with *C. equisetifolia* was introduced to Thailand in about 1900 and has become a commercial clonal plantation species for production of piling poles for the construction industry (Chittachumnonk 1983).

There has been increasing interest in planting *C. junghuhniana* and hence the search for suitable seed sources. However, information on the genetic variation within the species is limited to a small progeny trial in southern China established with seed from a small number of trees from Timor and from planted stands in Kenya and Tanzania. Not until the mid 1990s when the CSIRO Australian Tree Seed Centre organized provenance seed collection from major occurrences in Indonesia and planted stands in Australia, Kenya and Tanzania was it possible to investigate the genetic variation within the species and identify useful seed sources for reforestation and breeding programmes. Provenance trials were subsequently established in many countries in Asia and Africa. This paper presents results from one of the trials planted in Thailand at age four years.

Materials and methods

Planting material

Planting stock was raised as tube stock from seed obtained from 20 natural provenances from Indonesia and seven planted stands from Australia, Kenya and Tanzania (Table 1). In addition cuttings of the local commercial hybrid clone of *C. junghuhniana* × *C. equisetifolia* were included. Geographically, the origin of these materials can be categorized into nine groups: Java, Bali, Lombok, Timor, Wetar, Australia, Kenya, Tanzania and local commercial hybrid clone.

Planting site

The planting site belongs to the Thai Royal Forest Department's Lumpao-Lumsai Forest Tree Experimental Station in Kanchanaburi province (latitude 13° 58' N, longitude 99° 18' E, altitude 45 m). Mean annual temperature is 29.9 °C and mean annual rainfall is 900 mm with four to six months of dry season. The soil is sandy and silty loam, with a pH of 6.7. The area is subject to waterlogging for a few weeks each year.

Experimental design

The experiment was laid out in a latinised row-column design (Williams *et al.* 2002). The design generation package CycDesigN (Whitaker *et al.* 2002) was used to produce the design and randomization for four replicates each containing four rows of seven columns. There were 25 (5 × 5) trees in each plot spaced at 2 × 2 m. Two guard rows of the same species were planted surrounding the entire experiment. The experimental area was ploughed prior to the planting in August 1997.

Table 1 Origins of provenances of *Casuarina junghuhniana*

Prov. No.	CSIRO Seedlot No.	Provenance location		Latitude	Longitude	Altitude (m)	Rainfall (mm)
1	18952	Mt Willis, Java	Indonesia	7° 50' S	111° 47' E	1500	2500
2	18948	Mt Kawi, Java	Indonesia	7° 55' S	112° 25' E	2000	1900
3	18951	West of Mt Arjuno, Java	Indonesia	7° 45' S	112° 33' E	1350	2100
4	18950	Mt Bromo, Java	Indonesia	7° 55' S	112° 55' E	1600	2300
5	18954	Mt Bromo, Java	Indonesia	7° 55' S	112° 55' E	2500	2500
6	18949	Mt Argopuro, Java	Indonesia	8° 00' S	113° 3' E	1500	2500
7	18953	East of Mt Arjuno, Java	Indonesia	7° 45' S	112° 35' E	1350	2200
8	18847	Batu Kawu, Bali	Indonesia	8° 40' S	115° 05' E	1500	1200
9	18845	Bukit Pohen, Bali	Indonesia	8° 40' S	115° 05' E	2000	1400
10	18844	Bukit Tapak, Bali	Indonesia	8° 45' S	115° 15' E	1500	1400
11	18846	Mt Pengalongan, Bali	Indonesia	8° 50' S	115° 15' E	1500	1400
12	18849	Kintamari, Bali	Indonesia	8° 13' S	115° 20' E	1500	1300
13	18848	Bukit Abang, Bali	Indonesia	8° 55' S	115° 25' E	1500	1200
14	18850	Mt Santong, Lombok	Indonesia	8° 25' S	116° 28' E	1500	1300
15	19489	Kapan, Kupang, Timor	Indonesia	10° 13' S	123° 38' E	600	1300
16	19490	Camplong, Timor	Indonesia	10° 05' S	123° 57' E	600	1300
17	17878	Noelmina River, Timor	Indonesia	9° 59' S	124° 06' E	170	1400
18	17877	25 km SW Soe, Timor	Indonesia	9° 54' S	124° 14' E	550	1500
19	19491	Buat, Soe, Timor	Indonesia	9° 51' S	124° 16' E	800	1500
20	17844	Old Uhak, NE Wetar	Indonesia	7° 36' S	126° 30' E	5	1000
21	17559	Coffs Harbour Plantation, NSW	Australia	30° 18' S	153° 08' E	100	1800
22	19239	KARI Muguga, Kiambu	Kenya	1° 16' S	36° 36' E	2060	1300
23	19240	Muka Mukuu, Machakos	Kenya	1° 05' S	37° 12' E	1460	1000
24	19238	KEFRI, Muguga, Kiambu	Kenya	1° 13' S	36° 39' E	2080	1300
25	19241	Thika Municipality, Thika	Kenya	1° 02' S	37° 04' E	1440	1200
26	19237	Meru Forest, Meru	Kenya	0° 07' N	37° 37' E	1750	1400
27	18853	Kwai Mission	Tanzania	4° 19' S	38° 14' E	1600	1200
28		Local commercial hybrid clone	Thailand				

Assessment

At 48 months of age, all trees were measured for height (Ht) and diameter at 1.3 m above ground (dbh). Plot mean survival was calculated by counting the number of trees presented in the height data. Conical volume (V) was calculated for all trees using the equation

$$V = \frac{1}{3}\pi(dbh/2)^2Ht$$

In addition, each tree was scored subjectively for eight morphological characteristics: axis persistence; stem straightness; density, thickness and angle of permanent branches; and length, thickness and stiffness of branchlets. Details of the scoring procedures are given in Table 2. This set of morphological characteristics summarizes the morphological attributes of individual trees.

Data analysis

Each characteristic was analysed to determine differences between groups of provenances and provenances within groups. Measurements on the trees within each plot were summarized to plot means, variances and counts using the data pre-processing package DataPlus 3.0. Normality checks were conducted on the plot means of the data, especially the categorical measurements.

A mixed-model was fitted to the plot means with replicates and provenances as fixed effects and rows and columns within replicates as random effects. Variance component estimates were obtained using residual maximum likelihood in the statistical package GenStat 6 (Sixth edition, 2002). The estimated provenance means from this analysis were then further analysed to subdivide the provenance variation into differences between groups. This two-stage approach to analysis of nested treatment structures is described by Williams *et al.* (2002).

The mean squares for groups and provenances within groups are tested against the residual mean square from the initial analysis. Estimated provenance means for growth and morphological characteristics were subjected to a principal component analysis. This multivariate analysis was performed to investigate the combinations of these characteristics which would help elucidate the differences between provenances from different groups.

Results

The data pre-processing showed that a mixed model with normal errors could be used on plot means for all characteristics and no transformations were needed. Significant differences were found for most of the characteristics measured between groups and between provenances or seedlots within groups (Table 3). The characteristics that did not differ significantly were branch thickness between

Table 2 Characteristics assessed on each tree in the *Casuarina junghuhniana* provenance trial at Kanchanaburi, Thailand

Characteristic	Unit	Explanation
Qualitative traits		
Height (Ht)	m	Height of the tallest stem
Diameter (dbh)	cm	Measured at 1.3 m above ground
Tree volume (V)	cm^3	Conical volume per tree calculated using the equation $V = \frac{1}{3}\pi(dbh/2)^2Ht$
Qualitative traits		
Axis persistence (Axpst)	1–6	Ability of tree to retain its primary stem axis
		1 = Multiple stems from ground level
		2 = Forking in first (lowest) quarter of stem
		3 = Forking in second quarter of stem
		4 = Forking in third quarter of stem
		5 = Forking in fourth quarter of stem
		6 = No forking
Stem straightness (Strst)	1–4	1 = Very crooked, > 2 serious bends
		2 = Slightly crooked, > 2 small bends or < 2 serious bends
		3 = Almost straight, 1–2 small bends
		4 = Completely straight
Branching habit		
Permanent branches		First order branches originating from the main stem
Density (Denpb)	1–4	1 = Very high, regularly branched, internode mainly 15 cm
		2 = High, irregularly branched, internode around 15 cm
		3 = Low, irregularly branched, internode around 30 cm
		4 = Very low, sparsely branched, internode > 30 cm
Thickness (Thkpb)	1–4	1 = Very heavy, > 3 branches diameter > $\frac{1}{3}$ of adjacent stem
		2 = Heavy, 1–3 branches diameter > $\frac{1}{3}$ of adjacent stem
		3 = Light, branch diameter ≤ $\frac{1}{3}$ of adjacent stem
		4 = Very light, branch diameter ≤ $\frac{1}{4}$ of adjacent stem
Angle (Angpb)	1–2	1 = Upright, < 60°
		2 = Horizontal > 60°
Branchlet		
Length (Lenbl)	1–2	1 = Long, > 15 cm
		2 = Short, < 15 cm
Thickness (Thkbl)	1–2	1 = Coarse
		2 = Fine
Stiffness (Stfbl)	1–2	1 = Erect
		2 = Pendulous (somewhat weeping)

seedlots, and branch angle between groups and between seedlots. Provenance (seedlot) means, group means, overall trial mean and standard errors of differences for all growth characteristics are given in Table 4.

Characteristics discriminating groups and provenances

Survival

The top two provenances in survival were Kupang (No. 15) and Noelmina River (No. 17), both from Timor with a mean of 91 and 85% respectively. The poorest surviving provenance was from Tanzania (No. 27), with a mean of 30%. The single provenance from Lombok, Indonesia (No. 14) also recorded poor survival at 40%. Most seedlots from Bali and Kenya also recorded survival lower than overall trial mean of 59%.

Growth

Compared with other seed sources, the provenances from Lombok, Tanzania and most seedlots from Bali were significantly slower growing, with mean stem volumes of only 97–141 cm^3. The Timor group of provenances was most consistent with mean volumes of 192–223 cm^3. Seedlots from Wetar, Australia, local hybrid clone and a few from Java and Kenya also had mean stem volumes ≥ 200 cm^3. It

Table 3 Summarized results of analysis of variance for characteristics showing mean square values

Characteristic	Group	Group.Seedlot	Residual
Survival	1937.5***	596.1**	235.5
Height	16.0159***	3.0519***	0.9783
Diameter	9.3328***	2.1954**	0.9034
Tree volume	10973.2***	2092.9***	670
Axis persistence	1.2423***	0.596**	0.2447
Stem straightness	0.5887***	0.1274*	0.0705
Branch density	0.5948***	0.2808***	0.0632
Branch thickness	0.3838**	0.1176^{ns}	0.1157
Branch angle	0.0216^{ns}	0.0125^{ns}	0.0267
Branchlet length	0.0999***	0.1456***	0.0102
Branchlet thickness	0.1407*	0.1095*	0.0535
Branchlet stiffness	0.4834***	0.0613***	0.0223

Significant difference levels *, **, *** indicate significant differences at $p < 0.05$, 0.01, and 0.001 respectively; ns indicates no significant differences

Table 4 Mean values for growth and morphological characteristics of four-year-old *Casuarina junghuhniana* provenances at Kanchanaburi, Thailand

Provenance group	Prov No.	Survival (%)	Ht (m)	Dbh (cm)	Volume (cm^3)	Axis persistence (1–6)	Stem straightness (1–4)	Permanent branch Density (1–4)	Permanent branch Thickness (1–4)	Permanent branch Angle (1–2)	Branchlet Length (1–2)	Branchlet Thickness (1–2)	Branchlet Stiffness (1–2)
Java	1	70	7.2	5.7	189	5.4	1.7	2.4	2.2	1.9	1.1	1.5	1.0
	2	65	7.6	6.2	200	5.2	1.8	2.7	2.3	1.9	1.0	1.7	1.0
	3	51	6.7	5.1	175	5.0	1.9	2.1	2.2	1.8	1.1	1.9	1.1
	4	40	6.6	6.5	173	4.7	1.7	1.9	1.9	1.9	1.1	2.0	1.3
	5	72	7.7	6.1	202	5.4	2.0	2.5	2.3	1.9	1.1	1.8	1.0
	6	73	6.9	5.4	180	5.1	1.9	2.5	2.5	1.9	1.0	1.5	1.0
	7	77	7.7	7.0	200	5.4	1.9	2.4	2.2	1.9	1.0	1.6	1.1
	Mean	64	7.2	6.0	188	5.2	1.8	2.4	2.2	1.9	1.1	1.7	1.1
Bali	8	36	3.7	3.1	97	4.4	1.2	1.8	2.1	1.9	1.2	1.7	1.3
	9	50	4.5	4.0	118	3.8	1.4	1.8	1.9	1.7	1.2	1.8	1.3
	10	53	4.7	4.2	122	4.4	1.3	1.9	2.3	1.9	1.1	1.7	1.3
	11	45	4.6	4.0	120	4.3	1.4	1.9	2.2	1.7	1.1	1.9	1.7
	12	72	6.7	5.2	174	5.4	2.0	2.6	2.1	1.9	1.1	1.5	1.1
	13	46	6.7	5.9	175	5.2	1.7	2.4	1.8	1.8	1.1	1.6	1.2
	Mean	50	5.1	4.4	135	4.6	1.5	2.1	2.0	1.8	1.1	1.7	1.3
Lombok	14	40	4.6	4.0	120	4.2	1.5	1.8	1.8	1.7	1.1	1.6	1.7
Timor	15	91	7.9	6.0	207	5.4	2.0	2.5	2.3	1.9	1.2	1.8	1.1
	16	57	7.3	5.7	192	5.2	1.9	2.5	2.0	1.9	1.1	1.6	1.1
	17	85	8.5	7.0	223	5.2	1.9	2.6	2.4	1.9	1.0	1.7	1.0
	18	71	7.5	6.1	196	5.2	2.0	2.4	2.3	2.0	1.1	1.6	1.0
	19	70	7.5	6.1	196	4.9	1.8	2.2	2.1	1.9	1.2	2.0	1.1
	Mean	75	7.7	6.2	203	5.2	1.9	2.4	2.2	1.9	1.1	1.7	1.1
Wetar	20	71	7.6	7.5	200	5.3	1.7	2.7	2.1	1.9	1.0	1.4	1.1
Australia	21	78	8.0	6.4	210	5.4	2.0	2.6	2.0	1.9	1.0	1.7	1.1
Kenya	22	56	6.9	5.7	180	5.4	1.9	2.5	2.1	1.9	1.1	1.6	1.1
	23	51	7.1	6.5	186	5.0	1.8	2.2	1.9	1.8	1.1	1.9	1.2
	24	63	7.5	6.1	196	5.3	1.9	2.4	2.1	1.9	1.0	1.8	1.1
	25	42	5.2	4.7	136	5.2	1.6	1.9	1.7	1.9	1.2	1.9	1.2
	26	45	8.1	5.8	211	4.5	1.9	1.8	2.1	1.8	2.0	1.9	1.0
	Mean	51	6.9	5.8	182	5.1	1.8	2.2	2.0	1.9	1.3	1.8	1.1
Tanzania	27	30	5.4	5.0	141	5.1	1.8	2.0	1.8	1.8	1.0	1.9	1.6
Local hybrid	28	62	7.8	5.8	203	5.4	2.5	1.9	2.6	1.9	1.0	2.0	1.7
Overall mean		59	6.7	5.6	176	5.0	1.8	2.2	2.1	1.9	1.1	1.7	1.2
Standard error of differences		11	1.0	0.67	18	0.35	0.19	0.18	0.24	0.12	0.07	0.16	0.11

appeared that provenances having moderate to good survival also performed well in growth. This is reflected in the high correlation between these parameters shown in Table 5.

There was a clear variation within the Bali group. Stem volumes of two provenances from Kintamari (No. 12) and Bukit Abang (No. 13), 174 and 175 cm^3 respectively, were significantly greater than four other provenances from the same island, 97–122 cm^3.

Stem form

The majority of provenances scored highly in axis persistence, indicating the propensity of the species to be single-stemmed. The local hybrid clone was among the highest scoring in axis persistence at 5.4, and the best in stem straightness at 2.5. The plantation source from Australia also scored 5.4 in axis persistence and was second in stem straightness at 2.0. The single provenance from Lombok and most provenances from Bali performed poorly in both axis persistence and stem straightness.

Variation between provenances in stem form was observed among provenances from Bali. Provenances from Kintamari (No. 12) and Bukit Abang (No. 13) had better stem form, scoring significantly higher in axis persistence (5.2–5.4) and stem straightness (1.7–2.0), than other sources from the same island (3.8–4.4 for axis persistence and 1.2–1.4 for stem straightness).

Branching habit (permanent branches)

Branch density can generally be divided into two groups. The first group was characterized predominantly by densely but irregularly branched trees. The local

Table 5 Correlation matrix for nine characteristics in the *Casuarina junghuhniana* provenance trial at Kanchanaburi, Thailand

Dbh	1.000								
Axpst	0.677	1.000							
Strst	0.324	0.708	1.000						
Denpb	0.674	0.769	0.434	1.000					
Thkpb	0.232	0.281	0.437	0.324	1.000				
Angpb	0.367	0.630	0.271	0.568	0.402	1.000			
Lenbl	-0.133	-0.388	-0.105	-0.410	-0.156	-0.293	1.000		
Thkbl	-0.155	-0.282	0.087	-0.611	-0.045	-0.346	0.323	1.000	
Stfbl	-0.503	-0.419	-0.175	-0.650	-0.178	-0.560	-0.172	0.345	1.000
	Dbh	Axpst	Strst	Denpb	Thkpb	Angpb	Lenbl	Thkbl	Stfbl

Dbh = diameter at breast height; Axpst = Axis persistence; Strst = Stem straightness; Denpb = branch density; Thkpb = branch thickness; Angpb = branch angle; Lenbl = branchlet length; Thkble = branchlet thickness; Stfbl = branchlet stiffness hybrid clone and seed sources from Tanzania, Lombok and most of Bali were included in this group (mean score ≤ 2.0). The second group, having lower branch density, included seed sources from Java, Timor, Wetar and Australia, and had a mean score around 2.5.

Branch thickness varied between provenances although the majority of provenances tended to have thick branches, i.e. branch diameter greater than 1/3 of the adjacent main stem. The local hybrid clone clearly had the smallest branches, diameter ≤ 1/3 of the adjacent main stem.

There was little difference in the branch angle between provenances as all provenances had horizontal branches, the angle > 60°.

Deciduous branchlets

All but one seedlot had long branchlets. The only seedlot that had short branchlets came from Meru Forest, Kenya. There were, however, differences in the thickness of branchlets between provenances although the majority were considered to have fine needles.

Despite predominantly long and fine branchlets, they were classified as stiff with an erect appearance. Very few sources (i.e. local hybrid clone, Tanzania and one from Bali) showed weeping appearance.

Multivariate analysis

Principal component analysis was carried out for all but one growth and one morphological characteristics. Height was not included because it was highly correlated with diameter (Table 5). In addition, two seed sources, Meru Forest, Kenya (No. 26) and local hybrid clone (No. 28), were also excluded in this analysis. The Meru Forest seedlot was the only source found to have distinctively short branchlets, and this led to an exaggerated domination in the total variation. Similarly, the local commercial hybrid clone was genetically improved material, and its far better-than-average stem straightness over all other seed sources also dominated the analysis of principal components.

Loadings for the first two principal components, weighted according to the standard deviation of the characteristics, are given in Table 6. A large absolute value for a variate (characteristic) loading indicated the importance of the variate in the formation of the principal component. It can be seen that the first component was based largely on branch density, branchlet stiffness and growth while the second was related to branchlet stiffness. These first two components accounted for 65 and 11% of the total variation respectively.

A plot of the scores of the first and second principal components is shown in Figure 1. The position of the natural provenances from Indonesia showed a general pattern in that provenances from Java (Nos. 1–7), Timor (Nos. 14–18) and Wetar (No. 20) were separated from those from Bali (Nos. 8–11) and Lombok (No. 14). Two Balinese provenances (Nos. 12 and 13) were grouped with Java, Timor

Table 6 The first two principal component loadings weighted according to the standard deviations of the characteristics in the *Casuarina junghuhniana* provenance trial at Kanchanaburi, Thailand

Variance	Loadings	
	PCP 1	PCP 2
Diameter	0.4342	-0.3685
Axis persistence	0.3564	-0.1598
Stem straightness	0.3124	-0.2380
Branch density	0.5078	-0.1031
Branch thickness	0.1318	0.2421
Branch angle	0.1113	0.1643
Branchlet length	-0.1496	0.3916
Branchlet thickness	-0.1372	0.0152
Branchlet stiffness	-0.4970	-0.7265

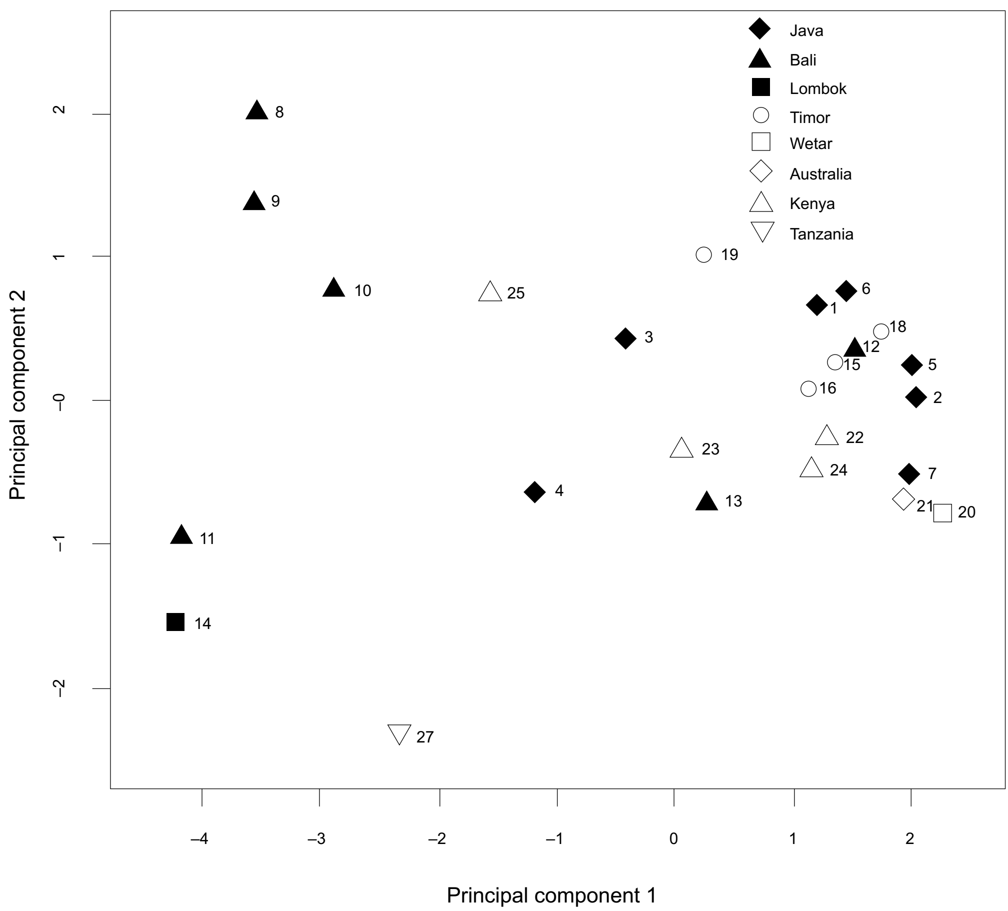

Figure 1 Plot of scores for principal components 1 and 2

and Wetar. These two provenances behaved differently from their counterparts as already described above.

Seedlots from planted stands in Australia (No. 21) and Kenya (Nos. 22–25) were positioned close to the main group of Java, Timor and Wetar. The sole seedlot from Tanzania (No. 27) did not appear to align with either groups.

Discussion

The results indicated marked variation among populations of *C. junghuhniana* in many growth and morphological characteristics. Despite significant differences between provenances within groups, the results showed some evidence of variation among groups.

There was an indication, as shown in the principal component analysis, of geographic variation among natural provenances from Indonesia. Data supported a separation of populations from Java, Timor and Wetar from Lombok and all but two seedlots from Bali (Nos. 12 and 13). Growth, branch density and branchlet stiffness were major contributing characteristics. In many ways, Bali provenances seemed to be at odds with the other regions, being so dispersed and spread out by principal components 1 and 2.

There was a tendency for provenances from low altitudes to grow better than those from high altitudes. Provenances from Wetar, Timor and Australia, which came from altitudes 5–800 m grew faster compared with Java, Bali and Lombok provenances which were higher altitude sources at 1350–2500 m asl. The altitude of this trial in Thailand was 45 m asl. The results thus indicated better adaptation in Thailand of low altitude provenances from Wetar and Timor. Similar results were obtained from a *C. junghuhniana* provenance trial on a low altitude site (8 m) at Dian Bai, Guangdong, China where Timor provenances grew better than Java and Bali provenances (Zhong & Bai 2003). However, the results are contrary to those obtained from a provenance trial established in Tanzania with the same seedlots. In Tanzania, high altitude provenances from Java, Bali and Lombok outperformed low altitude provenances from Wetar and Timor (Mwihomeke *et al.* 2002). The trial site in Tanzania was located at 1500 m altitude. These results thus suggested a possible site-by-provenance interaction for *C. junghuhniana*.

The performance of land races from Kenya was very variable. While the seedlot from Meru Forest (No. 26) was among the fastest growing, the seedlot from Thika (No. 25) was among the slowest. The land race from Tanzania (No. 27) was notably among the poorest in growth rate. Mwihomeke *et al.* (2002) revealed that the seed of *C. junghuhniana* currently being planted in Tanzania had originated from a single seed source introduced from Java. The poor performance of the planted stand from Tanzania could have been due to genetic deterioration over successive generations through build-up of inbreeding. Rapid genetic deterioration has been documented in several unmanaged land races of other species including tropical acacias (Luangviriyasaeng & Pinyopusarerk 2001). The Meru Forest seedlot (No. 26) was the only source found to have distinctly short branchlets; the origin of this seedlot has not been established.

This provenance trial demonstrated considerable variation not only in growth but also in stem form and branching habit among provenances and land races of *C. junghuhniana*. The local commercial hybrid clone showed good growth and stem form as expected. Other seed sources showing good growth and stem form included Mt Bromo, Java (No. 5), Kupang, Timor (No. 15), Noelmina River, Timor (No. 17) and Coffs Harbour, Australia (No. 21). With further selection and improvement on branching characteristics, these seed sources will offer a wider range of utilization potential especially as sawn timber in addition to the conventional use as poles.

Conclusions

The results of *C. junghuhniana* provenance trial in Thailand indicated considerable variation among provenances within the species. Selection of suitable provenances or seed sources to optimize plantation productivity for particular planting sites is feasible.

References

CHITTACHUMNONK, P. 1983. Silviculture of *Casuarina junghuhniana* in Thailand. Pp. 102–106 in Midgley, S. J., Turnbull, J. W. & Johnston, R. D. (Eds.) *Casuarina Ecology, Management and Utilization.* Proceedings of an international workshop. Canberra, Australia. 17–21 August 1981. CSIRO, Canberra.

DJOGO, A. P. Y. 1992. The possibility of using local drought resistant and multipurpose tree and shrub species as alternative to lamtoro (*Leucaena leucocephala*) for agroforestry and social forestry in West Timor. Working Paper No. 32. EAPI-East-West Center, Honolulu.

LUANGVIRIYASAENG, V. & PINYOPUSARERK, K. 2001. Genetic variation in a second-generation progeny trial of *Acacia auriculiformis* in Thailand. *Journal of Tropical Forest Science* 14 (1): 131–144.

MILE, Y. M. 1996. Notes on the distribution of *Casuarina junghuhniana.* Pp. 33–40 in Pinyopusarerk, K., Turnbull, J.W. & Midgley, S.J. (Eds.) *Recent* Casuarina *Research and Development.* Proceedings of the Third International Casuarina Workshop. Danang, Vietnam. 4–7 March 1996. CSIRO, Canberra.

MWIHOMEKE, S. T., MUGASHA A. G., CHAMSHAMA S. A. O., MGANGAMUNDO M. A., KUMBURA, O. C. & LUPALA, Z. 2002. Early performance of *Casuarina junghuhniana* provenances/land races at Lushoto, Tanzania. *Southern African Forestry Journal* 194: 7–14.

OKORIO, J., BYENKYA, S., WAJJA, N. & PEDEN, D. 1994. Comparative performance of seventeen upperstorey tree species associated with crops in the highlands of Uganda. *Agroforestry Systems* 26: 185–203.

PINYOPUSARERK, K. 1997. *Casuarina junghuhniana* Miquel. Pp. 89–92 in Faridah H. & van der Maesen, L. J. G. (Eds.) *Plant Resources of South-East Asia No 11. Auxiliary Plants.* Backhuys Publishers, Leiden.

PINYOPUSARERK, K. & HOUSE, A. P. N. 1993. Casuarina: *An Annotated Bibliography of* C. equisetifolia, C. junghuhniana *and* C. oligodon. International Centre for Research in Agroforestry, Nairobi.

WHITAKER, D., WILLIAMS, E. R. & JOHN, J. A. 2002. *CycDesigN: A Package for the Computer Generation of Experimental Designs.* CSIRO, Canberra.

WILLIAMS, E. R., MATHESON, A. C. & HARWOOD, E. R. 2002. *Experimental Design and Analysis for Tree Improvement.* CSIRO Publishing, Melbourne.

ZHONG, C. L. & BAI, J. Y. 1996. Introduction trials of casuarinas in southern China. Pp. 191–195 in Pinyopusarerk, K., Turnbull, J. W. & Midgley, S. J. (Eds.) *Recent* Casuarina *Research and Development*. Proceedings of the Third International Casuarina Workshop. Danang, Vietnam. 4–7 March 1996. CSIRO, Canberra.

ZHONG, C. L. & BAI, J. Y. 2003. Variation in *Casuarina junghuhniana* provenances in Southern China. *IUFRO WP 2.08.02 NFT News* 6: 5–6.