Kasetsart J. (Nat. Sci.) 46 : 394 - 407 (2012)

Provenance Variation in Seed Morphometric Traits and Growth Performance of *Senna siamea* (Lam.) Erwin et Barneby at Lad Krating Plantation, Chachoengsao Province, Thailand

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ABSTRACT

Genetic variation patterns of Khilek (*Senna siamea* (Lam.) Erwin et Barneby) an indigenous species with potential as a source of wood energy, were evaluated at the population level. Seed samples were collected from nine provenances throughout Thailand and examined for variations in seed morphometric traits and growth performance in provenance trials in the Lad Krating plantation. Analysis of variance revealed significant differences among provenances in all the study traits except the relative growth rate in some stages of development. The provenance effect as determined by broad sense heritability was 50–83% for seed morphometric traits, 53–85% for height, 33–62% for diameter at ground level, 14–67% for the height relative growth rate and 11–50% for the diameter at ground level relative growth rate. Significant correlations were found within seed mophometric traits and growth characters while the inter-character correlations between seed and growth characters were very weak. At this early stage, it is recommended that the top three most suitable provenances for planting are Potaram (Ratchaburi-seed lot 2002), Muang (Kanchanaburi), and Muaklek (Saraburi). The observed patterns of variation will have important implications for gene conservation and the tree improvement program of the species.

Keywords: *Senna siamea*, provenance variation, seed morphometric traits, growth performances, wood energy

INTRODUCTION

Senna siamea (Lam.) Irwin & Barneby (family Fabaceae), commonly known as Khilek, is a small-to-medium sized tree that is a very widespread medicinal and food plant cultivated in Southeast Asia and sub-Saharan Africa. The species is native to South and Southeast Asia from India, Sri Lanka, Bangladesh, Myanmar, Thailand and Malaysia down to Indonesia (Hassain, 1999; Rocas, 2003). The absolute distribution of *S. siamea* is difficult to identify since it has been cultivated worldwide and it has the ability to grow under many conditions, even in saline soil (Yuvaniyama and Dissataporn, 2003). Different parts of *S. siamea* are used for various medicinal purposes (Ahn *et al.*, 1978; Sanon *et al.*, 2003; Kaur *et al.*, 2006; Mbatchi *et al.*, 2006; Morita

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Received date : 04/10/11 Accepted date : 20/03/12

et al., 2007). The fresh young leaves and flowers are usually used as vegetables to make Khilek curry and can be used as a mild laxative and sleeping aid (Padumanonda and Gritsanapan, 2006). The wood is dense and excellent for fuel with a calorific value of 4,500 to 4,600 Kcal.kg^{-1} although it produces some smoke during burning (Forestry/Fuelwood Research and Development Project, 1994; Hassain, 1999). The heartwood is decorative and durable (Joker, 2000). It is also used in agroforestry systems in many countries (Mccaffery, 1996; Vanlauwe *et al.*, 2002; Luhende *et al.*, 2006). In India, it use as a hyper-accumulator plant for bioremediation of fly ash dumps has also been reported (Jambhulkar and Juwarkar, 2009).

Nowadays, sourcing fuel is a major problem for many countries. Fossil fuel sources are limited; so the price is expensive and tends to be continually increasing. The uses of fossil fuels also causes global warming which can affect the climate—for example, more frequent flooding events (Schiermeier, 2011). Attempts at finding alternative sources to fossil fuels (particularly tree biomass) have been conducted worldwide not only to substitute the fuel type but also to solve the problem of forest destruction. People in rural areas rely on fuelwood and source it from natural forest. Thus, the criteria for identifying a suitable wood species should include supporting the livelihood of people in the rural area too.

S. siamea is one of the potential species satisfying these requirements. It is an indigenous, multipurpose tree species having a wide distribution, is fast growing, and has the ability to coppice (Hassain, 1999). In Thailand, there is limited knowledge about provenance and genetic variability of important indigenous species and of *S. siamea* in particular. Since environmental conditions vary extensively within the natural range of the species, it is reasonable to expect genetic differentiation among *S. siamea* populations in a number of traits. Casual observations on the variation in vegetative growth and crown shape of the species in its natural habitat are indicators of the existence of genetic variation. Substantial genetic variation among natural populations for a variety of quantitative traits has been documented for economically useful, tropical plantation species such as *A. mangium, A. auriculiformis, Casuarina equisetifolia, C. junghuhniana, E. urophylla, Pinus caribea* and *P. merkusii* (Pipatwattanakul, 1989; Lawskul, 1991; Swatdipakdi, 1992; Rattanachol, 1997; Chunchaowarit, 2000; Maelim, 2000; Sengloung, 2002; Wattanasuksakul, 2002; Na Takuathung, 2005; Maid, 2006; Popromsree, 2006). The conservation and sustainable use of genetic resources is dependent upon knowledge of the extent and pattern of intra-specific variation. Therefore, variability studies are a prerequisite for the genetic improvement of any tree species. Seed source testing of native species is desirable to screen the available variation for higher productivity and future breeding work. Selection of the best provenance of a desired species for a given site or region is necessary to achieve maximum productivity in plantation forestry. Thus, the aims of this study were to evaluate the variation in seed morphometric traits and growth performance among nine provenances of *S. siamea*. The intercharacter correlations were also examined.

MATERIALS AND METHODS

Seed materials

The seeds of *S. siamea* used in this study were supplied by the Forest Tree Seed Research and Management Section, Silviculture Research Division, Royal Forest Department (RFD). Provenances were selected based on the seed sources of the RFD which were collected according to geographical regions in Thailand. In order to statistically analyze the data, the two seed lots of Potaram (Ratchaburi) provenance were counted as two provenances. The details are shown in Table 1.

Table 1 Details of *Senna siamea* (Lam.) Irwin et Barneby provenances.

Provenance Codes	Province	District	Region	Altitude (m)	Rainfall (mm)[/1]	Temperature (°C)[/1]	Soil series[/2]
1	Lampang	Ngao	North	400	1,137	26.9	62, 15
2	Tak	Muang	North	350	1,114	27.9	62, 46B
3	Lop Buri	Chaibadal	Central	160	1,159	28.5	62, 47B
4	Narathiwat	Takbai	South	5	2,626	27.2	16, 58
5	Saraburi	Muaklek	Central	270	1,191	28.5	62, 52B/28B
6	Kanchanaburi	Muang	West	40	1,120	28.5	62, 33/38
7	Ratchaburi (seed lot 2000)	Potaram	Central	9	1,086	27.8	4, 6/18
8	Ratchaburi (seed lot 2002)	Potaram	Central	9	1,086	27.8	4, 6/18
9	Songkhla	Muang	South	8	2,303	28.1	39B, 43B

Source: [/1] Thai Meteorological Department (2012).
[/2] Land Development Department (2001).

Seed morphometric characters

In order to determine the variability in seed morphometric characters, seed length, seed width, seed thickness and 100-seed weight were measured. From each provenance, a sample of 400 seeds was randomly selected (4 replicates of 100 seeds) and used for measuring each morphometric character. Seed length, seed width and seed thickness were measured on individual seeds using a micro caliper while seed weight was determined for each replicate (100 seeds) using a sensitive balance.

Provenance trials

A randomized complete block design was selected for the establishment of a provenance trial. *S. siamea* seedlings were planted on four blocks, each divided into nine plots corresponding to the nine studied provenances.

In fact, there were seeds from nine provenances of which one was composed of two seed lots. For the statistical analysis of the data, these two seed lots were counted as two provenances, resulting in 10 provenances covering the complete natural distribution of the species in Thailand. However, the seeds from the Northeastern provenance had a low germination rate that resulted in insufficient seedlings for inclusion in the provenance trial. Consequently, this provenance was omitted from study leaving the remaining nine provenances representing all regions of Thailand except the Northeastern region (Table 1).

Each plot comprised 49 trees. The density of each plantation was 100 trees per rai (625 trees per hectare) obtained using 4 × 4 m spacing. The provenance trials were established in the Lad Krating plantation of the Thai Plywood Company, Amphur Sanam Chaikhet, Chachoengsao province (13°14´ N, 101°06´ E) at an altitude of 45 m above sea level. The average annual temperature, rainfall, and relative humidity were 28°C, 1,220mm, and 88%, respectively. The dry period ranged from November to February, and the maximum peak rainfall was in September. The height and diameter at ground level were measured at 2, 6, and 36 months after planting. All trees were measured except the border trees of each plot. The relative growth rate (RGR) was used to detect growth performance without the influence of differences in seedling size at the initial stage. The RGR was calculated following the formula of Hoffmann and Poorter (2002).

Statistical analysis

The data were subjected to two-way analysis of variance. Means that exhibited significant ($P < 0.05$) or highly significant ($P < 0.01$) differences were compared using the least square difference test. In order to rank the nine provenances, a scoring system was used based on the method described by Maid (2006). Parameters that differed significantly were selected for ranking. The given score of each parameter was based on the averaged values of each provenance, whereby the best ranked provenance would eventually have the lowest score and conversely for the least ranked provenance. Provenances with an equal score were given an equal rank. All parameters were given the same weight because this study was composed of two parameter categories. The first category dealt with growth in the early stage which was important for tree establishment. The second category dealt with growth in the older stage which was important for production as well as the ability to survive in a future changing environment. The variance components were calculated according to the expected mean square equation of the experimental design. Where a negative variance component was detected, the restricted maximum-likelihood method was employed for variance estimation (Montgomery, 2001). To compare the magnitude of variation due to provenance and environment, the provenance coefficient of variation (PCV) and the environmental coefficient of variation were computed for seed and growth characters using the method described by Loha *et al.* (2006). To determine to what extent the provenance variations contributed to the total variations, broad sense heritability (H^2) was calculated as a ratio of the expected mean square of the provenance variance (σ^2_{pro}) to the total (phenotypic) variance ($\sigma^2_{pro} + \sigma^2_e$, where σ^2_e = the environmental variance) (Loha *et al.*, 2006). Pearson product-moment correlations were calculated to examine relationships between seed-related and growth parameters.

RESULTS

Seed morphometric traits

In the present study, highly significant differences among *S. siamea* provenances were found for all seed morphometric traits (Table 2). Average seed length, seed width, seed thickness and 100-seed weight are shown in Figure 1. Mean seed length varied from 7.21 to 8.28 mm. Seeds collected from Muang (Songkhla) had the largest value for seed length with the lowest being for seeds collected from Potaram (Ratchaburi-seed lot 2000). The mean seed width varied from 5.50 to 6.09 mm. Seeds collected from Muaklek (Saraburi) had significantly higher values compared to the other provenances with the lowest being for seed collected from Muang (Songkhla) and Takbai (Narathiwat). Mean seed thickness varied from 0.55 to 0.96 cm. The highest seed thickness was recorded for seed collected from Muaklek (Saraburi) with the lowest being for seed collected from Potaram (Ratchaburi-seed lot 2002) and Muang (Kanchanaburi). Mean 100-seed weight varied from 2.25 to 2.76 g. The highest seed weight was recorded for seed collected from Muang (Songkhla) and the lowest was for seed collected from Potaram (Ratchaburi-seed lot 2002).

Estimates of provenance and environmental effects indicated that the PCV was larger for seed thickness compared to seed length, seed width and seed weight (Table 3). In general, environmental factors appeared to play a minor role in shaping these traits, as 69–83% of the total variation was attributed to provenance

Table 2 Analysis of variance for seed morphometric traits of *S. siamea*.

Source of variation	DF	Variance component[1]						Expected mean square[2]
Seed morphometric traits		**SL**	**SW**	**ST**	**Swt**			
Provenance (P)	8	0.09**	0.03**	0.02**	0.02**			$\sigma_e^2 + 4\sigma_{Pro}^2$
Error (E)	27	0.04	0.03	0.004	0.004			σ_e^2
Tree growth parameters		**H2**	**H6**	**H36**	**D2**	**D6**	**D36**	
Block (B)	3	0	0	224	0	0	0	$\sigma_e^2 + 9\sigma_{Block}^2$
Provenance (P)	8	135.5**	298.46**	3,434.17**	0.008**	0.04*	0.15**	$\sigma_e^2 + 4\sigma_{Pro}^2$
Error (E)	24	23.99	259.77	1,219.72	0.005	0.08	0.14	σ_e^2
Relative growth rates		**1^{st}H**	**2^{nd}H**	**OH**	**1^{st}D**	**2^{nd}D**	**OD**	
Block (B)	3	0	0	0	0	0	0	$\sigma_e^2 + 9\sigma_{Block}^2$
Provenance (P)	8	0.006**	$1\text{x}10^{-5}$	$2.6\text{x}10^{-4}$	$9\text{x}10^{-4}$*	$2\text{x}10^{-6}$	$2\text{x}10^{-5}$	$\sigma_e^2 + 4\sigma_{Pro}^2$
Error (E)	24	0.003	$6\text{x}10^{-5}$	$2.5\text{x}10^{-4}$	0.002	$5\text{x}10^{-5}$	$2\text{x}10^{-5}$	σ_e^2

* = Significant (P < 0.05); ** = Highly significant (P < 0.01).

[1] SL = seed length; SW = seed width; ST = seed thickness; Swt = seed weight; H2 = height at age 2 months; H6 = height at age 6 months; H36 = height at age 36 months; D2 = diameter at ground level at age 2 months; D6 = diameter at ground level at age 6 months; D36 = diameter at ground level at age 36 months; 1^{st}H = height grown during age 2 to 6 months; 2^{nd}H = height grown during age 6 to 36 months; OH = height grown during age 2 to 36 months; 1^{st}D = diameter at ground level grown during age 2 to 6 months; 2^{nd}D = diameter at ground level grown during age 6 to 36 months; OD = diameter at ground level grown during age 2 to 36 months.

[2] σ_e^2 = environmental variance; σ_{pro}^2 = provenance variance; σ_{Block}^2 = block variance.

variation, except for seed width which was only 50%, as indicated by the broad sense heritability (Table 3). Of the seed morphometric traits, there was a strong inter-trait correlation. In particular, seed length and 100-seed weight as well as width and thickness had significant positive correlations (Table 4).

Growth performances

Provenances displayed highly significant differences in tree height after 2, 6 and 36 months of growth in the field (Table 2). The average tree height after 2, 6 and 36 months varied between 27.23 and 61.58, 57.39 and 113.39, and 336.61 and 521.79 cm, respectively. Tree height was considerably higher for the Muaklek (Saraburi) provenance compared to the other provenances after 2 and 6 months while the height of the Potaram (Ratchaburi-seed lot 2002) provenance was the highest when grown after 36 months (Figure 2). The slowest height growth was observed for the Muang (Songkhla) provenance after 2 and 6 months and the Ngao (Lampang) provenance after 36 months. Diameter at ground level after 2, 6 and 36 months varied between 0.48 and 0.74, 1.04 and 1.74, and 3.76 and 5.12 cm, respectively. The analysis of variance showed highly significant differences among provenances after 2 and 36 months while there was a significant difference after 6 months (Table 2). At age 2 and 6 months, diameter at ground level was greater for the Potaram (Ratchaburi-seed lot 2002) and

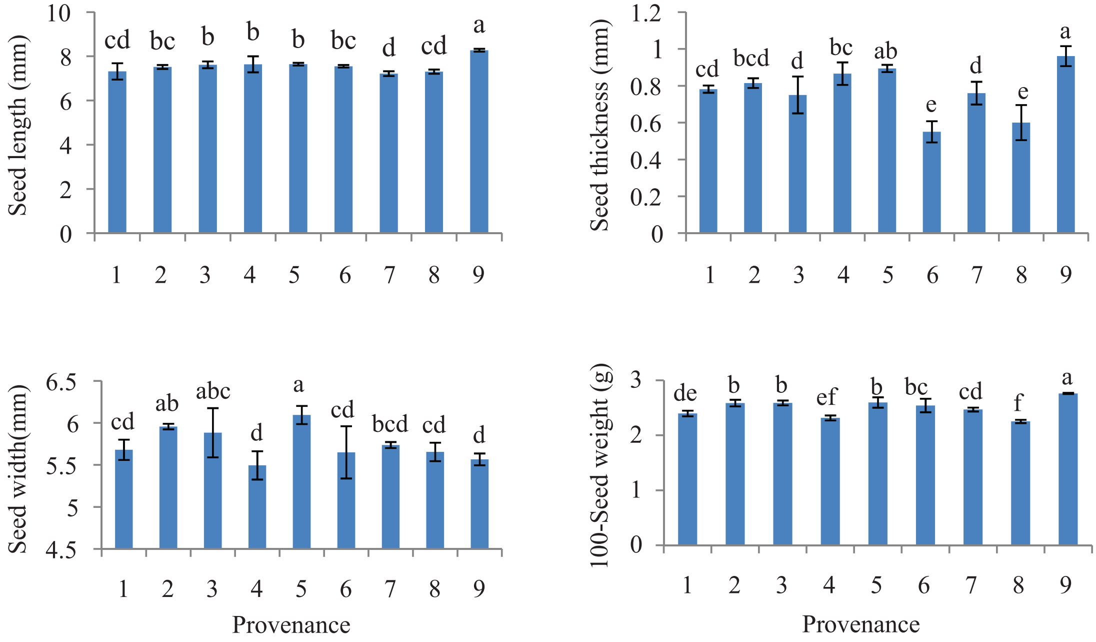


Figure 1 Mean seed length, seed width, seed thickness and 100-seed weight of nine provenances of *S. siamea*. Bars with the same letter (s) are not significantly different ($P < 0.05$).Vertical lines indicate ± SE.

Muaklek (Saraburi) provenances compared to the other provenances. However, after 36 months, the Muang (Kanchanaburi) provenance replaced the Muaklek (Saraburi) provenance as the leader (Figure 2). The lowest diameter at ground level was observed for the Potaram (Ratchaburi-seed lot 2000) provenance after 2 and 6 months and for the Ngao (Lampang) provenance after 36 months. There was no consistent trend for the best provenance in terms of diameter at ground level and height.

More than 50% of the total variation in tree height and diameter at ground level was attributed to a provenance effect as shown by the broad sense heritability values with the exception of diameter at ground level after 6 months (Table 3). Among seed-related parameters, all traits had very poor correlation with growth parameters. Diameter at ground level showed a significant age-age correlation among provenances. Height also had a good age-age correlation among provenances except for the height at age 2 and 36 months. Correlation among height and diameter values at ground level at the same age were highly significant while at different ages they were also significant except for growth parameters at age 36 months (Table 4).

Relative growth rate

The relative growth rates were examined by stage of development. The first stage of development was from age 2 to 6 months, the second stage was from age 6 to 36 months and the overall stage was from age 2 to 36 months. A highly significant difference among provenances was found only in the first stage of development for height, whereas the diameter at ground level was significantly different (Table 2). In the first stage, the relative growth rate for the diameter at ground level varied from 0.19 to 0.28 $cm.cm^{-1}.month^{-1}$. Trees from the Muang (Kanchanaburi) provenance had the highest value and the Potaram

Table 3 Provenance and environment coefficient of variation and broad sense heritability for seed- and tree-related traits of *S. siamea.*

Trait	Overall mean	Coefficient of variation (%)		Heritability (%)
		Provenance	Environment	
Seed parameters				
Length (mm)	7.56	4	2.6	69
Width (mm)	5.75	3	3	50
Thickness (mm)	0.78	18.1	8.1	83
100-Seed weight (mm)	2.50	5.7	2.5	83
Tree growth parameters				
Height, 2 months (cm)	38.71	30.1	12.7	85
Height, 6 months (cm)	81.97	21.1	19.7	53
Height, 36 months (cm)	459.57	12.8	7.6	70
Dgl, 2 months (cm)	0.58	15.4	12.2	62
Dgl, 6 months (cm)	1.35	14.8	21	33
Dgl, 36 months (cm)	4.46	8.7	8.4	52
Relative growth rates ($cm.cm^{-1}.month^{-1}$)				
Height at 1st stage	0.25	31	22	67
Height at 2nd stage	0.06	5.3	12.9	14
Height at overall stage	0.20	2.5	2.5	51
Dgl[1] at 1st stage[2]	0.23	13	19.4	31
Dgl at 2nd stage[3]	0.04	6.1	17.7	11
Dgl at overall stage[4]	0.06	11.8	11.8	50

[1]Dgl = diameter at ground level.
[2]1st stage = from 2 to 6 months.
[3]2nd stage = from 6 to 36 months.
[4]Overall stage = from 2 to 36 months.

Table 4 Inter-trait correlations of seed and growth parameters of *S. siamea* provenances (n = 9).

Parameter[1]	SL	SW	ST	Swt	H2	H6	H36	D2	D6	D36
SL	1.0	0.56	0.62	0.71*	-0.21	-0.13	0.18	-0.04	-0.02	0.30
SW		1.0	0.73*	0.51	-0.36	-0.48	-0.45	-0.18	-0.17	-0.11
ST			1.0	0.66	-0.05	-0.17	-0.08	-0.05	-0.04	-0.01
Swt				1.0	-0.06	-0.19	-0.14	0.18	0.04	0.04
H2					1.0	0.89**	0.61	0.86**	0.78*	0.63
H6						1.0	0.75*	0.83**	0.88**	0.76*
H36							1.0	0.43	0.46	0.83**
D2								1.0	0.94**	0.69*
D6									1.0	0.73*
D36										1.0

* = Significant (P < 0.05); ** = Highly significant (P < 0.01).
[1]SL = seed length; SW = seed width; ST = seed thickness; Swt = 100-seed weight; H2 = height at age 2 months; H6 = height at age 6 months; H36 = height at age 36 months; D2 = diameter at ground level at age 2 months; D6 = diameter at ground level at age 6 months; D36 = diameter at ground level at age 36 months.

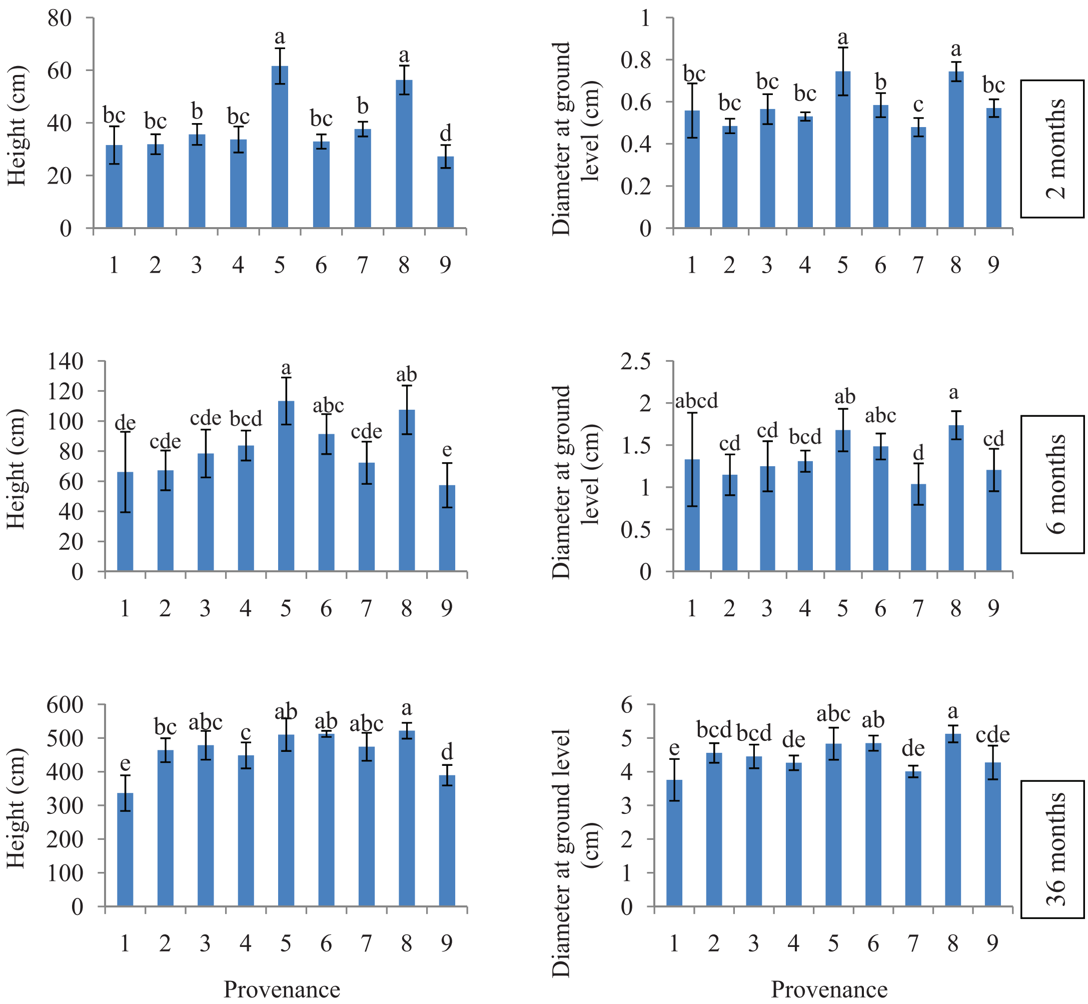
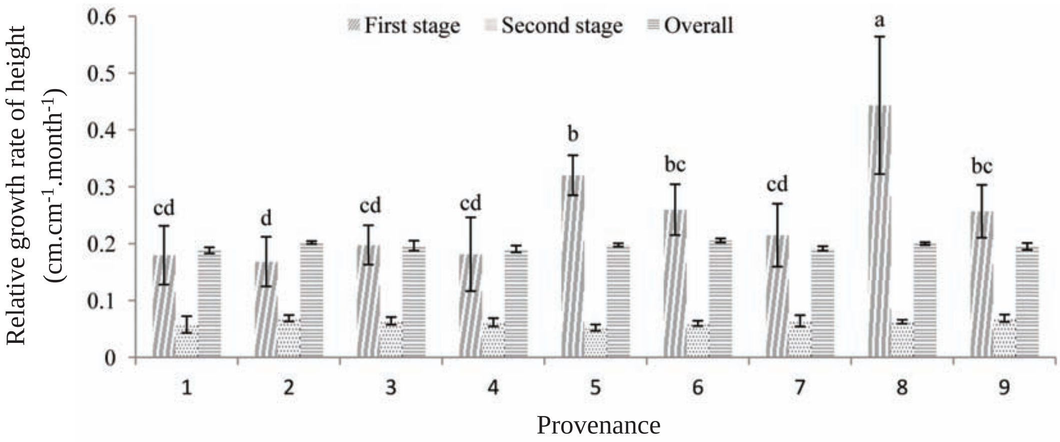


Figure 2 Mean tree height and tree diameter at ground level of nine provenances of *S. siamea* after 2, 6 and 36 months in the field. Bars with the same letter (s) are not significantly different ($P < 0.05$). Vertical lines indicate ± SE.

(Ratchaburi-seed lot 2002) provenance had the lowest value compared to the other provenances. In contrast, the highest value for the relative growth rate of height was found in the Potaram (Ratchaburi-seed lot 2002) provenance and the lowest was found in the Muang (Tak) provenance. The relative growth rate of height in the first stage ranged from 0.17 to 0.44 $cm.cm^{-1}.month^{-1}$ (Figure 3). In the second stage and the overall stage, there were no significant differences in any of the growth traits (Table 2). The relative growth rate of diameter at ground level varied between 0.04 and 0.05 and between 0.05 and 0.07 $cm.cm^{-1}.month^{-1}$ for the second and overall stages, respectively. The relative growth rate of tree height varied between 0.05 and 0.07 and between 0.19 and 0.21 $cm.cm^{-1}.month^{-1}$ for the second and overall stages, respectively. The heritability of relative growth rates was quite low. Only some traits, including height in the first stage and the overall stage, as well as diameter at ground level of the overall stage were higher than 50%.



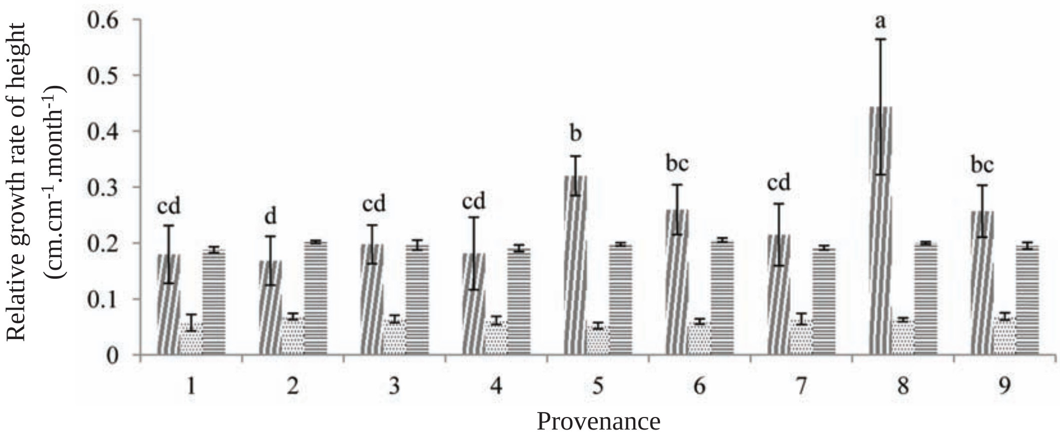


Figure 3 Mean relative growth rate of diameter at ground level and height of nine provenances of *S. siamea* in the first stage (2-6 months), second stage (6-36 months) and overall (2-36 months). Bars with the same letter (s) and no letter are not significantly different ($P < 0.05$). Vertical lines indicate ± SE.

DISCUSSION

The wide natural distribution of *S. siamea* encompasses a large range of environments. Variation among the populations in the provenance trials might be attributed to genetic differences caused by the adaptation of different populations to the different environments associated with their local sites. In the present study, highly significant differences in seed morphometric traits were observed among provenances (Table 2). Most of the total variation observed in these traits could be attributed to provenance variation, with the exception of seed width for which the provenance and environment coefficients were equal (Table 3). This indicated that seed width was also affected by other factors. As reported by Fenner (1985), variability in seed size (width, length and thickness) was probably a consequence of a compromise between the requirements for dispersal (which would favor small seeds) and the requirements for seedling establishment (which would favor large seeds). Based on the current results, it can be suggested that variation in seed morphometric traits could also be the result of adaptation to the diverse environmental conditions over the large natural distribution of this species including altitude (5–400 m), rainfall (1,086–2,626 mm), temperature (27.2–28.5 ºC) and fertility (soil series) as shown in Table 1. Genetic control of seed morphometric traits has been indicated for several tree species, including *Calophyllum inophyllum* (Hathurusingha *et al.*, 2011), *Cordia africana* (Loha *et al.*, 2006), *Gliricidia sepium* (Salazar, 1986), *Jatropha curcas* (Rao *et al.*, 2008) and *Juniperus procera* (Mamo *et al.*, 2006). There was a strong inter-trait correlation, especially for seed length and seed weight, as well as for seed width and seed thickness (Table 4). Correlated quantitative traits are of a major interest in an improvement program, as the improvement program of one trait may cause simultaneous changes in the other trait (Omokhafe and Alika, 2004; Loha *et al.*, 2006).

The provenances also displayed highly significant differences in tree height after 2, 6 and 36 months of growth in the field (Table 2, Figure 2). Most of the total variation (as much as 85% as shown in Table 3) was due to the provenance effect. This indicated that there is adequate genetic variability for tree height growth in the present material. The relatively high and consistent genetic variance shown by the high heritability for tree height will enhance the progress of selection, which is a function of heritability (Falconer, 1989). Similar results have been reported for several species (Lawskul, 1991; Loha *et al*., 2006; Maid, 2006; Krisanapant, 2007). Some strong correlation of tree height between ages was observed between age 6 and 36 months. Although there was no significant correlation between age 2 and 36 months, there seemed to be a high correlation (0.61 as shown in Table 4). This indicated that tree height could be employed as a proxy indicator for early selection of provenances for further testing. A similar result has been reported for *C. africana* for which the total height at age 4 months was able to predict the performance at 8 months (Loha *et al*., 2006). From the current study, seed morphometric traits had very poor correlation with tree height in both early and late growth (Table 4). This suggested that seed morphometric traits could not be used as an indicator of tree height.

Highly significant differences in diameter at ground level were found after 3 and 36 months while there was a significant difference after 6 months. Similar results were reported for other tree species (Lawskul, 1991; Krisanapant, 2007). For trees, stem diameter appeared to be more sensitive to environmental effects than height (Loha *et al*., 2006). As shown in the present study, heritability was greater for tree height (53–85%) than diameter at ground level (33–62%). The age-age correlation in diameter at ground level was significant between 2–36 and 6–36 months. This indicated that the diameter growth in the early stages could predict the diameter growth at age 36 months. However, it is risky to use this as the sole indicator since this trait is sensitive to environment. As happened with tree height, seed morphometric traits also had very poor correlation with tree diameter in both early and late growth (Table 4) indicating that seed morphometric traits could not be used as indicators for tree diameter.

The relative growth rate was used in this study due to the differences among seedlings in the initial stage. This was confirmed by the significant differences in both tree height and diameter at ground level after 2 months. The relative growth rates varied significantly only in the first stage (Table 2). Although differences of relative growth rates both in diameter and height of the overall stage were not significant, the highest values seemed to be for the Potaram (Ratchaburi-seed lot 2002) provenance (Figure 3). This could have been due to the growth development in the first stage which influenced the total growth more than the second stage (Figure 3). There was more competition between individuals in the second stage thus, the relative growth rate was reduced from the first stage so that there was no significant difference among the provenances. The results suggested that study on variation in the seedling stage of *S. siamea* is important since there was low variation in the relative growth rate after 36 months. The final production will be a consequence of the initial size of seedlings. The heritability of the relative growth rate for the overall stage was about 50% in both height and diameter, suggesting that environmental factors play an important role in growth acceleration. Silvicultural practices, such as weeding and fertilizer application could be applied to increase the growth rate.

The significant provenance variations for growth parameters (Table 2) suggested the possibility of provenance selection for the purpose of genetic improvement. After 36 months, the growth parameters of height and diameter at ground level were selected for ranking. The relative growth rates of height and diameter at ground level in the early stage were also selected because of their significance on total growth as discussed above. The top three most suitable provenances for immediate future plantations in the Lad Krating plantation and areas having similar conditions were Potaram (Ratchaburi-seed lot 2002), Muang (Kanchanaburi), and Muaklek (Saraburi) (Table 5). This could have been a result of the low soil moisture content in the provenance trials. Although the average rainfall during the study period was high (1,437 mm per year), the trees were planted with 4 × 4 m spacing and the crown development of *S. siamea* in the first three years did not fully cover the area. Consequently, there were many open spaces that allowed soil evaporation. The provenance from Potaram, Ratchaburi (seedlot 2002), had the lowest rainfall compared to other provenances (Table 1) so this provenance could adapt to the dry area better than the others. For the Muang (Kanchanaburi) provenance, the altitude was 40 m above sea level which was very close to the altitude at Lad Krating plantation (45 m above sea level). A similar result was reported by Mwase *et al.* (2010) for *Uapaca kirkiana* in which the superior performance in the provenance trials was attributed to the similarity of the climatic factors, especially rainfall and elevation between the seed source and the experimental site.

Table 5 Ranking of nine provenances of *S. siamea* based on height and diameter at ground level 36 months after planting and relative growth rate of height and diameter at ground level in the first stage of development.

Provenance code	Height (cm)	Diameter at ground level (cm)	HRGR[1] ($cm.cm^{-1}.month^{-1}$)	DRGR[2] ($cm.cm^{-1}.month^{-1}$)	Composite Ranking
1	336.61 (9)	3.76 (9)	0.18 (7)	0.21 (5)	9
2	464.05 (6)	4.56 (4)	0.17 (9)	0.20 (6)	6
3	478.58 (4)	4.46 (5)	0.20 (6)	0.20 (6)	4
4	448.57 (7)	4.26 (7)	0.18 (7)	0.20 (6)	7
5	510.09 (3)	4.83 (3)	0.32 (2)	0.25 (3)	3
6	512.42 (2)	4.85 (2)	0.26 (3)	0.29 (1)	2
7	474.15 (5)	4.01 (8)	0.21 (5)	0.19 (9)	7
8	521.79 (1)	5.12 (1)	0.44 (1)	0.28 (2)	1
9	389.83 (8)	4.28 (6)	0.26 (3)	0.24 (4)	4

Ranking numbers are presented in parentheses.
[1]HRGR = Height relative growth rate.
[2]DRGR = Diameter at ground level relative growth rate.

CONCLUSION

The study revealed the existence of considerable variation among provenances in seed morphometric traits and growth performance among provenances of *S. siamea*. The variations in all traits were mostly due to the provenance effect and also strongly heritable. No significant correlations between seed traits and growth performance were found indicating that the seed morphometric traits of this species have little importance in predicting tree growth. However, growth performance at different ages had some strong correlations and could be used as an indicator of future growth. The top three superior provenances for planting in the Lad Krating plantation based on the composite ranking result of growth performance at 36 months old and relative growth rate were Potaram (Ratchaburi-seed lot 2002), Muang (Kanchanaburi), and Muaklek (Saraburi). The observed patterns of genetic variation provide valuable information for gene conservation and the tree improvement program for this species.

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