Variation in the Wood Properties of the *Pinus elliottii* x *Pinus caribaea* var. *hondurensis* F_1 Hybrid, Its Parental Species, and Backcross to *Pinus elliottii* in Australia

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Abstract.--The *Pinus elliottii* (E) x *Pinus caribaea* var. *hondurensis* (H) F_1 hybrid (EH) has replaced improved E and improved H on poorly-drained and well-drained sites, respectively, in subtropical southeast Queensland due to its overall superiority. EH is being evaluated in the subtropics world-wide, including Florida. Due to its potentially greater frost-hardiness and only slightly lower productivity, the EH backcross to E (BC) may be of value in Florida and the coastal southeastern United States. Critical wood properties and bark thickness of EH, associated E and H parents, and BC were assessed in 21-year-old and 15-year-old studies at four locations. EH wood properties may be evaluated by the first five rings. Wood density and latewood percent tended to be greater at poorer sites and also increased with proximity to the equator. Taxa comparisons for density and latewood were E > BC > EH > H consistently across locations; for extractives content, EH = H BC E with considerable location effect; and for heartwood percent, minor differences. Extractives in EH and H heartwood generally exceeded that of E. Large family differences within taxa typically surpassed taxa differences. Taxa and families maintained their rankings for wood properties across locations in the study with 10 families per taxon, but taxa ranks changed in the study with only four families per taxon. Superior growth and generally acceptable wood properties of EH favor its use over the pure species in appropriate areas of the subtropics. Parental selection, followed by EH evaluation, will insure wood properties comparable to E. Commercial seed production and experimental vegetative propagation practices are established at the Queensland Forest Service (QFS).

Keywords: *Pinus elliottii*, *Pinus caribaea* var. *hondurensis*, hybrid, wood density, extractives content, latewood.

INTRODUCTION

Recent exotic pine planting in Queensland favored E on swampy sites in the southeast and H on naturally well-drained sites. Beginning with trials in 1958, the F_1 hybrid between the two species demonstrated excellent growth and stem,

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branch, and wood properties (Nikles et al. 1987), and in 1985, EH F_2 replaced E in commercial planting programs of the QFS, but H continued to be routinely planted on better drained central and southern coastal Queensland locations and on all northern Queensland locations (Last 1990). Seed orchard programs are in place to produce EH F_1 planting stock (Nikles and Robinson 1989), which will gradually replace all H and EH F_2 for operational planting in southern coastal Queensland (Nikles 1991). EH is of interest world-wide (Nikles et al. 1987, Nikles 1991), and evaluation trials have begun in Florida. Due to its potentially greater frost-hardiness, the BC may be of value in Florida and the coastal southeastern United States.

Considerable information exists on the wood properties of the parental taxa (e.g., Smith 1977), but only initial data are available for EH (Harding and Eccles 1990, Harding and Hagan 1990). Preliminary conclusions of several wood quality studies completed since 1971 by the QFS with E, H, and EH are: 1) EH is intermediate for density and latewood, 2) EH is similar for other wood properties, 3) EH sawn graded recovery is greater than E and relatively unimproved H (Bragg 1990), 4) EH resin % and defect incidence is similar to H, and 5) Between family variability exceeds between taxa differences.

For basic density, extractives content, heartwood percent, latewood percent, and bark thickness of EH, associated parents, and BC, this study had six objectives: 1) Investigate age-age relationships, 2) Confirm earlier indications of location effects, 3) Extend taxa by location interaction evaluations, 4) Broaden E, H, and EH comparisons, 5) Develop guidelines for predicting hybrid combining ability of E parents, and 6) Assess the potential of BC.

MATERIAL AND METHODS

Study 364, which contributed to Objectives 1 through 3, was planted near Whiporie, New South Wales, in 1969 and in 1970 at three Queensland locations (Table 1) with different soil and drainage characteristics. Open-pollinated (o-p) families of four E clones used as females for EH, o-p families of four H clones used as males for EH, and four EH families between these E and H clones were sampled to characterize the genetic growth range in their respective taxon. These families occurred within 60-tree noncontiguous plots at 3 x 2.7 m spacing. Stratified random sampling was used to select six trees, two trees from the lower-, mid-, and upper-1/3 of the DBH range, of each of the 12 families. Wood sampling consisted of 5 mm bark-to-bark cores taken at 1.0 to 1.2 m. Each tree's DBHOB, total height, and bark thickness were also determined. Volume inside bark was calculated by formulae appropriate for the taxa (Vanclay and Shepherd 1983, P. Gordon pers. comm.).

Study 464, which contributed to all objectives, was established in April 1976 at three Queensland locations, swampy sites with a range of productivity, and in June 1976 on a well drained site near Whiporie (Table 1). Ten E clones with o-p families also served as female parents for EH hybrids with a Beerburrum H pollen mix and a Byfield H pollen mix and for backcrosses with a Beerburrum EH pollen mix. A Beerburrum H bulklot (H_{Be}) and a Byfield H bulklot [illegible] represented the H parental populations. These genetic entries were allocated to 49- (7 x 7) or 80-tree (8 x 10) noncontiguous plots at 3 x 3 m spacing. Tree selection and wood sampling was as in Study 364. The E parents 1008 and 1011 and

Table 1. Summary of sampling by taxa and locations in Studies 364 and 464.

Taxon	Number of Sample Trees				Total
364 Location:	Whiporie (Wh)	Toorbul (To)	Coochin (Co)	Byfield (By)	
E	12	24	24		60
EH	12	24	24	24	84
H	—	24	24	18	66
Total	24	72	72	42	210
464 Location:	Whiporie	Husseys (Hu)	Tuan (Tu)	Byfield	
E	18	60	24	24	126
BC	18	60	21	24	123
EH_{Be}	18	60	24	24	126
EH_{By}		60			60
H_{Be}		30	24	24	78
H_{By}	—	30	—	—	30
Total	54	300	93	96	543

12 of the trees **in** the H_{Be} subsamples in Study 464 provided links to the larger subsamples and to Study 364.

Location and across-location effects were examined in subsets of genetic entries in 464-Tuan, 464-Byfield, and 464-Whiporie. Each subset taken in the field involved four E parents and 24 trees from the $_{HBe}$ population, except in 464-Whiporie (Table 1). Studies 364 and 464 also assessed age-age relationships.

Field tree selection and wood sampling started in January 1991 and was completed in mid-April; laboratory analysis commenced as the wood samples were received. All cores were sectioned at the pith and planed on one surface to facilitate accurate ring count. Each radial core was marked inward from the cambium to denote the outer latewood boundaries of the annual rings. Then, the 5-, 10-, 15-, and 19-th rings from the pith in Study 364, and the 5-, 10-, and 13-th rings in Study 464, were located and their radial distances from the pith recorded, along with the radial distance to the outer extent of heartwood. Latewood percentage for E, EH, and BC families derived from female parents 1008 and 1011 in Study 464 was estimated as a proportion of radial distance by linear measurement of latewood using a 10x eyepiece graticule. Study 364 cores were subsequently sectioned into segments representing 0-5, 6-10, 11-15, and 16-19 years from the pith, with Study 464 core segments for 0-5, 6-10, and 11-13.

The segments were processed for unextracted wood density, moisture content, extractives content, and extracted wood density. Segments were submersed in water in a vacuum dessicator until saturated and then weighed in water and air. After oven-drying at 102°C for 16 hours, they were reweighed to derive unextracted wood density and moisture content. Extraction involved first methanol in a soxhlet apparatus for six hours followed by a further 8 hours in hot water. After 16 hours of oven-drying at 102°C and reweighing, extractives content and extracted wood density were calculated.

Combined core segmental values weighted by radial distance squared were the basis for correlating 5-, 10-, 15-, and 19-ring wood properties in Study 364 and 5-, 10-, and 13-ring properties in Study 464.

For the taxa, location effects and interaction across locations were assessed by various analyses of variance. Family comparisons in within taxa analyses and taxa comparisons in the combined taxa analyses were conducted by Duncan's Multiple Range Test. All analyses were done by SAS.

RESULTS AND DISCUSSION

Growth

The EH hybrids in the wood sample were larger than the parental taxa in almost all study locations (Table 2). After 21 years in Study 364, EH families had up to 50% more volume inside bark than the taxon previously preferred at each location. At 15 years of age in Study 464, the better EH taxon also had a similar advantage over the standard parental taxon at each location. The volume superiority of EH was due to its greater height, larger DBH, more cylindrical form, and slightly thinner bark. The relative taxa rankings for tree volume in the wood study sample were virtually the same as rankings based on all surviving trees at 8.5-9.5 years of age (e. g., Nikles et al. 1987), suggesting that the wood sample trees were representative of the range of tree sizes.

Table 2. Individual tree volume inside bark and whole core extracted wood density for taxa and locations in Studies 364 and 464.

Taxon	m^3	kg/m^3	m^3	kg/m^3	m^3	kg/m^3	m^3	kg/m^3
364 Location:	Whiporie		Toorbul		Coochin		Byfield	
E	.427a	452	.468b	511a	.355ab	530a	-	-
EH	.569a	438	.700a	475b	.469a	508ab	.523a	480a
H	-	-	.512b	461b	.327b	487b	.472a	475a
464 Location:	Whiporie		Husseys		Tuan		Byfield	
E	.158a	422	.295c	437a	.320b	465a	.166b	482a
BC	.177a	423	.368b	430ab	.300b	468a	.253a	488a
EH_{Be}	.230a	405	.437a	422b	.368a	436b	.304a	464b
EH_{By}	-	-	.400ab	426ab	-	-	-	-
H_{Be}	-	-	.300c	427ab	.391a	431b	.298a	460b
H_{By}	-	-	.383b	420b	-	-	-	-

Age-Age Relationships

Young wood properties in core samples were often correlated with older wood properties in EH cores on both individual and family bases. For example, extracted wood density of rings 0-5 and later segments tended to be correlated with older segments as well as with pith to 10-, 15-, and 19-ring cores in Study 364 and 10-, and 13-ring cores in Study 464 (Table 3). These trends were stronger than in other taxa. Such relationships suggest that EH could be evaluated for wood properties using rings 0-5. Whole core values were used for subsequent analyses.

Location Effects

Extracted wood density tended to increase with decreasing latitude in all taxa (Table 2). Wood density was typically highest at Byfield, the most

Table 3. Age-age phenotypic correlations for extracted core wood density of individual EH trees (I) and EH families (F) by Study 364 locations Toorbul, Coochin, and Byfield, and Study 464 locations Husseys, Tuan, and Byfield.

Age: Loc.	Growth Ring Age (years) 6-10	11-15	16-19	0-10	0-15	0-19
Study 364	I / F	I / F	I / F	I / F	I / F	I / F
0-5:To	.68*/.41	.54*/.14	.66*/.41	.89*/.64	.82*/.39	.79*/.21
Co	.26 /.54	.01 /.53	-.03 /.89	.72*/.83	.53*/.78	.45+/.82
By	.66*/.98+	.45+/.53	.37 /.34	.84*/.99*	.73*/.98+	.70*/.91
6-10:To		.69*/.40	.81*/.57	.92*/.84	.94*/.94	.93*/.96+
Co		.67*/.71	.39 /.87	.82*/.91	.87*/.93	.82*/.91
By		.77*/.67	.56*/.52	.94*/.99*	.93*/.99*	.90*/.98+
11-15:To			.89*/.95+	.62*/-.07	.80*/.69	.75*/.56
Co			.61*/.69	.42+/.69	.70*/.81	.70*/.62
By			.79*/.91	.71*/.60	.81*/.65	.82*/.76
16-19:To				.76*/.19	.88*/.81	.87*/.66
Co				.20 /.99*	.36 /.97+	.55*/.99+
By				.54*/.41	.62*/.51	.73*/.69
Study 464	6-10	11-13		0-10	0-13	
0-5:Hu	.68*/.68+	.54*/.52		.87*/.93*	.77*/.87*	
Tu	.45+/.88	.42+/.51		.74*/.90	.74*/.98*	
By	.52*/.59	.30 /-.01		.76*/.89	.71*/.86	
6-10:Hu		.76*/.89*		.91*/.90*	.91*/.94*	
Tu		.54*/.09		.92*/.99*	.88*/.84	
By		.51+/.62		.92*/.89	.90*/.90	
11-13:Hu				.68*/.74+	.73*/.80*	
Tu				.51+/.11	.72*/.62	
By				.48+/.36	.67*/.45	

+ and * - Significant at the 5- and 1-% levels, respectively

northerly location (22°50'S), and lowest at Whiporie, the southernmost location (29°15'S), with a differential of about 10% in Study 364 and some 15% in Study 464. However, in Study 364-Coochin, a very poor site, extracted wood density was higher than at any other Study 364 location. Extractives content also increased with decreasing latitude in the older trees of Study 364, but no such trend was evident in the more recently planted Study 464.

Taxa by Location Interactions

No taxa x location interactions were detected for any wood properties in Study 464 (Table 4). In Study 364, though, extractives content, moisture content, and unextracted wood density displayed interactions due to a change of taxa positions at the Coochin location.

Table 4. Analyses of variance across locations and taxa in Studies 364 and 464 for whole core extractives content, moisture content, extracted wood density, and unextracted wood density,

Source	Extractives Content	Moisture Content	Extracted Wood density	Unextracted Wood density
Study 364:				
Location	NS	NS	*	NS
Taxa	NS	NS	**	NS
Families/T	NS	NS	NS	NS
L x T	**	**	NS	**
L x F/T	NS	NS	NS	NS
Study 464:				
Locations	NS	**	**	**
Taxa	NS	NS	*	*
L x T	NS	NS	NS	NS
Families	*	NS	NS	NS
L x F	NS	NS	NS	NS
T x F	NS	NS	NS	NS
LxTxF	NS	NS	NS	NS

NS, *, and ** - Nonsignificant and significant at the 5- and 1-% levels, respectively

E. H. and EH comparisons

Studies 364 and 464 establish that all taxa have virtually the same extracted wood density in the first five rings, EH achieves a density slightly above that of the H parent as early as 10 rings, and EH has a nearly intermediate density between the parental taxa by 19 rings (Table 2). Extractives content of EH was much less predictable. Latewood percent of EH was typically intermediate between the parental taxa, as was heartwood percent.

Combining Ability of E Parents

General o-p combining abilities of the 10 E parents in Study 464-Husseys were of varying reliability in predicting EH wood properties. For extracted wood density, combining abilities of pure E, EH_{By}, and backcrosses with EH_{Be} were strongly correlated but not with EH_{Be} (Table 5). Thus, the potential for selecting E parents for EH_{By} or backcross breeding based on the densities of their o-p families in traditional breeding programs appears good. In fact, the range of variability in extracted wood density in these breeds is such that EHBy and BC families can be generated that equal or exceed the desirably high average wood density of E.

0-p combining abilities of E parents for extractives content were of little use in predicting EH extractives content, another important trait. As for EHBy unextracted wood density, though, o-p combining abilities may be helpful in making desirable hybrids with the H_{By} population. Certain E parents had a strong influence on EH extractives content.

Table 5. Correlations among combining abilities of E females in 464-Husseys for 0-13 extracted wood density and 0-5 extractives content of 0-P, BC, and EH families,

Combining Ability of E Females in	Combining Ability of E Females in BC Families	EH_{Be} Families	EH_{Be} Families
	Extracted Wood Density		
0-P Families	.67*	.62	.87**
BC Families		.58	.62
EH_{Be} Families			.32
	Extractives Content		
0-P Families	.44	.33	.81**
BC Families		-.21	.41
EH_{Be} Families			.06

EH Backcross to E

The BC was often intermediate between E and EH_{Be} in Study 464. In terms of volume inside bark, BC was better than E except at Tuan. Its wood properties frequently were more desirable than those of EH_{Be} except that its extractives content tended to be higher. Accordingly, the BC appears to have potential for Florida and the southeastern United States for a higher growth rate than E with wood properties similar to E; the frost-hardiness and fusiform rust susceptibility of the BC and even EH remain critical traits however.

Hybrid Breeding Strategy

Procedures for the production of EH in Queensland include parent selection, hybrid testing, monoclonal orchards, and vegetative propagation. E parents with good combining ability for volume in o-p families are generally better as EH seed parents, but o-p combining abilities of H parents typically provide little indication of their potential for superior EH families. Consequently, an extensive field testing program is conducted to identify superior EH. Selected E parents are then grafted onto H rootstock to establish monoclonal orchards in the Byfield area that are hedged regularly beginning in the first year to promote early and abundant flower production (Nikles and Robinson 1989). Pollen collected in advance of E flowering from the complementary H parent is mass applied by wanding to produce the maximum possible seed. Due to the large quantity of propagules required, a substantial number of the EH seedlings produced are also hedged to provide commercial rooted cuttings.

CONCLUSIONS

Critical wood properties and bark thickness of EH, associated E and H parents, and BC were assessed. EH wood properties may be evaluated by the first five rings. Density and latewood tended to be greater at poorer sites and also increased with proximity to the equator. Taxa comparisons for density and latewood were E > BC > EH > H; extractives content, EH – H > BC > E; and heartwood percent, minor differences. Extractives in EH and H heartwood exceeded that of E. Large family differences within taxa typically surpassed taxa differences. Location interactions with taxa and families were not observed in the study with 10 families per taxon, but location by taxa interactions were detected in the study with only four families per taxon. Superior growth and generally acceptable wood properties of EH favor its use over the pure species in appropriate areas of the subtropics. Parental selection, followed by EH evaluation, will insure wood properties comparable to E. Seed production systems and vegetative propagation practices such as those developed at the QFS can be implemented to produce EH if evaluations underway in the subtropics, including recent trials in Florida, demonstrate growth superiority of the EH. Due to its potentially greater frost-hardiness, the BC may be of value in the coastal southeastern United States.

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