Genetic variation in growth traits in whitewood (*Endospurmum medullosum* LS Smith) in Vanuatu

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ABSTRACT

*Whitewood (*Endospermum medullosum *LS Smith) is a very important timber tree in Vanuatu. It is relatively easy to grow and early maturing. This tree species is contributing to Vanuatu's economy in a big way in terms of employment and revenue but its stands are getting thinner due to continuous logging and lack of replanting. Therefore to establish a breeding programme, genetic variation studies were conducted on a four year-old whitewood family trial established by the Vanuatu Department of Forests under the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG). A total of 97 whitewood families with seed lots collected throughout the Vanuatu were assessed using a row-column design. Characters of economic importance like tree height, diameter at breast height (dbh), wood volume and survival rate were included in this study. Mean height of four year-old trees in families in this trial ranged from 7.8 - 9.2 meters, dbh from 14.8 - 16.8 cm, volume ranged from $0.09m^3$ - $0.12m^3$ and survival rate from 70 - 88%. Ranking of the trees within and between families was based on differential weighting system for different characters. Therefore economic weight of 1 was assigned to height and 2 to dbh. All the trees in the trial were ranked but only 20 best trees in the ranking were discussed in detail with the focus on the five best trees for their utility in hybridization programme to improve whitewood provenances. Estimated volume per hectare from the best families and provenances was $166m^3$ and $100m^3$ respectively. Mean annual increment (MAI) for the fastest growing family and provenances were 29.2 and $25.0m^3$ $ha^{-1}yr^{-1}$ respectively. Analysis of variance showed highly significant differences ($P<0.001$) in height, dbh, volume, survival rate and growth of families at 4 years of age. The nested analysis of variance for families and provenances also indicated highly significant differences ($P<0.001$)) for height, dbh, volume and survival rate.*

1 INTRODUCTION

The native forests of Vanuatu have sometimes been regarded as having limited potential for commercial timber exploitation. Like many tropical hardwood forests, there are hundreds of species, but in Vanuatu only about 12 to 15 species are being exploited commercially. In Vanuatu 900,000 ha or 75 percent of the total land area is under forest vegetation but much of it is too steep for commercial forestry. Nearly all the forests have been disturbed by conversion to pasture or cash crop cultivation (Oliver, 1999). Relying heavily on natural regeneration is risky and not entirely appropriate concept for a small island country like Vanuatu, especially taking into account increasing pressure on the forest resources every year. Hassal and Associates (1998) reported that the considerable effort put into ecological research and attempts at silviculture manipulation of tropical forests, to induce so-called "natural regeneration" have little success.

Whitewood (*Endospermum medullosum* LS Smith) is a very important indigenous timber tree and the most important native timber tree in Vanuatu accounting for 40% to 60% of timber harvest (Vanuatu Department of Forests Conservation Strategy). Its presence in more accessible areas of native forest is down to a residual of few young and a few old poorly formed and senescent trees. The introduction and promotion of small sawmills businesses has accelerated the logging and extraction of whitewood, thereby reducing the stands in Vanuatu (Sam 1997, Thomson 1998). Large-scale agriculture development programs undertaken in the past to clear the forest to plant coconut and cocoa and rearing livestock have also contributed to reduction of whitewood populations (Clark and Thaman 1993).

Whitewood's natural stands (populations) are found on the different islands in Vanuatu (Figure1). Thus, over a long period of time, populations of whitewood in different environments have the potential to allow genetic diversity to evolve in traits of economic importance. Diversity present in natural stands would largely reflect natural selection, genetic drift in small populations, gene flow pattern within and among islands, and selection by humans. Determining genetic diversity in species, and interpreting this diversity in terms of its origin, organization and maintenance, is of fundamental significance for tree breeding work (Young *et al*. 2000).

In order to be sustainable the forest industry in Vanuatu must undertake and/or foster replanting of the major timber species, especially whitewood. Reliance on natural regeneration from the exiting forest for a future crop of whitewood is considered to be a highly risky strategy. Casey (1993) identified a pressing need to select a suitable timber species for plantation activities in Vanuatu and recommended that the phenology, propagation and planting of the native timber tree species should be studied to determine their plantation potential. Whitewood had been identified as the most promising timber species with good timber properties, coupled with moderately rapid growth and high cyclone resistance. The latter is an important character for forestry plantations in Vanuatu. Pests and diseases of this species are limited and do not pose great danger. Field trial observations in 1990's showed that whitewood have a reasonably good growth rate relative to other native

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timber tree species. Therefore the present study was conducted:

1. to obtain information on genetic structure of a base population of source-identified diverse germplasm of *Endospermum medullosum* for future selection.

2. to identify genetically superior trees from an interim local seed source for vegetative propagation, germplasm conversation and tree improvement programme.

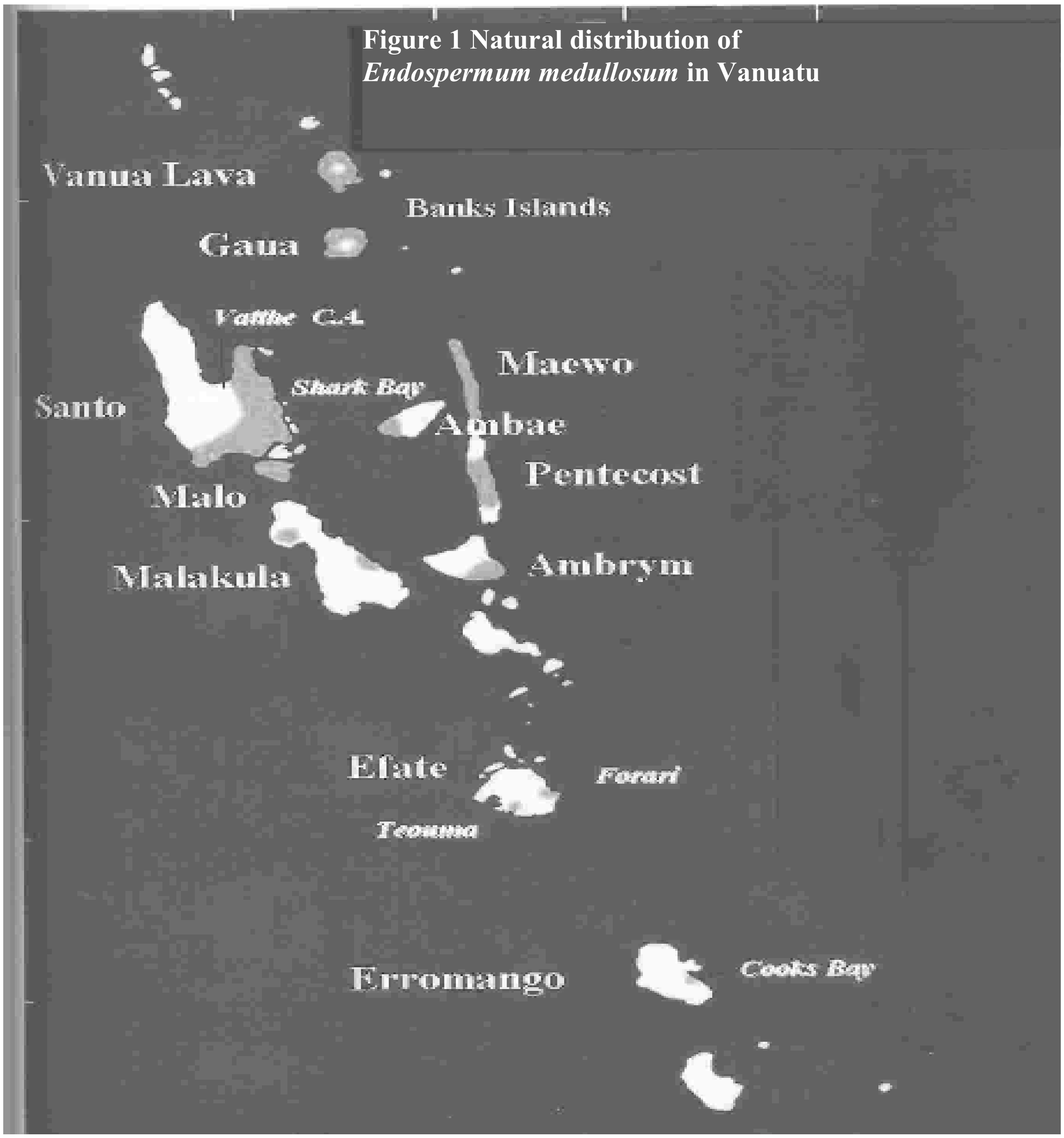

Figure 1 Natural distribution of *Endospermum medullosum* in Vanuatu

Note: Vanuatu islands where whitewood populations are found situated between 15.13 – 17.69°S and 167.01 – 168.54°E.

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

The whitewood family trial was located at the Shark Bay Research Station, East Coast of Santo Island in Vanuatu. The trial was established in December 1998-January 1999. The experimental area was 6.25 hectares including border rows. Experimental design was a Row Column design with 8 replicates each comprising 100 plots (each representing a single seed-lot from a different family) in each replicate. Families were randomly assigned to the 100 plots. With a total of 800 plots, individual plot area was 0.005 hectares. Each replicate consists of 20 rows and 5 columns. The plot size was 1 row of 6 trees with a spacing of 6 meters between rows by 2 meters within rows. Initial stockings were 833 trees per hectare. A total of 100 families of whitewood with seed-lots from randomly selected open pollinated mother trees were collected throughout the islands in Vanuatu established in the trial and assessed. Three seed sources from PNG were excluded from analysis, because they were found to be a different, but very closely related species viz. *Endospermum myrmecophilum*. Thus only 97 families were analysed. Seedlots were assigned into respective provenances that made up 10 groupings. Table 1 shows environmental conditions at the provenance locations and the environmental conditions of the family trial.

Table 1 Environmental conditions in the Provenance and Family trial locations

Island/Seed lot area (Provenance)	Latitude (°S)	Longitude (°E)	Average Annual Rainfall (mm)	Average Annual Temp. (°C)	Soil Type	Fertility Status
East Coast Santo	-15.13	167.09	2500-3000	27-31	Reddish Brown Clay soils	Fertile
Central East Santo	-15.18	167.01	2500-3000	27-31	Reddish Brown Clay soils	Fertile
Forari Efate	-17.69	168.54	2000-2500	26-30	Thick black top soils	Fertile
South Santo	-15. 30	167. 10	2000-2500	27-31	Thick black top soils	Fertile
South east Santo	-15. 30	167. 10	2000-2500	27-31	Thick black top soils	Fertile
Maewo	-15. 01	168. 06	2500-3000	27-31	Volcanic ash soils	Fertile
Central Pentecost	-15. 76	168.187	2500-3000	23-27	Volcanic ash soils	Fertile
Malel	-15. 19	167. 01	2500-3000	27-31	Red clay soils	Fertile

2.2 METHODOLOGY

Data were collected on tree height using a clinometer, tree diameter at breast height (dbh-1.3 m above ground) using a measuring tape. Estimation of individual tree volume (up to diameter of 5 cm) was done using a volume equation derived from a sample of randomly selected 34 trees from the trial. The volume estimate employed the Huber's method (Philip, 1994). Survival percentage and tree forms were recorded by taking into account original planting and tree shape from established trial of SPRIG.

2.2.1 TREE HEIGHT MEASUREMENTS

Tree height was measured using the formula:

Total tree height ht = AB (tan bottom angle 1 + tan top angle 2)

Where ht is height of tree and AB is the distance from the base of the tree to the position of taking the angle readings standing at a distance from where the treetop was clearly visible

2.2.2 TREE DIAMETER AT BREAST HEIGHT (dbh)

To determine the diameter at breast height (dbh) a measuring tape was used and diameters of all trees measured at 1.3m above the ground.

2.2.3 WOOD VOLUME ESTIMATES

To estimate the wood volume the Huber's method was used. Trees were cut at ground level and following measurements were made: base diameter (D1), top diameter (D2), mid diameter (DM) and log length. The log length was from the base (or bottom) of the log to 5 cm below the top of the tree.

Huber's formula (Philip, 1994): $V = \pi L d^2/4$

Thus $d = (d1 + d2)/2$ and L is the length of log in meters. Where d is the average diameter of both ends of the log measured in meters.

This is a direct method involving felling a sample of 34 trees with boles, cutting into workable sizes and measuring (Carron, 1968). Lengths of boles were measured, cross sectional areas of logs were estimated and volume obtained by using Huber's formula. Basic volume calculation involves multiplying the length of log by the average cross sectional area. With the calibrated tapes, diameter of the log was read straight from the tape. Measurements were in centimetres and converted to meters in the calculation.

2.2.4 SURVIVAL PERCENTAGE

Survival percentage was calculated by direct observation and counting in trial plots. Total number of trees survived in families from provenances divided by total number of trees planted families from provenances multiplied by 100. Thus the simple formula:

$$\text{Survival percentage} = \frac{\text{Total survived}}{\text{Total planted}} \times 100$$

REGRESSION EQUATION

The relationship among different variables may be expressed in terms of mathematical equations (Quinn and Keough, 2002). To calculate the volume of the trees for the analysis samples of 34 trees selected randomly were measured and a regression equation was obtained.

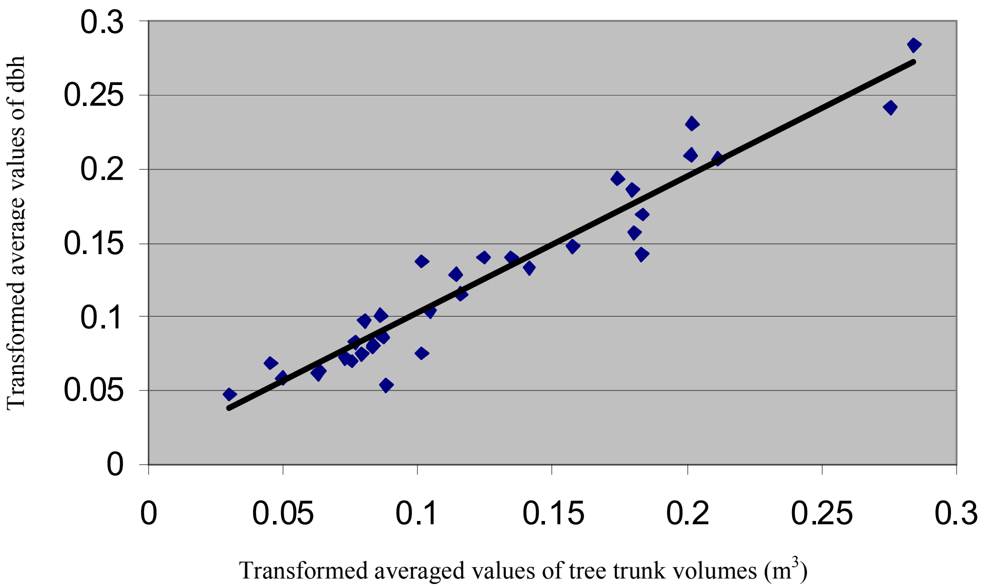

Figure 2 Regression analysis of the volume to get a regression equation

Accordingly a better fit to the volume data was given by the equation:

Volume = 0.0898 - (0.01851dbh) + (0.001018dbh^2) + (0.00491height)

In this case the R^2 of variation was 0.92. The above equation was then applied to the complete data set to estimate the volume of the trees used in this study.

2.2.5 DATA ENTERING AND SORTING

Data collected were entered into the computer and sorted for analysis. To facilitate the use of DataPlus and GenStat for data analysis, data sheets were prepared with indexing information including replicate number, row, column, plot number, seedlot, tree number and values from assessment (i.e. height, dbh and volume). Content of data sheets were entered into the computer on Excel spreadsheets and once data file constructed, the data were checked in detail against original data. During data checking and review there was a reduction from 100 to 97 seedlots, the 3 PNG seedlots were removed because these were damaged by cyclone and later identified as a different species. For the study the experimental layout consist of 97 families, 8 replicates of 6 trees per plot.

2.2.6 DATA ANALYSIS
ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance for all the variables was carried out using the GenStat program (gen.txt). The GenStat program calculated the ANOVA for height, dbh, volume and survival rate. Treatments (plants in plots) and families were considered as fixed sources of variation, while replicates were considered as random source of variation. Thus treatments, families and replicates were used as source of variation. GenStat was also used to undertake a nested ANOVA for the family and provenance using random model.

Residual Maximum Likelihood (REML), (reml.gen) programme was used to carry out a REML analysis for the mixed-effects model where the incomplete blocking factors (due to death of certain families in some replicates) were specified as random so that recovery of inter-block treatment information was possible. The REML was used to estimate variance components. In a nested treatment structure (e.g. families within provenances) it is usually better to first carry out the REML mixed-model analysis ignoring the nested treatment structure to obtain a set of estimated treatment means (Williams *et al*. 2002).

Fit (fit.gen) programme produces a non-orthogonal analysis of variance for the incomplete blocking structures (i.e. blocks or rows and columns). If one (or more) of these blocking factors were not significant then it usually indicates that the term can be dropped from the model.

Thus this programme was used to reduce the model. In a Fit output, the plot of residuals against fitted values from analysis of variance of a variable (e.g. height of tree) could be observed and where values were high, the data sheet were checked against it (Williams *et al.*1999).

2.2.7 SELECTION PROCEDURE

Data collected needed to be analysed for genetic variation in growth traits to identify best families among various provenances DataPlus provides a facility to rank individual trees in the experiment according to their usefulness for breeding by means of a selection index (Cotterill and Dean, 1990). The different traits in the index were combined for individual and family information for each trait. The indexing takes into account the variance of each economic trait using different economic weights that have been assigned to the various traits.

In the ranking of selected tees, values were assigned for the variables for the GenStat program, including the Weight Coefficient (Cotterill and Dean 1990). The higher the value, the more emphasis was placed on family information rather than individual value in constructing the index, meaning thereby to select families with higher correlation coefficient values which can be used in future breeding programme.

The number selected refers to the number of individuals to be included in the list of ranked individuals. Often it is the best to list all the individuals in the trial (Cotterill and Dean, 1990). In the selection analysis, each variate in the index needed to be specified with three values, viz. discrimination (disc.), variance (var.) and economic weight (econ.).

Discrimination (disc.) was the weight used to construct selection index to reflect the discriminating power of each trait. Wald or F statistics provides option for this information. The variance (var.) associated with each trait was obtained from the residual mean square of the analysis (ANOVA, Fit or REML). The aim was to make variation in different traits comparable by converting variation into units of standard deviation (Cotterill and Dean, 1990). For this study an economic weight of 2 assigned for dbh and 1 for height reflecting the fact that dbh contributes more to volume than height (as volume is related to the square of the diameter, whereas height has a linear relationship to stem volume).

The magnitudes of the genetic variance components were determined by the variation in the material under trial (the set of seedlots to test) with the expression of genetic difference affected by the environment in which they were tested (Falconer and Mackay 1996 and Snedecor and Cochran 1967).

3 RESULTS

3.1 RANKING OF TREES IN THE TRIAL

A ranking of individual trees for their utility for incorporation into a whitewood improvement program was undertaken. All the individual trees in the trial were ranked, with only the best 40 trees listed which would be used in tree improvement programme in Vanuatu (Table 2) and discussion is based on the best 5 trees. The best 20 trees out of 40 ranked originated from the islands of Santo, Efate and Maeow with numbers of trees, 17, 2 and 1 respectively.

The origins of the best 20 ranked trees were from East Coast Santo, Central East Santo and South-East Santo with numbers of trees, 9, 6, and 2 respectively. Other provenances each have one tree; Maewo, Teouma (Efate) and Forari (Efate). The best five trees in the ranking were from families MS2, MS3, MS44 and MS32 mostly from the East Coast and Central East Santo provenance. The best families averaged had very good height ranging from 7.22m to 12.98m and dbh from 26.68cm to 30.48cm.

Table 2 Ranking of whitewood trees at 4 years of age with economic values of 1 for height and 2 for dbh (showing only a sample of the best 40 trees).

Replicate	Row	Column	Tree	Family	Provenance	Height (m)	dbh (cm)	Individual tree index	Rank
5	1	1	1	MS2	East coast Santo	12.98	30.48	34.9	1
2	18	5	1	MS3	East coast Santo	10.82	29.4	33.19	2
2	7	2	3	MS2	East coast Santo	11.35	26.68	30.54	3
2	4	2	2	MS44	CE Santo	12.77	26.03	30.27	4
4	2	2	3	MS32	East coast Santo	7.22	27.21	29.95	5
4	3	2	6	MS2	East coast Santo	10.37	26.21	29.79	6
8	5	1	3	MS47	CE Santo	11.64	25.64	29.55	7
5	9	5	3	JT39	Forari_Efate	10.15	25.99	29.5	8
1	20	4	3	MS32	East coast santo	11.4	25.52	29.36	9
7	8	2	2	MS47	CE Santo	11.82	25.11	29.06	10
5	8	4	5	JT7	Teouma_Efate	8.42	25.74	28.77	11
5	10	5	1	GD8	East coast santo	10.86	24.98	28.66	12

Table 2 continued

Replicate	Row	Column	Tree	Family	Provenance	Height (m)	dbh (cm)	Individual tree index	Rank
8	7	5	6	MS32	East coast Santo	10.88	24.61	28.29	14
2	2	3	2	GD11	East coast Santo	11.87	24.28	28.22	15
8	7	3	1	MS44	CE Santo	9.95	24.7	28.12	16
2	12	3	3	MS53	S& SE Santo	9.71	24.74	28.1	17
3	3	2	3	MT29	Maewo	11.12	24.34	28.07	18
2	4	2	6	MS44	CE Santo	10.27	24.53	28.04	19
2	14	3	5	MS55	S & SE Santo	11.09	24.1	27.82	20
5	20	3	1	MS44	CE Santo	10.68	24.08	27.69	21
6	15	1	4	MS32	East coast Santo	9.91	24.15	27.55	22
4	12	2	3	MT17	Central Pentecost	9.18	24.33	27.53	23
2	16	4	4	MS56	S& SE Santo	10.23	23.89	27.37	24
5	4	1	3	MT6	Central Pentecost	10.51	23.78	27.33	25
3	14	4	4	MS3	East coast Santo	9.44	24.06	27.32	26
3	12	4	4	MS51	S & SE Santo	9.88	23.7	27.08	27
7	12	3	2	MT8	Central Pentecost	10.74	23.45	27.06	28
2	17	4	6	MS5	CE Santo	10.5	23.44	26.98	29
4	11	1	5	MS53	S & SE Santo	10.87	23.33	26.97	30
1	7	4	3	MS17	East coast Santo	9.62	23.61	26.91	31
4	13	1	6	MS55	S & SE Santo	10.75	23.3	26.9	32
4	11	1	3	MS53	S & SE Santo	10.08	23.43	26.85	33
2	7	2	6	MS2	East coast Santo	10.52	23.22	26.76	34
3	9	5	1	GD11	East coast Santo	14.27	22.14	26.68	35
2	4	2	1	MS44	CE Santo	10.87	23.03	26.66	36
1	6	3	5	GD11	East coast Santo	13.74	22.26	26.66	37
5	14	2	6	GD7	East coast Santo	11.8	22.78	26.66	38
8	7	1	4	GD9	East coast Santo	10.11	23.19	26.61	39
5	8	4	2	JT7	Teouma_Efate	10.12	23.14	26.57	40

Table 3 Summary of averaged means in whitewood best families and provenance (*Endospermum medullosum*) and their predicted estimates at 4 years of age.

Source	Height (m)	dbh (cm)	Volume (m^3)	Stock per Hectare (Trees/ha)	Volume per Hectare (m^3/ha)	Stand Basal Area (m^2/tree/ha)	Mean Annual Increment (m^3/ha/yr	Prediction1 0 years (m^3/ha)
Family	10.2	17.8	0.15	833	117	20.5	29.2	292
Provenance	9.2	16.3	0.12	833	100	17.4	25.0	250

Table 3 shows summary of averaged means for economic characters in whitewood. It should be noted that families and average of families from provenances showed variation with regard to almost all characters. Mean annual increment in m^3/tree/ha averaged over all families was 29.2 while provenance (thus families within a provenance) showed an increment of 25m^3/tree/ha. Prediction difference over 10 years time in families and provenances is 42m^3/tree/ha.

Table 4 shows the range of means for height, dbh, volumes and survival percentage of 97 families in 10 provenances.

Table 4 Range of means for height, dbh, volume and survival percent of whitewood families from different provenances at the age of 4 years.

Provenance Group	Families	Range of Means (height)	Range of Means (dbh)	Range of Means (volume)	Range of Percentage (survival)
1. Central Pentacost	MT1, MT3 - MT21	7.7 – 9.0	13.8 – 16.5	0.08 – 0.11	58 – 90
2. Forari, Efate	JT29 – JT39, JT41 - JT42	7.1 – 8.4	13.5 – 16.4	0.07 – 0.12	61 - 89
3. Kole, E. Santo, Shark Bay, E. Santo Sara, E. Santo and Palon, E. Santo	GD2 – 13, MS2, MS3, MS10, MS17, MS32	8.4 – 10.2	14.7 – 17.8	0.09 – 0.14	62 – 86
4. Maewo	MT 23, MT26 – MT34	7.5 – 9.6	13.5 -16.8	0.07 – 0.12	54 - 83
5. Malel, C.E. Santo, Butmas, C.E. Santo	MS1, MS5, MS43 – MS47	8.5 – 9.6	16.0 – 17.8	0.10 – 0.12	62 – 86
6. S.E. Santo, S.E. Santo	MS49 – MS56 MS61, MS62	8.0 – 9.2	15.7 – 17.4	0.10 – 0.14	70 – 86
7. Teouma, Efate	JT1 – JT3, JT6 – JT10	7.7 – 9.3	14.8 – 16.8	0.09 – 0.12	52 – 85
8. Uri-Wiaru, Malekula	JT11, JT13, JT14, JT17, JT19, JT20,JT23, JTBULK, B26	8.2 – 9.0	13.9 – 15.7	0.08 – 0.10	60 – 84
9. W. Ambae	MT35 – MT40	8.2 – 9.4	14.6 – 16.4	0.09 – 0.12	74 – 91
10. IFP Plantations	SBC13	9.2 (Mean only)	16.3 (Mean only)	0.12 (Mean only)	88 (Mean only)

3.2 MEAN HEIGHT

The tallest family was GD11 (Shark Bay, East Santo) with a mean height of 10.2m, followed by MT29 (Maewo) and MS47 (Malel, Central East Santo) both with a mean height of 9.6m. Other taller families / seedlots were SBC13 (IFP Plantation), MS55 (South - East Santo), MT37 (West Ambae) and JT23 (Uri-Wiaru, Malekula) with 9.2m, 9.5m, 9.4m and 9.0m, respectively, indicating faster growing families did originate from different islands in Vanuatu. The shortest families were JT35 (Forari, Efate) 7.1m, and MT33 (Maewo) and JT30 (Forari, Efate) with 7.5m each in height (Table 4).

3.3 MEAN DIAMETER AT BREAST HEIGHT (dbh)

Families MS44 (Malel, Central East Santo) and MS32 (Palon, East Santo) had the highest mean dbh of 17.8cm, followed by families GD11 (Shark Bay, East Santo) and MS2 (Sara, East Santo) with 17.5cm, and family MS55 (South East Santo) with 17.4cm. Other families with high mean dbh were JT1 (Teouma, Efate) and MT29 (Maewo) with 16.8cm, followed by MS1 (Malel, Central East Santo) with 16.7cm (Table 4). Families with lower mean dbh were MT32 (Maewo) and JT35 (Forari) with 13.5cm, and MT3 and MT4, both from Central Pentecost, with 13.8cm. Seven families from Central East Santo were identified to had a small range in the dbh mean, from 16cm to 17.8cm each, when compared to other provenances. Of the seven families, one was from Butmas (MS5) and six from Malel (MS1, MS43, MS44, MS45, MS46 and MS47).

3.4 MEAN WOOD VOLUME

The family with the highest wood volume was MS2 (Sara, East Santo) with 0.15m^3 wood volume per tree followed by MS32 (Palon, East Santo) and GD11 (Shark Bay East Santo), MS55 (South East Santo) with 0.14m^3, and MS3 (Kole East Santo) with 0.13m^3. Other families with greater wood volume production (0.12m^3) were JT42 (Forari, Efate), GD7 and GD8 (Kole, East Santo), GD13 (Shark Bay East Santo), MS10 (Shark Bay, East Santo). These were followed by MS17 (Kole, East Santo), MT29 (Maewo), MS1 (Central East Santo), MS44, MS46 and MS47 (Malel, Central East Santo), MS53 and MS62 (South East Santo), JT1 (Teouma, Efate), MT38 (West Ambae) and SPC13 (from IFP Plantation). The families with the low volume mean of 0.07m^3 were JT35 (Forari, Efate) and MT32 (Maewo) (Table 4).

3.5 MEAN SURVIVAL RATE

Families with highest survival rate (88-91%) were MT39 (West Ambae), MT20 (Central Pentecost), JT41 (Forari, Efate) and SBC13 (IFP Plantation). Other families with higher survival rate (84-86%) were GD3 (Kole, East Santo), MS1 (Malel, Central East Santo), MS52 (South-East Santo), MT16 (Central Pentecost), GD10 (Kole East Santo), JT6 (Teouma, Efate) and JT11 (Uri-Wiaru, Malekula). Seedlots with the lowest survival (<60%) were JT3 (Teouma, Efate), MT30 (Maewo), JT7 (Teouma, Efate) and JTBULK (Uri-Wiaru, Malekula) (Table 4).

ANALYSIS OF VARIANCE OF THE VARIABLES

A simple analysis of variance and nested ANOVA of trees without the source of variation was carried out for the families and provenance of Whitewood at 4 years of age for height, dbh, volume and survival. Analysis of variance has indicated highly significant differences (P <0.001) in height, dbh, volume and survival rate of different Whitewood families at 4 years of age. The nested Analysis of variance for families and provenance also indicated highly significant difference (P<0.001) in height, dbh, volume, and survival rate (Table 5).

Table 5 Simple and nested ANOVA (without the sources of variation) of economic traits in whitewood families and provenances at 4 years of age.

Trait	Provenance Seedlot	Family Seedlot	Residual Mean square	Nested Residual Mean square	Mixed Provenance Seedlot	Mixed Family Seedlot	F - Prob.
Height	0.373	0.515	1.060	0.560	0.197	0.272	<0.001
Survival	7.178	9.907	392.600	354.900	6.489	8.956	<0.001
dbh	0.846	1.167	5.451	2.997	0.465	0.642	<0.001
Volume	0.124	0.170	0.0012	0.0007	0.072	0.099	<0.001

Analysis of variance of the economic traits presented in Table 5 showed highly significant differences (P <0.001) in height, dbh, volume and survival rate (%) of different whitewood families at 4 years of age. In the ANOVA for the provenance seedlots survival had the highest variance of 7.178 followed by dbh, height and volume with σ^2 = 0.846, σ^2 = 0.373 and σ^2 = 0.124, respectively.

The ANOVA for family seedlots showed a similar pattern (Table 5). Variance (σ^2) for survival was the highest (σ^2 = 9.907) followed by dbh, height and volume with σ^2 = 1.167, σ^2 = 0.515 and σ^2 = 0.170 respectively. A similar pattern of variances (σ^2) was observed for the averaged provenance seedlots and averaged family seedlots.

By using the Nested ANOVA, the residual mean square (error component) was reduced and therefore the precision to compare provenance was improved (Williams *et al.* 2002). Replications and family x replication interaction was excluded as source of variation to avoid confounding (Table 6).

Table 6 Nested ANOVA for height, dbh and volume in whitewood families and provenances at 4 years of age

Height					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F prob.**
Provenance	9	101.7653	11.3073	20.188	<0.001
Prov. Family	87	118.2746	1.3595	2.427	<0.001
Residuals (error)	484		0.5601		
SURVIVAL					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F prob.**
Provenance	9	8020.62	891.18	2.511	<0.01
Prov. Family	87	50302.66	578.19	1.629	<0.01
Residuals (error)	491		354.9		
dbh					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F prob.**
Provenance	9	280.0202	31.1134	10.382	<0.001
Prov. Family	87	471.0911	5.4148	1.807	<0.001
Residuals (error)	483		2.997		
Volume					
Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F prob.**
Provenance	9	0.075913	0.0084348	12.503	<0.001
Prov. Family	87	0.127219	0.0014623	2.168	<0.001
Residuals (error)	476		0.0006746		

The nested analysis of variance presented in Table 6 for families and provenance also indicate highly significant difference ($P < 0.001$) in height, dbh, volume, and survival rate between family and provenances. This clearly indicates that there was exploitable variance present in families from almost all provenances.

4 DISCUSSION

4.1 MEAN HEIGHT

Studies of tree species have shown that local seed sources sometimes grow better in their local sites than in geographically different sites (Namkoong 1979, Sedgley and Griffin 1989). However, in these islands of Vanuatu climatic conditions including rain fall, temperature and soil type etc were not very different from each other (Table 1). In this study, family GD11 from Shark Bay (East Santo), where the trial was located, had the superior mean height of 10.2m followed by family MT 29 from Maewo and MS47 from Malel, (Central East Santo) both with 9.6m. In fact most of the superior trees were progeny of mother trees located in East Santo (Table 4). Better performance by local provenance sources may be expected given their longer adaptation to local conditions. Other reasons for better performance of height by different families under investigation may be due to gene flow (Lanner 1966, Sarvas 1967, Namkoong 1979) which was possible over long-distance by wind blown pollen because this species is wind pollinated. Studies on pollen dispersal for other tree species showed that air turbulence could effectively carry pollen for many miles (Boyer 1966). Corrigan *et al.* (1999) noted that fruit bats and pigeons might be responsible for the fruit/seed dispersal of whitewood within and among group of islands.

Better height performance by family MT29 from Maewo indicates genetic diversity or phenotypic plasticity present for growth (height) because environmental conditions were almost similar in Maewo and Shark bay where trial was conducted. On the other hand Wright (1978) noted that an inherently slow growing tree grow rapidly in fertile soils and favourable environmental conditions. Also offspring of such plants will grow faster given similar environmental conditions.

Other families with mean height within the extreme ranges with good potential were the JT23, SBC13 IFP, MT37 and MS55 with 9.0m, 9.2m, 9.4m, and 9.5m respectively. The mean height from these different families may constitute basis for a diverse genetic material for more rapid growth in height which is also valuable for tree improvement in breeding programs.

4.2 MEAN dbh

Family MS44 from Malel (Central East Santo) and family MS32 from Palon (East Santo) had the superior mean dbh of 17.8cm followed by family GD11 from Shark Bay (East Santo) and family MS2 from Sara (East Santo) with 17.5cm and family MS55 from South East Santo with 17.4cm. Superior growth performances in dbh were in the most families from East Santo and only one family from South-East Santo. A difference in dbh growth by only a few centimetres may appear small but is considerable in wood volume and timber utilization terms particularly when considering the tree improvement for this trait.

Families with low dbh mean were MT32 from Maewo and JT35 from Forari with a dbh of 13.5cm followed by MT3 and MT4 from Central Pentecost with 13.8cm each. Most of these were from different islands and poor dbh growth may be due to lack of adaptation to the new environment such as soil type or lack of resistance to cyclone damage and climate or low genetic diversity for this particular trait. The whitewood stands in Forari, Efate had been subjected to a number of disturbances in the recent past due to logging activities which may have resulted in the removal of superior trees (dysgenic selection) and / or leaving a population of whitewood stand with a narrow range of genetic diversity. Williams *et al.* (2002) noted that natural patterns of genetic variation in many species have become blurred through human interference. Provenance variation as a response to environmental variation appeared to had been heavily overlain by the effects of centuries of human activity, including possible movement of seed between provenances and in some cases, the local selection of desirable phenotypes.

4.3 MEAN WOOD VOLUME

Wood volume is a dependent trait related to characters like height, dbh, and tree-form. Higher values for height and dbh will result in a higher volume whereas lower values for height and/or dbh will give rise to lower volume (Lantican and Baldwin, 1994). In the present study the families with superior volume means were MS2 from Sara (East Santo) with $0.15m^3$ followed by MS32 Palon (East Santo) and GD11 Shark Bay (East Santo) with $0.14m^3$ each and family MS3 from Kole (East Santo) with $0.13m^3$.

The families with superior volume were mostly from East Coast Santo, Central East Santo and South Santo. Family MS2 from Sara (East Santo) and MS32 from Palon (East Santo) were from areas with good (phenotypic) whitewood stand where logging was in progress. Other families such as MS55 from South East Santo are from mother trees located in a few remaining scattered stands with well formed trees in gardens or in coconut plantations and had genetic potential for more rapid diameter growth.

The large difference was recorded between average ($0.12m^3$) and the superior mean volume ($0.15m^3$). This is a vital information, which can be used to develop a base population with diverse germplasm for *E. medullosum* using the best families in the different islands for tree improvement and/or *ex situ* conservation. From an economic point of view volume is the most important trait.

4.4 MEAN SURVIVAL PERCENTAGE

Families with superior survival means were MT39 from West Ambae, MT20 from Central Pentecost, JT41 from Forari, (Efate) and SBC13 from IFP Plantation provenance with 91 %, 90 %, 89 %, and 88 % survival rate respectively (Table 4).

Some of the families from the different islands had a higher survival percentage than families from Santo. although their mean height, c
than the families from Santo. Genetic analysis of survival showed similar results in *Eucalyptus globules* as reported

by Chambers *et al.* (1996). Survival is quite important for tree breeding and beneficial to farmers especially in Vanuatu where there are, on an average, 2-3 cyclones every year (Barrance 1986 a, b). Only one family from Santo; SBC13 from the IFP plantation had a survival rate of 88 %, which is 3 % less than family MT39 from West Ambae. It is possible that seeds of family SBC13 were collected from selected trees (South-East Santo) in plantations and established at the IFP plantations. Such seed sources may perform better than the local provenances because inbreeding has been eliminated and individual trees were well adapted to the exotic environment (William *et al*. 2002).

Simple and nested ANOVAs (Table 5 and 6) showed that there are highly significant differences in families from the same provenance and among families from different provenances. This indicates the presence of exploitable variations in height, dbh, volume and survival percentage. Selected trees can be used in further breeding programmes to develop faster growing whitewood tree varieties (Eldridge *et al*., 1993). Predicted gain per year and over ten year period also indicates that best trees from best families can be used for tree improvement programmes in Vanuatu.

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