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Genetic Variation of Growth and Disease Resistance Traits in Open-Pollinated Provenance-Progeny Trials of *Falcataria moluccana* Growing on Two Rust-Affected Sites at Age-18 Months

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Abstract

Two Falcataria moluccana (sengon) progeny trials, incorporating 100 different families from 12 provenances growing on two highly gall rust (Uromycladium falcatarium) prone sites were used to estimate genetic parameters and potentially identify rust-resistant material. Analysis was performed to assess provenance- and family-level survival, rust incidence, and growth at the two progeny trials. Height, diameter, survival, and rust incidence was measured at two progeny trials at 18 months-of-age located at Jember and Lumajang, East Java. Rust incidence at the two trial sites was severe, with only 39% overall survival (35% and 43% at Jember and Lumajang, repectively). The analysis revealed significant genetic variation at the provenance level for survival, rust incidence, and growth. No statistically meaningful narrow-sense heritability of these traits was indicated, though this is probably reflective of the inadequate within-family replication and effects associated with uneven stocking resulting from rust-induced mortality. Significant genotype-by environment (provenance-by-site) interaction was also indicated, though the performance of some of the best- and worst-performing provenances was relatively stable, allowing recommendations of suitable provenances for further testing on rust-prone sites.

Keywords: Falcataria moluccana, progeny trial, multilocation, growth, genetic parameter

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Introduction

Falcataria moluccana (Miq.) Barneby & J. W. Grimes, previously *Paraserianthes falcataria* (L.) I. C. Nielsen or *Albizia falcataria* (L.) Fosberg, with the common name *sengon* is a fast-growing species (Wagner *et al*. 1999) that occurs naturally over a broad geographic range encompassing the Moluccas, New Guinea, New Britain, and the Solomon Islands (Wagner *et al*. 1999; Soerianegara & Lemmens 1993). In Indonesia, this species is found naturally in Eastern Indonesia i.e. Papua, South Sulawesi, and Moluccas (Krisnawati *et al*. 2011). In the Hawaian lowlands, Samoa, and Indian Ocean islands it is a widespread exotic and considered an environmental weed (Hughes & Uowolo 2006; Hughes *et al*. 2012; CABI 2014). In Java, however, it is one of the highest priority species for the development of plantation and community forestry. Introduction of the species to Java Island commenced in the 1970s with the planting at Bogor Botanical Garden of a seedlot from Biak Island. From this planting, the species was distributed to all regions of Java Island for land rehabilitation purposes (Rimbawanto 2008). Previous studies found low genetic diversity within the Java population, reflecting the narrow genetic base of the original introduction from Biak (Seido & Widyatmoko 1993; Suharyanto *et al*. 2002).

Sengon is widely grown in Java because it has a relatively short rotation length (4–5 years), is able to grow in a wide range of environmental conditions, and is commercially valuable for carpentry, pulpwood, particle board, and wood energy (Atmosuseno 1994). Moreover, *sengon* products can be promoted as environmentaly friendly wood commodity because plantations are grown mostly on private land as community forest and many final *sengon* products are combined with other wood materials derived from plantations (Nemoto 2002). The substantial annual demand for *sengon* wood and its attractive pricing (500,000 m^3 with a price of IDR650,000 m^{-3} in 2009, Siregar *et al*. 2009) provides incentive to grow the species. However, to meet the high demand from industry, survival and resistance to pest and disease attack must be improved.

The production and use of genetically improved seed to obtain productivity gains in *sengon* plantations is increasing (Na'iem & Winarni 1996). One of the simplest means of securing some genetic improvement is through screening provenances and using the best performers for plantation establishment. Susanto *et al*. (2014) reported the results of a trial established in Cikampek, West Java testing 5 provenances including *sengon* from Biak (Papua), Wamena (Papua), Lombok (West Nusa Tenggara), Candiroto (Java), and Kediri (Java). It showed that provenance lombok performed highest growth at 2 and 4 years old compared to other provenances. Leksono (1998) also reported the variation in the height growth between 19 provenances of *sengon* at a trial established in Muara Teweh, Central Kalimantan. The trials consisted of 19 provenances from Irian Jaya, Molucas, and Java; with Java provenances showed the best growth.

A major issue with the establishment of *sengon* is the susceptibility of seedlings and young *sengon* plantations to gall rust (*Uromycladium falcatarium*). *U. falcatarium* been identified as the cause of gall rust disease in plantations in Philipina, East Timor, Sabah Malaysia, and Java Indonesia (Dongsa *et al*. 2015). Gall rust diseases causing formation of galls on foliage, branches, and stem at all developmental stages of the plant from the nursery stage to mature trees in the field (Rahayu *et al*. 2009). Generally, damage is most severe when shoot and stem are affected, as stems are girdled by the rust and then insects and saprophytes invade and live in the galls. As shoots are partially girdled and become under severe stress, massive defoliation occurs, and eventually, large trees can be killed; moreover, stems will also easily fall down when there is severe wind (Baskorowati *et al*. 2012). Initial outbreak of gall rust was reported in East Timor (Old & Cristovao 2003) and spread out to Bali since 2009 and during 2011 had been found the disease at East and West Java since 2009 (Rahayu 2014). Acording to Rahayu *et al*. (2011), the plantations become less affected by gall rust during first to third years of plantation; in general, the disease intensity and severity of plantations will reduce as the age of plantation increase.

Though this disease can have a major impact on plantations, Charomaeni and Ismail (2008), Rahayu *et al*. (2009), Baskorowati *et al*. (2012), and Setiadi *et al*. (2014) found that the provenance from Wamena (Papua) was relatively more tolerant of gall rust attack than Java seed sources. According to Doran *et al.* (2002) a common strategy to secure additional genetic gain is to establish breeding populations as progeny trials, which, after they have supplied data on variation in growth and estimates of genetic parameters, are converted to seedling seed orchards to supply genetically improved seed for plantation establishment by open pollination. Genetic parameter estimates during tree development of *sengon* outside of Indonesia are described in multiple papers, but this information is limited from trials within Indonesia. This study was based on provenance-progeny trials established in November 2012 comprising 100 families across two sites in East Java i.e. Lumajang and Jember. Both sites are located within the zone of incidence of gall rust. The aim was to quantify genetic variation in growth and disease parameters, to partition the genetic variance to the provenance and family (i.e. additive) levels, and to determine genotype-by-environment interactions, heritability and genetic correlations among traits. This information will contribute directly to future *sengon* breeding strategies in East Java.

Methods

Research sites Center for Forest Biotechnology and Tree Improvement established two progeny trials, one at Lumajang (Kayu Enak, Kandang Tepus Village, Senduro Sub-district, Lumajang District) and the other at Jember (RPH Sumberjati, BKPH Sempolan, KPH Jember), during 2012 in collaboration with Lumajang District Forestry Service and Perum Perhutani KPH Jember, East Java. Data were recorded from these two trials when the trees were 18 months-of-age. The descriptions of the sites are presented in Table 1. Soil analyses were also undertaken for complementary data and carried out in the laboratory of

Table 1 Descriptions of sengon progeny trial sites in Jember and Lumajang, East Java

	Progeny trial Jember	Progeny trial Lumajang
Topography and surrounds	Sloping topography but not steep, located in the middle of a pine stand	Moderately hilly and steep. Single stand surrounded by settlements to the east and west, open fields in the south and plantations in the north
Slope (Tilt-class slopes are measured using the clinometer and expressed in percent (%) with guidelines. An angle of 45º is classified as slope class of 100%)	1º and 7% thus it is included in B class which is sloping or undulating	7º and 29% included in D class
Altitude	About 600 masl	750 masl
Rainfall	Average of 2,351mm year^{-1}	Average of 4,001mm year^{-1}
Temperature and humidity	The average temperature is 22.63 ºC The average humidity is 65.16%	20.09 ºC 74.86%

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Table 2 Results of soil analysis in the two research sites

Site	pH H_2O	Texture (hydrometer)			C-org. Spectrometry	N-total Kyel dahl	P2O5 Olsen (ppm)	K available Am. Asetat 1N, pH 7.0 (me $100g^{-1}$)
		sand	silt	clay				
		(%)						
Jember	5.28	48.00	41.00	11.00	1.91	0.37	10.00	0.26
Lumajang	6.04	60.67	30.33	9.00	3.24	0.25	4.00	0.25

Table 3 The origin of the seed used in the sengon (*Falcataria moluccana)* progeny trials in Jember and Lumajang, East Java

Provenance	Location	Families	Latitude (South)	Longitude (East)	Altitude (m asl)
Holima	Wamena	1−6, 51−59, 66−75	04º 03’74.5"	138º 52’43.9"	1,669
Hobikosi	Wamena	7−18	04º 10’45.3"	139º 10’654"	1,700
Kurulu	Wamena	19−24, 60−65	03º 13’81.7"	138º 30’83.2"	1,730
Antimoi	Serui	25−28	01^0 52’16 .9"	$136^0$53’ 46.6"	110
Angkaisera	Serui	29−30	01^0 49’ 37. 4”	136^0 17’ 42. 3”	227
Mimiki	Nabire	31−36, 43−48	03º 10’04.5"	135º 39’07.3"	22
Kimi	Nabire	37−42	03º 09’13.3"	135º 41’52.6"	25
Subsay	Manokwari	49	00º 58'07.2"	133º 53'119"	1,720
Masni	Manokwari	50	00º 44'08.5"	133º 47'12.7"	1,695
Solomon	Solomon	76−100	na	na	na

Notes: na = data is not available (seed is the result of exploration in 1995)

Indonesian Agency for Agricultural Research and Development in Yogyakarta. Result of soil analyses is presented in Table 2.

Research methods The progeny trials used a similar experimental design at each site, namely a resolvable randomised incomplete block design, i.e. the trail was layed out in complete blocks but planting rows and columns formed additional incomplete blocking structures. The progeny trial of *sengon* at Jember consist of 100 seedlots (individual families), four-tree line plots and six block replicates. Meanwhile Lumajang included 97 seedlots (families) in four-tree line plots and seven block replicates. Height and diameter were recorded for all surviving individual trees at the two sites. Height referred to the total tree height, measured to the nearest 0.1m. Diameter (dbh) was defined as the stem diameter taken at 1.3 m from ground level and was measured to the nearest 0.1 cm. Rust incidence was scored on a scale of 0−1, with 0 corresponding to no visual symptoms of rust, values of 0−1 relating to progressively more-serious rust effects generally galls appears on canopy, and 1 relating to a rust-induced death of the tree. The distribution of families across provenances included in the progeny trials is given in Table 3.

Data analysis Trait data from the measurement at 18 months were analysed using a mixed model solved by REML (restricted maximum likelihood) implemented in Genstat 17 (VSN International, UK). The model included within-site spatial effects (complete block-replicates, plots, rows, and columns) and the main effects of genotypes and environments and their interaction where:

$$Y_{ijklmno} = \mu + S_i + B_j(_i) + Row_{k(i)} + Col_{l(i)} + Plot_{m(i)} + P_n + F_{0(n)} + (P_n * S_i) + (F_{o(n)} * S_i) + \varepsilon_{ijklmno} \quad [1]$$

Note: $Y_{ijklmno}$ = observation on i^{th} location, j^{th} replicate in i^{th} location, k^{th} row in i^{th} site, l^{th} column in j^{th} replicate, m^{th} provenance, n^{th} family in m^{th} provenance, μ = general average, L_i = the fixed effect of i^{th} site, $B_{j(i)}$ = the fixed effect of j^{th} replicate at the i^{th} site, $Row_{k(j)}$ = the random effect of k^{th} row at the i^{th} site, $Col_{l(j)}$ = the random effect of l^{th} column at the i^{th} site, $Plot_{m(i)}$ = the random effect of the m^{th} plot at the i^{th} site, P_n = the random effect of n^{th} provenance, $F_{o(n)}$ = the random effect of o^{th} family in n^{th} provenance, $F_{o(n)}$. S_i = the random effect of interaction between o^{th} family in n^{th} provenance with i^{th} site, $\varepsilon_{ijklmno}$ = random error in $ijklmno^{th}$ observation

Survival was assessed as plot-mean survival. This was analysed using the model described by Equation *[1]* excluding the plot term.

The partitioning of genetic effects and site-by-genotype effects was carried out as follows:

1 Proportion of additive variance to total genetic variance
The additive genetic variance component is given by $F_{o(n)}$ as described in model 1. For comparative purposes the overall genetic variance was estimated by dropping the provenance term (P*n*) from model 1.
2 Proportion of genetic and genotype-by-site variance

The additive and additive-by-site components are given by Model 1 ($F_{o(n)}$ and $F_{o(n)}.S_i$ respectively.

Results and Discussion

Survival Overall survival across the two trial sites was low, 43% at Lumajang and 35% at Jember. The predominant cause of the mortality was gall rust. Though there was no additive variance for this trait (i.e. a zero family-within-provenance variance component), there was a significant difference among the provenances as gauged by the size of the variance component relative to the overall variance and its standard error (Table 5). The range of phenotypic survival among provenances, averaged over sites, was 32–52%, the most resilient provenance was solomon (46% overall Table 6, and 32–60% among families). There was a significant family-by-site interaction (Table 5), with considerable re-ranking of families at Lumajang relative to Jember. The range of family survival at Jember was also greater (10–70%) than Lumajang (23–60%).

Though no additive variation in survival was detected in this pair of trials, the significant provenance-level variance implies that selection of better-performing provenances such as solomon and avoidance of the most susceptible provenances such as wamena and antimoi on rust-prone sites should result in increased survival and plantation productivity. However, these trials have amply demonstrated that gall rust resistance is a high priority for these and similar site types, as even the best-surviving provenances would likely achieve unacceptably poor overall stocking.

Rust incidence The overall effects of gall rust attack at the two trial sites was were very serious, with the majority of the deaths noted above ascribed to gall rust. At the time of assessment, trees that hadn't already died varied between being symptom-free and heavily affected by gall rust. While the family main effect was not significant, there was again significant provenance and site-by-family variance in the trait (Table 5).

In this study, provenance from Antimoi, Wamena, and Hubikosi shows prone to rust resistance compared to other provences. However, previous study by Baskorowati *et al.* 2012 found at 3 years old of gall rust disease resistance trial at Kediri East Java that seed source from Wamena indicated the low index of disease incidence and severity compared to seed

Table 4 The individual (h^2i) and family (h^2f) heritabilities for height and diameter of sengon at various ages in progeny trials at several sites

Location	Age	h^2i		h^2f		Reference
		Height	dbh		dbh	
Cikampek (West Java)	4 months	0.16	0.10			Hadiyan (2009)
Cikampek (West Java)	4 years			0.39	0.32	Susanto *et al.* (2014)
Candiroto (Central Java)	4 months			0.75		Susanto (1997)
Cikabayan (Bogor)	6 months	0.14	0.05	0.31	0.14	Mukmin (2004)
Bondowoso (East Java)	6 months	0.07	0.11			Setiadi *et al.* (2014)
Bondowoso (East Java)	12 months	0.08	0.27			Setiadi *et al.* (2014)
Kediri (East Java)	8 months		0.16		0.42	Ismail & Hadiyan (2008)
Kediri (East Java)	24 months		0.02			Baskorowati *et al.* (2012)
Candiroto (Central Java)	3 years			0.78	0.68	Susanto (1999)
Arid (India)	3 years	0.24	0.20			Toky (1995)

Table 5 Variance components and F probability statistics for across-sites analyses of survival, disease, and growth traits at 18 months-of-age

	Survival	se	Disease	se	Diameter	se	Height	se
Variance component (Random effects)								
Provenance	0.00262	0.00165	25	18	0.341	0.178	1,843	984
Family	~0	0.0011	~0	2.16	~0	0.059	~0	331
Family-by-site	0.0039	0.00174	104	32	0.325	0.104	2,439	597
Residual	0.0532	0.00227	1833	42	2.927	0.104	11,171	400
F probability (Fixed effect)								
site	<0.001		<0.001		0.003		0.91	

Table 6 Across-sites means and average standard errors of difference for survival, disease, and growth traits at 18 months-of-age

Provenance	Survival	Disease and death	Diameter	Height
Angkaisera	38%	54	5.8	533
Antimoi	34%	60	5.2	481.9
Hubikosi	35%	57	4.7	433.3
Kimi	41%	49	4.9	446
Kuluru	36%	55	4.6	418.2
Masni	38%	55	5.4	503.5
Mimiki	43%	47	5.0	456.7
Solomon	46%	47	6.3	517.8
Subsay	44%	33	5.0	474.4
Wamena	34%	57	4.5	408.5
Av. SED	*0.03879*	*6.524*	*0.3168*	*23.06*

source from Candiroto (Centre of Java), Kediri (East Java), and Lombok (West Nusa Tenggara). Another study based on artificial inoculation on *F. moluccana* seedlings were also revealed that Wamena seedlings to be the best seed source in relation to gall rust resistance (Rahayu *et al*. 2009). The variation of results might happen in rust disease study. Since the value of the resistance achieved can be influenced by many factors, such as age of the host, nutrient status, water capacity, potential of inoculum, weather conditions of the season when the disease develops, latitude, and other environmental conditions of the experimental sites, and also subjective bias of assessing by personal (Martinsson 1986). In this trials, provenance originated from different altitude hence the respond to the disease vary between provenance.

Variation of height and diameter growth The average growth in height and dbh at Jember was superior to that at Lumajang at age-18-months. Growth differences were possibly caused by the differences in environmental factors. For example, the results of the soil analysis (Table 2) showed that the site at Jember had higher macro-nutrient content than the site at Lumajang with higher levels of nitrogen, phosphorus, and potassium. The content of these three elements in the soil will affect tree growth rates. It should be noted that the stocking is uneven and low at both of the sites, and this is likely to present as a source of residual (i.e. unexplained) variance in these trials. Precise estimation of growth trait parameters is very challenging under the circumstances of heavy mortality, and is an ongoing issue for making simultaneous selection for both disease resistance and growth on these sites. It should be noted that though we have not identified a significant additive variance component for the growth traits, other authors have been able to do so in this species, and more generally in forest trees (Cornelius 1994). This is again likely explained by the poor survival and loss of analytical precision associated with low statistical replication.

The summary of environmental factors at the two sites (Table 1) shows differences in topography, slope, rainfall, average temperature, humidity, and altitude that can be expected to influence growth. Lumajang had steeper slopes and much higher rainfall (4,001 mm year^{-1} c.f. 2351 mm) than Jember which will affect soil fertility due to soil erosion and runoff. The higher rainfall will also influence humidity. The site at Jember had a lower humidity than at Lumajang (65.16% in Jember and 74.86% in Lumajang). Data on the species indicates that *sengon* prefers a humidity of around 65% rather than 75%.

Sengon trees growing in the community forests are able to grow to a height of 45 m with a diameter of 100 cm at the age of 25 years. It means the annual average growth of sengon is approximately 2m with an increase in dbh of 4 cm (Alrasyid 1973). Based on this study at Jember and Lumajang, the height and diameter of the trees in progeny trials are greater than the data presented by Alrasyid (1973). The results of variance analysis show that all sources of variation (location, repetition in location, row in repetition, column in repetition, provenance, family in provenance, and interaction between families with location) have a significant influence on tree height and stem diameter.

High diversity at the family level within provenance is advantageous in the selection process. Family ranks in Jember differ from family ranks in Lumajang. The interaction between family and location indicates that the performance of the families tested in this study is determined by location. This will affect the strategy of selecting superior performing families across sites in the progeny trial of *sengon* in both sites.

Variation in growth at the trial location, provenance and family levels is typical in this species. For example, Susanto *et al*. (2014) found high diversity in height and stem diameter growth at the provenance and family level at age of 2 and 4 years in progeny trials at Cikampek West Java attributed to environmental factors. Other examples reporting variations of height and diameter growth of *sengon* in progeny trials include: at Cikampek, for ages six and 12 months (Hadiyan 2006); ages four and 36 months at Candiroto (Susanto 1999), age eight months at Kediri (Ismail & Hadiyan 2008), as well as the age of six and 12 months in Bondowoso (Setiadi *et al*. 2014). Variation in other traits such as log properties, basic density, and fiber length were reported in 13-year-old *sengon*, indicating that wood quality of *sengon* might also be improved through selection and breeding (Ishiguri *et al*. 2008).

Conclusion

The growth (of height and diameter) at 18 months of *sengon* in progeny trials on two sites varies significantly across locations, between provenances, and between families within provenances. There was also significant family by site interaction for both traits. Estimations of individual heritability for both height and diameter were categorised as moderate with reasonable levels of additive genetic variation and there was a strong and positive genetic correlation between these two traits. Economic gains in growth traits can be expected from a recurrent selection and breeding program given the genetic parameters indicted in this study. The best option for future breeding strategy might be by separating the breeding population for each site and culling out highly susceptible individuals and retaining resistant individuals, for providing seed with good rust resistance.

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