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Impact of within family variation on growth superiority of improved seeds of *Eucalyptus pellita* observed in genetic gain trial

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Abstract. Progenies from two seedling seed orchards (SSO) consisting of the same families could perform different growths. Concerning this fact, improved seeds of *Eucalyptus pellita* collected from two SSOs based primarily on the same families and provenances were tested together in a genetic gain trial. The study aims to observe the impact of within family seed trees in two SSOs on growth superiority of the improved seeds. The trial was established in Wonogiri, Central Java and laid out in randomized complete block design with three seed sources: SSO-A, SSO-B and one seed stand (as control), 100 trees/plot, 4 replications and 4x1.5m spacing. Measurements were conducted at seven periodical times (16 months up to 66 months of ages). Improved seeds from the two SSOs displayed better growths than that from seed stand at all measurements. The growth superiority of SSO over the control varied among the two SSO. SSO-A showed consistently higher superiority relatively than SSO-B, on average of 110%, 236%, 122% and 165% in height, dbh, stem volume, and stand volume, respectively. The results demonstrated the importance of within family variation of *E. pellita* in establishing seed orchard for seed production and further breeding.

1. Introduction

Eucalyptus pellita F. Muell. is one of the main species for Industrial Plantation Forest (HTI) to supply raw materials for pulp and paper industry. Several performance advantages of *E. pellita* trees are fast growth, good form traits and wood properties suited for industries, and easy to clonally propagate [1]. *E. pellita* was recognized to grow well in the tropics and tropical humid areas and it is also relatively resistant to pests and diseases [2] [3] [4] [5] [6].

In relation to increasing plantation productivity of *E. pellita*, intensive tree improvement programs have been carried out to produce genetically improved seeds. Following the breeding strategy, genetically improved stocks have been produced either through seed collected from seedling seed orchards (SSO) or clonal development. The SSOs are then commonly established in some regions to ensure the quantity and sustainability of seed production. Concerning to the realized genetic gain from the improved seeds collected from the SSO, further verification of the productivity in operational scale is necessary. However, there are some issues regarding the discrepancy of genetic gain predicted from the SSO to the gain realized in operational plantation. One of the issues is the impact of within family variation in SSO on the different quality of seed. This is because progenies from two seedling seed orchards (SSO) consisting of the same families could perform different growth.



The Center for Biotechnology and Tree Improvement (CFBTI) under technical cooperation with Japan International Cooperation Agency (JICA) has initiated tree improvement program of *E. pellita* through establishing first-generation SSO in several sites in 1994 and 1995 [7][8][9]. Genetic materials of *E. pellita* from CFBTI collection were distributed to some sites for establishing the progeny trial that was followed by successive selection procedures for conversion into SSO as seed sources. Seeds produced from the SSO were then used for establishing genetic gain trial to verify the realized genetic gain [10]. Realized genetic gain to evaluate the achievement of breeding program could be assessed through genetic gain trial where the improved seeds are compared to unimproved seeds in the plots with the same silvicultural treatment [11] [12].

In this study, growth of *E. pellita* trees derived from improved seed collected from two different SSOs but consisting of the same genetic background of family structures were observed in genetic gain trial. The study aims to identify the impact of within family variation in the two SSO on growth superiority of the improved seeds. The results of study are expected to provide alternative strategy in optimizing the increase of productivity from improved seeds produced in the SSO.

2. Material and method

2.1. Genetic gain trial

The observation was conducted in genetic gain trial of *E. pellita* established in Wonogiri, Central Java in 2006. The genetic gain trial is located at 07° 32'S and 110° 41'E, an altitude of 141 m above sea level with annual rainfall of 1645 mm and climate type C according to Schmidt and Ferguson [13]. The soil type in the trial is Vertisols and the previous vegetation was dominated by *Dalbergia latifolia*.

The improved seed collected from two SSOs consisting the same genetic background of family structures were planted together with unimproved seed as control in the gain trial. Thus, the treatment in the trial consisted of improved seeds collected from two SSOs: Ep 06A (hereinafter referred to as SSO-A) and Ep 06B (hereinafter referred to as SSO-B), and unimproved seed through bulking of seed collected from natural distribution in South and North of Kiriwo, Papua New Guinea (Table 1). The two SSOs were converted from first-generation progeny trial consisting of the same families originated from provenances of Australia, Indonesia and Papua New Guinea. The experimental design of trial was a randomized complete block design (RCBD) with a 4 x 1.5m spacing, three seed sources as treatment, 100 squared-tree plot, and 4 replications.

Table 1. Seed information in the genetic gain trials *E. pellita* in Wonogiri, Central Java

No	Seed source		Location	Provenance	Remarks
1.	Ep 06A	SSO-A	SSO site 1, Perawang, Riau	Australia, Ind, PNG	Single population SSO
2.	Ep 06B	SSO-B	SSO site 1, Perawang, Riau	Australia, Ind, PNG	Single population SSO
3.	Natural stand	C (control)	South of Kiriwo and North of Kiriwo, PNG	South of Kiriwo, North of Kiriwo	Bulking seed

Ep=*Eucalyptus pellita*; SSO=Seedling Seed Orchard; PNG=Papua New Guinea; IND=Indonesia

2.2. Data collection

Field measurements were conducted for survival rates and growth traits involving total tree height and diameter at breast height (dbh) at seven periodical times: 16 months, 22 months, 28 months, 36 months, 48 months, 53 months and 66 months after planting. To get accurate data, measurements were only made on 64 inner trees (8 x 8 trees) in each plot. Stem volume was calculated for each individual trees using formula as follows [18]:

$$v = EXP(-10.8706) \times H^{1.2596} \times D^{1.9316} \dots\dots\dots (1)$$

The stand volume in each plot was calculated by summing the stem volume from living trees per plot, which was then used to determine the productivity of stand volume per hectare (m^3/ha) using the following equation [17]:

$$\text{Stand volume per hectare} = \frac{\sum \text{volume living trees per plot}}{\text{Area per plot in m}^2} \times 1000 \dots\dots\dots (2)$$

2.3. Data analysis

In this purpose of study, the analysis data was made using analysis of variance (ANOVA) to observe the differences among the three seed sources tested. The analysis was calculated using the linear model as follows [14]:

$$Y_{ij} = \mu + B_i + S_j + E_{ij} \dots\dots\dots (3)$$

where:

Y_{ij} = average seed sources i-th and j-th repetition; μ = general population average;

B_i = effect of the i-th repetition; S_j = effect of the j-th seed sources; and E_{ij} = error.

If the results of the analysis show significant differences, an analysis with Duncan's Multiple Range Test (DMRT) was then proceeded to distinguish seed sources based on the average parameters observed.

2.4. Genetic gain

To observe the growth superiority, realized genetic gain of improved seeds from two SSO (SSO-A and SSO-B) over the control (natural stand) was calculated using the following formula [15]:

$$\Delta G = \frac{\bar{x}_{\text{improved}} - \bar{x}_{\text{unimproved}}}{\bar{x}_{\text{unimproved}}} \times 100\% \dots\dots\dots (4)$$

The differences in growth superiority between the two SSOs over the control were then used to observe the impact of within family variation on the improved seed quality produced from the two SSOs.

3. Result and discussion

3.1. Survival rate

In the genetic gain trial, it is necessary to calculate the survival rate which shows the number of survived trees to adapt to the environment of planting. In this study the survival rate was used to determine the adaptability and the level of success in planting the improved seed from the two SSO in Perawang, Riau to different environments of Wonogiri, Central Java. The ability to survive in a new environment as a form of adaptation is a mechanism of individuals in dealing with environmental changes that affect physiological processes in themselves [16].

The survival rates of *E. pellita* in genetic gain trial at seven periodical measurements are presented in Table 2. The average survival rate of *E. pellita* varied among the three seed sources. The two SSOs showed consistently higher survival rate over the control along all measurements. At the final age of observation (66 months) the survival rate was 75% for SSO-A, followed by SSO-B at around 67%, and control at around 61%. It indicated that improved seed of *E. pellita* collected from SSO of different sites could perform better adaptation than unimproved seed in the new environment of planting. This result also indicated that the two SSOs consisting the same families structure produced improved seed with different qualities for site adaptation. Nirsatmanto *et al.* [17] reported that high survival rate provides an advantage in estimating the effect of seed sources on increasing stand productivity.

Table 2. Average survival rates of *E. pellita* in genetic gain trial plot in Wonogiri, Central Java

No	SS	16 months		22 months		28 months		36 months		48 months		53 months		66 months	
		N	SR	N	SR	N	SR	N	SR	N	SR	N	SR	N	SR
1	SSO-A	58	91,67	58	91,15	58	91,67	57	90,10	54	84,38	51	79,69	48	75,00
2	SSO-B	53	83,33	54	84,90	53	83,33	51	80,21	48	75,00	45	70,83	42	66,67
3	C	51	79,69	52	81,77	50	78,65	50	78,13	45	70,83	44	69,27	39	60,94

SS=seed sources; N=average number of plants per plot; SR=survival rate (%);C=control

3.2. Growth trend

The growth trend of *E. pellita* in the gain trial across the six periodical measurements are presented in Table 3. Although the analysis of variance showed an insignificant difference in all growth traits, the highest growth traits were found in SSO-A, followed gradually by SSO-B and control.

Table 3. Growth of *E. pellita* in genetic gain trial in Wonogiri, Central Java

No	Ages (month)	Seed Sources								
		SSO-A			SSO-B			C		
		h	dbh	vol	h	Dbh	vol	h	dbh	vol
1	16	3,24 (14,2) ^a	2,82 (9,6) ^a	0,91 (36,9) ^a	3,10 (9,2) ^a	2,64 (3,4) ^a	0,80 (21,6) ^a	2,83 ^a	2,55 ^a	0,64 ^a
2	22	4,10 (13,3) ^a	4,04 (15,5) ^a	2,44 (53,0) ^a	3,81 (5,0) ^a	3,63 (3,0) ^a	1,89 (15,9) ^a	3,61 ^a	3,52 ^a	1,57 ^a
3	28	7,63 (21,0) ^a	6,48 (6,6) ^a	11,84 (48,5) ^a	7,07 (11,7) ^a	6,24 (2,2) ^a	11,06 (37,4) ^a	6,30 ^a	6,13 ^a	8,08 ^a
4	36	8,26 (13,4) ^a	7,38 (12,5) ^a	16,42 (44,8) ^a	8,00 (9,4) ^a	6,83 (3,7) ^a	14,01 (22,1) ^a	7,27 ^a	6,57 ^a	11,31 ^a
5	48	11,77 (18,6) ^a	10,00 (8,5) ^a	41,75 (38,5) ^a	10,56 (6,6) ^a	9,41 (2,2) ^a	33,65 (12,2) ^a	9,88 ^a	9,21 ^a	29,92 ^a
6	53	13,69 (11,9) ^a	11,26 (9,2) ^a	61,52 (28,3) ^a	12,30 (0,6) ^a	10,80 (4,4) ^a	50,19 (4,3) ^a	12,23 ^a	10,34 ^a	48,11 ^a
7	66	16,55 (11,0) ^a	13,16 (5,0) ^a	104,13 (18,0) ^a	15,84 (6,8) ^a	12,71 (1,2) ^a	94,37 (7,3) ^a	14,93 ^a	12,56 ^a	88,96 ^a

h=height (m); dbh=diameter at breast height (cm); vol= stem volume ($\times 10^{-3} \text{m}^3$)

Numbers in parentheses are the genetic gain (%); numbers with the same letters are not significantly different

In general, the growth of *E. pellita* in the genetic gain trial in Wonogiri, Central Java was lower when compared to *E. pellita* in the other location. In Pelaihari, Riau height and diameter growth were 2-3 times faster [18]. This is due to differences in soil fertility and climatological conditions between Wonogiri and the other location. The planting site of the genetic gain trial in Wonogiri is categorized as marginal land with relatively low rainfall, which is $< 2000 \text{ mm/year}$ [13].

The improved seed from two SSOs showed consistently better growth than the control, and SSO-A performed better than SSO-B along all measurements. In detail, this result also shows that within family variation in the two SSOs affected not only survival rates, but also the growth traits including height, dbh and stem volume. From the two parameters of survival rates and growth traits, it is clear that SSO-A has better seed source than SSO-B although the two SSOs consist of the same families.

3.3. Stand volume productivity

Genetic improvement is commonly represented as the value of productivity increase in stand volume per unit area. This is because individual stem volume cannot always be used as a good indicator in estimating the potential increase of total volume productivity [17]. The general aim of tree breeding is to increase stand volume at harvest, through indirect selection of stem size at the beginning of rotation [19]. In this study, the results of analysis of variance showed that seed sources did not significantly affect stand volume productivity of *E. pellita* up to the age of 48 months. The significant differences in

stand volume were observed starting from the age of 53 months. It indicated that the genetic impact on stand volume becomes evident only as the trees getting older [17] [20].

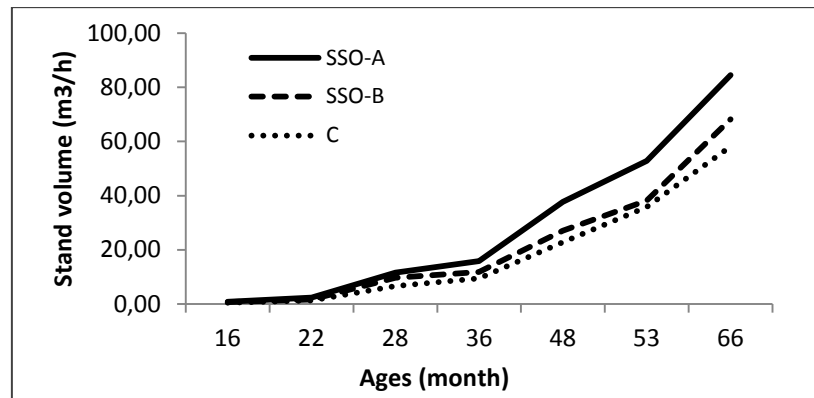


Figure 1. Stand volume productivity

The trend of stand volume among the seed sources observed in genetic gain trial at seven periodical time of measurements are presented in Figure 1. The two SSOs showed better stand volume than the control. As observed in growth traits (Table 3), SSO-A was consistently showing better stand volume than SSO-B, and it was significantly different at 66 months of age. Tree density, closely related to plant survival rate, is an important factor of stand volume. However, the effect of differences in survival rate between the two SSOs (Table 2) provided less impact on stand volume as compared to the effect of genetic.

Table 4. Average stand volume (m³/ha) and realized genetic gain (%) in genetic gain trial in Wonogiri, Central Java

No	SS	16 months		22 months		28 months		36 months		48 months		53 months		66 months	
		Vol	G	Vol	G	Vol	G	Vol	G	Vol	G	Vol	G	Vol	G
1	SSO-A	0,89 ^a	57,53	2,40 ^a	70,53	11,59 ^a	73,14	15,87 ^a	67,02	37,67 ^a	64,98	52,89 ^a	47,62	84,50 ^a	45,29
2	SSO-B	0,72 ^a	27,18	1,69 ^a	20,28	9,71 ^a	44,99	11,92 ^a	25,40	27,14 ^a	18,85	38,22 ^{ab}	6,68	68,24 ^b	17,33
3	C	0,56 ^a		1,41 ^a		6,70 ^a		9,50 ^a		22,84 ^a		35,83 ^b		58,16 ^c	

SS=seed source; C=control; Vol=stand volume; G=realized genetic gain

Values followed by the same letter on the same line are not significantly different at test level 5%

3.4. Realized genetic gain

Realized genetic gain calculated as increase percentage of improved seed from each SSO over the control was used to identify the differences in growth superiority in this study. Along with the age of measurements, SSO-A showed consistently higher genetic gain than SSO-B for all measured traits. The average of genetic gain across the measurements for SSO-A were 14.8% for height, 9.6% for dbh, 38.3% for stem volume, corresponding for the SSO-B were 7.0%, 2.9%, 17.3% for height, dbh, stem volume, respectively (Table 2). A remarkable higher genetic gain was observed in stand volume averaging at around 60.9% for SSO-A and 23.0% for SSO-B (Table 4). In general, following the growth pattern, the magnitude of genetic gain tended to decrease as the ages increase.

The results in this study showed that SSO-A produced higher genetic gain than SSO-B for all growth parameters in all ages. Although the two SSOs consisted of the same genetic background in family structures, the differences in the productivity of seed produced was evident. Observing the realized genetic gain would be important to identify the superiority value among the tested seed sources. This is because assessing the magnitude of potential increase or loss in productivity would

become easy. Imposing the stand volume as one of growth parameters is also important as it is a good parameter to access the economic value of productivity in plantation as final target of improving productivity from tree improvement program.

Genetic variation tends to be higher in populations that have greater growth and more suitable environmental conditions [21] [22]. Superior growth in SSO-A over SSO-B indicates a higher genetic variation in SSO-A, and because the two SSOs consist of the same families, thus additional genetic variation should occur within the family. The increase in growth and genetic parameters of SSO-A would affect the magnitude of genetic gain.

Table 5. Average of realized genetic gain across seven measurement ages for two SSOs in genetic gain trial of *E. pellita* in Wonogiri, Central Java

Seed Source							
SSO-A				SSO-B			
h	dbh	Stem Vol	Stand Vol	h	dbh	Stem Vol	Stand Vol
14,78 (110,17)	9,57 (235,80)	38,31 (122,00)	60,87 (165,12)	7,03	2,85	17,26	22,96

Numbers in parentheses are the increased genetic gain (%) of SSO-A over SSO-B

4. Conclusion

The results of study revealed that the improved seed produced from the two SSOs of *E. pellita* showed better growth and survival rate than unimproved seed in genetic gain trial. The realized genetic improvement clearly varied between the two SSOs, although they consisted of the same genetic background of family structures. This indicated that the impact of within family variation evidently affected the genetic quality of seed produced from the SSO. The results of study imply that information from genetic gain trial is necessary to assess total genetic quality in SSO in order that the quality of seed produced could be optimized to provide maximum productivity. The verified SSO in producing high quality seed could be further multiplied and deployed through establishing a clonal seed orchard to ensure the same genetic quality of seed production.

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