Assessment of *E. globoidea* wood properties at Atkinson

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

This report refers to the SWP work plan WP060 'Wood quality assessment of *E. globoidea*'.

While growth characteristics of *E. globoidea* compare favourably to other eucalypt species in the NZDFI programme, its wood properties in particular natural durability (class 2), ease of drying and to some degree stiffness are good rather than exceptional. Therefore, wood properties should be considered in a tree breeding programme if ground durable solid wood products are envisioned as the future market.

144 families of *E. globoidea* were assessed at age 8 years old for heartwood quantity, extractive content (i.e. natural durability), drying defects (i.e. collapse) and stiffness (i.e. acoustic velocity). All traits were heritable and having a degree of variation enabling improvements through a breeding programme. The high heritability (h^2 = 1.16) and large coefficient of genetic variation (CGV = 52%) of heartwood extractive content encourages selection for heartwood quality, as *E. globoidea* is in contrast to the other NZDFI species rated not class 1 but class 2 ground durable.

An unfavourable genetic correlation (-0.44; CI_{95} -0.62, -0.25) was found between heartwood quantity and extractive content, indicating the need for compromise between growth and natural durability. A favourable less strong genetic correlation (-0.27; CI_{95} -0.51, -0.02) was found between heartwood collapse and extractive content, indicating improvement in both if one is selected for. The other key traits were not correlated and therefore need to be selected for independently.

That data has been made available to the NZDFI partners to allow them to select superior genetics for commercial plant production.

Only 1 of 3 sites planted at the same time with the same genetics was assessed and environmental effects remain to be quantified.

INTRODUCTION

Eucalyptus globoidea is one of the 3 key species included in the NZDFI breeding programme (http://nzdfi.org.nz/research-trials/research-priorities/genetics-and-tree-improvement-research/). While the species has shown good growth characteristics, its wood does not match the durability and stiffness of *E. bosistoana* (Table 1; Sharma and Altaner 2017). Therefore, it is important to assess wood properties in the breeding trials to ensure genetics of adequate wood properties and determine suitable end-uses.

*Table 1. Properties of eucalypts relevant in the New Zealand context. Data from Australian old-growth trees (Bootle, 2005). ND: no data available; *(Anonymous, 2013; Cookson et al., 2009) (from Sharma and Altaner 2017)*

Species	MoE (GPa) old growth	Air-dry density (12% MC) (kg/m^3)	In-ground life expectancy (years)	Lyctid susceptibility of sapwood	Termite resistance
E. nitens	*13*	*700*	*0 – 5*	*Susceptible*	*Not resistant*
E. fastigata	*14*	*750*	*0 – 5*	*Susceptible*	*Not resistant*
E. regnans	*13*	*680*	*0 – 5*	*Depending on origin*	*Not resistant*
E. bosistoana	***21***	***1100***	***>25***	***Susceptible***	***Resistant***
*E. argophloia**	*14 (age 13)*	*1055*	*>25*	*Susceptible*	*Not resistant*
E. tricarpa / E. sideroxylon	*17*	*1130*	*>25*	*Susceptible*	*Resistant*
E. quadrangulata	*18*	*1030*	*15 – 25*	*Not susceptible*	*Resistant*
E. globoidea	***17***	***880***	***15 – 25***	***Not susceptible***	***ND***
E. cladocalyx	*17*	*1090*	*>25*	*Susceptible*	*Resistant*
Pinus radiata	*9*	*480*	*0 – 5*	*Not susceptible*	*Not resistant*

Heartwood

The durability of old-growth Australian *E. globoidea* heartwood is listed as class 2 (Table 1; Bootle 2005). *E. globoidea* vineyard posts cut from old NZ-grown trees showed decay after 10 years in service (technical report SWP-T039).
Preliminary tests of NZ-grown *E. globoidea* of different ages for termite resistance showed generally good performance, however variation was present between trees (Kakitani 2017).

A previous SWP funded study showed that a) the extractive content (EC) is highly variable (1 – 14%) in *E. globoidea* heartwood and that b) EC can be predicted with NIR (RMSE ~1%) (Technical report SWP-T040, Li and Altaner 2019). Judging from experience with *E. bosistoana* EC is partly heritable and related to natural durability (technical report SWP-T017, SWP-T028, Li et al. 2018).

Heartwood quality and quantity are key wood properties for the envisaged utilisation of *E. globoidea* and therefore need to be assessed for their potential incorporation into a breeding programme.

Previous work on stiffness of NZ grown *E. globoidea*

A target product for these eucalypts are high stiffness veneers for use in LVL. While exceeding the MoE of radiata pine, *E. globoidea* is not as stiff as other species in the NZDFI breeding programme (Table 1). This is a result of lower density but also higher microfibril angle (for which acoustic velocity is a surrogate measurement) (Figure 1).
Especially when looking at young trees, *E. globoidea* might benefit from selection for higher stiffness. Jones et al. (2010) reported an average MoE of 12 GPa for 25 year-old NZ-grown *E. globoidea* , similar to the 12.7 GPa of peeled veneers from 30 year-old trees (Guo and Altaner 2018). These values are sufficiently low to warrant investigation of breeding potential. However, >18 GPa boards/veneers were also present in the samples.

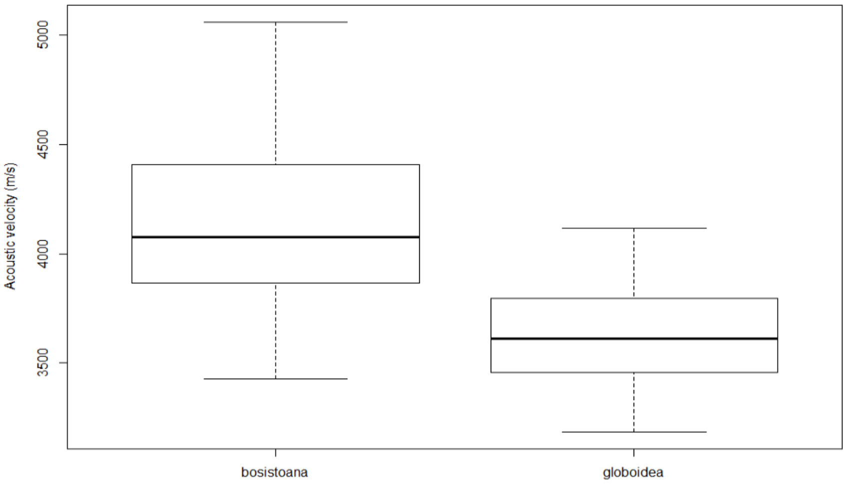

Figure 1. Acoustic velocity of nine E. bosistoana and nine E. globoidea in juvenile corewood (within 2.5 cm of the pith at the base of the stem. (Sharma and Altaner 2017)

Collapse

During the assessment of the *E. globoidea* cores for heartwood properties, a significant amount of collapse was recognised (Figure 2). No collapse was observed in identically treated *E. bosistoana* cores previously assessed for heartwood properties. Therefore it was retrospectively decided to additionally quantify this phenomenon and calculated genetic parameters.

Figure 2. Collapse in oven-dried cores of E. globoidea.

Challenges of *E. globoidea* timber seasoning due to collapse timber was reported earlier (Poynton 1979). However Jones et al. (2010) reported little drying collapse for the species in a sawing study.

METHODS

Trial

NZDFI planted three *E. globoidea* progeny trials in September 2011 with 100-160 open pollinated families to select superior genotypes of this species for future deployment. The seed was collected from across the natural range of the species in Australia and from three NZ plantation sites with a known seedlot. The progeny trials were planted at JNL's Ngaumu forest (Wairarapa); Avery (Marlborough) and Atkinson (Wairarapa).
The Atkinson trial was a sets-in-reps, single tree plot design that includes 144 families with each family replicated 40 to 80 times across the site. There were 36 trees per plot and spacing is 2.4 m between rows and 1.8 m within the rows. There were a total of 240 blocks planted with a one row surround. 23 plots have been abandoned due to high mortality. There are springs in various locations throughout the site. While some of these were avoided when laying out the trial, other wet areas resulted in early losses due the wet soil conditions.
The trial had been assessed in 2015 for growth, form and DBH and was also thinned to reduce the total trees remaining to 3444. The trial was thinned again in March 2019, removing another approx.1900 trees. At that time, cores were taken for heartwood assessments.

Coring

All living trees with a diameter larger than 30 mm were sampled. A bark to bark 14 mm diameter core including the pith was extracted at 50 cm above from 2160 trees in March 2019 (Figure 3).

Figure 3. Coring an E. globoidea tree using a light weight battery powered corer.

Heartwood quantity

The heartwood diameter in the stem was assessed by measuring the heartwood length with a ruler on the core samples in the green state after the heartwood was highlighted with 0.1% solution of methyl orange.

Heartwood quality

Extractive content in the heartwood was predicted by NIR spectroscopy according to Li and Altaner (2019). The NIR spectra were taken from the sanded radial-tangential surface of the oven-dried cores using a fibre optics probe (Bruker) every 5 mm along the heartwood. The spectra were acquired from 9,000 to 4,000 cm^{-1} at 4 cm^{-1} intervals and 32 scans were averaged for each spectrum. Heartwood extractive content for individual spectra were predicted with a previously ,under SWP, developed model and the average heartwood extractive content for the tree was calculated by averaging the radial values per core weighted by the representative heartwood area.

Collapse

After the NIR measurements, the cores were equilibrated (~3 weeks) to a stable moisture content at 60% relative humidity and 25°C. To obtain a reference measurement, 10 cores were selected randomly and their widest tangential diameter was with a Vernier calliper. These values were averaged and used as $D1$ in the equation below. Collapse was assessed as the maximum tangential shrinkage in the core, separately for heartwood and sapwood. The two narrowest tangential diameters of each core were averaged ($D2$) in the heartwood and the narrowest tangential diameter was used for the sapwood.

$$Tangential\ shrinkage = \frac{D1 - D2}{D1}\ x\ 100\%$$

Standing tree acoustic velocity

Analysis under SWP Milestone 1.2.2.8 - objective 1 optimised the sampling intensity for wood quality traits of durable eucalypts in the breeding programme, considering accuracy of the obtained genetic information and resources needed for the measurements. Based on these results, a random sample of 10 trees per family was identified for families with more than 10 standing trees present. For families for which there were 10 or less standing trees, all trees in the family were sampled. A total of 1,252 trees were randomly selected for sampling in the trial.

Acoustic velocity was measured on these trees with the standing tree time-of-flight TreeTap tool. The peg was put in the stem at a height of 0.3 m up the stem while the two probes were inserted at a height of 0.6 m and 1.6 m respectively facing the peg at a 45 degree angle (as specified by the TreeTap operating manual). A total of 8 measurements were taken per tree for all trees that were selected for sampling. Out of the 1,252 trees that were selected, 1,147 trees were able to be measured. 105 of the trees that were intended to be measured were not found in the field. Measurements were taken on only one side of the tree as family averages rather than values for individuals were targeted.

Data collected in the field using the TreeTap tool were regularly uploaded into Excel spreadsheets and matched to the corresponding block number, tree position and family number for each tree sampled.

Data analysis

Data was analysed with the R software (R Core Team 2019). For the subsequent analysis, the average of the 8 acoustic velocity measurements per tree was used.
Univariate analyses were conducted to estimate the individual variance components for the trait (acoustic velocity) and covariance between pairs of each trait. The univariate analysis was used to generate the foundational parameter of the traits. A linear mixed model was used for the univariate analyses using the equation below.

$$Y_{ij} = \mu + b_i + c_j + \sigma_{ij}$$

Where Y_{ij} is an observation of each trait, μ is the overall mean, b_i is the fixed block effect, c_j is the random family and σ_{ij} is the residual error.

The model was fitted with the ASReml package (Gilmour et al. 2009) to generate the correlation between the traits' phenotypic and genotypic variation. The phenotypic and genotypic variation was estimated to compute the narrow sense half-sib heritability (h^2) of each trait using the equation below

$$h^2 = \frac{Var(A)}{Var(Y)} = \frac{4\sigma_f^2}{\sigma_f^2+\sigma_b^2+\sigma_r^2}$$

Where σ_f^2 is the additive genetic variance for the family; σ_b^2 is the variance for the block and σ_r^2 is the residual variance. The heritability estimated in this study assumed a relationship coefficient among families of one quarter, i.e. true half sibling progeny.

The coefficient of genetic variation (CGV) for each trait was determined using the equation below

$$CGV = \frac{\sqrt{4x\sigma_f^2}}{population\ mean}$$

The genetic correlation is a measure of the strength of the genetic relationship between two traits. It is used to measure the association between the breeding values. This was determined using the equation below

$$r_g = \frac{\sigma_{fij}}{\sqrt{(\sigma_{fi}{}^2 * \sigma_{fj}{}^2)}}$$

σ_{fij} is the family covariance; $\sigma_{fi}{}^2$ is the variance for the ith trait and $\sigma_{fj}{}^2$ is the variance for trait j, r_g is the genetic correlation and has no unit.

RESULTS AND DISCUSSION

The summary statistics of the measurements in the NZDFI *E. globoidea* breeding population at Atkinson at age 8 years old are given in Table 2. The main traits of interest are natural durability (i.e. extractive content) and heartwood quantity (i.e. heartwood diameter), followed by collapse (in the heartwood) and probably stiffness (i.e. acoustic velocity). These traits are highlighted in Table 2.

Table 2. Summary statistics of E. globoidea traits at Atkinson aged 8 years old; 95% confidence intervals (CI_{95}) in brackets. CPV: coefficient of phenotypic variation; CGV: coefficient of genetic variation.

	Mean	Standard deviation	Min	Max	CPV (%)	CGV (%)	h^2
Acoustic velocity (km/s)	2.96	0.31	2.13	4.27	10.47	6.53	0.39 (0.21, 0.56)
Core length (mm)	141.8	33.83	48	255	23.86	19.42	0.66 (0.48, 0.84)
Heartwood diameter (mm)	90.75	26.51	0	190	29.21	21.07	0.52 (0.36, 0.67)
Sapwood diameter (mm)	51.1	16.42	6	150	32.13	26.29	0.66 (0.49, 0.83)
Extractive content (%)	9.30	4.52	-4.35	31.68	48.60	51.88	1.16 (0.91, 1.38)
Heartwood collapse (%)	18.76	6.90	-2.20	45.95	36.78	20.32	0.30 (0.17, 0.42)
Sapwood collapse (%)	12.44	0.69	9.62	14.66	5.55	2.00	0.13 (0.05, 0.22)

Acoustic velocity

The standing tree acoustic velocity (TreeTap) of 2.96 km/s was similar to the 2.5 km/s (ranging from 2.2 to 2.8 km/s) reported for the species at age 25 years (Jones et al. 2010) using the IML hammer standing tree acoustic tool. This compares to 2.65 km/s for 10 year old *P. radiata* in Australia measured with TreeTap (Toulmin and Raymond 2007). No standing tree time-of-flight data is available for comparison for the other durable eucalypts in the NZDFI breeding population. At age 8 years old *E. fastigata* was reported to average 3.43 km/s (standard deviation 0.27 km/s) (Suontama et al. 2018), *E. nitens* averaged close to 4 km/s at harvesting age (Blackburn et al 2019, Sargent and Gaunt 2018) and *Pseudotsuga menziesii* averaged 3.85/4.97 km/s at two sites at age 20 years old (Klápště et al. 2019), all measured with the ST300 standing tree time-of-flight acoustic tool. The ST300 tool appeared to yield faster velocities than the IML hammer, with ~3.7 km/s and ~2 km/s for 11 year old *P. menziesii*, respectively (Dungey et al. 2012).

Heritability of standing tree acoustic velocity (h^2 = 0.39; CI_{95} 0.21, 0.56) in *E. globoidea* at age 8 years old was comparable to that found in other species (Dungey et al. 2012, Suontama et al. 2018, Klápště et al. 2019).

Stiffness is the product of acoustic velocity squared and density. In young trees, where microfibril angle is high and variable (and consequently acoustic velocity is low and variable), acoustic velocity has a dominating influence on stiffness. If stiffness is considered a selection trait it might be more accurate to include density measurements of the individual trees, which could be obtained retrospectively from stored cores. This, however is a question of available resources and selection on acoustic velocity should be beneficial at least in the first instance when variation is large.

Family rankings based on average tree acoustic velocity measurements are displayed in Figure 4. Top families averaged more than 3.2 km/s, while the worst performing families barely exceeded 2.5 km/s.

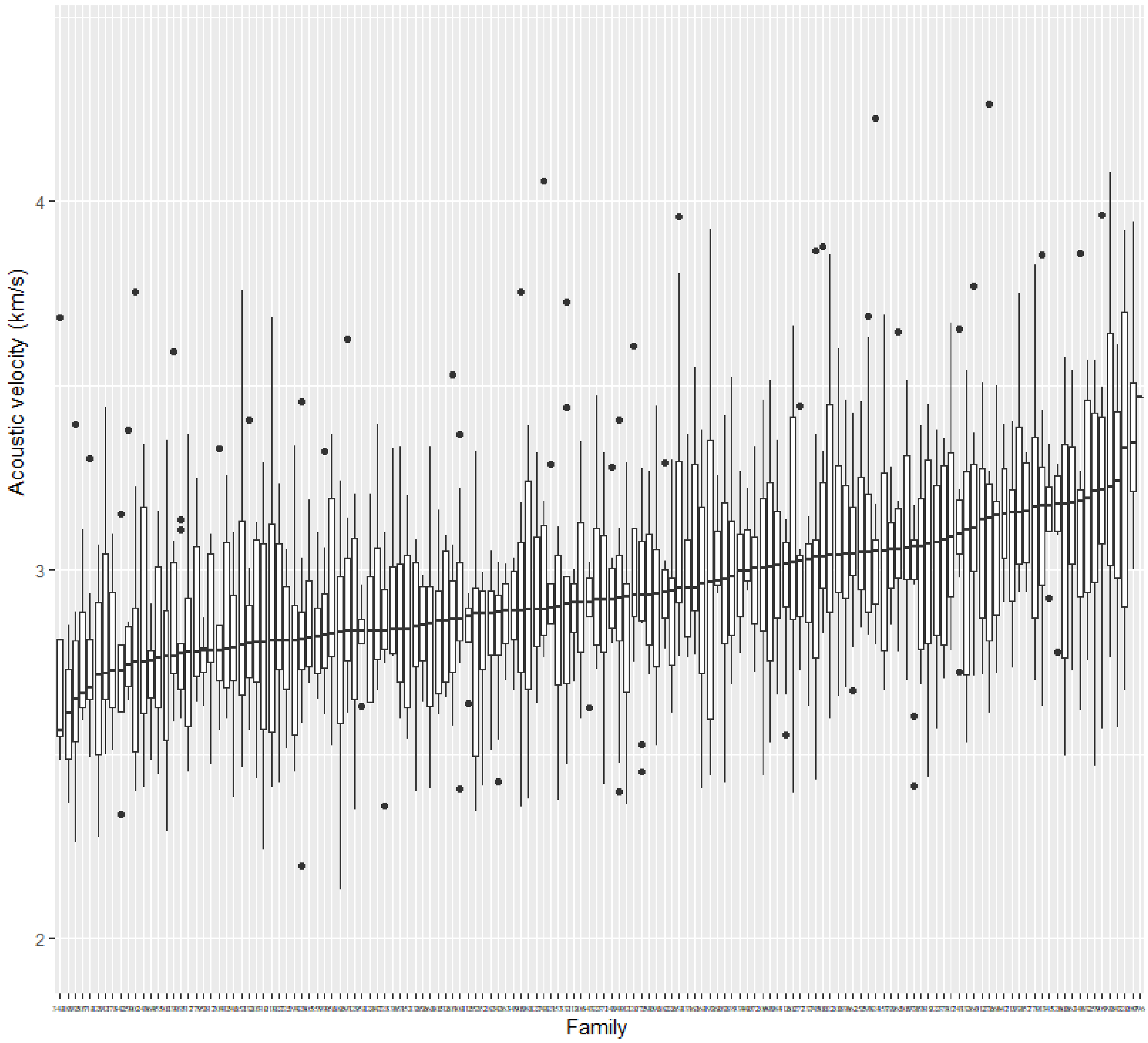

Figure 4. Boxplots of standing tree acoustics of E. globoidea families at Atkinson at 8 years old ranked by mean.

Collapse

The collapse in the heartwood region ranged from -2.2 to 45.95% with a mean of 18.76% (Table 2). Consistent with what is known of collapse (Chafe et al. 1992), this was larger than the observed collapse in the sapwood (mean 12.44%; min 9.62% and max 14.66%).

The heritability estimates for heartwood collapse was h^2 = 0.30 (CI_{95} 0.17, 0.42), similar to what was reported for *E. nitens* (Hamilton et al. 2004) and *E. dunnii* (Harwood et al. 2005).

Family rankings for heartwood collapse are displayed in Figure 5. Top families averaged ~10% tangential collapse, while the worst performing families averaged ~25%.

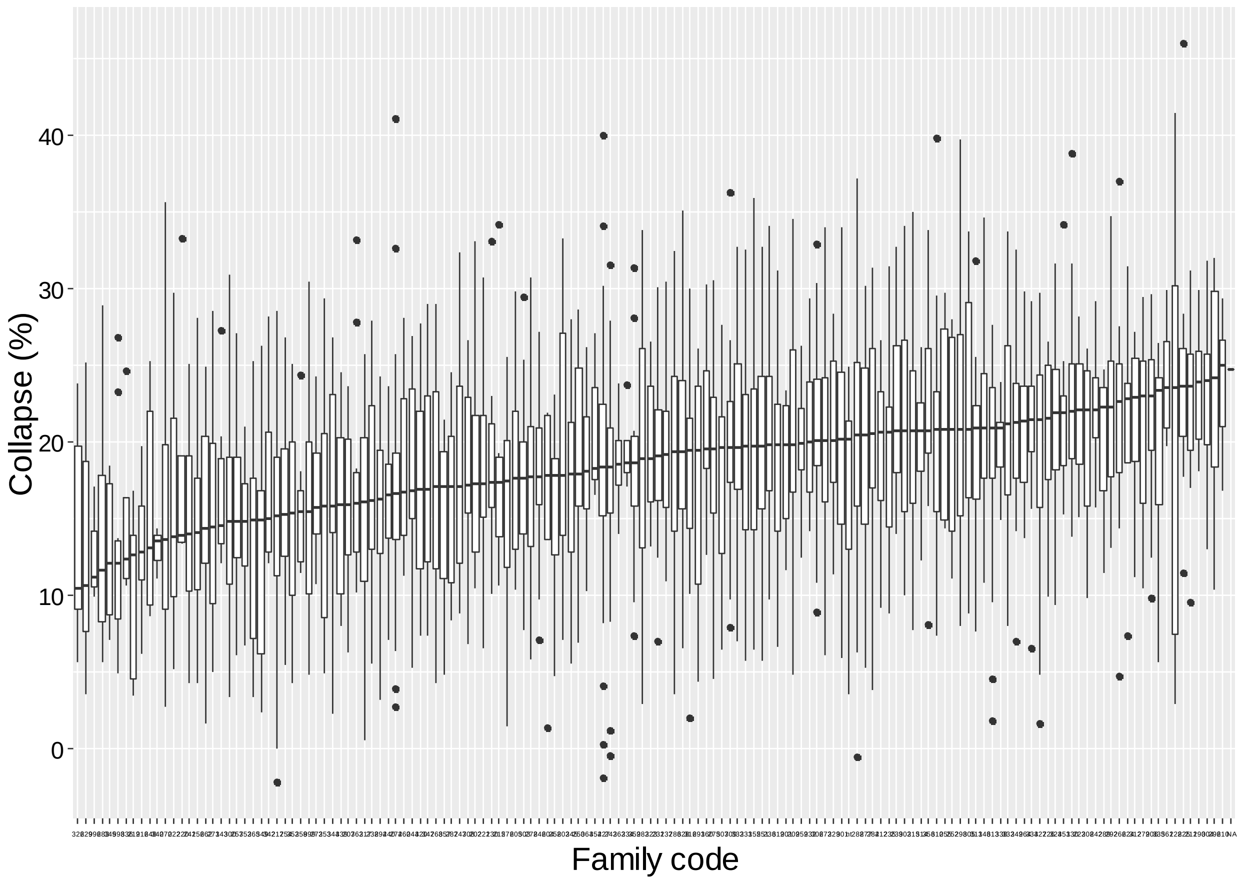

Figure 5. Boxplots of heartwood collapse of E. globoidea families at Atkinson at 8 years old ranked by mean.

Heartwood

Variability and heritability (h^2 = 0.52; CI_{95} 0.36, 0.67) of heartwood quantity (heartwood diameter) was comparable to that of tree diameter and sapwood width (Table 2), but lower than those reported for *E. bosistoana* (Li et al. 2018). Top families had with an average heartwood diameter of ~120 mm at age 8 years old twice as large heartwood diameter as the bottom families (~60 mm) (Figure 6).

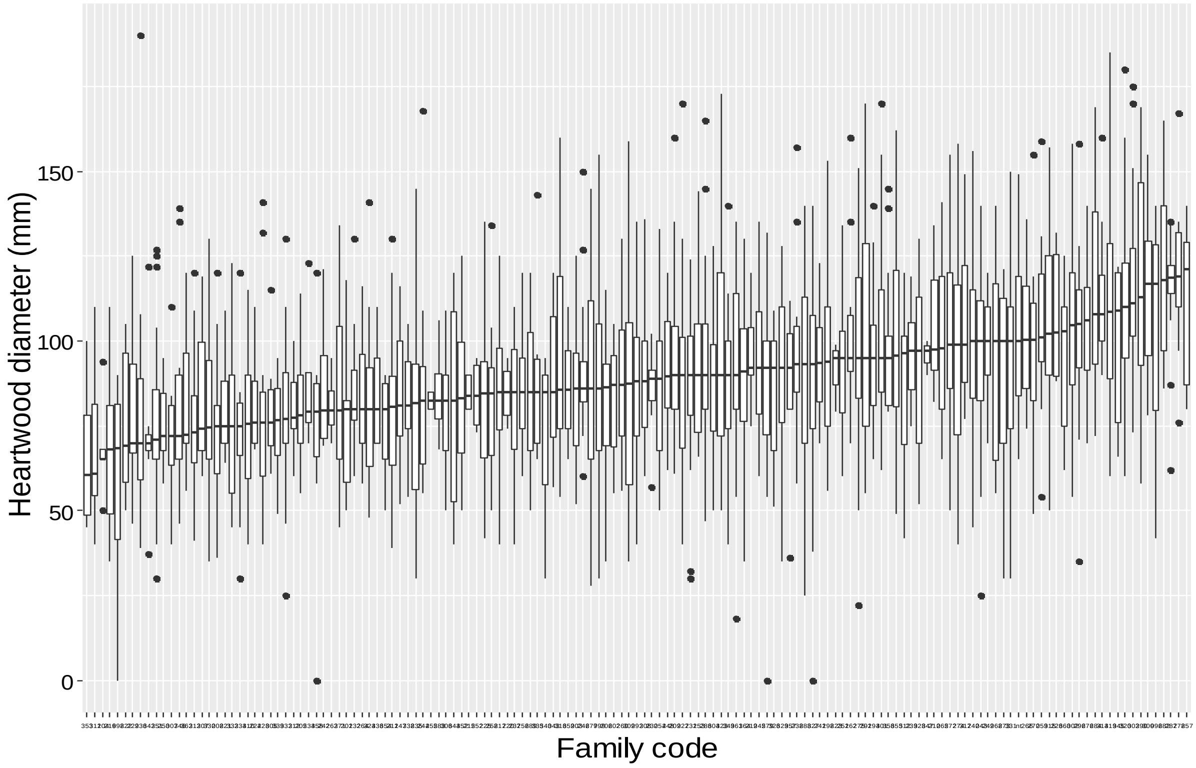

Figure 6. Boxplots of heartwood diameter of E. globoidea families at Atkinson at 8 years old ranked by mean.

The heritability estimate for extractives was h^2 = 1.16 (CI_{95} 0.917, 1.38) (Table 2). Consequently, the needed improvement of heartwood quality of the class 2 ground durable *E. globoidea* for use in the envisaged agricultural post market might well be possible. The heritability estimate of >1 suggested deviation of the true relatedness of the trees in the trial from the assumed half-siblings, an observation made also for *E. bosistoana* (Li et al. 2018).
Similar studies found lower heritabilities for heartwood extractives in the class 1 durable *E. bosistoana* (h^2 = 0.2 to 0.4) at age 7 years old (Li et al. 2018) and *E. cladocalyx* (h^2 = 0.25) at age 8 years old (Bush et al. 2011).

The worst performing families had an average heartwood extractive content of less than 5%, while the best performing families averaged ~15% (Figure 7).

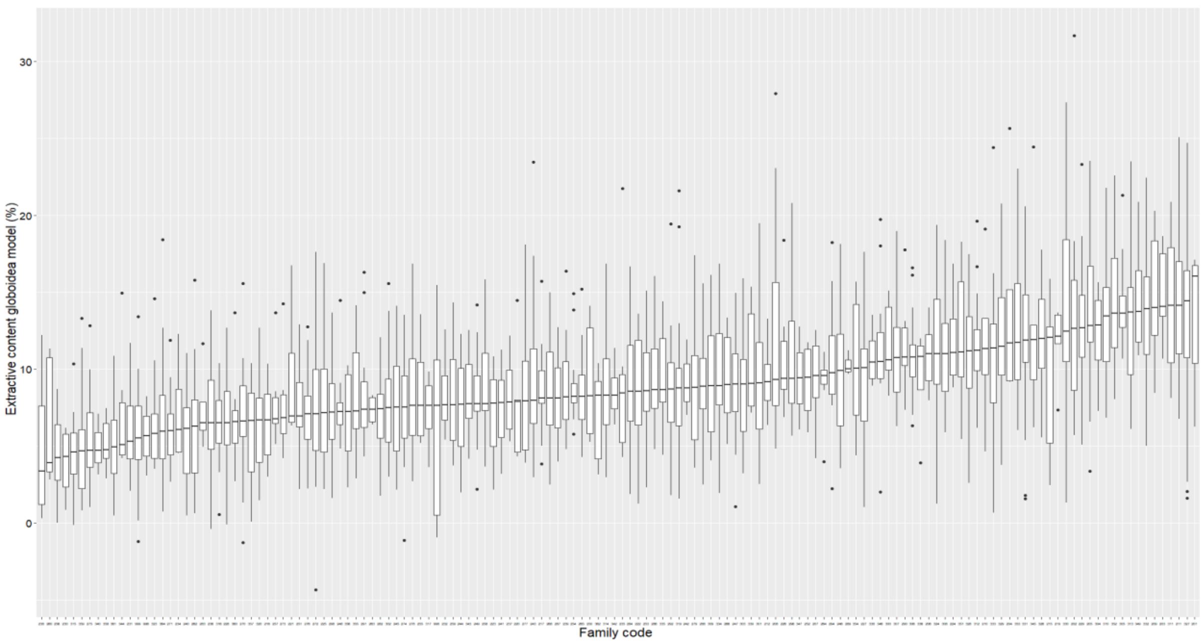

Figure 7. Boxplots of predicted extractive content in heartwood of E. globoidea families at Atkinson at 8 years old ranked by mean.

Correlation between traits

Genetic correlations between the trials have been calculated (Table 3). The main traits of interest are natural durability (i.e. extractive content) and heartwood quantity (i.e. heartwood diameter), followed by collapse (in the heartwood) and probably stiffness (i.e. acoustic velocity). These traits are highlighted in Table 3.

Acoustic velocity was independent of heartwood diameter and had a weak and unfavourable correlation to heartwood collapse and extractive content. This implies that heartwood quantity and acoustic velocity need to be independently selected for, while increases in acoustic velocity might compromise durability (i.e. extractive content) and drying quality (i.e. heartwood collapse).

Heartwood collapse was independent of heartwood quantity and favourably correlated to extractive content. Therefore selections for heartwood durability are expected to also improve drying behaviour.

The strongest correlation (-0.44; CI_{95} -0.62, -0.25) of the traits of interest was the unfavourable linkage between extractive content and heartwood diameter. But as the correlation is not perfect correlation breakers with superior heartwood volume and quality should exist.

Table 3. Genetic correlation between the wood traits for 8-year old E. globoidea (95% confidence interval)

Trait	Core length	Sapwood collapse	Heartwood diameter	Sapwood diameter	Extractive content	Acoustic velocity
Heartwood collapse	-0.05 (-0.32, 0.19)	-0.67 (-0.92, -0.41)	-0.03 (-0.29, 0.25)	-0.06 (-0.3, 0.21)	-0.27 (-0.51, -0.02)	0.15 (-0.22, 0.55)
Core length		-0.15 (-0.5, 0.19)	0.90 (0.86, 0.94)	0.78 (0.68, 0.87)	-0.68 (-0.82, -0.55)	0.17 (-0.09, 0.44)
Sapwood collapse			-0.32 (-0.61, -0.04)	-0.06 (-0.39, 0.26)	-0.04 (-0.35, 0.27)	0.12 (-0.47, 0.68)
Heartwood diameter				0.43 (0.23, 0.62)	-0.44 (-0.62, -0.25)	0.0004 (-0.32, 0.32)
Sapwood diameter					-0.78 (-0.87, -0.68)	0.36 (0.08, 0.62)
Extractive content						-0.19 (-0.44, 0.09)

The data has been uploaded to the NZDFI Kathmandu database and is available for industry to make selections in order to produce improved germplasm.

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