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Wood and fibre properties of dryland conifers

**A report for the RIRDC/Land & Water
Australia/FWPRDC/MDBC
Joint Venture Agroforestry Program**

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Foreword

Forestry is seen as an increasingly desirable option for rural land in many regions of Australia, both for economic and environmental reasons. However, a key impediment to wider scale plantings in the Australian landscape is the lack of relevant information concerning the suitability of tree species for processing into marketable products.

Of particular concern is the shortage of information about the market opportunities and processing options for conifers grown in dryland plantations in temperate areas. The primary market will be for sawlogs but alternative markets also require investigation as reasonable quantities of residual wood will be generated as thinnings, toplogs and sawmill residues. These make up more than 50% of the wood volume produced over a rotation, even in a plantation managed for sawlogs.

This publication reports the results of laboratory tests for sawn timber quality, kraft and thermomechanical pulp and paper, medium density fibre board and extractives contents of five conifer species and provenances sampled from dryland plantations. The data are compared with results typical of existing radiata pine pulpwood resources from higher rainfall regions. The information should assist in the selection of species with the potential to produce an optimum mix of products for the markets in their region.

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This report, a new addition to RIRDC's diverse range of over 1000 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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Contents

Foreword	iii
Acknowledgements	iv
About the authors	iv
List of Tables	vi
List of Figures	vii
Abbreviations	ix
Executive Summary	x
1. Introduction	1
2. Objectives	2
3. Methodology	3
3.1 Sampling	3
3.2 Sample preparation	4
3.3 Kraft pulping and papermaking	6
3.4 TMP pulping and papermaking	8
3.5 MDF manufacture	10
3.6 Extractives testing	11
3.7 Sawing studies	12
4. Results	18
4.1 Wood density	18
4.2 Kraft pulp and paper properties	18
4.3 TMP pulp and paper properties	22
4.4 MDF properties	27
4.5 Extractives contents	29
4.6 Sawn timber properties	35
5. Discussion of Results	57
6. Implications	59
7. Recommendations	59
8. References	60
Appendix 1 – KRAFT Unbleached Papermaking Properties	61
Appendix 2 – TMP Papermaking properties	62
Appendix 3 - Photographs of sawmill study.	63
Appendix 4 - Photographs of kiln drying	64
Appendix 5 -Weighting system of basic densities from strips for the whole disc	65
Appendix 6 - Shrinkage versus MC%	68
Appendix 7 - Spiral grain measurements for individual trees.	69

List of Tables

Table 1:	Origins and ages of conifers sampled	3
Table 2:	Kraft cooking conditions	6
Table 3:	Refining conditions for TMP.....	10
Table 4:	Nominal sizes of green boards.....	12
Table 5:	Number of sample blocks from the inner and outer heartwood locations.	17
Table 6:	Mean basic densities of woodchip composites representing each conifer genotype	18
Table 7:	Kraft pulping properties of woodchip composites representing each conifer genotype...	18
Table 8:	Buffering capacities and initial pH of dryland conifers species/provenances.	27
Table 9:	MOR and MOE of MDF panels	28
Table 10:	Internal bond strength of MDF panels given in ranges for each species/provenance.....	28
Table 11:	Thickness swell and water absorption for MDF panels.....	29
Table 12:	Colour difference measurements on finished MDF panels.....	29
Table 13:	Total acetone extractives, free fatty acids, resin acids and glycerides in dry-land pine species.....	30
Table 14:	Summary statistics for each dryland conifer species.	31
Table 15:	Tree and log measurements of selected trees for both species and a summary of the sawn board dimensions	37
Table 16:	Summary of information on structural boards (90 x 35 mm) from the central cant of logs.....	38
Table 17:	Summary of information on appearance boards cut from the log wings	39
Table 18:	In-grade testing results on 90 x 35 mm structural boards from the central cants	40
Table 19:	Summary of clearwood properties for <i>P. canariensis</i> and <i>P. brutia</i>	41
Table 20:	Summarised means for acetone extractives, resin acid content and kraft pulp yield.....	58

List of Figures

Figure 1: Wirrabara site, South Australia. Left <i>P. canariensis</i> , right <i>P. brutia</i>	3
Figure 2: Sampling strategy designed to account for within-tree variation.	4
Figure 3: Billets after debarking and splitting.....	4
Figure 4: Chipping the billets in a Bruks pilot-scale chipper.....	5
Figure 5: Preparing woodchip composite samples.....	5
Figure 6: Air bath used for kraft pulping trials with pressure vessels in foreground.....	6
Figure 7: Bauer refiner.....	7
Figure 8: Sunds Defibrator CD300 woodchip refiner used for primary refining.....	8
Figure 9: Schematic of the Sunds Defibrator CD300.....	8
Figure 10: The Sunds Defibrator ROP20 used for secondary refining.....	9
Figure 11: Resin and wax application to dried fibres.....	11
Figure 12: Sawing pattern showing the sawing of central cant (indicated by dotted lines) into structural sizes (103 mm x 43 mm).....	13
Figure 13: Drying kiln schedules used for Charge 1 (100 x 43 mm boards) and Charge 2 (all remaining boards).....	13
Figure 14: Preparation of sample material from 300 mm thick billets.....	15
Figure 15: Density and shrinkage block showing measuring points at midpoint on the tangential, radial and longitudinal face.....	16
Figure 16: (A) Diametrical strip showing grain angle and (B) the fixed platform and digital protractor used to measure the grain angle.....	17
Figure 17: Kraft pulp yield of woodchip composites representing each conifer genotype.....	19
Figure 18: Wood volume required per tonne of pulp.....	19
Figure 19: Handsheet bulk at 350 mL CSF.....	20
Figure 20: Tear index at 350 mL CSF.....	20
Figure 21: Tensile index at 350 mL CSF.....	21
Figure 22: Compression index at 800 beating revolutions.....	21
Figure 23: Ring crush index at 800 beating revolutions.....	22
Figure 24: Tear index versus tensile index.....	22
Figure 25: Tensile index versus pulp freeness.....	23
Figure 26: Tearing resistance versus pulp fibre length.....	24
Figure 27: Freeness versus specific energy consumption.....	25
Figure 28: Tensile index versus specific energy consumption.....	25
Figure 29: Light scattering coefficient versus bulk.....	26
Figure 30: Light scattering coefficient versus tensile index.....	26
Figure 31: Extractives in <i>Pinus brutia</i>	32
Figure 32: Extractives in <i>Pinus canariensis</i>	32
Figure 33: Extractives in <i>Pinus radiata</i> (Cedros).....	33
Figure 34: Extractives in <i>Pinus radiata</i> (Tallaganda).....	33
Figure 35: Extractives in <i>Pinus radiata</i> (Guadalupe).....	34
Figure 36: Extractives in <i>Pinus pinaster</i>	34
Figure 37: Typical knot characteristics.....	42
Figure 38: Photo showing the abundance of pith-in material among the in-grade test samples for (A) <i>P. canariensis</i> and (B) <i>P. brutia</i>	43
Figure 39: Graphs showing clearwood properties (bending strength (A&B) & stiffness (C&D), compression strength (E&F) and Janka hardness (G&H) in relation to board position for <i>P. canariensis</i> and <i>P. brutia</i>	44
Figure 40: Mean basic and air dry density of the shrinkage blocks from 20-30% (inner heartwood) and 60-80% (outer heartwood) of the distance from the pith.....	45
Figure 41: Mean basic density for the disks from the top and bottom of the 5 randomly selected logs of each species.....	46
Figure 42: Radial pattern of basic density with relative distance from pith.....	47

Figure 43; Mean shrinkage and unit shrinkage from blocks at 20-30% (inner heartwood) and 60-80% (outer heartwood) of the distance from the pith..	49
Figure 44: Radial pattern of tangential shrinkage expressed as relative distance from pith.	50
Figure 45: Radial pattern of radial shrinkage expressed as relative distance from pith.	51
Figure 46: Radial pattern of longitudinal shrinkage expressed as relative distance from pith.	52
Figure 47: Radial pattern of tangential unit shrinkage expressed as relative distance from pith.	53
Figure 48: Radial pattern of radial unit shrinkage expressed as relative distance from pith.	54
Figure 49: Radial pattern of longitudinal unit shrinkage expressed as relative distance from pith.	55
Figure 50: Mean spiral grain measurements for top and bottom strips.	56
Figure 51: Weighting system used to estimate basic density of disk from the basic density of the shrinkage blocks from the diametrical strips.	66
Figure 52: Limitation of weighting system with elliptical, off centre or out of round stems.	67
Figure 53: Shrinkage against MC%.	68
Figure 54: Plot of spiral grain for each individual strips from the top and bottom of the five randomly selected logs of <i>P. canariensis</i> and <i>P. brutia</i> .	69

Abbreviations

AA	Active Alkali
Abs. coeff	Absorption Coefficient
ABC	Acid Buffering Capacity
B/ness	Brightness
BBC	Basic Buffering Capacity
BD	Basic Density
CSF	Canadian Standard Freeness
FBC	Fibre Buffering Capacity
g/L	Grams per Litre
kg/m³	kilograms per Cubic Metre
LWA	Length Weighted Average
MDF	Medium Density Fibreboard
mm	Millimetres
m³	Cubic Metres
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
OSB	Oriented Strand Board
RPM	Revolutions Per Minute
Scatt. coeff	Scattering Coefficient
TMP	Thermomechanical Pulp
UF	Urea-Formaldehyde

Executive Summary

The objective of this project was to obtain a preliminary indication of the suitability of wood from dryland conifers for the production of sawn timber, kraft and thermomechanical pulp and paper and medium density fibreboard relative to existing commercial *Pinus radiata* pulpwood resources from higher rainfall regions.

Trees representing five conifer genotypes identified as having potential for dryland climatic conditions were sampled from sites in South Australia and Western Australia with mean annual rainfalls of 650 mm and 750 mm respectively. The species were: *Pinus canariensis* (Canary Island pine), *Pinus brutia* (Brutian/Red/Turkish/Calabrian pine), *Pinus pinaster* (Maritime pine), *Pinus radiata* (Guadalupe provenance) and *Pinus radiata* (Cedros provenance). A sixth sample was collected from a higher rainfall site in NSW to represent *Pinus radiata* (Mainland provenance), which comprises the bulk of the current resource.

Overall the dryland conifers were comparable to *P. radiata* for sawn structural timber products and MDF manufacture but at a disadvantage for both kraft and TMP production. Both *P. canariensis* and *P. brutia* show good potential for sawn structural products. Knots are a major concern for both species. Both species are of medium to high density for exotic conifers and have comparable or better (*P. canariensis*) stiffness properties than for *P. radiata*. However, the strength of both species was poor or at best marginal (*P. canariensis* was slightly better than *P. brutia*) compared with *P. radiata*, this was largely due to the size and distribution of knots

For MDF production, the wood from the dryland pine species could be used successfully. The high pressure refining of dryland pine species was successful in producing acceptable fibre furnish with no compounds present which might interfere with the cure of urea-formaldehyde resins. Panel properties were generally found to be similar to those of panels made with a radiata pine resource currently used for the manufacture of commercial MDF.

For kraft pulp and paper production, the dryland pines are at a significant pulp yield disadvantage compared with the current *P. radiata* resource. The mainland provenance of *P. radiata* had the highest pulp yield (59.4% at Kappa number 92). *P. canariensis* had the lowest yield (54.6% at Kappa number 93) with the other four samples covering a range of only 1.1%. Results for papermaking tests appeared to be predominantly influenced by the densities of the wood samples, with *P. canariensis* exhibiting the highest bulk and tearing resistance and the lowest tensile strength, whereas *P. radiata* (Mainland) had lower bulk and tear and the highest tensile strength.

For TMP paper production, the dryland conifers would generally be considered inferior raw materials compared to the control samples of *P. radiata*. Energy is the single largest cost in producing TMP, and the control samples and *P. radiata* (Cedros) required 15% less energy to produce a sheet at a given tensile strength than the other conifers. The higher density species (*P. canariensis* and *P. brutia*) were particularly disadvantaged, with inferior pulp strength properties as well. Although the scattering coefficients of pulps produced from these two species were high, this advantage was generally at the expense of higher energy requirements.

1. Introduction

In the future, many areas of Australia with rainfalls that would normally be considered marginal for commercial forestry might be planted with trees. These dryland plantings (defined here as within the 400-600 mm annual rainfall range) could provide financial benefits from the returns from wood, fibre, fodder and energy. Environmental benefits may accrue from increased shelter for stock and crops, the lowering of water tables, the control of salinity and the sequestration of carbon.

Most dryland plantations will be grown for production of sawlogs as this is considered to be the highest value product thus potentially maximising returns to the grower. However, considerable volumes of residual wood will also be produced as thinnings, toplogs and sawmill residues make up at least 50% of the volume produced. A commercial outlet must be found for this residual material. Potential markets include kraft or thermo-mechanical pulp (TMP) or wood composites such as oriented strand board, medium density fibreboard (MDF) and particleboard.

The wood and fibre properties which are optimal for each potential market and product class will differ. The potential for the dryland conifers to supply each market segment requires investigation so that future market opportunities and processing options can be determined for conifers grown in dryland plantations in temperate areas.

2. Objectives

The present project set out to obtain a preliminary indication of the suitability of wood from dryland conifers for the production of sawn timber, kraft and TMP pulp and paper, MDF manufacture and to determine variability in extractives contents of the wood. Spencer (2001) canvassed the range of conifer species with potential for dryland plantings. Some of these species have been planted in trials around Australia and the trees are old enough to be tested for their suitability for forest products. Samples were collected from sites in southern Australia and processed in a range of laboratories, using conditions approximating the processes used on an industry scale.

This study is not a definitive assessment of the potential of each species because only one stand of each genotype was sampled. More detailed study was not possible because of the lack of statistically robust trials accounting for the variation in site and genetics, whilst taking into account tree age.

3. Methodology

3.1 Sampling

Trees representing five conifer genotypes identified as having potential for dryland sites were sampled from trials in South Australia and Western Australia. A sixth sample was collected from a site in NSW to represent a current *P. radiata* resource. For the TMP and MDF studies an additional sample was included; *P. radiata* sawmill residues from Victoria. The origins and ages of the trees are summarised in Table 1. All sample sites had rainfalls higher than average for dryland regions (i.e. 620-900 mm rather than 400-600 mm). A view of the Wirrabara site is shown in Figure 1.

Table 1: Origins and ages of conifers sampled

Species	Age	Location	Rainfall mm/yr
<i>P. brutia</i>	38	Wirrabara Forest, Wirrabara, SA	625
<i>P. canariensis</i>	38	Wirrabara Forest, Wirrabara, SA	625
<i>P. radiata</i> (Guadalupe)	22	Wirrabara Forest, Wirrabara, SA	625
<i>P. radiata</i> (Cedros)	22	Wirrabara Forest, Wirrabara, SA	625
<i>P. pinaster</i>	22	Pinjar Plantation, Wanneroo, WA	700
<i>P. radiata</i> (Mainland)	22	Buccleuch SF, Tumut, NSW	900
<i>P. radiata</i> (Sawmill residues)	n/a	Dominance Industries	n/a



Figure 1: Wirrabara site, South Australia. Left *P. canariensis*, right *P. brutia*

Wood samples for pulp testing and MDF manufacture were collected together. As a large quantity of wood was required, three billets were collected from each tree. The merchantable length of each stem was dividing into three equal length logs and a 1-m long billet was cut from the midpoint of each log (Figure 2). Taking three billets from each tree allowed for within-tree variation. To

adequately account for between-tree variation, six trees were sampled to represent each conifer genotype.

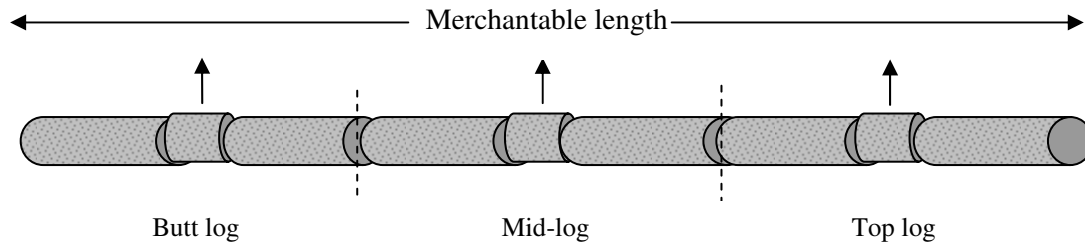


Figure 2: Sampling strategy designed to account for within-tree variation

Disc samples (2 cm thick) for extractives testing were cut from the bottom of each log as well as from the end of the top log (i.e. 4 discs in total).

The sawing study concentrated on the 38 year old *P. canariensis* and *P. brutia* from Wirrabra. Twenty trees from each species were sampled with each tree selected based on having a diameter at breast height under bark (DBHUB) of at least 28-30 cm, straight stem and good branching characteristics. The butt logs (3.9 – 4.2 m long) were harvested from each tree. Billets (30 cm long) were cut from the top (~4 m height in tree) and bottom (~0.2 m height in tree) of 5 randomly selected logs of both species. From these billets specimens were prepared for the spiral grain, shrinkage and compression wood measurements.

3.2 Sample preparation

The billets for pulp testing were debarked and split, as necessary (Figure 3), to fit the in-feed mechanism of a pilot scale chipper (Figure 4).



Figure 3: Billets after debarking and splitting



Figure 4: Chipping the billets in a Bruks pilot-scale chipper

Composite samples were produced to represent each conifer genotype by mixing woodchips from each billet (Figure 5).



Figure 5: Preparing woodchip composite samples

For the sawing study the butt logs were forwarded out of the plantation and then disks (20 cm thick) were cut from the end of each log. Log ends were then coated with a commercial wax emulsion end-coat. Logs were transported, with the bark left on, to the Timber Training Creswick sawmill in Victoria within 2 days of harvesting and stored under water spray. Logs were sawn to green nominal sizes of products cut from the central cant (103 x 43mm) and the wings (90 x 22, 70 x 22, 40 x 22

and 90 x 12mm) with the dimensions targeted at appearance products for light decking and lining boards. Boards were tracked through the mill using a sequential colour code on the small end face. Boards were block stacked and kiln dried. Boards were then square dressed.

3.3 Kraft pulping and papermaking

Moisture contents were determined in triplicate by drying 100g of chips in an oven at 105°C for 3 days. Basic density is defined as the oven-dry weight per unit volume of green wood. The basic density of the woodchips was measured according to Australian Standard AS/NZS 1301.001s, using the alternative boiling method. The kraft cooks were carried out in 3-litre pressure vessels, held horizontally and rotated in an electrically heated air bath (Figure 6).



Figure 6: Air bath used for kraft pulping trials with pressure vessels in foreground

All the cooks used the same mass of woodchips and the same temperature profile, but the active alkali charges were varied to obtain a Kappa number (a measure of the degree of delignification) of 90-100. These conditions were chosen to approximate the conditions used in an industrial-scale pulp mill producing unbleached long fibre kraft pulps for packaging products. The cooking conditions were as follows:

Table 2: Kraft cooking conditions

Parameter	Value
Sulfidity	35%
Liquor to wood	5:1
Temperature	145°C
Time to Temp	~65 min
Time at Temperature	4h
H-factor	440

After each cook, the chips were rinsed with 20L of water to remove spent cooking liquor (black liquor) then disintegrated in a Bauer refiner (2 passes, Figure 7).



Figure 7: Bauer refiner

The pulps were then further rinsed with cold water and shives were removed using a packer screen with 0.2-mm wide slots. After dewatering in a press and crumbling, the pulps were analysed for residual lignin content, determined as Kappa number according to Australian /New Zealand Standard AS NZS 1301.P201m-86. The moisture contents of the pulps were determined in triplicate by drying 10-g lots in an oven at 105°C overnight. The pulp yield and shive content, as percentages on an oven dry basis, were calculated.

Handsheets were prepared according to AS/NZS 1301.P203s:1993 from unbleached pulp beaten in a PFI mill using 24 g (o.d.) pulp charge, 10% stock concentration and 3.33 N/mm beating load (AS/NZS 1301.209rp-89) and tested according to AS/NZS 1301.208s-1997.

3.4 TMP pulping and papermaking

The TMP primary samples were prepared in a Sunds Defibrator CD300 (Figure 8).

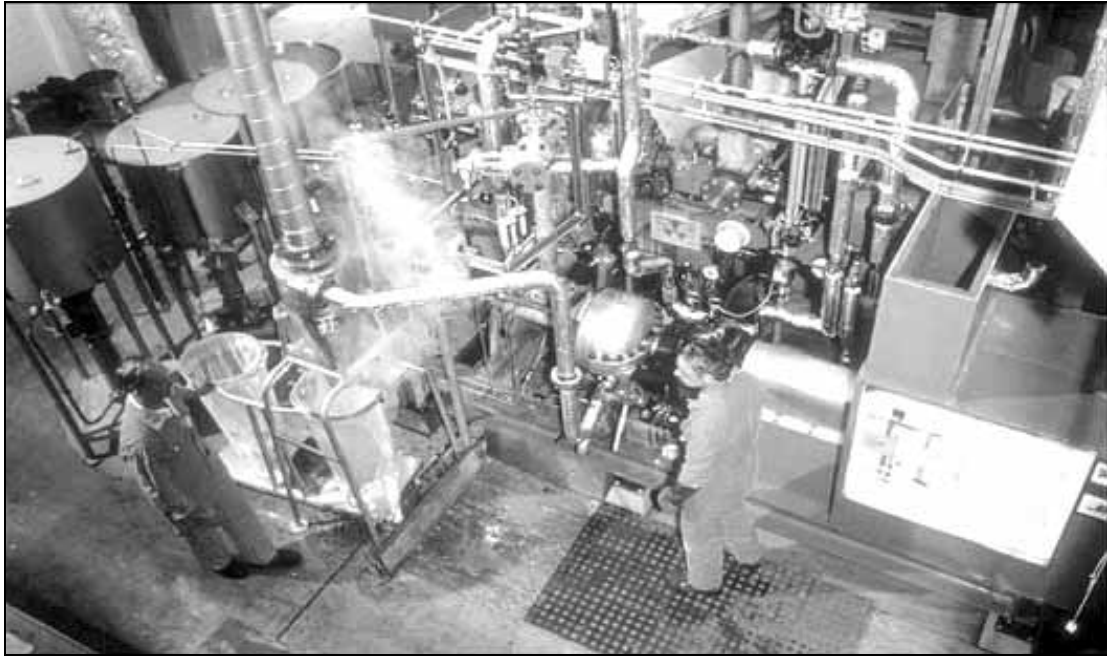


Figure 8: Sunds Defibrator CD300 woodchip refiner used for primary refining

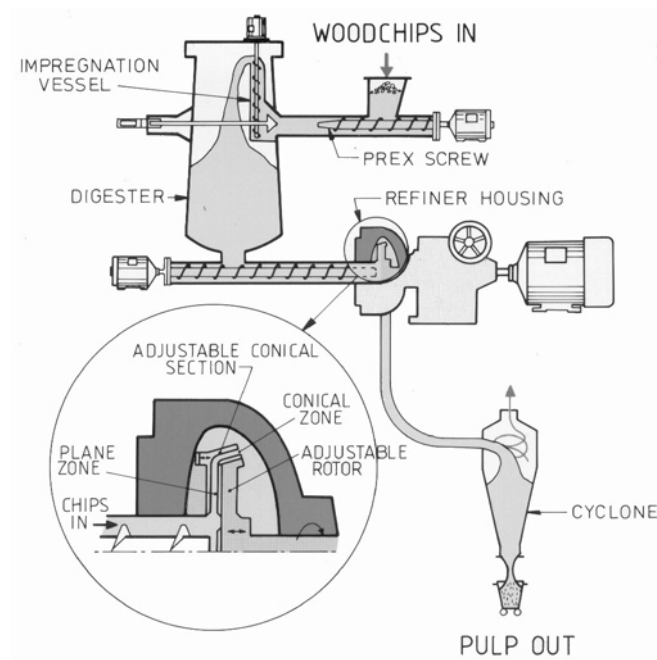


Figure 9: Schematic of the Sunds Defibrator CD300

The Sunds Defibrator CD300 is a single disc unit driven by a 105 kW motor running at 3000 rpm. It consists of a PREX® screwfeeder, which compresses the woodchips to aid fibre separation. The compression ratio is 4:1. After compression, the woodchips are passed into the lower part of the

impregnation vessel. Twin screws lift the macerated woodchips and feed them into the preheater. The refiner has both disc (300 mm diam.) and conical (100 mm diam.) elements for refining, both of which can be adjusted independently for gap width. The system may be pressurised by steam to a maximum of 1.73 MPa (250°C). In the present investigation the plate patterns used for the primary refining in the CD300 were R3811 (stator) and R3801 modified (rotor).

The ROP-20 refiner (Figure 10) is used for secondary refining. It is a single disc refiner connected to a 160 kW motor running at 1500 rpm. In the present investigation the 20 inch diameter discs (stator and rotor) used were numbered 5811 SH 602.



Figure 10: The Sunds Defibrator ROP20 used for secondary refining

In the primary stage, woodchips were atmospherically presteamed in the hopper of the CD300 pilot plant unit for about 30 minutes and then screw fed into a PREX (PPressure EXpansion) plug screw feeder prior to being fed into the preheater. The chips were retained in the preheater for 3 minutes at 180 kPa (130°C) before the primary refining stage. Dilution water was added to the refiner housing to achieve a pulp consistency at discharge of about 30%. For secondary refining, primary pulp was metered to the infeed screw of the ROP-20 open discharge refiner by means of a conveyor belt. Dilution water was added to give a discharge consistency of about 25%. The plate gap was adjusted to achieve at least 3 pulps within the freeness range of 100-500 mL.

Latency was removed from the washed pulps produced from the CD300/ROP-20 refiners according to Australian Standard AS/NZS 1301.215s:1997. Handsheets were prepared according to Australian Standard AS/NZS 1301.203s:1993 except that white water recirculation was not carried out. Handsheets were conditioned at 23°C and 50% relative humidity, and evaluated according to Australian Standard AS/NZS 1301.208s:1997. Fibre length measurements were conducted using a Kajaani FS200 Fibre Analyser and reported as length-weighted average. Shive determinations were carried out using a Pulmac Fibre Analyser with a 0.15-mm slotted screen plate. Data is expressed in terms of conditioned grammage.

3.5 MDF manufacture

The pilot scale Sunds Defibrator CD300 described above was used to refine the wood chip material into MDF fibre furnish. The key aim of thermomechanical pulping is to heat the woodchips to a temperature where the lignin component of the wood is softened sufficiently so that the shearing action of the refiner discs separates the wood into single fibres and fibre bundles without significantly reducing fibre length. The refiner processing details used for this work are detailed in Table 3.

Table 3: Refining conditions for TMP.

Species	Wood chip moisture content (%)	Refining temperature (°C)	Retention time (min)	Throughput (kg/min od*)	Energy input (kWh/t)
<i>P. radiata</i> (commercial)	45.9	175	4	0.84	175
<i>P. radiata</i> (Mainland)	40.6	175	4	0.89	190
<i>P. radiata</i> (Guadalupe)	49.8	175	4	0.9	183
<i>P. radiata</i> (Cedros)	49.2	175	4	1.09	161
<i>P. brutia</i>	47.5	175	4	0.99	153
<i>P. canariensis</i>	51.8	175	4	0.78	140
<i>P. pinaster</i>	43.8	175	4	0.97	151

*oven dry fibre basis

The refined fibre was then oven dried to 3-4% moisture content and sealed in plastic bags until used for panel making. The pH and buffering capacity of wood materials is particularly important in reconstituted products because the cure characteristics of resins can be significantly affected. Extremes in pH can either inhibit resin cure or accelerate it too quickly. Similarly, some weak acids and bases present in wood can resist changes to pH and consequently influence resin curing.

The fibre buffering capacities and pH of the dryland conifers samples were determined using a modified method described by Johns and Niazi (1980). Samples of ‘never dried’ MDF fibre (1.0 g oven dry equivalent) were steeped in 100 mL of distilled water until a steady pH was reached, at which point the suspension was titrated against 0.01 N NaOH or H₂SO₄ until a pH of 7 or 3 was reached respectively. Titrating with the base to pH 7 yields the acid buffering capacity (ABC in mmol/g) and titrating with the acid to pH 3 gives the base buffering capacity (BBC in mmol/g). The fibre buffering capacity (FBC) is the sum of the two buffering capacities. The initial pH of the suspended wood meal prior to titration was taken to represent the pH of the wood.

Urea-formaldehyde (UF) resin, supplied by Borden Chemical Australia Pty Ltd¹ and a petroleum wax, supplied by BP Australia² were used in an air-gun sprayer to coat the MDF fibres. Resin and wax emulsion were sprayed onto fibres in a single operation using a compressed air spray-gun and a laboratory scale closed-loop dry blender (see Figure 11). Resin was applied at an 8% loading and wax at 0.6% (wt of solids on wt of oven dry fibres). In addition to the wax, approximately 20-30 mL of water was added in each spraying operation to raise the moisture content of the furnish to approximately 9.5%.

¹ Resin No. CASCORESIN MBP 1285

² Water emulsified wax, Technimul 9363.



Figure 11: Resin and wax application to dried fibres

Blended furnish was formed into mattresses measuring 38.5×38.5 cm using a forming box. The preformed mattresses were then hot pressed between teflon sheets (0.1 mm thick) and aluminium caul plates (2.5 mm thick) at 200°C for 180 seconds. The target panel thickness was 16 mm (on exit from the press) and the target panel density was 750 kg/m³. The pressing operation was conducted using CSIRO Hot Board Press v.2.4 ‘position control’ software. Panels were fabricated in triplicate for each species/provenance.

After cooling and conditioning at 20°C and 65% RH all MDF panels were sanded with 180 grit paper and test coupons for mechanical and physical properties were cut. Three point flexural tests were carried out on test specimens of 50×320 mm (2 tests per panel) to determine modulus of elasticity (MOE) and modulus of rupture (MOR) according to: AS/NZS 4266.5 (Int):2001 – *Method 5: Modulus of elasticity in bending and bending strength*. Internal bond strength determinations were made on test specimens 50×50 mm (4 tests per panel) with test samples hot-melt bonded to aluminium specimen holders according to: AS/NZS 4266.6:1995. *Method 6: Determination of internal bond strength*. Thickness swell determinations were made on test specimens 50×50 mm (8 tests per panel) in water at 21±1°C according to: AS/NZS 4266.8:1995. *Method 8: Determination of thickness swell*. The colour of finished MDF panels has been an important consideration in the export marketing of some Australian-made panels, wherein ‘lighter’ coloured panels have been favoured in certain Asian markets. In an attempt to quantify any differences in the colour obtained in finished panels, determinations via the CIELab colour coordinate system were made using a Technidyne ‘Color Touch’ (Model ISO) measuring instrument. Spectral data were obtained from the surface of sanded MDF panels, with the commercial *P. radiata* acting as the control standard and the dryland pine species/provenances being sampled against the standard for colour difference ΔE.

3.6 Extractives testing

Eighteen samples comprising three replicates of wood chips from six species, *P. brutia*, *P. canariensis*, *P. pinaster*, *P. radiata* (Cedros), *P. radiata* (Tallaganda) and *P. radiata* (Guadalupe), were selected for extraction and analysis. The Technical Services Laboratory at the Norske Skog Albury mill prepared wood chip samples for extraction according to AS 1301.002S “Preparation of Wood Samples for Chemical Analysis”. Wood chip samples were prepared for milling by drying at 40°C rather than air drying or freeze drying as specified in the standard. The total acetone extractives for each of the eighteen samples were determined in duplicate by the Albury laboratory as per AS1301.012S “Organic Solvent Extractives in Wood and Pulp”. The free fatty acid, resin acid and glyceride content of the acetone extractives were determined by gas chromatography of the methylated extracts at the Norske Skog Process & Product Support Group according to standard and documented in-house methods.

3.7 Sawing studies

The general sawing pattern used is shown in Figure 12. Table 4 shows the green nominal sizes of products cut from the central cant and the wings. The nominal dimensions of the appearance products were targeted for light decking and lining boards.

For most logs the central cant was sawn parallel to the North-South axis of the standing tree (sweep considerations were more critically important with a number of logs). Boards were tracked through the mill using a sequential colour code on the small end face. The position the board came from within the log was recorded by half painting the large end of the logs, the edge of the paint line indicated the North-South Axis of the tree (See Appendix 3).

Table 4: Nominal sizes of green boards

	Nominal Green Dimensions (mm)	Dried Dressed Dimensions (mm)
Central cant	103 x 43	90 x 35
Wings	103 x 28	90 x 22
	84 x 28	70 x 22
	53 x 28	40 x 22
	103 x 18	90 x 12

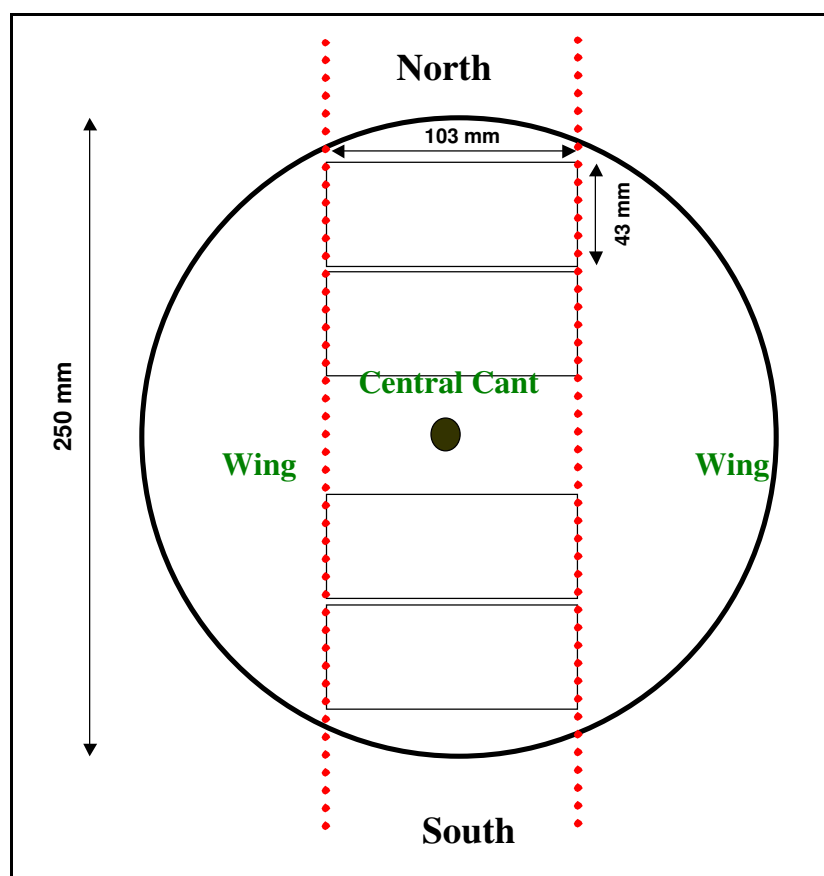


Figure 12: Sawing pattern showing the sawing of central cant (indicated by dotted lines) into structural sizes (103 mm x 43 mm). A range of appearance dimension products were cut from the two wings.

All boards were block stacked and transported to CSIRO's drying facilities in Clayton, Victoria. Two kiln drying runs were undertaken to dry the boards to approximately 10-12% MC. All the 103 x 43 mm boards were dried in the first charge, while all remaining dimensions were dried together in the second charge. Boards were dried in a converted shipping container (see Appendix 4 for photographs of kiln). The stacks were 1.10 m wide and there was a 450 mm spacing between stickers (30 x 22 mm). Air flow in the charges was 4-5 m/s, the maximum speed the fans could operate at. All boards were docked to 3.6 m long to fit into the kiln and a density/moisture content (MC) section cut from the docked material. The green volume of this section was determined using the water displacement method and the MC determined by the Oven Dry (OD) method.

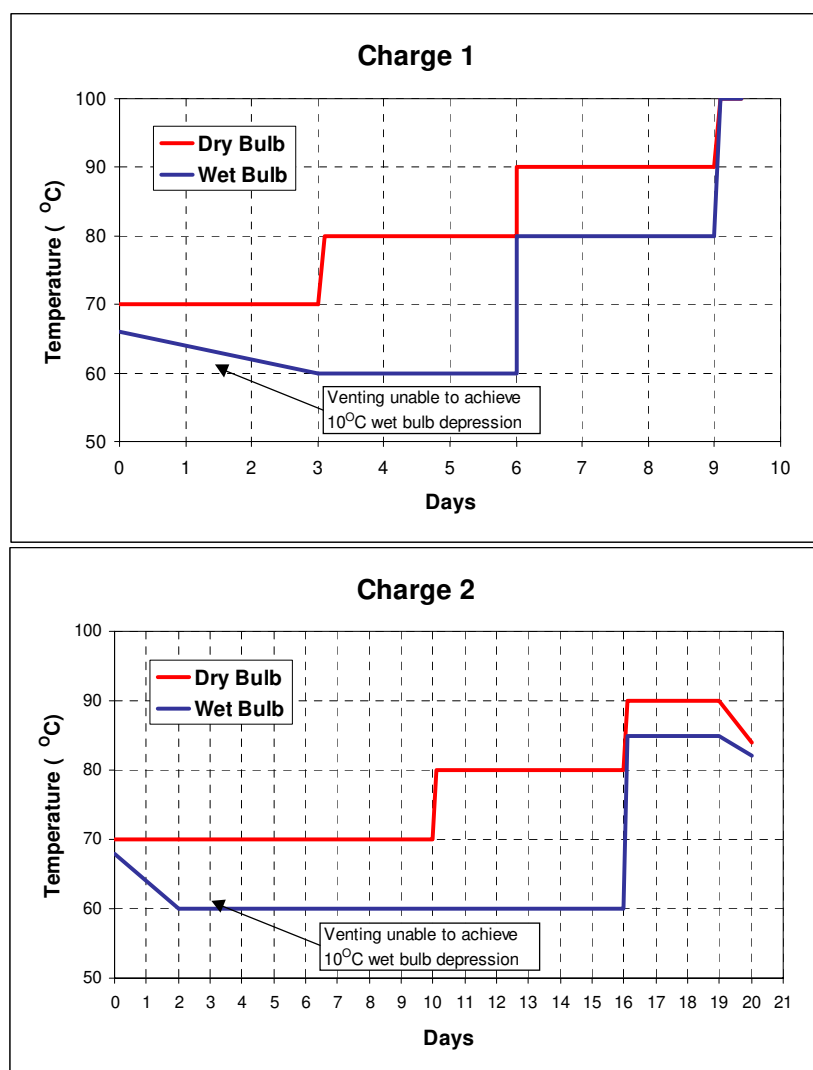


Figure 13: Drying kiln schedules used for Charge 1 (100 x 43 mm boards) and Charge 2 (all remaining boards)

All boards were square dressed at Australian Timber Machining Pty Ltd in South Dandenong, Victoria. The final dried dressed dimensions are shown in Table 4. All 90 x 35 mm boards were

visually stress graded by CSIRO personnel to AS 2858:2001³. The structural grade (1-5) were recorded for each species. Provisionally, *P. canariensis* was assigned as SD6 (Mean density at 12% of 690 kg/m³) and *P. brutia* as SD7 (Mean density at 12% of 600 kg/m³) by the density method in AS/NZS 2878:2000⁴. Boards could be end docked back to 2.4m if it improved the grade by one grade.

All boards cut from the wings were graded by CSIRO personnel to AS 4785.1⁵ and AS 4785.2:2002⁶. The intended products for the dimensions cut were for either lining boards or light decking. The boards were only square machined on four sides. To evaluate the potential to cut short length furniture components or to finger joint clear boards the total length of clear material (in 30cm increments) was also recorded and expressed as a % of the dried dressed volume of boards.

All dried and dressed 90 x 35 mm boards were transported to the Research and Development Division, State Forests of New South Wales site at West Pennant Hills, NSW. All boards were run through a Machine Stress Grader (*Eldeco DART*) and assigned an F-grade based on the minimum grading modulus settings used for *P. radiata*. This was necessary as there are currently no established grading programs for *P. canariensis* or *P. brutia*. The machine was set to a relatively low feed speed to minimize vibrational effects on the stiffness measurements as the boards passed through the machine. Each board was passed through once and the information on stiffness along its length together with minimum and mean values were captured electronically.

The in-grade strength and stiffness properties of all boards were then determined in accordance with Australian and New Zealand Standard AS/NZS 4063:1992⁷. Essentially, this required cutting a specimen from each board at a random location and destructively testing it in a four-point bending test. The test span in bending was 18 times the board width, ie. 1620 mm.

A sub-sample (ca.50-60%) of the dried boards were also tested for clearwood properties to provide important information on strength grouping and bench marking against other conifer species. The clearwood test specimens were taken from near the breast height of the tree (1.3 m) to minimise any effects due to height. The test methods and specimen sizes generally followed that of J.J. Mack⁸ for mechanical properties and that of AS/NZS 1080⁹ for physical properties. The wood properties determined were:

- bending strength (MOR) & stiffness (MOE)
- compression strength parallel to grain
- hardness (Janka)
- wood density
- moisture content

Billets (30 cm long) were cut from the top (~4 m height in tree) and bottom (~0 m height in tree) of 5 randomly selected logs of both species. From these billets specimens were prepared for the spiral grain, shrinkage and compression wood measurements.

³ AS 2858 – 2001: Timber - Softwood – Visually graded for structural purposes

⁴ AS/NZS 2878 – 2000: Timber – Classification into strength groups

⁵ AS 4785.1 – 2002: Timber SoftwoodSawn and milled products. Part 1: Product Specification

⁶ AS 4785.2 – 2002: Timber SoftwoodSawn and milled products. Part 2: Grade Description

⁷ AS/NZS 4063 – 1992: Timber – Stress graded – in grade strength and stiffness evaluation.

⁸ Mack J.J. – 1979. Australian methods for mechanically testing small clear specimens of timber. CSIRO Div. Build Res. Technical Paper No. 31

⁹ AS/NZS 1080 1997 Timber – Methods of Test

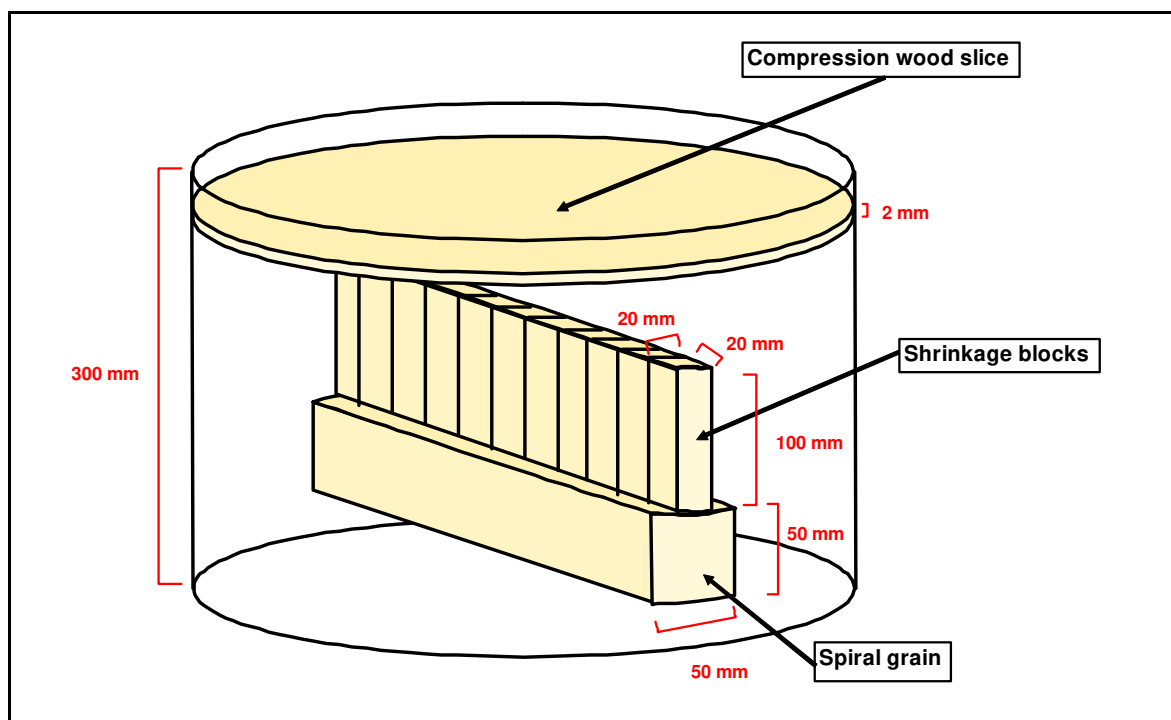


Figure 14: Preparation of sample material from 300 mm thick billets

The procedures used for determining densities and shrinkages were similar to those used by Kingston and Risdon¹⁰. The main difference was that the sample specimens were 20 mm (tangential) by 20 mm (radial) by 100 mm (longitudinal) instead of the standard 25 x 25 x 100 mm (Figure 15). Samples from the diametrical strip were cut sequentially from the bark to the pith.

The test specimens were weighed and measured in the following conditions:

1. Green
2. After drying in a conditioned chamber (at 65% relative humidity and 30°C) to a uniform moisture content (MC) of about 12%.
3. After drying in a conditioned chamber (at 25% relative humidity and 30°C) to a uniform moisture content of about 5%.

Weight was re-measured after oven drying at 103±2°C, until a constant dry weight was established.

The radial and tangential dimensions were measured using a digital displacement gauge with readings graduated to 0.001 mm. A pneumatic ram using 250 KPa of air pressure was applied to the upper contact point, a 10mm flat disc, while the specimens rested on a 58 mm flat disc. The specimen lengths were measured with a horizontal digital displacement gauge with readings graduated to 0.001 mm in a specially built jig. A standard 150 mm length was used to zero the gauge, and specimen lengths were derived from the difference between the two. Volume was calculated from the measured dimensions. Masses were weighed with a balance graduated to 0.001 g.

Basic density was calculated using oven-dry mass and green volume. An estimate of the basic density of the whole disk was determined from the density and shrinkage blocks using the method outlined in Appendix 5.

¹⁰Kingston R.S.T. and Risdon C.J.E. (1961) Shrinkage and Density of Australian and other South-west Pacific Woods. CSIRO Division of Forest Products Technological Paper No. 13. pp. 65. Melbourne

Shrinkage from green to 12% was expressed as a percentage of green dimensions. Unit shrinkages were calculated by dividing the difference in shrinkage between 12% and 5% MC by the change in moisture content.

Variation in timber properties within and between different species will give rise to variation in the expected equilibrium moisture content (EMC). In this case, individual air dry densities and shrinkages (both measured at 12%) were adjusted to 12% using the unit shrinkages for the individual test specimens.

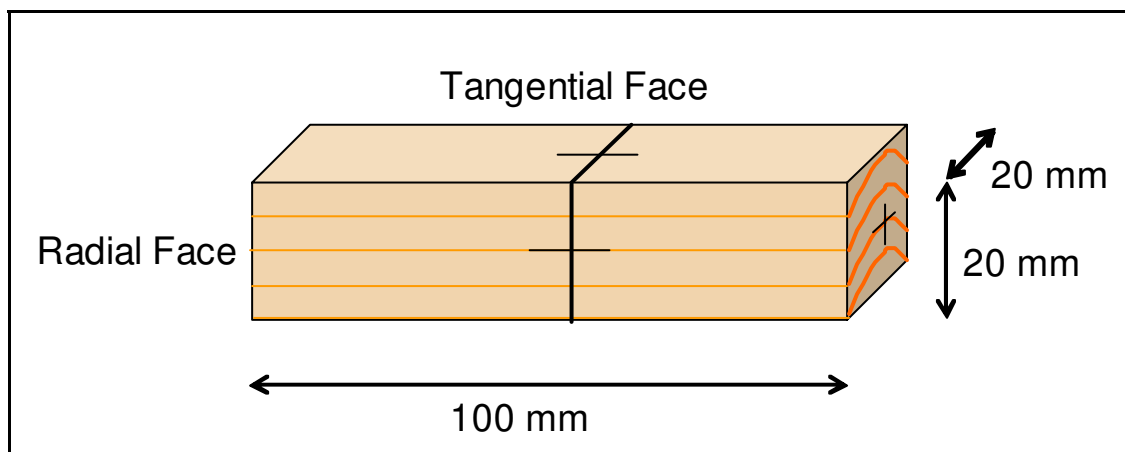


Figure 15: Density and shrinkage block showing measuring points at midpoint on the tangential, radial and longitudinal face.

The position (relative to the pith) that an individual shrinkage specimen came from within the diametrical strip was calculated using the following formula:

$$\text{Relative Position (\%)} = 100 - (\text{AP} - 0.5) / \text{AN} * 100$$

Where: AP = Position number in radial axis counting from the bark (starting at 1) towards the pith.

AN = Total number of samples in radial axis

Samples containing the pith were assigned a value of 0%. For samples containing the pith the tangential and radial measurements were made consistent with the block on either side, even though if the pith was exactly in the centre of the block measurements on both dimensions are deemed to be radial.

Mean density and shrinkage for inner and outer heartwood were calculated by averaging all the blocks included between 20-30% (inner) and 60-80% (outer) of the radius. Table 5 shows the number of sample blocks that were used for the inner and outer heartwood measurements.

Table 5: Number of sample blocks from the inner and outer heartwood locations.

Location	Species	Number of blocks
Inner heartwood (20-30% of distance from pith to bark)	<i>P. brutia</i>	16
	<i>P. canariensis</i>	15
Outer heartwood (60-80% of distance from pith to bark)	<i>P. brutia</i>	23
	<i>P. canariensis</i>	22

Diametrical strips (north-south axis) were machined, to dimensions of 25 mm (tangential) by 25 mm (longitudinal) to include the full tree diameter (Figure 16) from the disks cut from a bottom and a top disk (Figure 14) of the five randomly selected trees for both species. Growth rings were marked and numbered individually on the transverse surface of specimens. The tangential surfaces, within growth rings, of the strips were progressively exposed using a cleaving knife and mallet, proceeding radially from bark to pith.

A digital protractor attached to a fixed platform (Figure 16) was used to measure the grain angle to 0.1°. The protractor was fitted with a clear plastic screen with parallel grid lines that were aligned with the grain direction on the exposed surface. Deviations to the left or right of vertical, were distinguished by positive or negative protractor readings respectively. Measurements from the same growth ring at both ends of the strip were averaged to account for the vertical alignment of the pith.

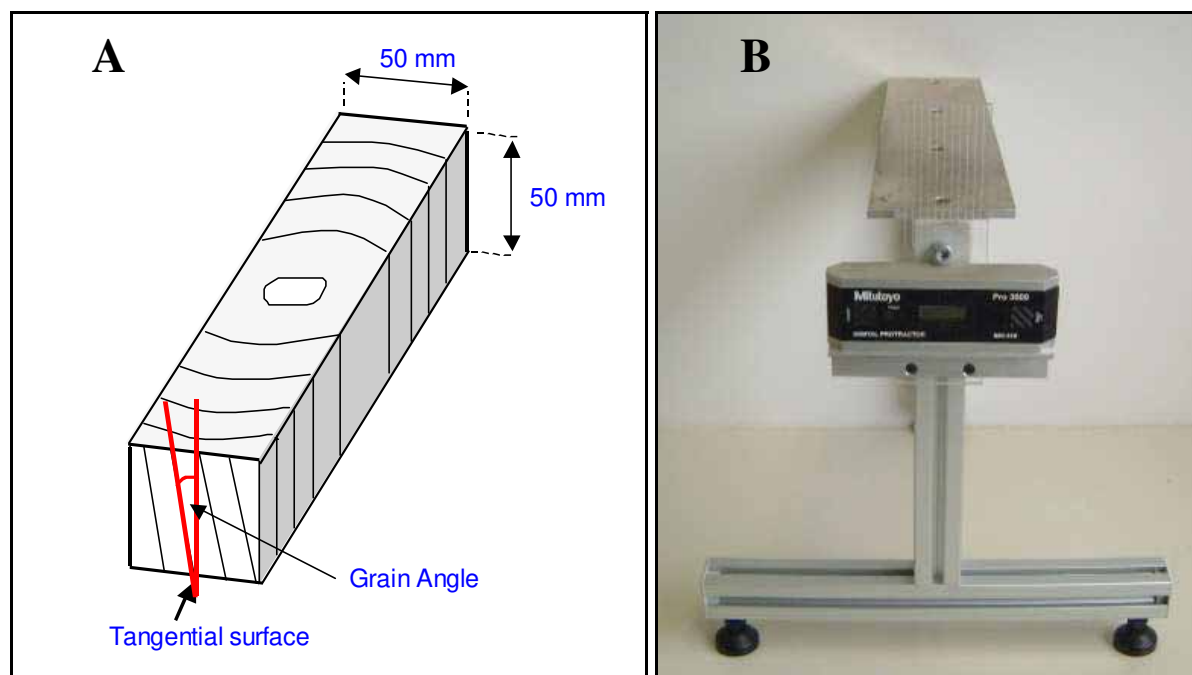


Figure 16: (A) Diametrical strip showing grain angle and (B) the fixed platform and digital protractor used to measure the grain angle.

The thin compression wood slice was placed on a light box to visually identify areas of compression wood. In both species there was little evidence of compression wood found.

4. Results

4.1 Wood density

Basic densities of the woodchip composites representing six trees from each conifer genotype are presented in Table 6 together with the air dry densities from the sawing study for *P. canariensis* and *P. brutia*. The Mainland provenance of *P. radiata* had the lowest basic density and *P. canariensis* the highest basic density. The basic densities of the remaining four samples were all within 24 kg.m⁻³ of each other.

Table 6: Mean basic densities of woodchip composites representing each conifer genotype

Genotype	Basic density kg/m ³	Air dry density kg/m ³
<i>Pinus brutia</i>	465	558
<i>Pinus canariensis</i>	534	647
<i>Pinus radiata</i> (Guadalupe)	444	
<i>Pinus radiata</i> (Cedros)	441	
<i>Pinus pinaster</i>	453	
<i>Pinus radiata</i> (Mainland)	375	
<i>Pinus radiata</i> (Sawmill residues)	445	

4.2 Kraft pulp and paper properties

The kraft pulping properties of the woodchip composites representing six trees from each conifer genotype are presented in Table 7 and illustrated in Figures 17 and 18.

Table 7: Kraft pulping properties of woodchip composites representing each conifer genotype.

Genotype	Active Alkali % Na ₂ O	Total yield %	Kappa no.	Wood consumption m ³ /t a.d. pulp
<i>Pinus canariensis</i> (Canary Island pine)	20.0	54.6	93.4	3.1
<i>Pinus brutia</i> (Brutian/Red/Turkish/Calabrian pine)	17.0	57.1	91.9	3.4
<i>Pinus pinaster</i> (Maritime pine)	18.0	56.5	89.6	3.5
<i>Pinus radiata</i> (Guadalupe)	17.0	56.0	92.3	3.6
<i>Pinus radiata</i> (Cedros)	18.0	56.7	91.6	3.6
<i>Pinus radiata</i> (mainland)	17.0	59.4	92.4	4.0

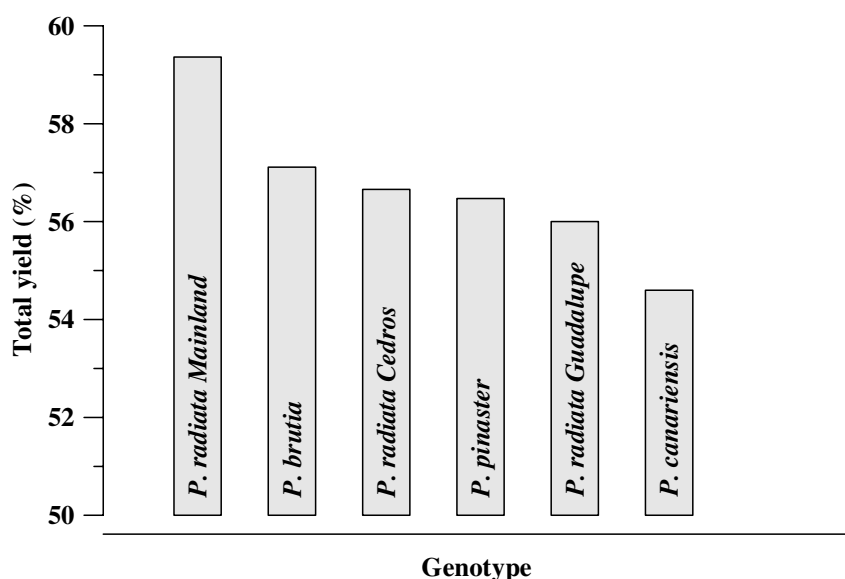


Figure 17: Kraft pulp yield of woodchip composites representing each conifer genotype

The sample with the highest pulp yield was the mainland provenance of *P. radiata*. The sample with the lowest yield was the *P. canariensis*. The pulp yields of the remaining four samples were all within 1.1% of each other.

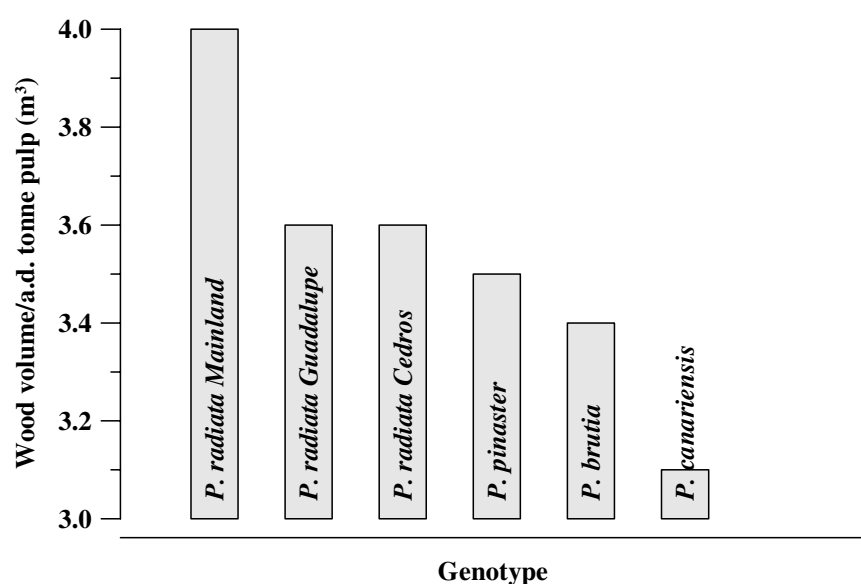


Figure 18: Wood volume required per tonne of pulp

When the pulp yields were combined with the basic densities to calculate the volume of wood required to produce a tonne of air-dry pulp, *P. canariensis* gave the best result and *P. radiata* (Mainland) gave the worst. The remaining samples covered a range of only 0.2 m³.

The papermaking properties of the unbleached kraft pulps are detailed in Appendix 1. Summary data interpolated at 350 mL CSF, or 800 beating revolutions as appropriate, are illustrated in Figures 19-23.

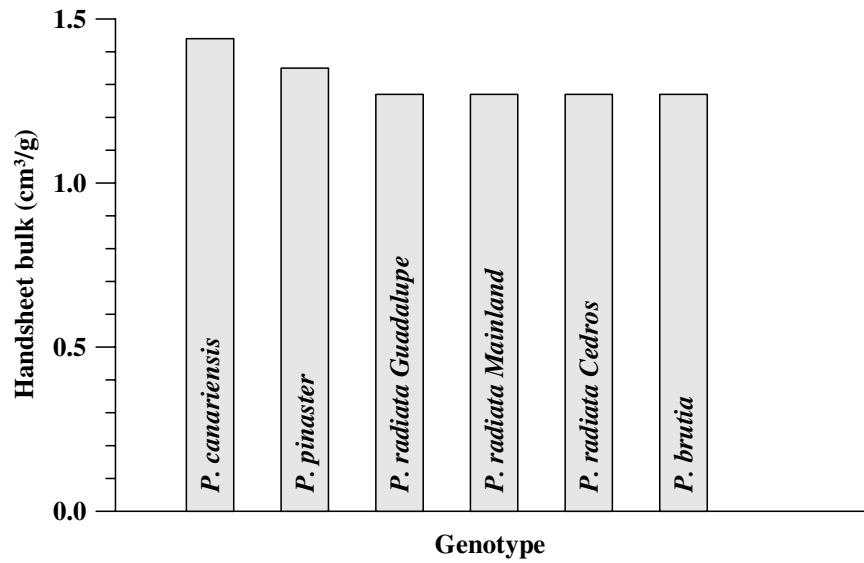


Figure 19: Handsheet bulk at 350 mL CSF

P. canariensis had the highest handsheet bulk, followed by *P. pinaster*. The remaining samples had handsheet bulks that were lower and not appreciably different from each other.

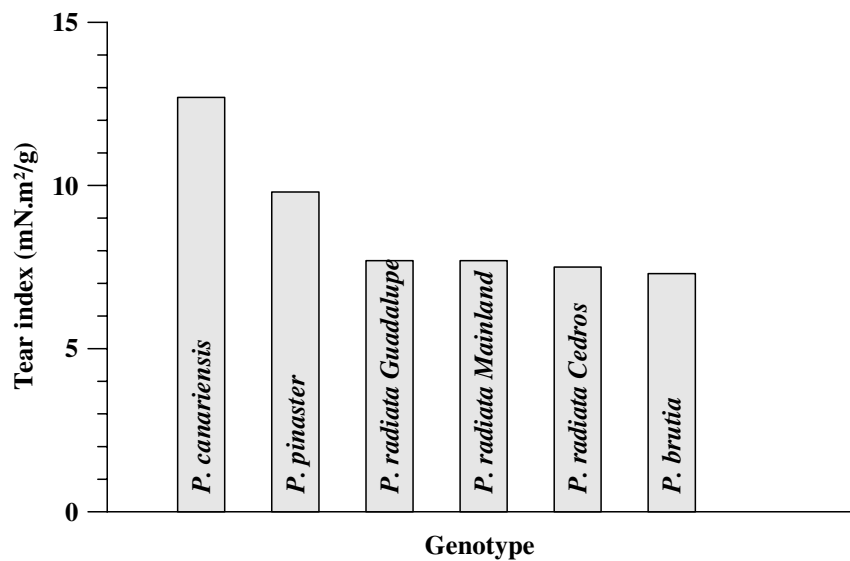


Figure 20: Tear index at 350 mL CSF

The trends in tearing resistance among the samples were similar to those for handsheet bulk, with the highest tear indexes in *P. canariensis*, followed by *P. pinaster*. The remaining samples had tearing resistances lower again and all within half a unit of each other.

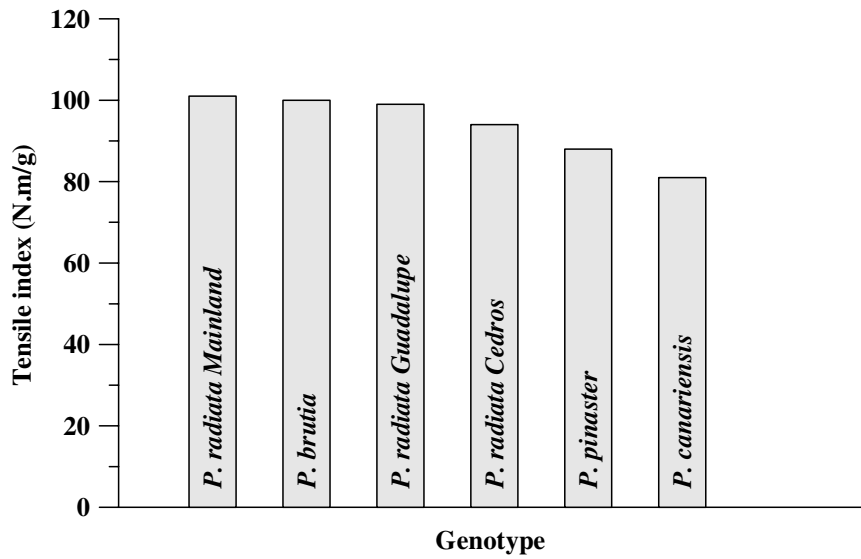


Figure 21: Tensile index at 350 mL CSF

The trends in handsheet tensile strength were almost the inverse of those found in bulk and tearing resistance. The Mainland provenance of *P. radiata* had the highest tensile strength, with those of *P. brutia* and *P. radiata* (Guadalupe) nearly the same. *P. radiata* (Cedros) and *P. pinaster* were each lower again and *P. canariensis* had the lowest handsheet tensile strength of all the samples.

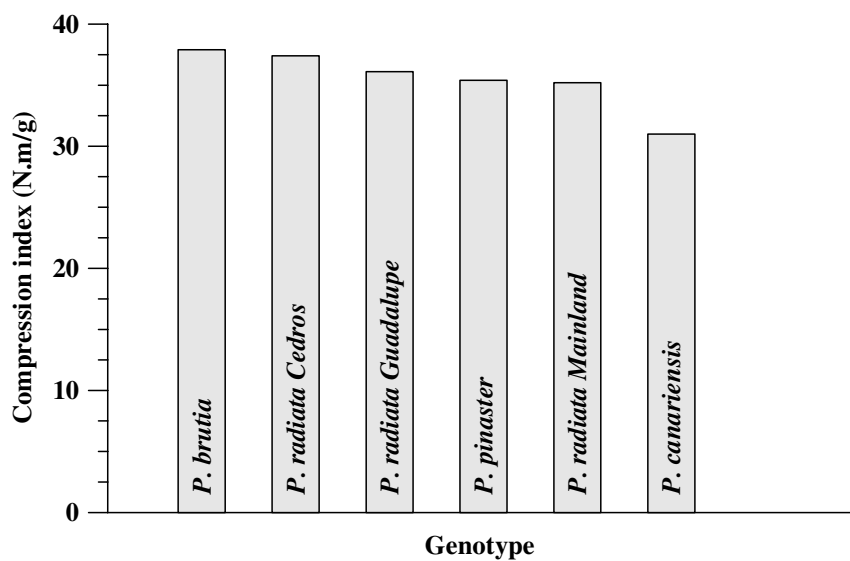


Figure 22: Compression index at 800 beating revolutions

Significant differences in compression index were few, the only large differences being between *P. canariensis* and the remainder of the samples.

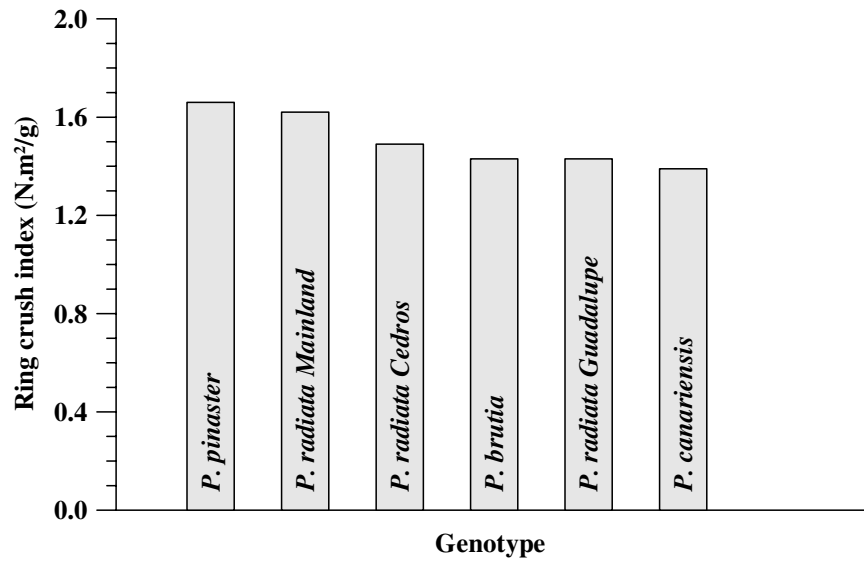


Figure 23: Ring crush index at 800 beating revolutions

P. pinaster and *P. radiata* (Mainland) had the highest ring crush properties. Next was *P. radiata* (Cedros), followed by *P. brutia* and *P. radiata* (Guadalupe). *P. canariensis* had the lowest ring crush index.

4.3 TMP pulp and paper properties

The papermaking properties are detailed in Appendix 2 and illustrated below in Figures 24-30. Pulps have been compared on the basis of related pairs. This method of comparison illustrates the effect of a change in one parameter on the value of another parameter.

It should be noted that the *P. radiata* (Cedros) data for the mid freeness range (about 100 to 300 mL CSF) were considered erroneous and were not used in any of the comparisons. Only 3 data points were therefore available for use, one point at low freeness and two points at high freeness.

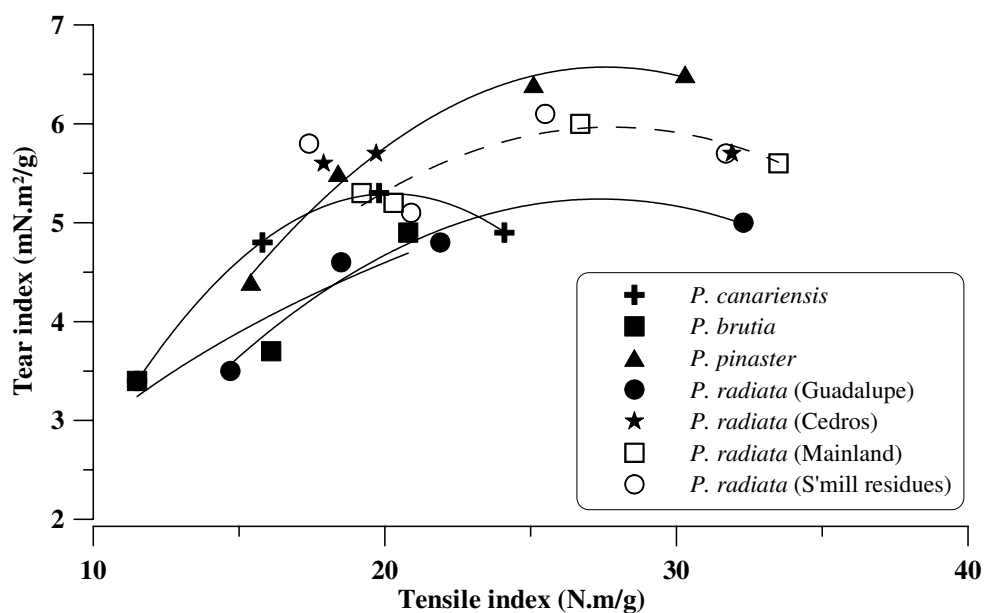


Figure 24: Tear index versus tensile index

The relationship between tear and tensile index is shown in Figure 24. At a tensile index of 25 N.m/g, the *P. pinaster* pulp had a tearing resistance slightly higher than those of the two control samples, which in turn were higher than those of *P. radiata* (Cedros), *P. brutia*, *P. canariensis* and *P. radiata* (Guadalupe).

Overall, the tear indexes were lower than expected. In a previous study (Williams *et al.* 2001), which assessed TMP papermaking properties for *P. radiata* samples from a genetically structured field planting in Tallaganda, ACT, tear strengths at a given tensile strength were generally much higher than those of the dryland conifers. However, the average annual rainfall for the Tallaganda site is 1750 mm, two to three times greater than the rainfall reported for the dryland conifer sites. On the other hand, the low results obtained in the present study for the control samples from high rainfall sites suggest that other factors (e.g. tree genetics) may also have influenced the results.

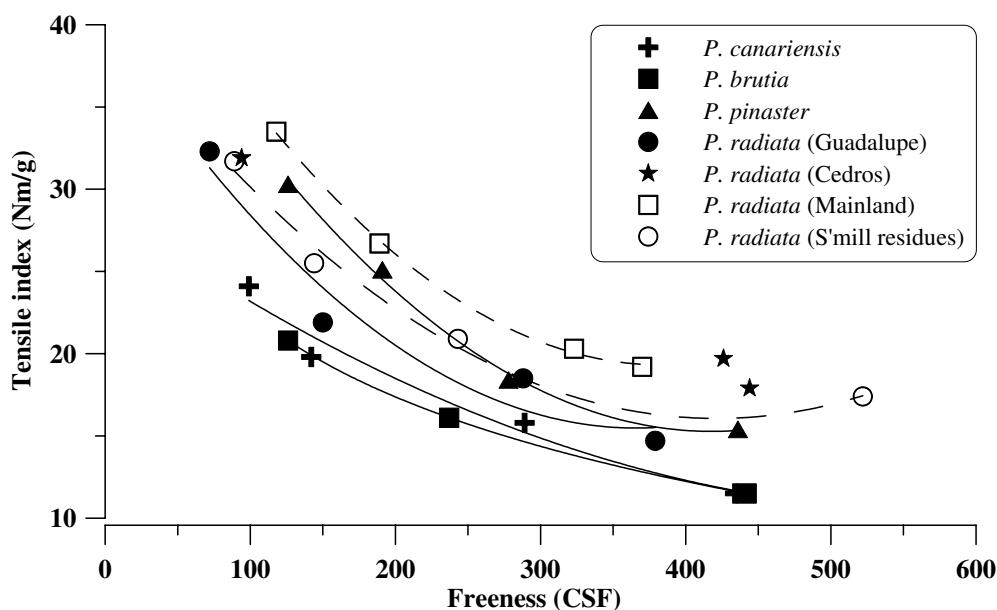


Figure 25: Tensile index versus pulp freeness

Plotting tensile index against freeness (Figure 25), it was evident that the Mainland *P. radiata* control sample had the highest strength, followed by *P. radiata* (Cedros), *P. pinaster* and the *P. radiata* sawmill residue control sample. *P. canariensis* and *P. brutia* developed the lowest tensile strengths. These two species had the highest wood basic densities.

Corson (1991) discusses the relationship between wood basic density and the tensile index of *P. radiata* TMP pulps. Tensile index generally increases as basic density decreases. When the density is high, the wall thickness is usually large. This means that lower density wood will produce pulps with thinner-walled fibres, which will collapse more readily to form flat ribbons with increased fibre-to-fibre contact area. The higher interfibre bonding potential leads to higher pulp tensile strength properties. However, caution must be exercised when comparing species on the basis of basic density alone. Basic density averages out differences in cross-sectional dimensions relevant to refining response and collapse potential rather than differentiating between them (Corson 1999). In other words, woods with different diameter and wall-thickness fibres can have the same basic density.

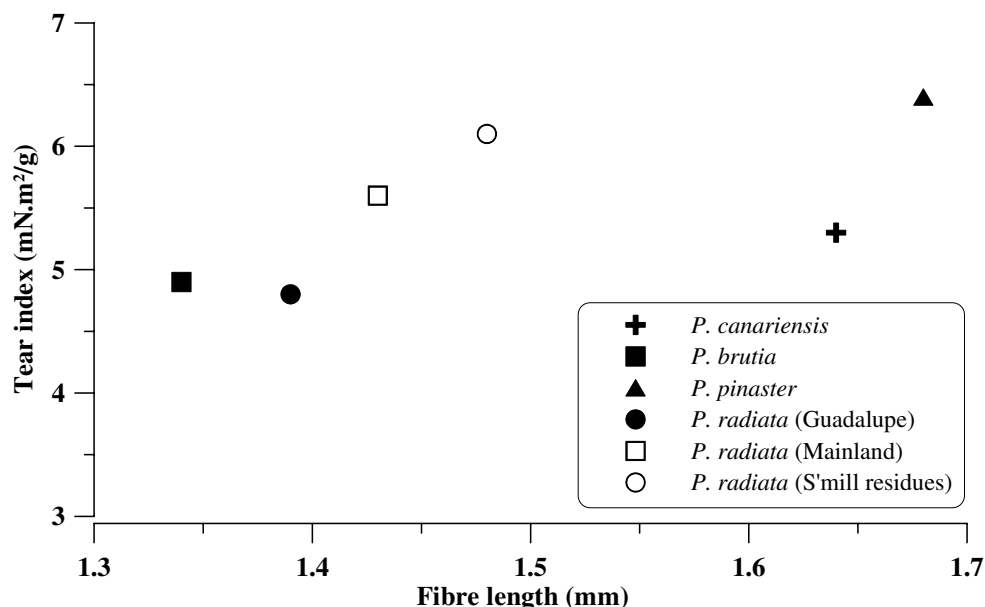


Figure 26: Tearing resistance versus pulp fibre length

The relationship between pulp tearing resistance and fibre length is illustrated in Figure 26. The fibre length of only one pulp from each species was measured, corresponding to the freeness level of newsprint TMP furnish (about 120 mL CSF). The results for *P. radiata* (Cedros) were omitted from this graph because the data were considered erroneous.

Although there was considerable scatter in the results, it was evident that as fibre length decreased tearing resistance tended to reduce. This relationship was expected since there is often a strong correlation between these two parameters. Tearing resistance can be thought of as the work (force x distance) done in breaking and pulling out fibres from paper. Longer fibres mean the distance component of the force by distance equation increases. *P. pinaster* had the longest fibres whereas *P. brutia* had the shortest. The two control samples were between these extremes. Overall, the fibre lengths were considered to be low, even for the control samples. It is possible that fibre damage occurred during pulping or refining, but with only one fibre length measurement from each species, the reasons for the low results cannot be determined with certainty.

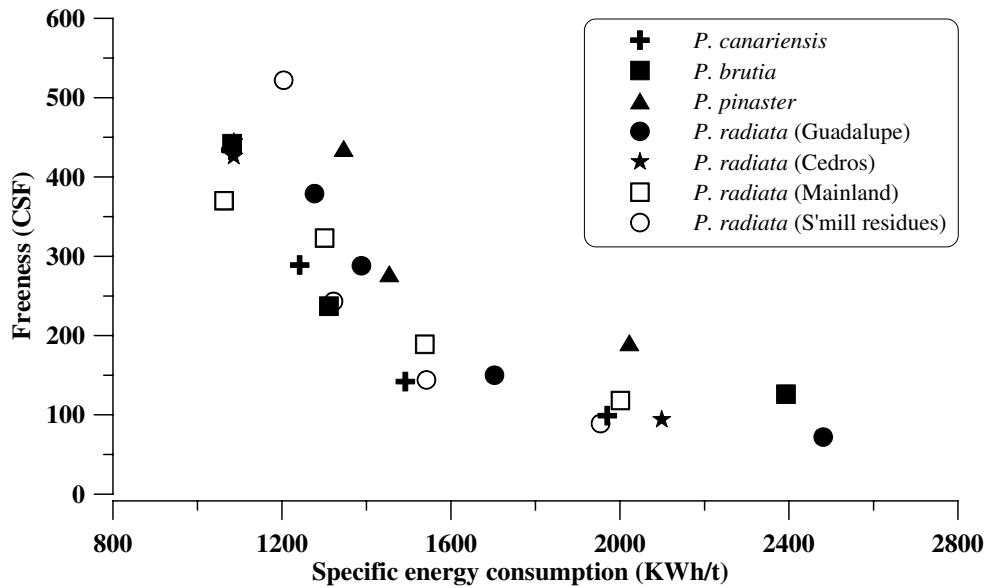


Figure 27: Freeness versus specific energy consumption

Figure 27 illustrates the relationship between energy input and the freeness of the TMP pulps. The dryland conifers required similar energy to the control species to achieve a given freeness. One exception could be *P. pinaster*, whose results gave an (inconsistent) indication of a higher energy requirement.

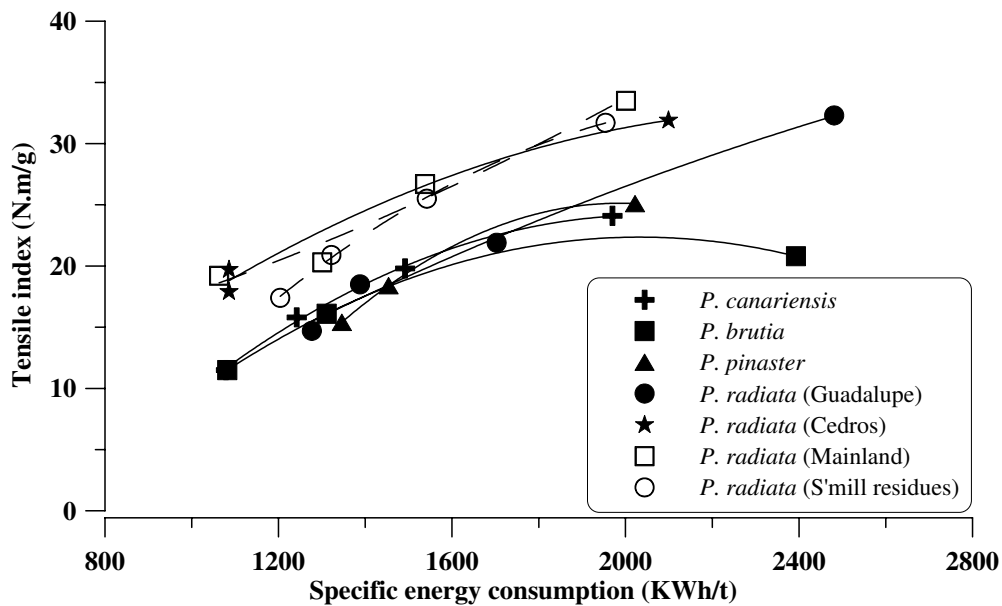


Figure 28: Tensile index versus specific energy consumption

In the graph of tensile index versus energy consumption (Figure 28), it is evident that the control samples of *P. radiata*, as well as *P. radiata* (Cedros), exhibited higher tensile strengths at a given energy input. In other words, it took less energy to refine to a particular tensile strength for these wood samples, the difference being about 15% at a tensile index of 20. Of additional interest is the plot for *P. brutia*, which shows that as the energy was increased, tensile strength was not developed. This interpretation is open to question however, as there was only one point at the higher energy level. A further study is required to confirm this trend.

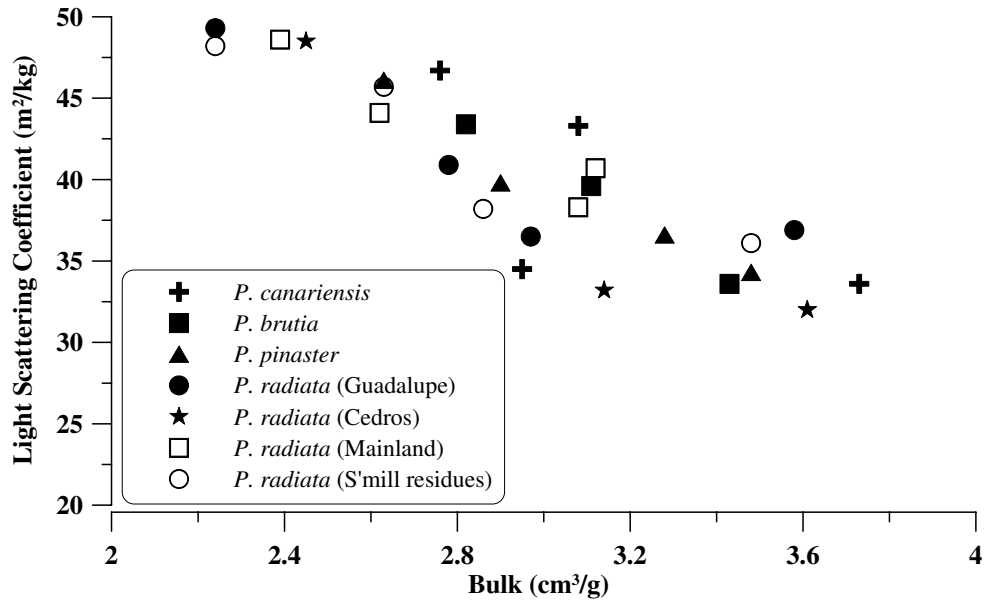


Figure 29: Light scattering coefficient versus bulk

The relationship between light scattering coefficient and bulk is illustrated in Figure 29. The amount of light scattered by a paper sheet is an important quality parameter in papermaking, particularly for publication grades where a higher scattering coefficient means less filler is required to achieve a target paper opacity. The differences between species may provide an indication of differences in fibre cross-section (McKenzie 1994). Allowing for some data scatter, it is evident that *P. canariensis* had a higher sheet bulk than the other species at the same scattering coefficient. This is to be expected since a higher density wood, with thicker-walled fibres, will not collapse and conform to the same extent as a lower density wood and will therefore have a higher sheet bulk.

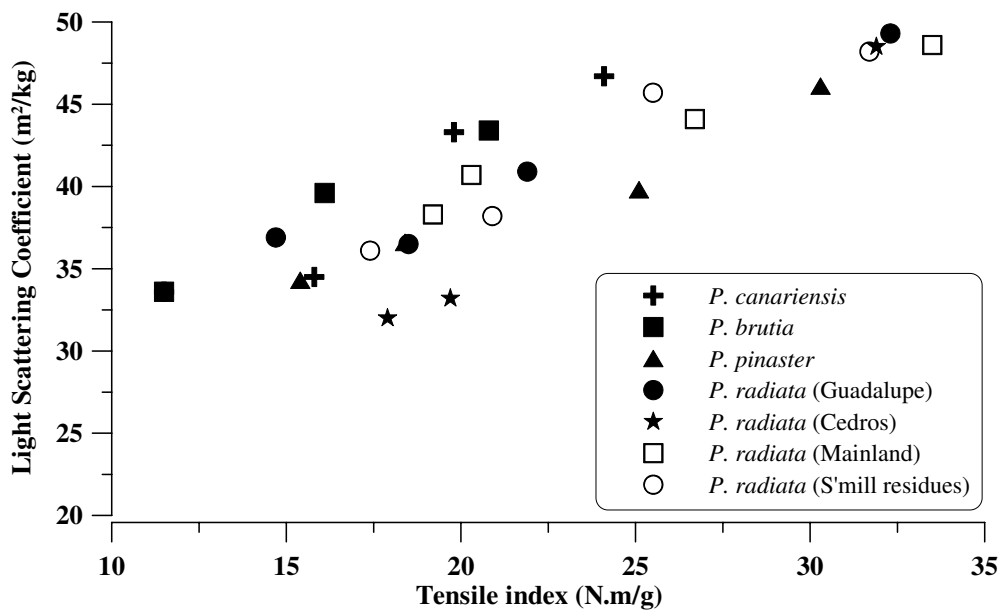


Figure 30: Light scattering coefficient versus tensile index

Plotting scattering coefficient against tensile index (Figure 30), it is evident that the species with the highest basic density, *P. canariensis*, had one of the highest scattering coefficients, equal with *P. brutia* (the sample with the second highest basic density). A previous study of *P. radiata* (Corson 1999) found that scattering coefficient increased with tensile index as basic density decreased.

Further, scattering coefficient and sheet smoothness benefited from a decrease in fibre wall thickness and perimeter. In other words, higher density wood with thicker wall fibres produced paper with fewer surfaces to scatter light and so a lower scattering coefficient. The results obtained for *P. brutia* and *P. canariensis* in this study appear to conflict with Corson's findings for *P. radiata*. In the present study, it is possible that the additional refining required for pulps produced from high-density woods to reach a given tensile strength has resulted in the generation of more fines, leading to a higher scattering coefficient. The data presented in Figure 25 supports this interpretation, with the pulps produced from the two high-density woods having much lower freeness at the same tensile index.

4.4 MDF properties

Fibre buffering capacities and initial fibre pH are shown in Table 8 along with individual acid and base buffering capacities.

The results showed very little variation between species/provenances and little variation in comparison to the commercial *P. radiata* sample from North Eastern Victoria. From these results one would not expect any residual acidic or basic compounds in the MDF furnish to interfere with UF resin cure.

The flexural properties of finished panels are shown in Table 9 and represent the mean of two tests per panel for each of the three replicate panels per species/provenance.

Table 8: Buffering capacities and initial pH of dryland conifers species/provenances.
Data are the average of two determinations.

Species	Initial pH	ABC	BBC	FBC
		mmol/g	mmol/g	mmol/g
<i>P. radiata</i> (commercial)	4.2	0.0643	0.1026	0.1669
<i>P. radiata</i> (Mainland)	3.9	0.0778	0.0981	0.1759
<i>P. radiata</i> (Guadalupe)	4.0	0.0825	0.0806	0.1631
<i>P. radiata</i> (Cedros)	3.9	0.0758	0.1206	0.1963
<i>P. brutia</i>	4.2	0.0776	0.1275	0.2051
<i>P. canariensis</i>	3.9	0.0823	0.0725	0.1548
<i>P. pinaster</i>	4.0	0.0678	0.1001	0.1679

Comparing the dryland conifer data in Table 9 with that for the control *P. radiata* (commercial and Mainland), very similar results were obtained for all species/provenances. A small variation was found for Mainland *P. radiata* and a smaller variation in *P. pinaster*. Small variations in the moisture content of pre-pressed mattresses would largely account for such observed differences.

Internal bond strengths in Table 10 are shown as ranges rather than individual values due to this test resulting in variability (as in other forest product laboratories) between panels within species/provenances. Bond strengths appeared to be similar for all species, with no test species being significantly inferior to the two radiata controls.

Table 9: MOR and MOE of MDF panels

Species	Panel Density (kg/m ³)	MOR (MPa)	MOE (MPa)
<i>P. radiata</i> (commercial)	776 (10 [#])	37.0 (3.4*)	3420 (132*)
<i>P. radiata</i> (Mainland)	752 (12)	28.6 (2.7)	2930 (204)
<i>P. radiata</i> (Guadalupe)	758 (5)	37.1 (3.1)	3130 (256)
<i>P. radiata</i> (Cedros)	764 (16)	37.7 (3.1)	3170 (161)
<i>P. brutia</i>	757 (9)	36.0 (5.2)	3260 (154)
<i>P. canariensis</i>	767 (15)	38.4 (2.1)	3410 (191)
<i>P. pinaster</i>	757 (11)	32.1 (1.6)	2890 (135)

[#] Standard deviation n=3

* Standard deviation n=6

Table 10: Internal bond strength of MDF panels given in ranges for each species/provenance

Species	Internal Bond Strength (Range - kPa)
<i>P. radiata</i> (commercial)	300-435
<i>P. radiata</i> (Mainland)	215-280
<i>P. radiata</i> (Guadalupe)	280-435
<i>P. radiata</i> (Cedros)	315-360
<i>P. brutia</i>	350-460
<i>P. canariensis</i>	250-370
<i>P. pinaster</i>	230-280

Results for the total immersion of test coupons in water for 24 hours are shown in Table 11 in the form of thickness swell and total water absorption, by weight, in that time. All dryland species/provenances gave comparable performance to the control species.

Table 11: Thickness swell and water absorption for MDF panels

Species	Thickness Swell (%)	Water Absorption (%)
<i>P. radiata</i> (commercial)	9.7 (0.6)	26.7 (2.4)
<i>P. radiata</i> (Mainland)	11.0 (0.5)	38.0 (2.5)
<i>P. radiata</i> (Guadalupe)	9.7 (1.3)	29.6 (3.2)
<i>P. radiata</i> (Cedros)	9.2 (0.6)	29.4 (2.6)
<i>P. brutia</i>	8.8 (0.8)	24.2 (2.4)
<i>P. canariensis</i>	8.6 (0.8)	25.7 (1.9)
<i>P. pinaster</i>	10.2 (0.8)	29.8 (2.7)

The results for colour difference between the commercial *P. radiata* and dryland pines are shown in Table 12. Colour difference, ΔE , is a mathematical indicator of change rather than a visual aid and to this end the Hunter whiteness index indicates that the dryland pines were less white than the control panel.

Table 12: Colour difference measurements on finished MDF panels

Control	Species	Colour Difference* (ΔE)	Colour Change (Hunter whiteness index)
<i>P. radiata</i> (commercial)	<i>P. radiata</i> (Mainland)	3.3	-2.07 Less white
	<i>P. radiata</i> (Guadalupe)	2.7	-6.12 Less white
	<i>P. radiata</i> (Cedros)	4.4	-6.39 Less white
	<i>P. brutia</i>	2.3	-5.26 Less white
	<i>P. canariensis</i>	5.6	-7.87 Less white
	<i>P. pinaster</i>	2.0	-4.66 Less white

* Based on the mean of 5 measurements.

It is likely that the colour differences observed in this work would not be a significant impediment to product acceptance in the majority of domestic and overseas markets.

4.5 Extractives contents

The % acetone extractives, free fatty acids, resin acids and glycerides are summarised for individual samples in Table 13. The data in Table 14 summarises the statistics obtained by averaging the data for all samples analysed within each species, and are ranked according to their average % extractives. Data from the analysis of extractives in *Pinus radiata* chips used at the Albury mill between 1996 and 1997 are also included in Table 14. The data for all samples is displayed graphically in Figures 31-36. The following discussion will separately compare the % acetone extractives and composition data for the samples.

Table 13: Total acetone extractives, free fatty acids, resin acids and glycerides in dry-land pine species.

Results quoted as average standard deviation (n=2).

Wood Sample	Acetone Extractives (%)	Free Fatty Acids (% on od Wood)	Resin Acids (% on od Wood)	Glycerides (% on od Wood)
<i>Pinus brutia</i> - SA - 1	9.17±0.25	0.15±0.07	5.80±2.42	0.63±0.27
<i>Pinus brutia</i> - SA - 2	7.09±0.08	0.05±0.02	1.89±0.46	0.28±0.13
<i>Pinus brutia</i> - SA - 3	7.60±0.17	0.05±0.01	1.76±0.06	0.24±0.02
<i>Pinus canariensis</i> - SA - 1	7.22±0.12	0.05±0.01	2.10±0.41	0.35±0.11
<i>Pinus canariensis</i> - SA - 2	7.07±0.32	0.05±0.01	2.21±0.46	0.46±0.09
<i>Pinus canariensis</i> - SA - 3	7.60±0.06	0.08±0.01	1.97±0.08	1.31±0.03
<i>Pinus radiata</i> Cedros - SA - 1	6.68±0.30	0.05±0.01	1.25±0.07	0.26±0.02
<i>Pinus radiata</i> Cedros - SA - 2	6.56±0.00	0.04±0.00	1.26±0.01	0.09±0.01
<i>Pinus radiata</i> Cedros - SA - 3	5.50±0.15	0.05±0.00	0.99±0.04	0.04±0.00
<i>Pinus radiata</i> - Tallaganda - NSW - 1	5.65±0.05	0.22±0.02	1.73±0.04	0.38±0.04
<i>Pinus radiata</i> - Tallaganda - NSW - 2	3.08±0.01	0.06±0.01	0.56±0.02	0.25±0.01
<i>Pinus radiata</i> - Tallaganda - NSW - 3	2.28±0.00	0.05±0.00	0.30±0.04	0.13±0.02
<i>Pinus radiata</i> - Guadalupe Prov. - 1	6.19±0.04	0.07±0.00	1.41±0.06	0.19±0.00
<i>Pinus radiata</i> - Guadalupe Prov. - 2	7.07±0.01	0.08±0.00	1.54±0.03	0.16±0.00
<i>Pinus radiata</i> - Guadalupe Prov. - 3	7.86±0.11	0.09±0.01	1.69±0.10	0.15±0.01
<i>Pinus pinaster</i> - 1	3.83±0.04	0.04±0.00	0.39±0.04	0.48±0.23
<i>Pinus pinaster</i> - 2	2.95±0.11	0.04±0.00	0.34±0.02	0.33±0.06
<i>Pinus pinaster</i> - 3	3.71±0.05	0.05±0.00	0.39±0.01	0.38±0.05

Table 14: Summary statistics for each dryland conifer species.

Extractives levels in *Pinus radiata* chips used at Albury mill between 1996 and 1997 are included for reference.

Results quoted as average $\pm$ standard deviation (n=6 for this study and n=50 for Albury mill results).

Wood Species	Acetone Extractives (%)	Free Fatty Acids (% on od Wood)	Resin Acids (% on od Wood)	Glycerides (% on od Wood)
<i>Pinus brutia</i> SA	7.96 $\pm$ 0.98	0.09 $\pm$ 0.06	3.15 $\pm$ 2.33	0.38 $\pm$ 0.24
<i>Pinus canariensis</i> SA	7.29 $\pm$ 0.29	0.06 $\pm$ 0.02	2.10 $\pm$ 0.30	0.70 $\pm$ 0.48
<i>Pinus radiata</i> Guadalupe	7.04 $\pm$ 0.75	0.08 $\pm$ 0.01	1.54 $\pm$ 1.14	0.16 $\pm$ 0.02
<i>Pinus radiata</i> Cedros SA	6.24 $\pm$ 0.60	0.05 $\pm$ 0.01	1.17 $\pm$ 0.14	0.13 $\pm$ 0.10
<i>Pinus radiata</i> Tallaganda NSW	3.67 $\pm$ 1.58	0.11 $\pm$ 0.09	0.86 $\pm$ 0.68	0.25 $\pm$ 0.11
<i>Pinus pinaster</i>	3.50 $\pm$ 0.43	0.04 $\pm$ 0.01	0.37 $\pm$ 0.04	0.40 $\pm$ 0.13
<i>Pinus radiata</i> Albury mill '96-'97	2.17 $\pm$ 0.39	0.14 $\pm$ 0.08	0.37 $\pm$ 0.14	0.21 $\pm$ 0.12

The precision of the duplicate analyses of the % acetone extractives was well within acceptable limits, with the relative standard deviation varying from 0% to 4.5%. There were differences both within and between species with respect to the relative amounts of acetone extractives. *Pinus brutia*, *Pinus canariensis*, *Pinus radiata* Guadalupe, and *Pinus radiata* Cedros all exhibited % acetone extractives levels approximately double that of the *Pinus radiata* Tallaganda and *Pinus pinaster* species and approximately treble the levels found in *Pinus radiata* used at the mill between 1996 and 1997. The *Pinus radiata* Tallaganda samples showed significantly higher sample to sample variation in % extractives (relative standard deviation of 43%) than any of the other samples.

Apart from the results for the *Pinus brutia* SA 1 and 2 samples and the *Pinus canariensis* SA 1 and 2 samples, duplicate analyses for free fatty acids, resin acids and glycerides were generally within the precision limits expected for this type of analysis. The sample to sample variation was high for all components in *Pinus brutia* and *Pinus radiata* Tallaganda and glycerides in *Pinus canariensis* and *Pinus radiata* Cedros.

Generally the free fatty acid levels in all species were low compared to either the resin acid or glyceride levels. The average amount and the variation between samples was not too different for the fatty acids in the six species to that in the mill feed wood. By contrast, the variation in the resin acid levels between species varied by almost a factor of 10 from *Pinus pinaster* at 0.37% to *Pinus brutia* at 3.15% resin acids. Of significant note is that the *Pinus radiata* species examined in this study were much higher in resin acid content than the feedstock to the Albury mill, ranging from more than double (*Pinus radiata* Tallaganda NSW) to four times (*Pinus radiata* Guadalupe) that of the average mill feedstock value of 0.37%. The variation in glyceride levels was not as pronounced as for the resin acids with levels varying from 0.13% in *Pinus radiata* Cedros to 0.70% in *Pinus canariensis*. This compares to an average value in mill feedstock of 0.21%.

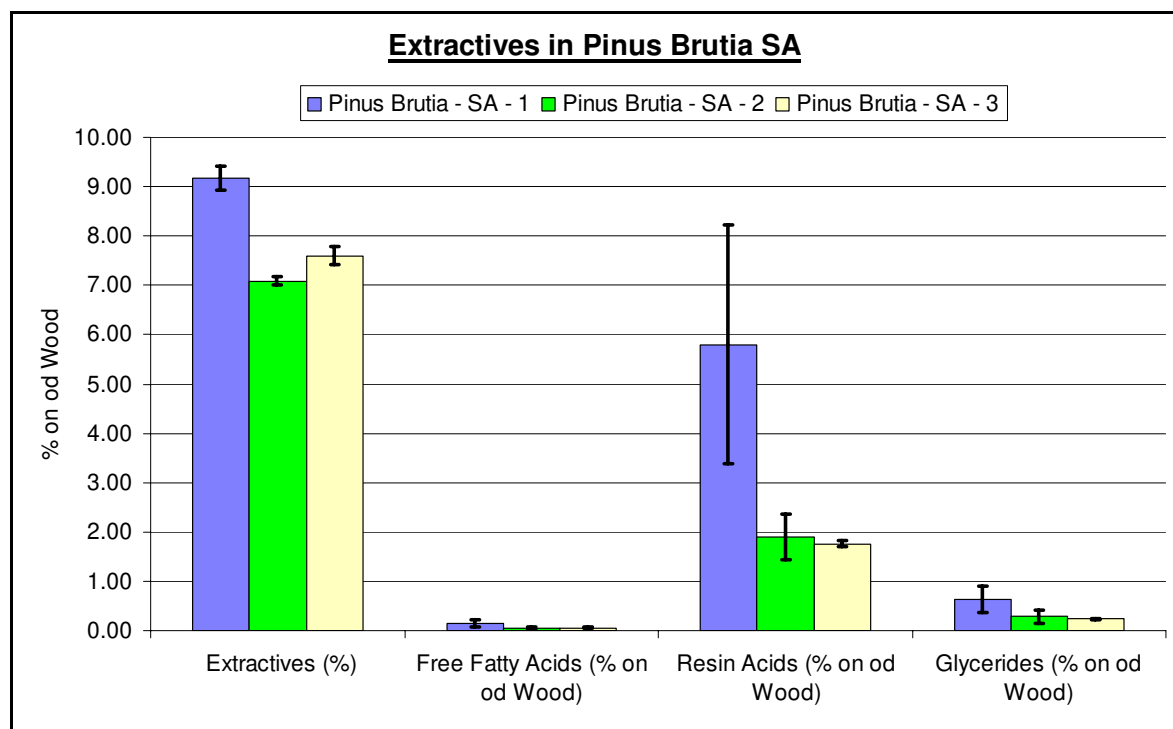


Figure 31: Extractives in *Pinus brutia*

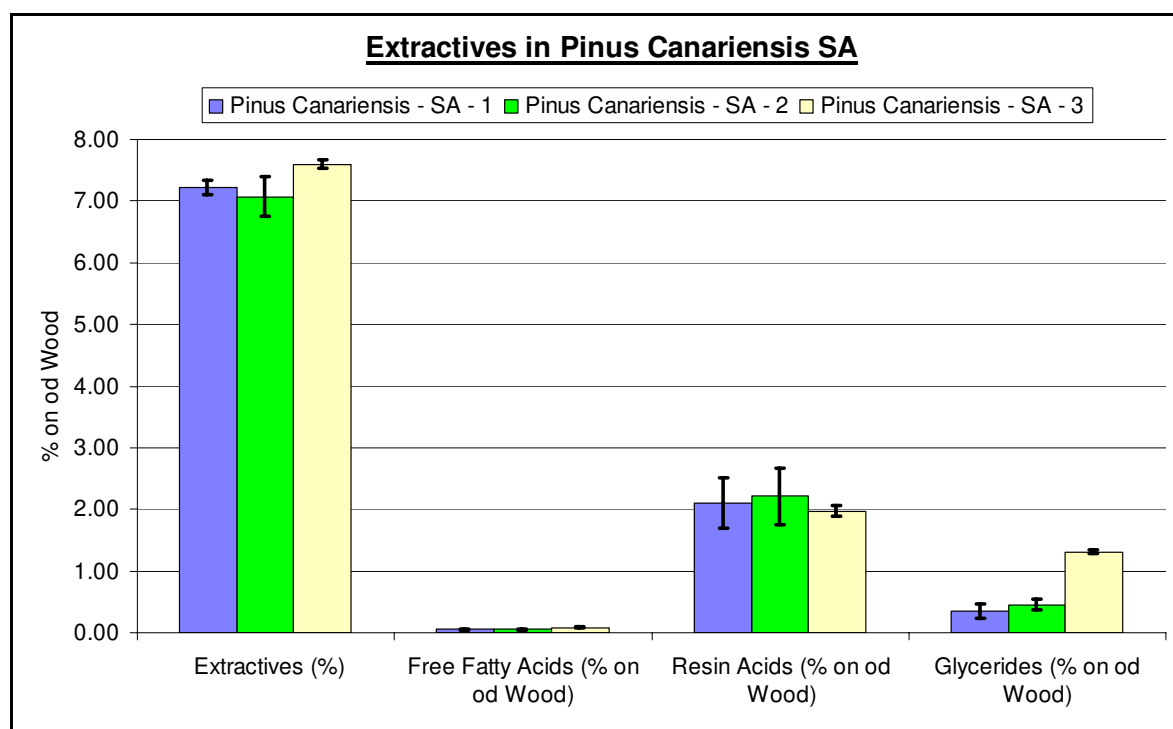


Figure 32: Extractives in *Pinus canariensis*

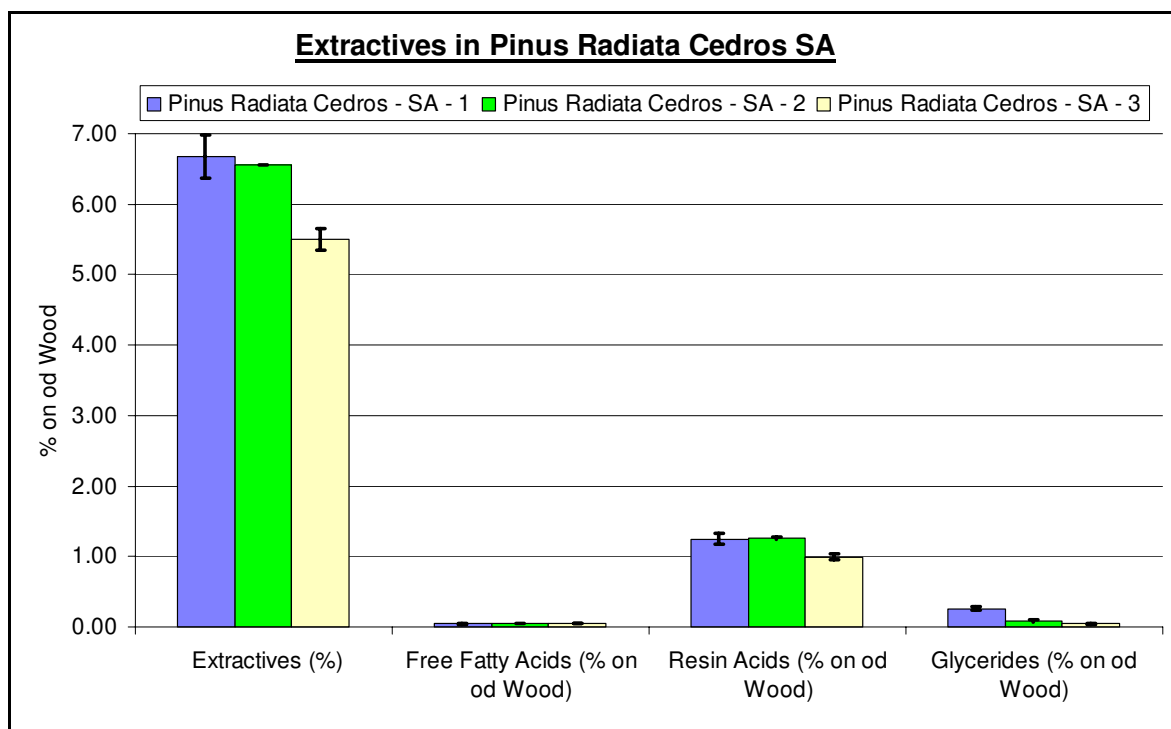


Figure 33: Extractives in *Pinus radiata* (Cedros).

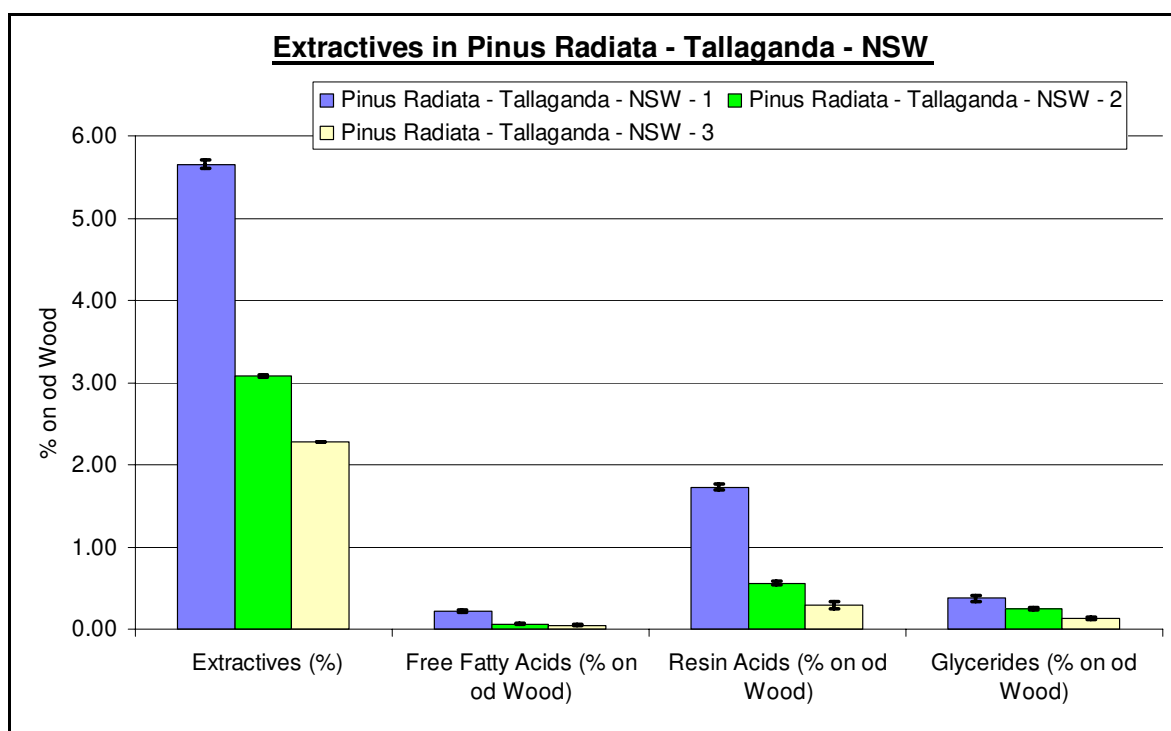


Figure 34: Extractives in *Pinus radiata* (Tallaganda)

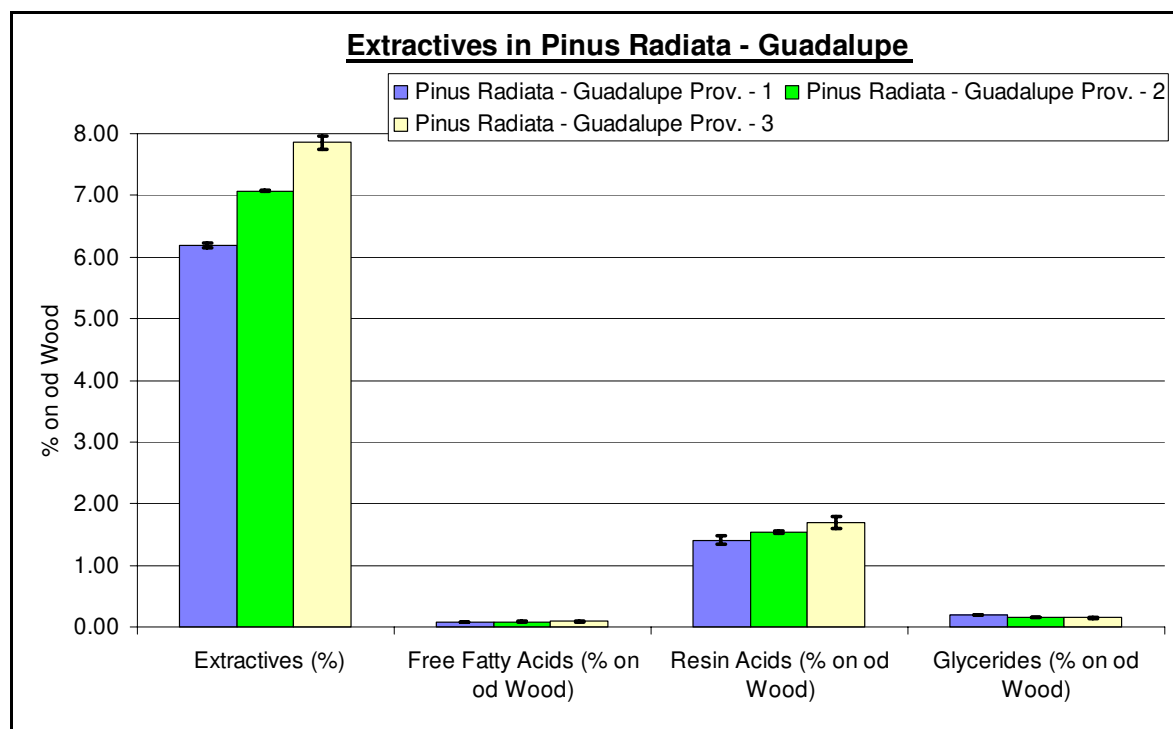


Figure 35: Extractives in *Pinus radiata* (Guadalupe)

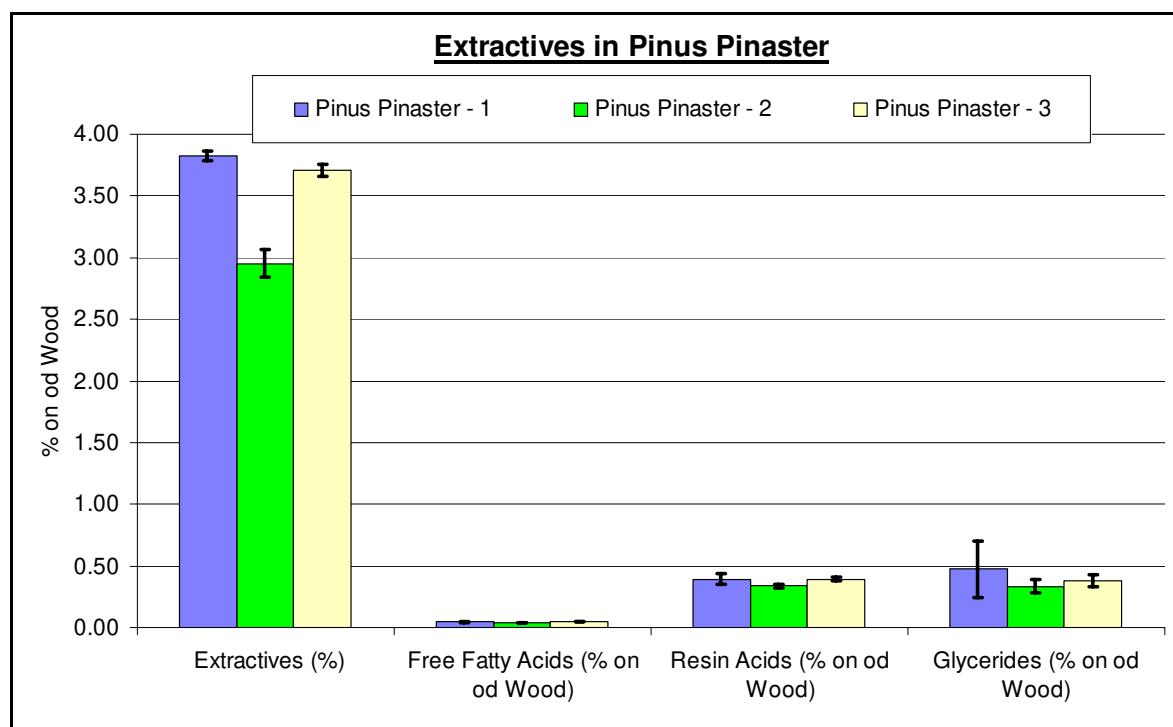


Figure 36: Extractives in *Pinus pinaster*

4.6 Sawn timber properties

Table 15 summarises the tree and log data for the twenty sample trees of each species. It can be seen that despite the larger size of the *P. brutia* logs, small end diameters being 6 cm bigger on average, the green off saw (G.O.S.) recovery was slightly lower for *P. brutia* than for *P. canariensis*. This was probably because of greater sweep in the *P. brutia* logs. The density information presented in this table is only for these structural dimension boards. Within and between tree density variation is dealt with more thoroughly in the following section on density and shrinkage.

About 75% of the *P. brutia* boards were machine stress graded (MSG) as F5 (using settings for *P. radiata*) with most of the rest being F8 and a small number of F4 (Table 16). In contrast, over 20% of the *P. canariensis* boards were F4 or reject, but over 20% of the boards also made F11. Knots were the most obvious problem with both species although some undersizing and distortion was also present. Visual stress grading resulted in about 75% of boards being rejected for both species. Most boards were rejected because of knots. Figure 37 shows the typical knot characteristics of both species. If visual grading were to be pursued, allowances for these particular species, similar to those for cypress pine and hoop pine, would need to be developed.

All the boards from the wings were dried, machined and appearance graded (Table 17). Neither species produced any full length clear grade boards. Mirroring the results of the structural grading, *P. canariensis* produced a higher percentage of select grade material but also produced a higher percentage of reject material than *P. brutia*. The percentage of clear material (in 30 cm increments) that could be cut for both species was higher for *P. canariensis* than for *P. brutia*. This is again a reflection of the longer internodal branching characteristics of *P. canariensis*.

In-grade test results for both species are summarised in Table 18. The strength properties (MOR) of both species was lower than required for the respective F-grades the boards were graded to, and well short of the figures for the equivalent MGP *P. radiata* grades. The stiffness (MOE) of both species exceeded the requirements for the respective F-grades, *P. canariensis* also exceeded the values of the corresponding MGP grades for *P. radiata*.

It should be borne in mind that the in-grade strength results are very sensitive to small sample sizes as was the case with this study and this affects the 5th percentile values used to calculate characteristic and basic working stresses. Moreover, with all the structural boards coming from the central cant, the sampling was biased towards the pith material (Figure 38). Even so, especially for *P. brutia* it is likely that the MSG parameters (grading modulus) used to grade the boards would need to be altered so that a percentage of boards were graded one grade lower to bring the within-grade strength characteristics up to the required level. Further in-grade testing on larger sample sizes would also be required to provide more reliable estimates of the characteristic properties for both *P. canariensis* and *P. brutia*.

A summary of the clearwood properties for *P. canariensis* and *P. brutia* is given in Table 19 showing the mean values for bending strength and stiffness, compression strength, Janka hardness, density and the moisture content at time of testing. Also given are the Strength Group classifications for the two species as derived according to the Australian and New Zealand Standard AS/NZS 2878:2000¹¹. Based on the combined values of bending strength and stiffness, the Strength Group of a species is important as this affects utilisation in respect to visual assignment of F-grades.

The results show *P. canariensis* to be superior to, whilst *P. brutia* is comparable to *P. radiata* in strength and stiffness properties. This is reflected in the overall Strength Group for *P. canariensis*

¹¹ AS/NZS 2878:2000 Timber - Classification into strength groups, Standards Australia

(SD5) being is one strength group higher than either *P. brutia* (SD6) or *P. radiata* (SD6 - AS 2858¹² or AS/NZS 2878¹¹).

Interestingly, the clearwood results showed bending strength not to be an issue compared to stiffness, as indicated by the preliminary Strength Groups in Table 19. In both cases, the preliminary Strength Group based on bending strength was two strength groups higher than that based on bending stiffness, ie., SD4 v SD6 for *P. canariensis* and SD5 v SD7 for *P. brutia*. This is in contrast to the result obtained from in-grade testing, where the characteristic bending strength was lower than required for the respective F-grades the boards were graded to. This suggests that ultimately, it will be the strength reducing characteristics such as knots that will govern the quality and performance of the product. In determining the Strength Group of a species, it is the mean bending strength or stiffness value that is critical. Whereas, in determining the in-grade strength characteristics, it is the lower percentile strength values as influenced by the size and type of knots that are important.

The Janka hardness given in Table 19 indicates a reasonably high value (5.2 kN) for *P. canariensis* making the species quite suitable for flooring timber. This is not unexpected given the relatively high density compared with other conifers. The hardness for *P. brutia* (3.8 kN) was more comparable to *P. radiata* (3.3 kN, cf Bootle¹³).

Figure 39 shows the above clearwood properties (bending strength & stiffness, compression strength and hardness) in relation to board position. For *P. canariensis*, the clearwood properties all appeared to increase with distance from the pith, whereas for *P. brutia* the same properties were more uniform across the growth rings. It was not entirely obvious why there was a difference in the radial variation between the two species; however, the results here are consistent with the density profiles noted elsewhere in this report.

¹² AS 2858:2001 Timber- Softwood- Visually stress-graded for structural purposes, Standards Australia.

¹³ Bootle, K.R., 1983. Wood in Australia – types properties and uses. McGraw-Hill, Sydney.

Table 15: Tree and log measurements of selected trees for both species and a summary of the sawn board dimensions

			<i>P. canariensis</i>			<i>P. brutia</i>		
			Mean		SD	Mean		SD
Log details								
No. trees	-		20		-	20		-
Tree Height	(m)		23.3		1.6	21.0		1.2
Bole Height	(m)		19.1		2.1	16.4		1.5
Large End Diameter	(cm)		31.7		3.1	33.8		4.6
Small End Diameter	(cm)		26.1		2.5	32.2		4.7
DBHUB	(cm)		29.5		3.0	27.5		3.6
Log Length	(m)		3.91		0.15	3.97		0.16
Log Volume	(m ³)		0.261		0.041	0.303		0.094
Volume of sawn boards (nominal green dimensions)	(m ³)		0.156		0.041	0.176		0.069
Green off saw recovery (nominal green dimensions)	(% of log volume) (Smalian's)		59.5		4.7	57.4		5.7
Nominal Green Dimension Boards	Thickness (mm)	Width	Count	Volum e (m ³)	% (by volume)	Count	Volume (m ³)	% (by volume)
	43	103	97	1.675	53.5	100	1.763	50.0
	28	103	86	0.970	31.0	102	1.179	33.5
		84	25	0.229	7.3	27	0.255	7.2
		53	32	0.184	5.9	34	0.201	5.7
	18	103	10	0.072	2.3	17	0.125	3.5
			250	3.129		280	3.523	

Table 16: Summary of information on structural boards (90 x 35 mm) from the central cant of logs

Variables	Units	<i>P. canariensis</i>		<i>P. brutia</i>	
		Mean	SD	Mean	SD
No Boards	-	97	--	98	-
Mean Basic Density	(kg/m ³)	550	<i>53.1</i>	499	<i>58.7</i>
Density (weight and volume at time of strength testing)	(kg/m ³)	669	<i>54.4</i>	577	<i>40.5</i>
Moisture Content (resistance meter - corrected using <i>P. canariensis</i> correction for both species)	(%)	10.1	<i>0.64</i>	10.1	<i>0.8</i>
Mean Stiffness (Machine Stress Graded Mean Board MOE)	(GPa)	10.87	<i>3.67</i>	9.07	<i>1.27</i>
Average Min Stiffness (Machine Stress Graded Minimum Board MOE)	(GPa)	8.53	<i>3.29</i>	7.70	<i>1.13</i>
Mean In-grade Stiffness (MOE)	(GPa)	11.95	<i>3.81</i>	9.42	<i>1.61</i>
Mean In-grade Strength (MOR)	(MPa)	47.8	<i>28.4</i>	36.7	<i>17.9</i>
		%	<i>Count</i>	%	<i>Count</i>
Machine Stress Grading (using <i>P. radiata</i> settings)	Reject	10.4	<i>10</i>		
	F4	11.5	<i>11</i>	2.0	<i>2</i>
	F5	30.2	<i>29</i>	74.5	<i>73</i>
	F8	27.1	<i>26</i>	23.5	<i>23</i>
	F11	20.8	<i>20</i>		
Visual Stress Grading SD5 for <i>P. canariensis</i> and SD6 for <i>P. brutia</i> - (based on short clear testing, Table 19)	Reject	74.2	<i>72</i>	70.7	<i>70</i>
	Corewood Stud	2.1	<i>2</i>	--	<i>-</i>
	5	7.2 (F7)	<i>7</i>	20.2 (F5)	<i>20</i>
	4	8.2 (F8)	<i>8</i>	8.1 (F7)	<i>8</i>
	3	3.1 (F11)	<i>3</i>	1.0 (F8)	<i>1</i>
	2	5.2 (F14)	<i>5</i>	-	<i>-</i>

Table 17: Summary of information on appearance boards cut from the log wings

	Thickness	Width	Count	Volume (m ³)	Clear	Select	Standard	Utility	Reject	Clear (30cm inc) % of total volume
	Dried and machined dimensions				% of total volume					
<i>P. canariensis</i>	12	90	10	0.0389	0	0.0	26.9	0.0	73.1	25.0
	22	40	32	0.1014	0	7.1	11.6	40.2	41.1	52.5
		70	25	0.1386	0	13.0	16.4	16.0	54.6	46.6
		90	86	0.6130	0	45.2	11.6	7.0	36.2	54.1
	Grand Total		153	0.8919	0	33.9	13.0	11.9	41.2	51.5
<i>P. brutia</i>	12	90	18	0.0700	0	8.8	10.2	31.3	49.7	20.4
	22	40	35	0.1109	0	2.5	9.0	36.5	51.9	41.1
		70	27	0.1497	0	13.9	6.6	29.5	50.0	41.6
		90	102	0.7271	0	28.5	19.6	22.5	29.4	40.3
	Grand Total		182	1.0576	0	22.4	16.0	25.5	36.0	39.2

Table 18: In-grade testing results on 90 x 35 mm structural boards from the central cants¹⁴

MSG	Strength/ Stiffness		<i>P. canariensis</i>	<i>P. brutia</i>	F-grade	MGP (<i>P. radiata</i>)
F4	MOR (MPa)	Mean	29.3	16.97		
		No. of boards	11	2		
		SD	19.8	-		
		5 th percentile	14.6	-		
		R _{k,norm}	6.3		13.0	
		R _{basic}	2.1	-	4.3	
	MOE (GPa)	Mean	7.87	7.12		
		No. of boards	11	2		
		SD	1.23	-		
		5 th percentile	6.08	-		
		E _k	7.61	-	6.1	
F5 (MGP 10)	MOR (MPa)	Mean	38.0	33.3		
		No. of boards	29	73		
		SD	18.8	14.1		
		5 th percentile	18	14.8		
		R _{k,norm}	13.8	13.6	16.0	16.0
		R _{basic}	4.7	4.6	5.5	5.5
	MOE (GPa)	Mean	9.77	8.92		
		No. of boards	29	73		
		SD	1.58	1.28		
		5 th percentile	7.46	7.03		
		E _k	9.56	8.82	6.9	10
F8 (MGP 12)	MOR (MPa)	Mean	53.6	49.2		
		No. of boards	26	23		
		SD	25.7	22.8		
		5 th percentile	25.4	22.8		
		R _{k,norm}	19.6	17.5	25.0	28.0
		R _{basic}	6.6	5.9	8.6	9.5
	MOE (GPa)	Mean	13.57	11.19		
		No. of boards	26	23		
		SD	2.00	1.18		
		5 th percentile	11.07	9.54		
		E _k	13.30	11.02	9.1	12.7
F11 (MGP 15)	MOR (MPa)	Mean	74.6			
		No. of boards	20			
		SD	32.3			
		5 th percentile	27.5			
		R _{k,norm}	21.4		35.0	41.0
		R _{basic}	7.2		11	14.0
	MOE (GPa)	Mean	17.17			
		No. of boards	20			
		SD	2.03			
		5 th percentile	13.79			
		E _k	16.85		10.5	15.2

NB: R_{k,norm} = Normalised characteristic strength (MPa)
R_{basic} = Basic working strength (MPa)
E_k = Characteristic value of the modulus of elasticity (GPa)

¹⁴ AS/NZS 4063:1992 Timber-Stress-graded – In-grade strength and stiffness evaluation

Table 19: Summary of clearwood properties for *P. canariensis* and *P. brutia*

	Variable	Units	No. tested	Mean	Std Dev.	Preliminary Strength Group*	Overall Strength Classification*
<i>P. canariensis</i>	Bending strength (MOR)	(MPa)	54	105.9	25.1	SD4	SD5
	Bending stiffness (MOE)	(GPa)	54	11.97	4.16	SD6	
	Compression strength	(MPa)	61	55.0	12.1	-	
	Janka hardness	(kN)	60	5.2	1.4	-	
	Dry Density**	(kg/m ³)	54	647	68	-	
	MC**	(%)	54	9.7	2.5	-	
<i>P. brutia</i>	Bending strength (MOR)	(MPa)	50	92.7	13.0	SD5	SD6
	Bending stiffness (MOE)	(GPa)	50	10.46	1.78	SD7	
	Compression strength	(MPa)	58	48.8	4.8	-	
	Janka hardness	(kN)	57	3.8	0.5	-	
	Dry Density**	(kg/m ³)	50	558	28	-	
	MC**	(%)	50	10.7	0.4	-	

*Classification in accordance with AS/NZS 2878:2000

**Based on bending specimens at time of testing

A range of appearance dimension products were cut from the two wings.



Figure 37: Typical knot characteristics. A & B shows clusters of smaller diameter knots with distinct nodal spacing in *P. canariensis*. C & D show less uniform spacing of larger knots in *P. brutia*.

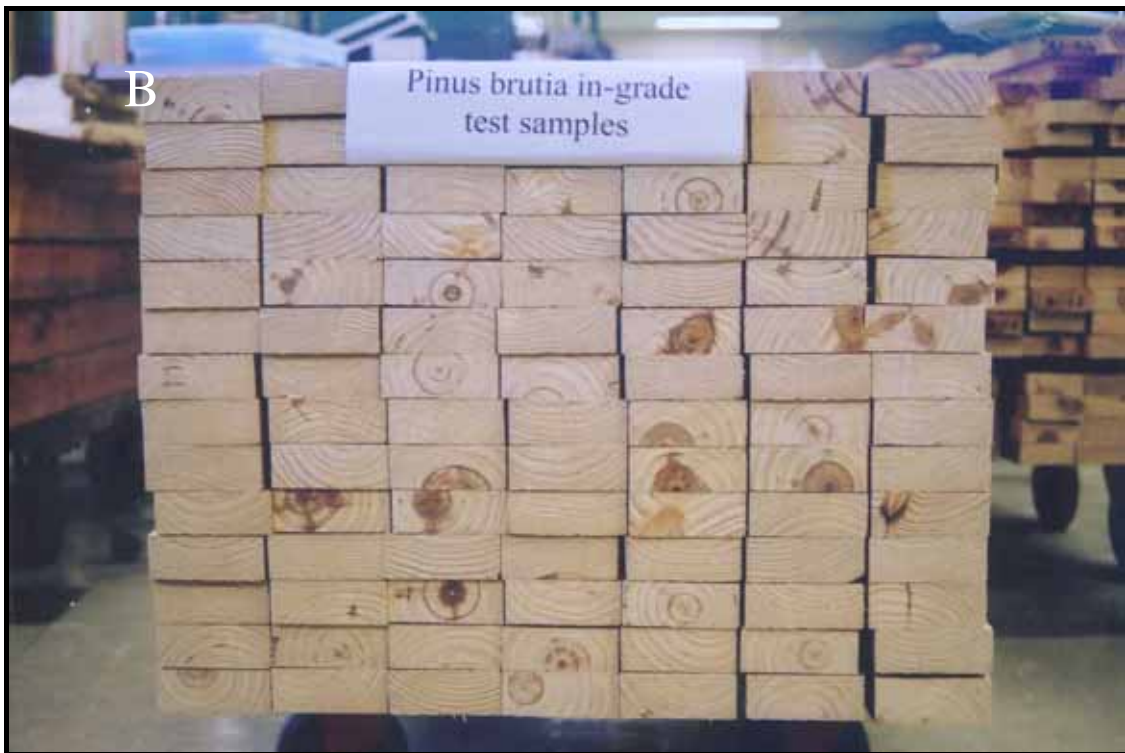


Figure 38: Photo showing the abundance of pith-in material among the in-grade test samples for (A) *P. canariensis* and (B) *P. brutia*.

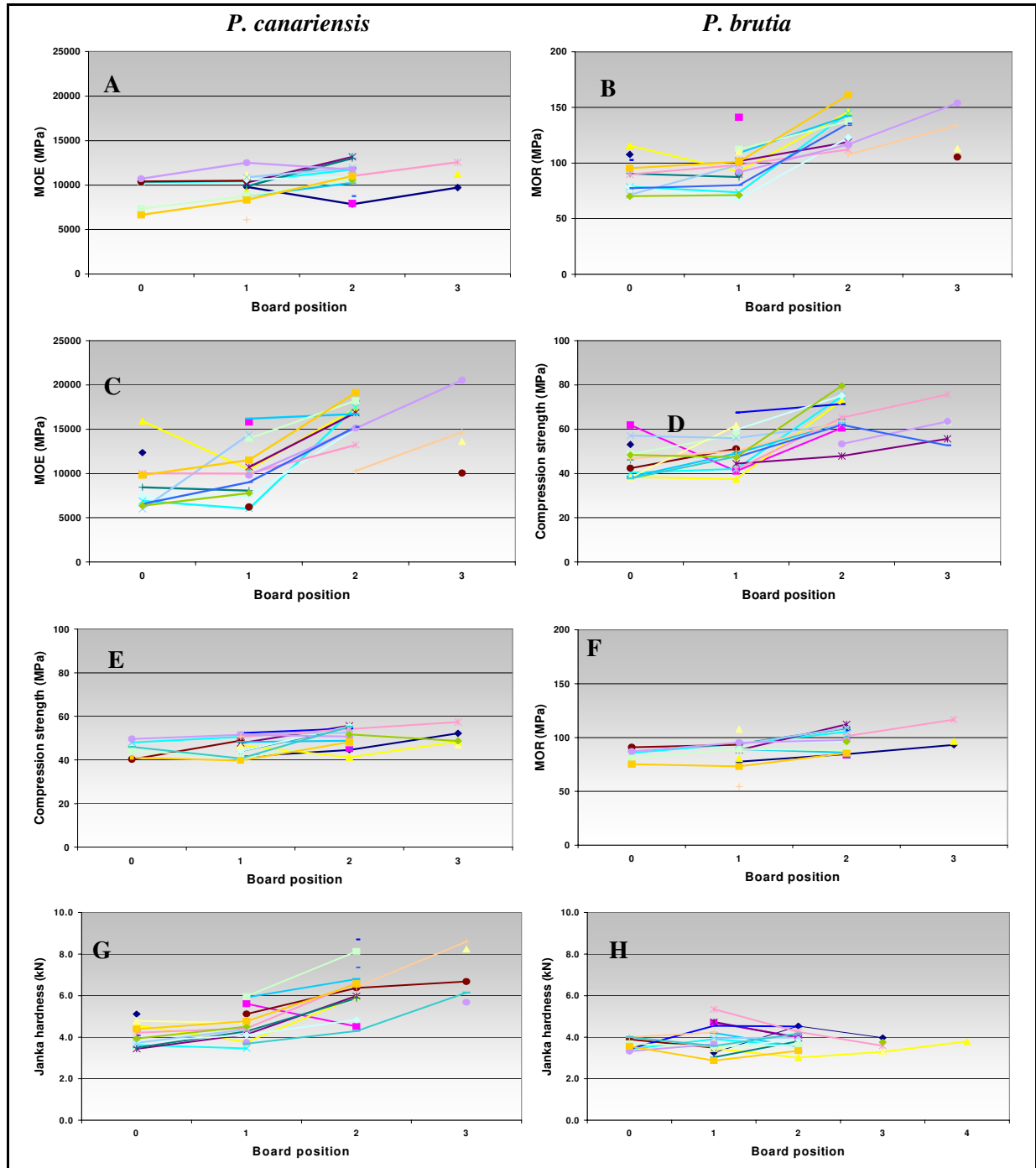


Figure 39: Graphs showing clearwood properties (bending strength (A&B) & stiffness (C&D), compression strength (E&F) and Janka hardness (G&H) in relation to board position for *P. canariensis* and *P. brutia*. Different coloured lines indicate boards coming from the same tree.

Mean densities from the shrinkage block specimens are presented for inner (20-30% distance from pith) and outer (60-80% distance from pith) heartwood (Figure 40) regardless of height in the tree. Also included in this graph are data for *P. radiata*¹⁵ of a younger and similar age (grown in W.A. or S.A.) to provide an indication of the approximate values for inner and outer heartwood. There is little difference in the density of the inner and outer heartwood of the *P. brutia*, and the basic density values are very similar to those of the *P. radiata*. The inner heartwood densities of the *P. canariensis*

are also similar to those of the *P. brutia* and *P. radiata*, although the densities of the outer heartwood are significantly higher.

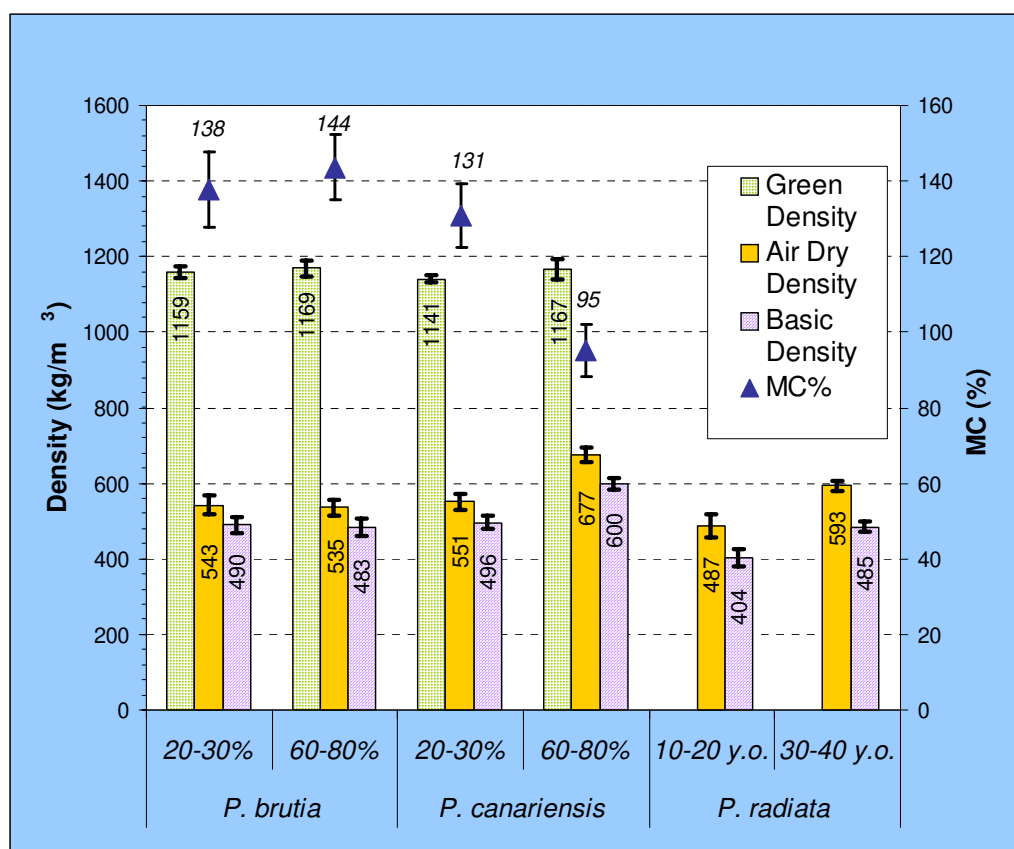


Figure 40: Mean basic and air dry density of the shrinkage blocks from 20-30% (inner heartwood) and 60-80% (outer heartwood) of the distance from the pith

Error bars show the 95% confidence interval for the mean. Error bars show the 95% confidence interval for the mean. For comparison, data for 10-20 y.o. and 30-40 y.o. *P. radiata* 15 grown in W.A. or S.A. are also included.

Figure 41 shows an analysis on the weighted basic densities (See Appendix 5) used to estimate the density of the whole disks from the top and bottom of the 5 randomly selected logs of both species. The large difference in basic density between the two species is clearly shown. Furthermore, there was a statistically significant difference between the 0 m and 4 m high disks.

¹⁵Kingston R.S.T. and Risdon C.J.E. (1961) Shrinkage and Density of Australian and other South-west Pacific Woods. CSIRO Division of Forest Products Technological Paper No. 13. pp. 65. Melbourne.

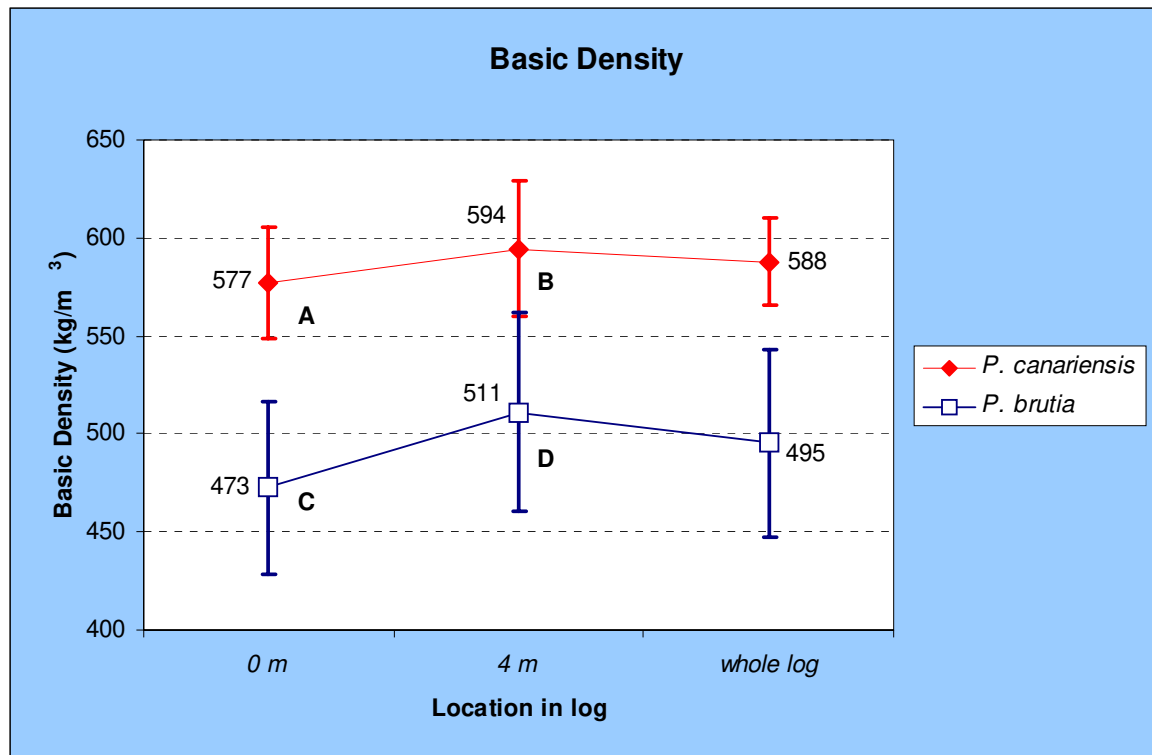


Figure 41: Mean basic density for the disks from the top and bottom of the 5 randomly selected logs of each species. Letters indicate statistically significant differences between means (ANOVA with top and bottom modelled as a repeated measure factor).

Figure 42 shows how basic density varied radially with distance from the pith. Both species show very high densities close to the pith due to resin build up in the inner core. As suggested earlier, for *P. canariensis*, there is a clear pattern of increasing basic density with distance from the pith. Apart from the high densities due to high resin content in the inner core in *P. brutia*, there does not appear to be a significant change in basic density with distance from pith.

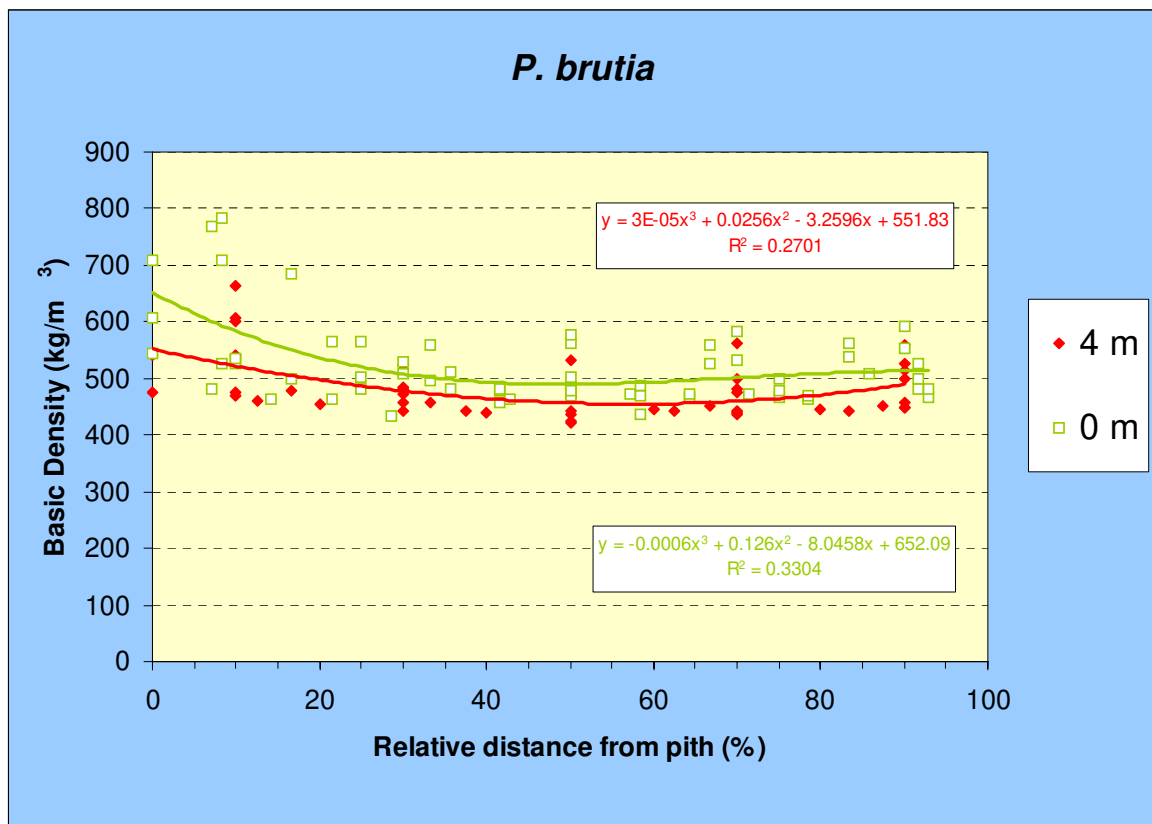
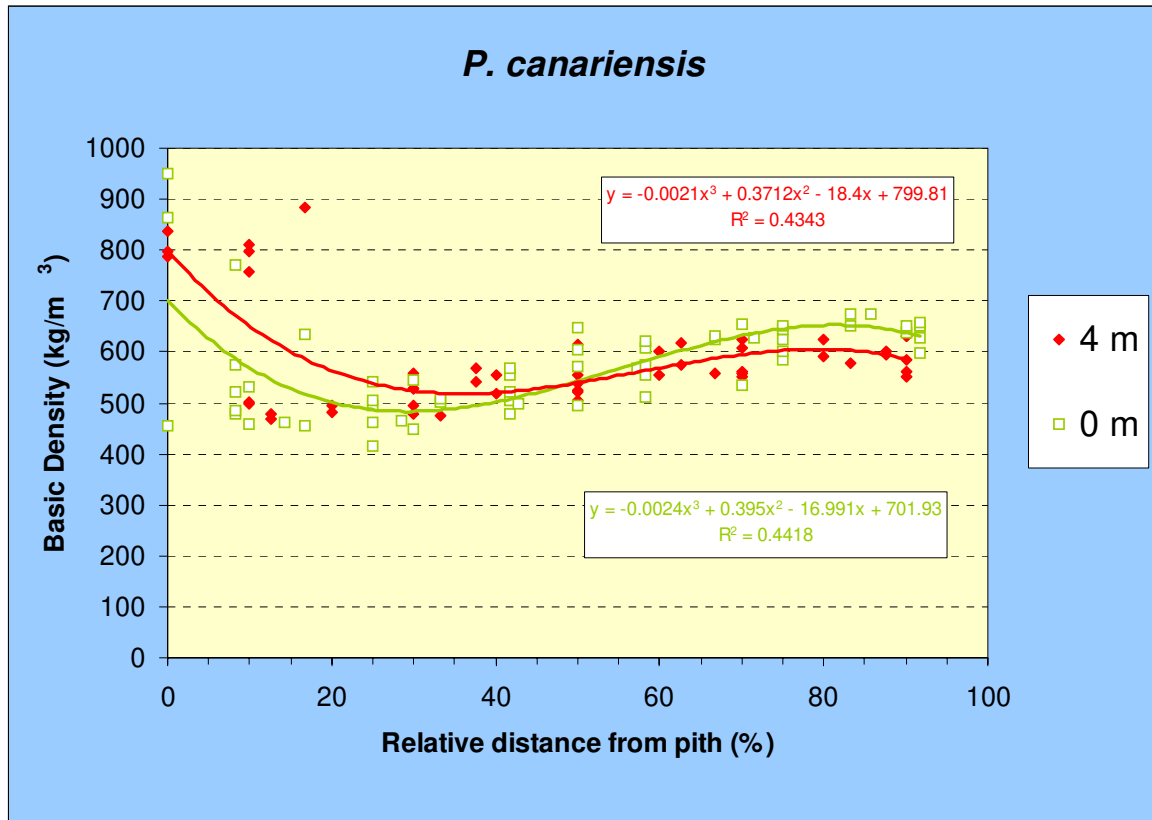


Figure 42: Radial pattern of basic density with relative distance from pith

Figure 43 shows the mean shrinkage and unit shrinkage values for the inner and outer heartwood blocks. The shrinkage values for both *P. canariensis* and *P. brutia* are generally lower than for *P. radiata* of a similar age. The unit shrinkages are similarly lower except for the outer heartwood *P. canariensis* which had the highest unit shrinkage values. This is not surprising given that outer heartwood of *P. canariensis* also had the highest basic densities of the species being considered here. Nevertheless, shrinkage problems should be minimal with *P. brutia* and no worse with *P. canariensis* than occurs with *P. radiata*.

Figure 44 to Figure 49 shows the radial patterns for the different shrinkage properties and how they differed in the strips from the 0 m and 4 m height in the trees. For *P. canariensis* the tangential and radial shrinkages are very low close to the pith where the resinous core is restricting shrinkage (Figure 44 and Figure 45). Figure 47 and Figure 48 also show a clear pattern of increasing unit shrinkage in the outer heartwood and sapwood. This is to be expected given the pattern of increasing density in *P. canariensis* (Figure 42) and that unit shrinkage is normally positively correlated with density. The radial patterns for *P. brutia* are less clear, and this is most likely due to the confounding effects of the knots prevalent in the samples for this species. Apart from a reduction of shrinkage close to the pith, again due to resin build up, there was little change in the shrinkage properties radially. This again also reflects the flat radial density profile for this species (Figure 42).

Figure 46 and Figure 49 shows that longitudinal shrinkage to 5% and longitudinal unit shrinkage were generally higher close to the pith but negligible towards the bark. *P. brutia* in particular had a number of high shrinkage values close to the pith. While the two *P. canariensis* samples with very high longitudinal shrinkage came from next to each other in the same radius, there were no obvious signs of compression wood found to correspond to these samples. Appendix 6 shows the plot of shrinkage against MC%.

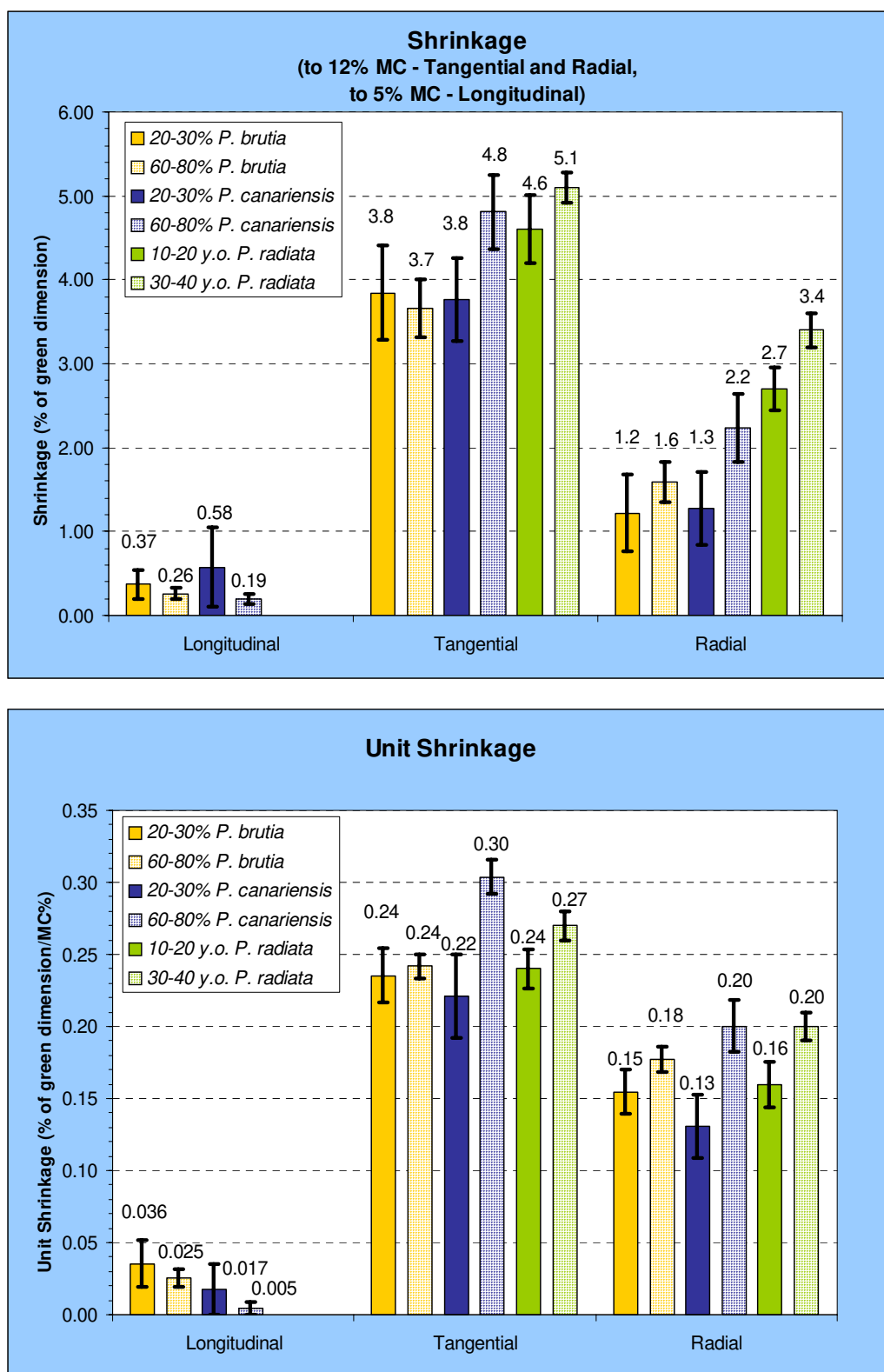


Figure 43: Mean shrinkage and unit shrinkage from blocks at 20-30% (inner heartwood) and 60-80% (outer heartwood) of the distance from the pith. Error bars show the 95% confidence interval for the mean. Data for 10-20 y.o. and 30-40 y.o. *P. radiata*¹⁶ grown in W.A. or S.A. are included.

¹⁶Kingston R.S.T. and Risdon C.J.E. (1961) Shrinkage and Density of Australian and other South-west Pacific Woods. CSIRO Division of Forest Products Technological Paper No. 13. pp. 65. Melbourne.

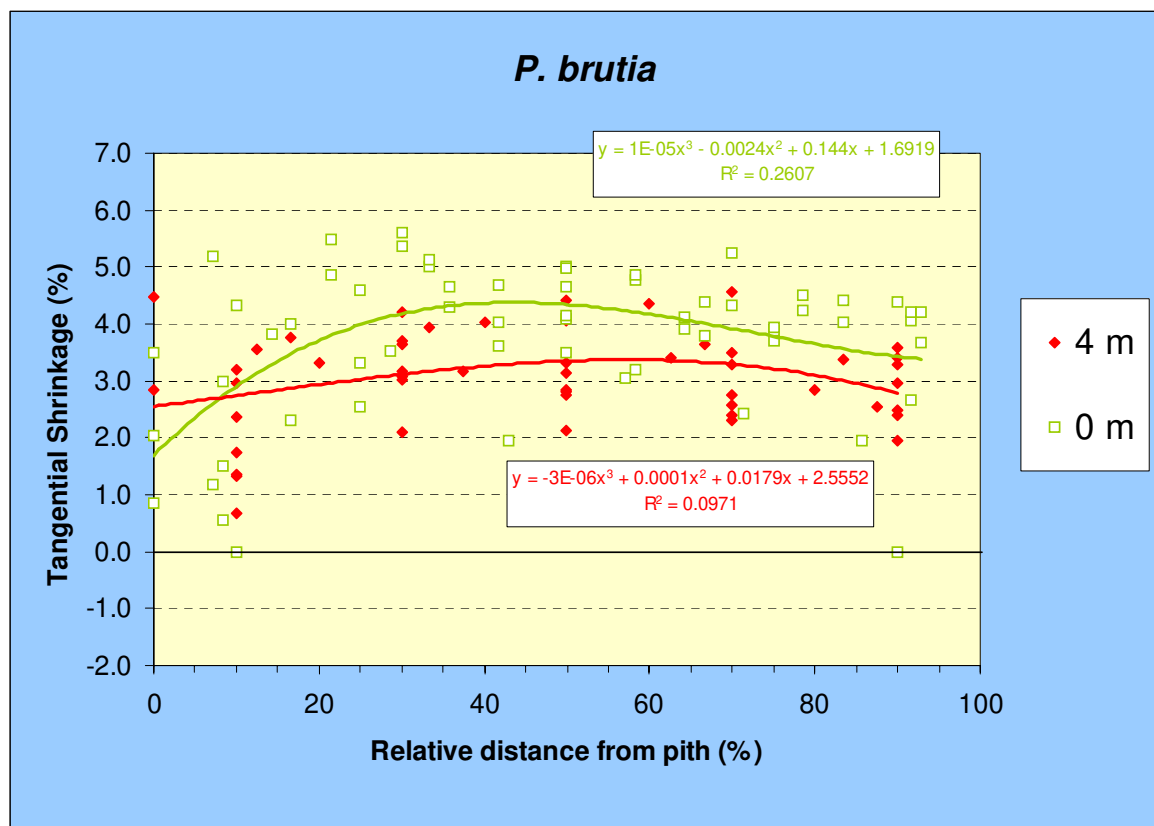
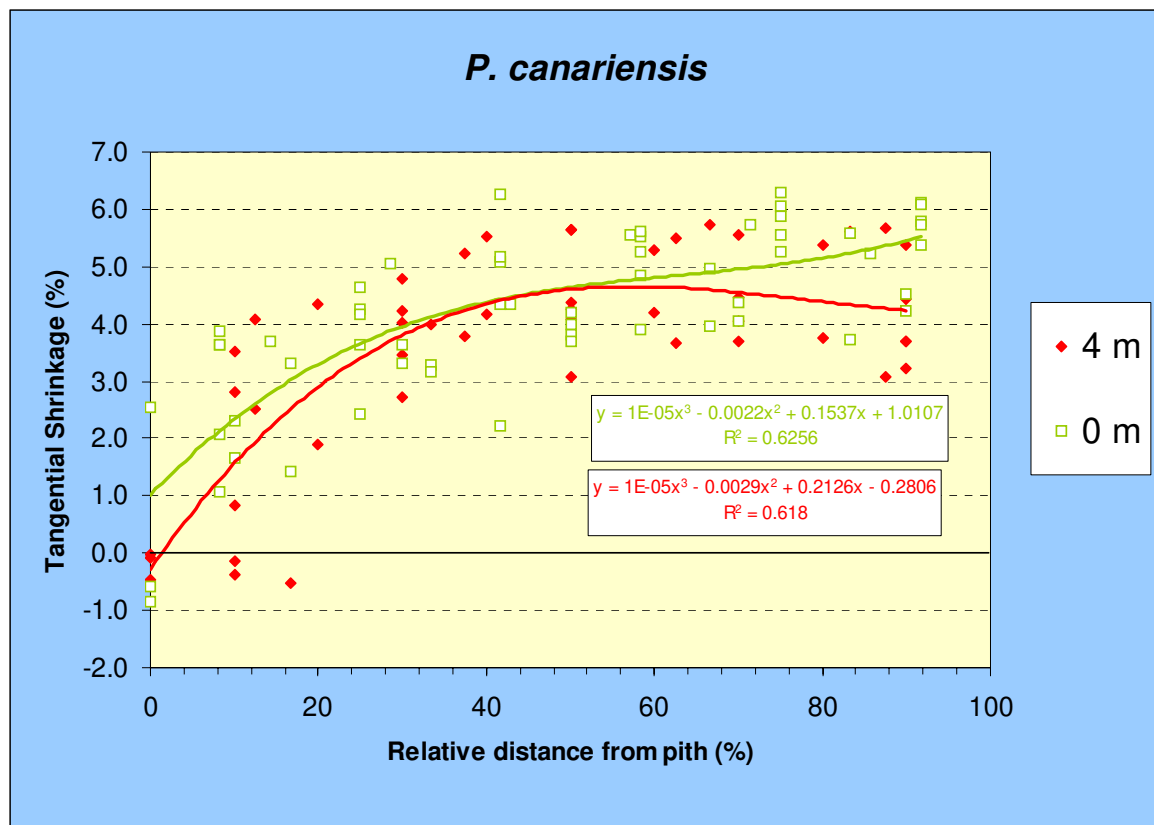


Figure 44: Radial pattern of tangential shrinkage expressed as relative distance from pith

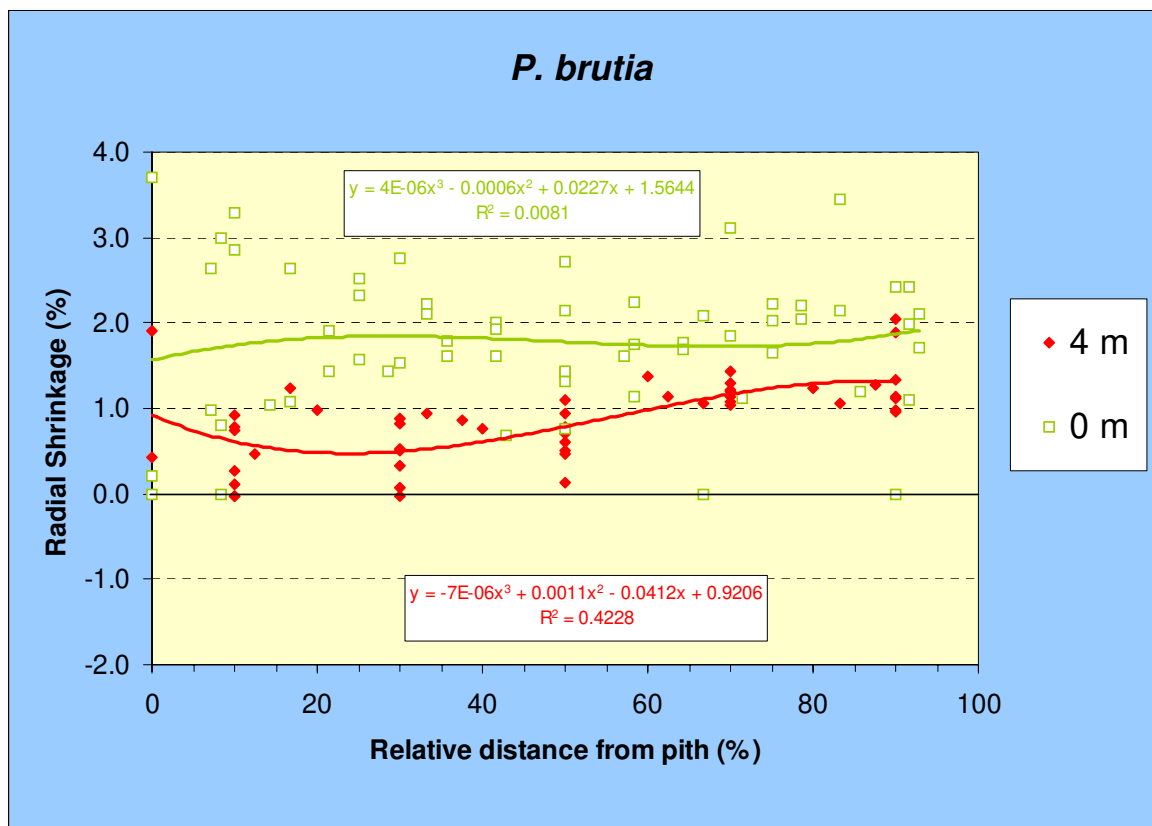
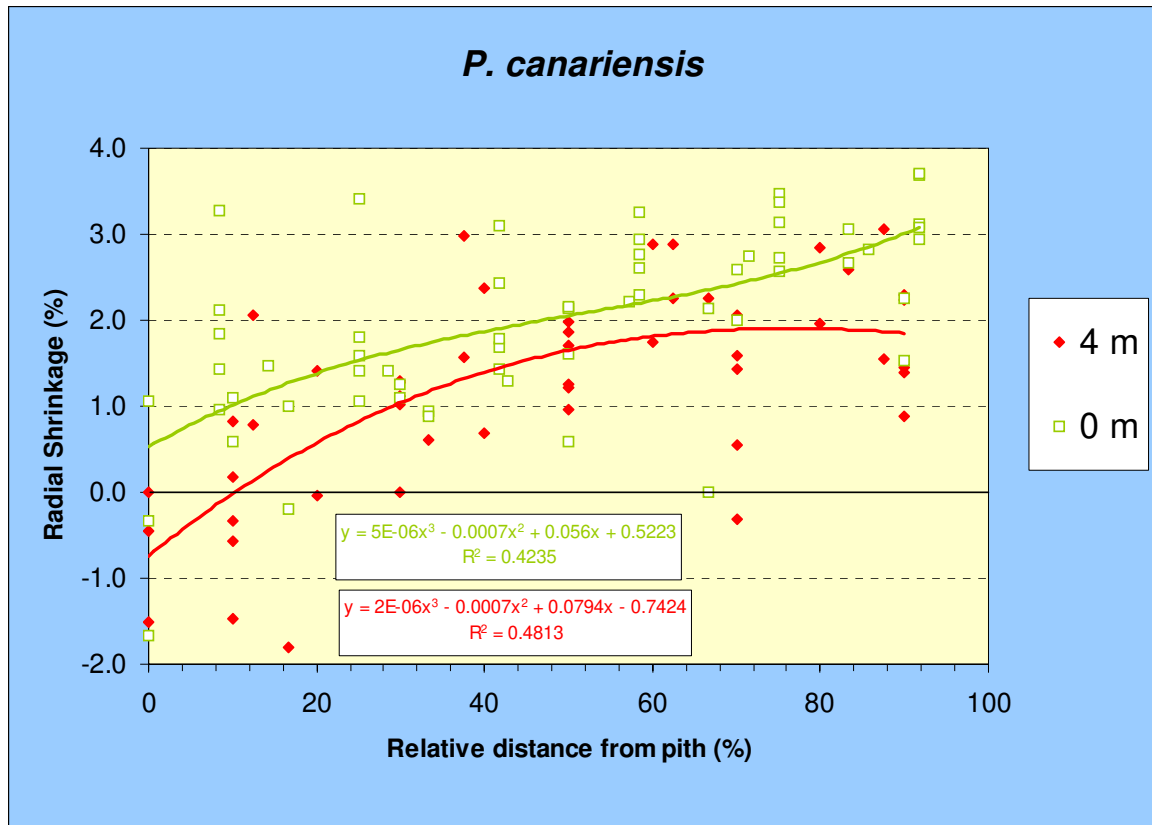


Figure 45: Radial pattern of radial shrinkage expressed as relative distance from pith

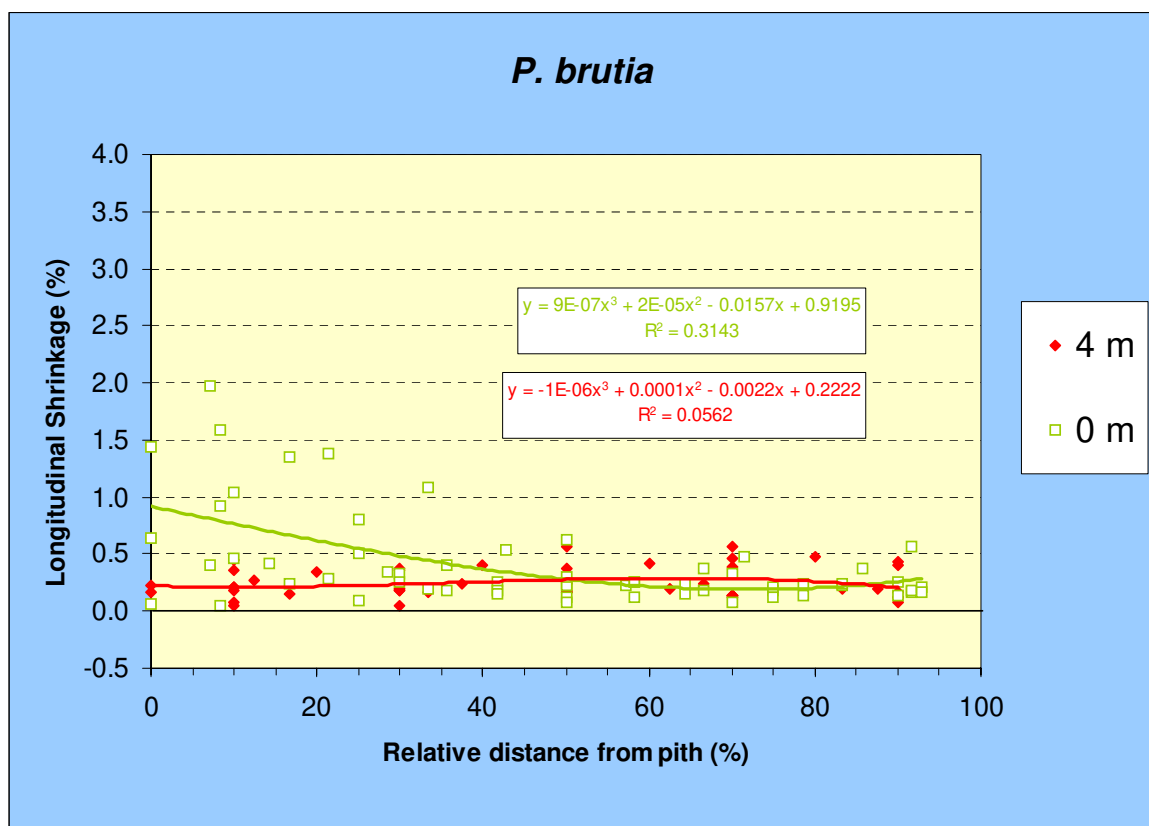
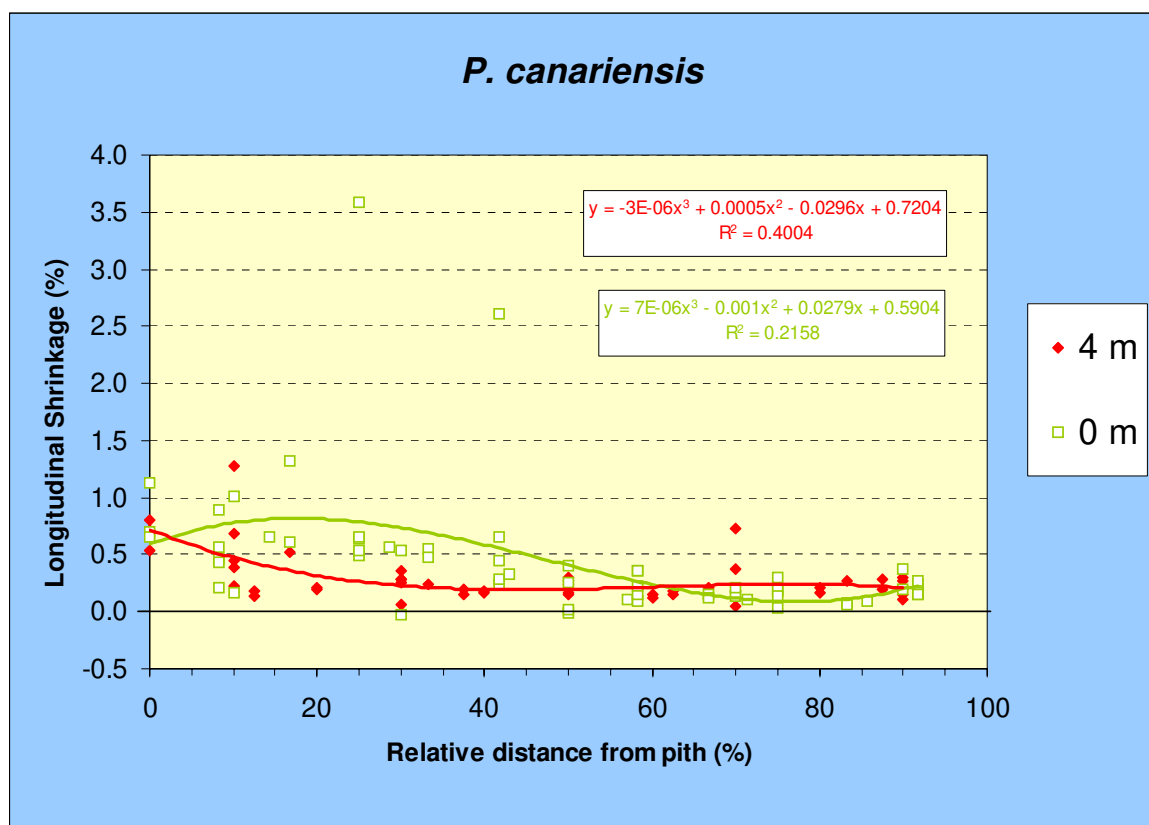


Figure 46: Radial pattern of longitudinal shrinkage expressed as relative distance from pith

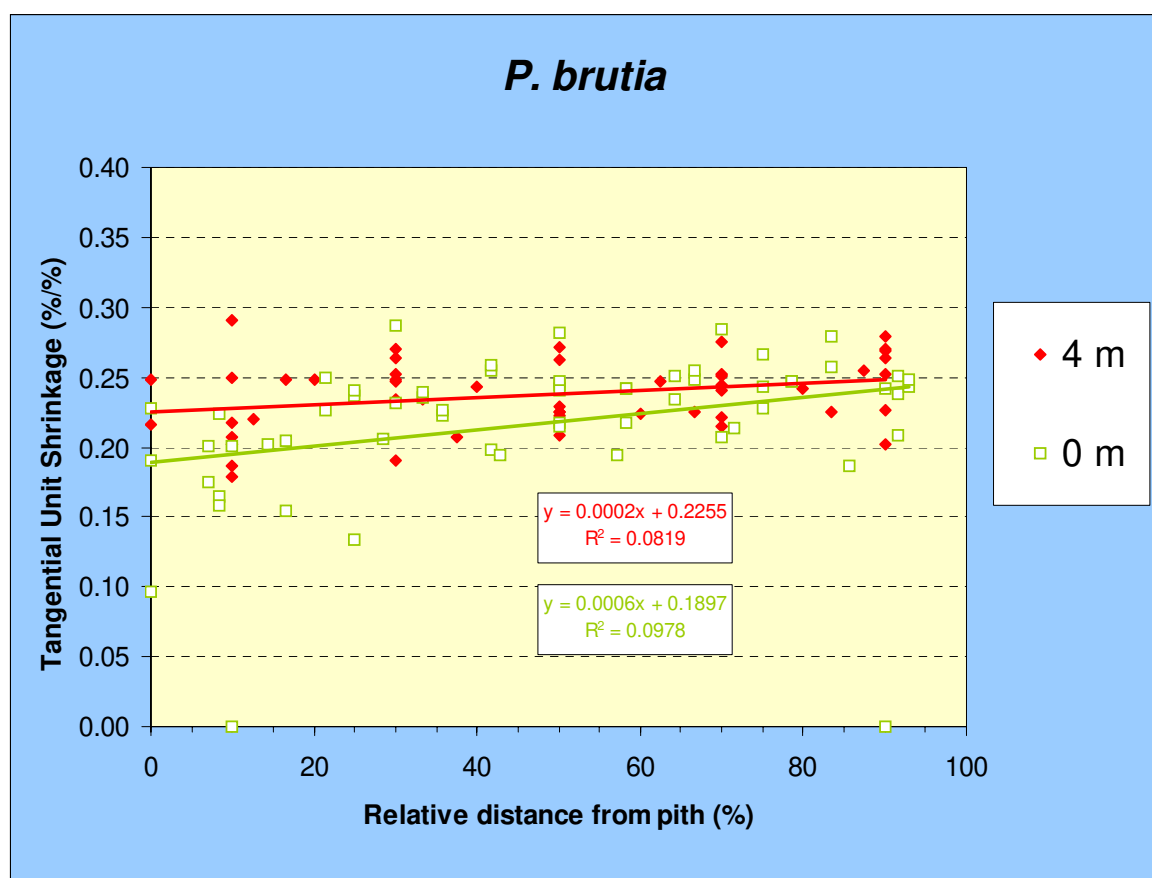
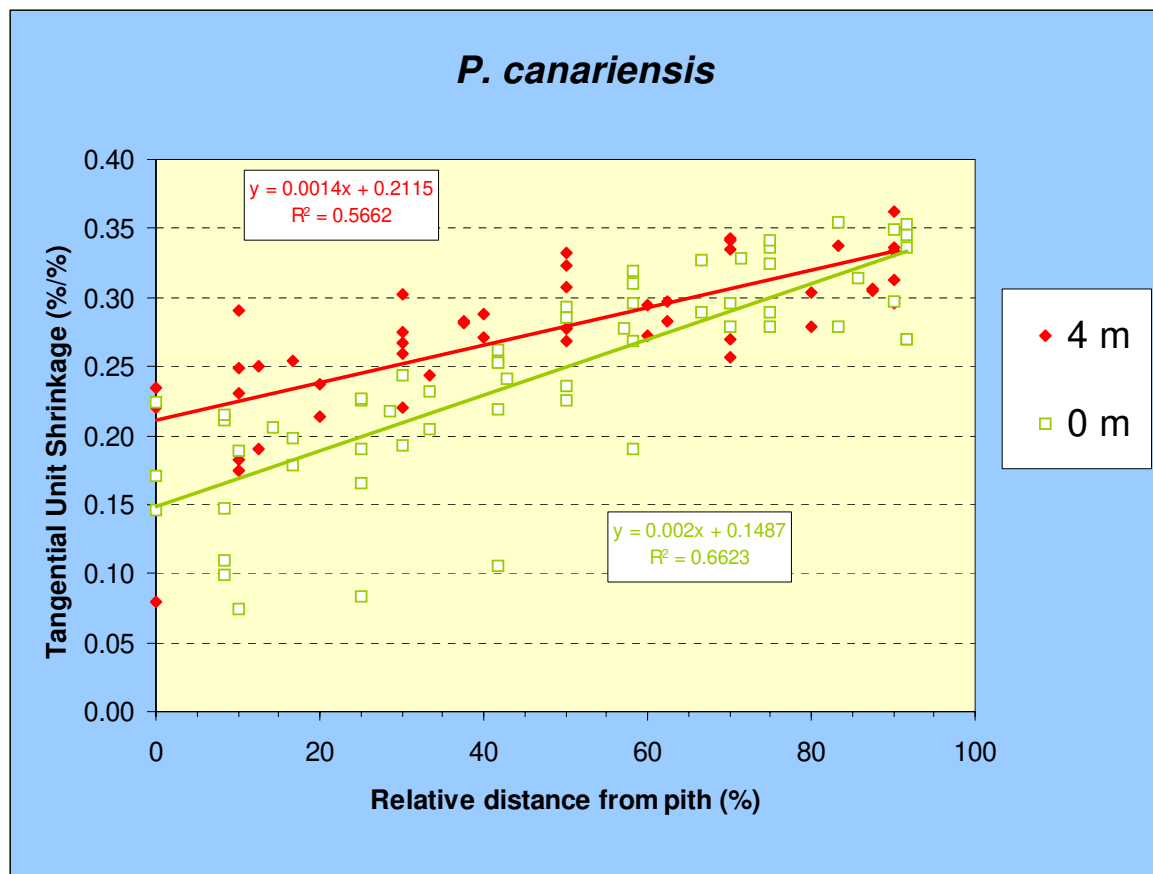


Figure 47: Radial pattern of tangential unit shrinkage expressed as relative distance from pith

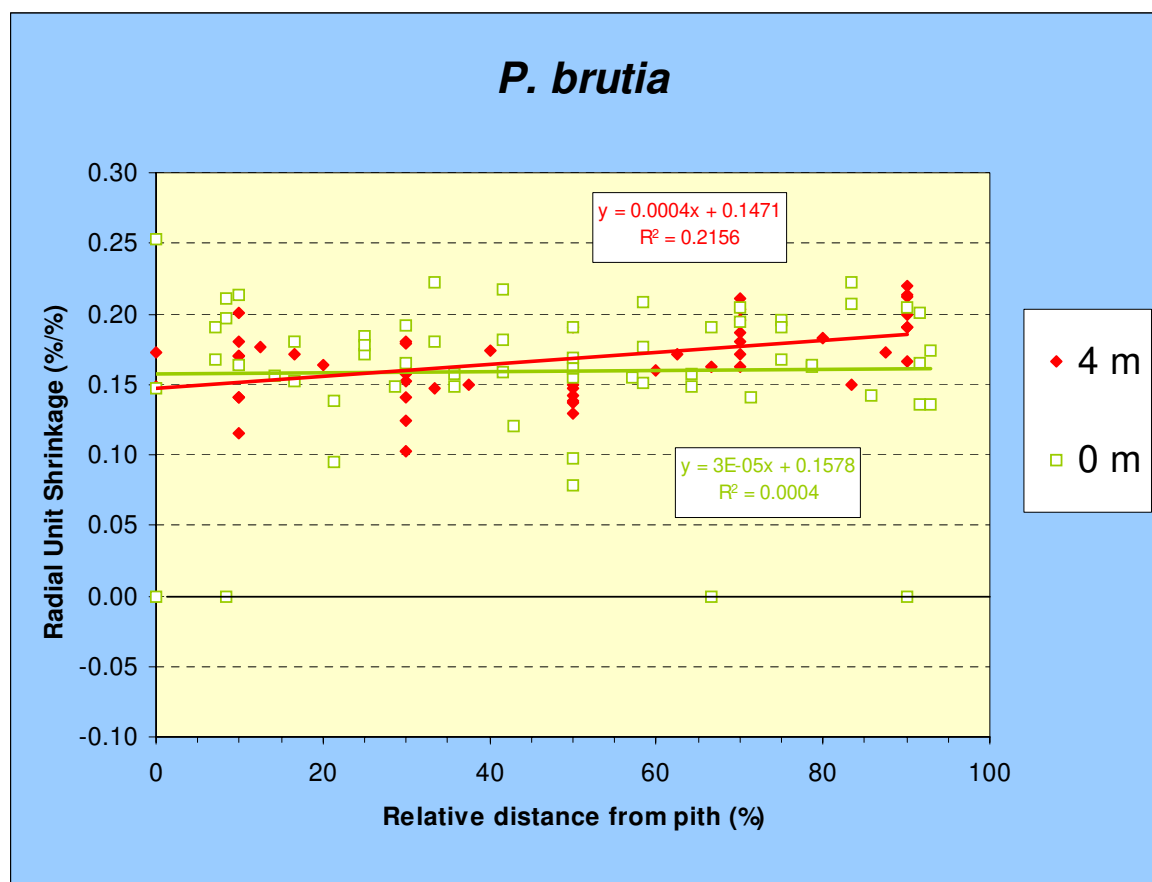
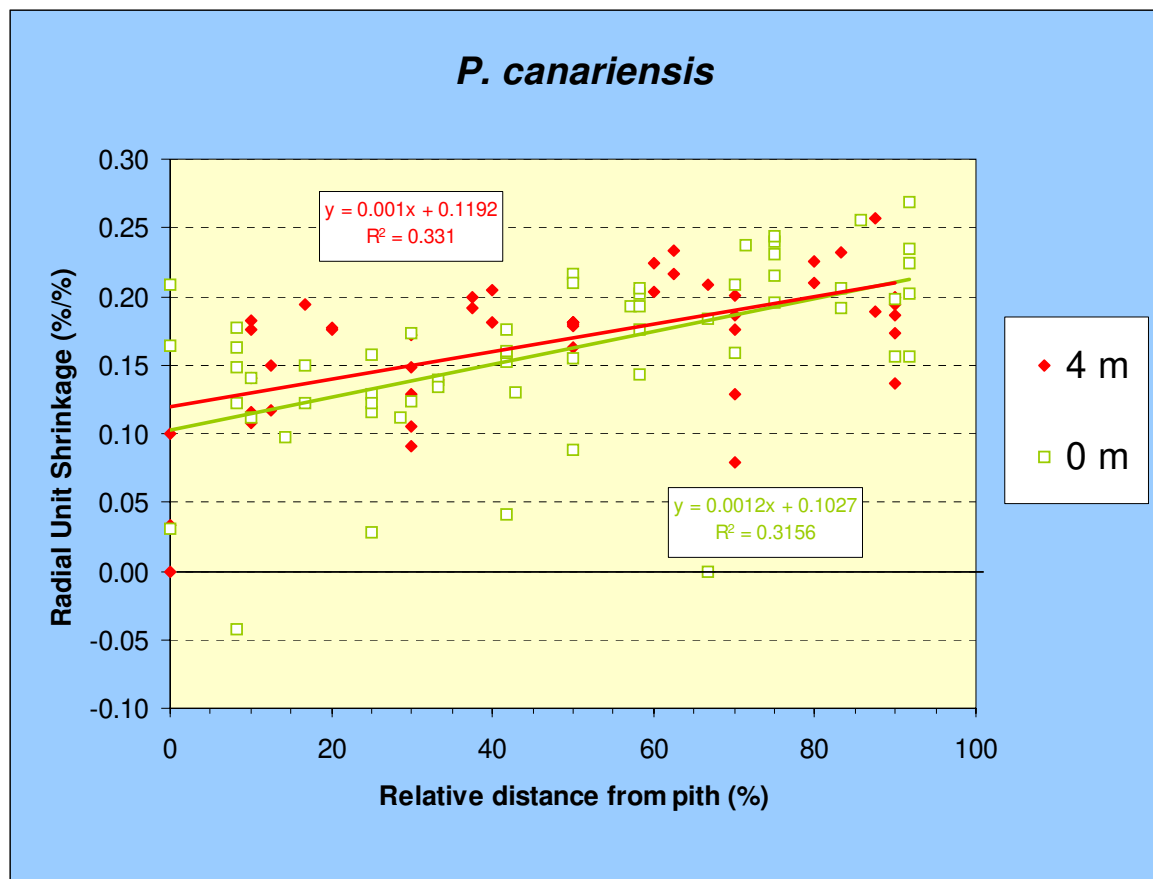


Figure 48: Radial pattern of radial unit shrinkage expressed as relative distance from pith

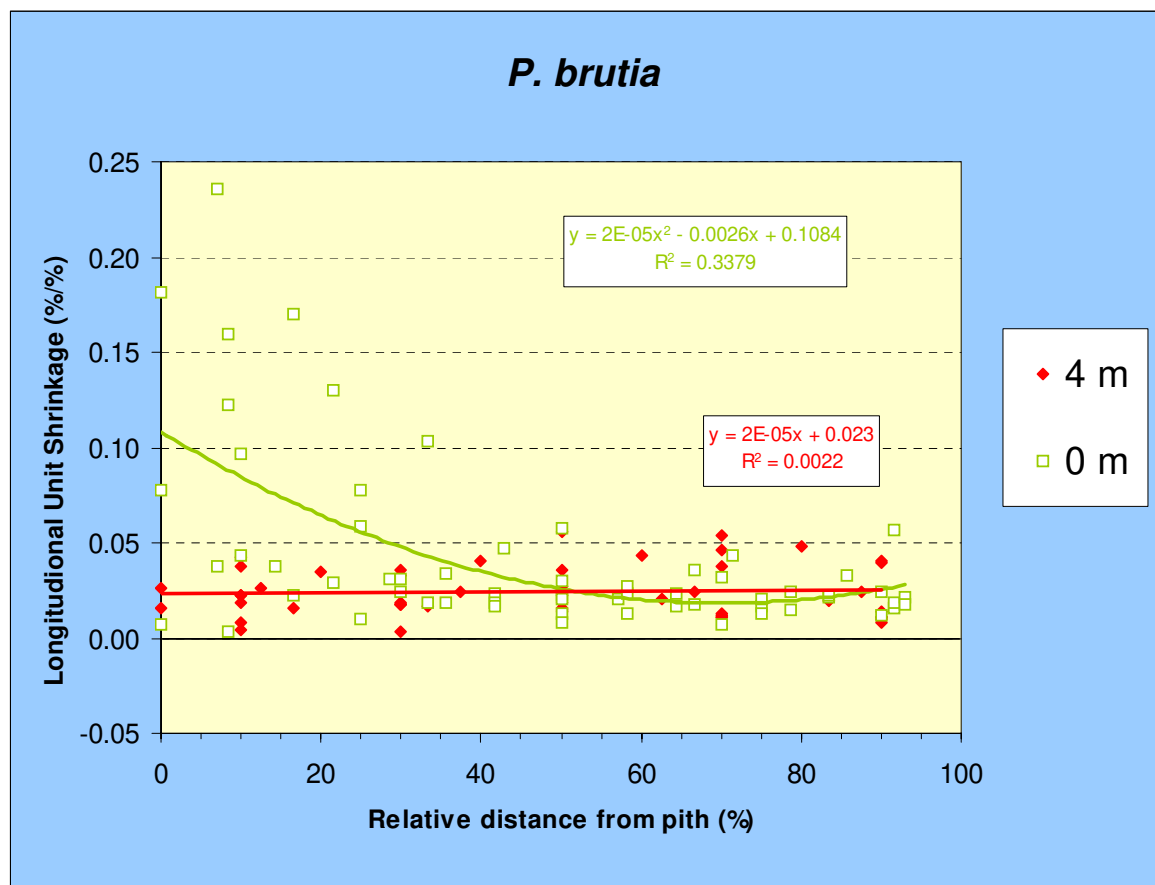
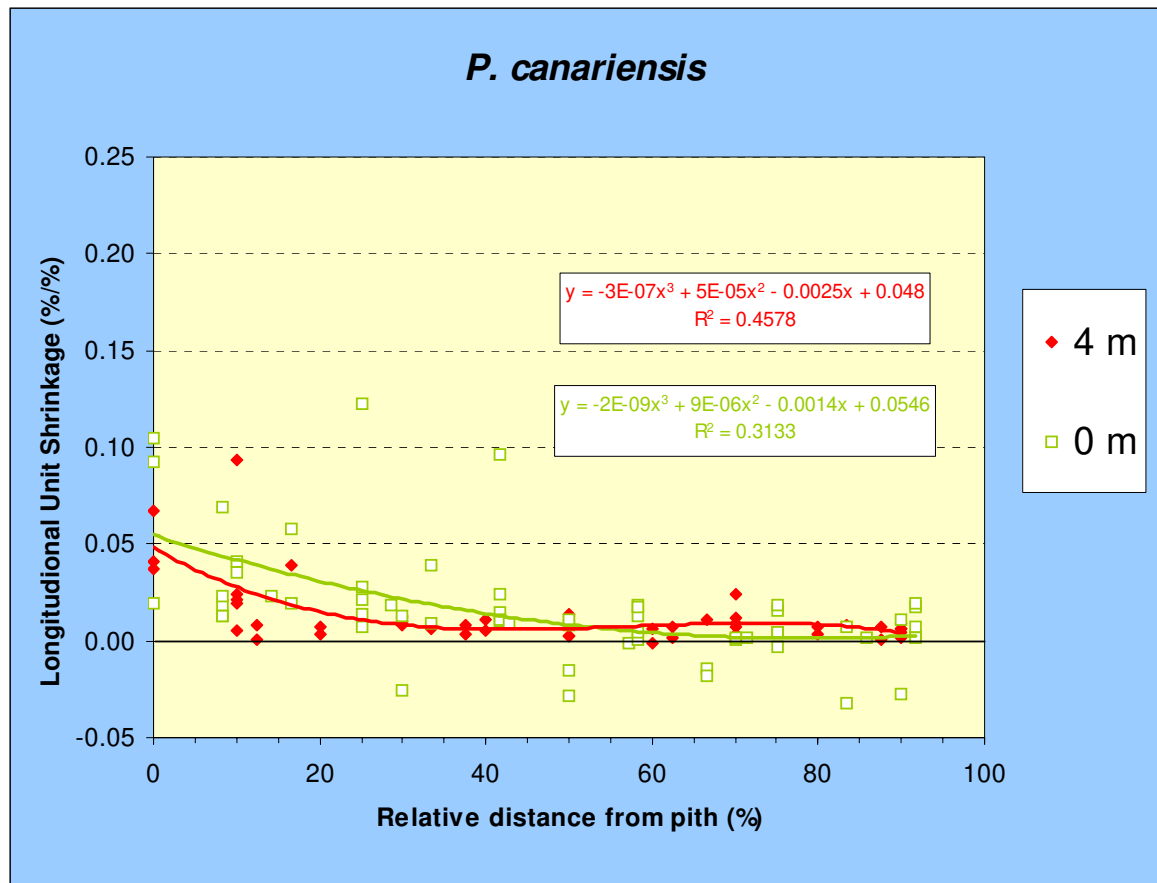


Figure 49: Radial pattern of longitudinal unit shrinkage expressed as relative distance from pith

Figure 50 shows the mean spiral grain data for *P. canariensis*, *P. brutia* and 22 y.o. New Zealand grown *P. radiata*¹⁷ for comparison. The individual tree data are shown in Appendix 7. The pattern for *P. canariensis* is similar to that of *P. radiata*. For *P. canariensis* spiral angles close to the pith were quite high and likely to cause twist in boards cut from close to the heart. The rate of decrease in spiral angle appears greater than for *P. radiata* and drops below 2° by ring 6 instead of about ring 10 for *P. radiata*. The prevalence of knots in the *P. brutia* made it hard to interpret the significance of the right hand spiralling at 0 m and left hand spiralling at 4 m. It is possible that while the magnitude of the spiral angle deviations is not that great, the difference may lead to distortion problems during drying of sawn boards. Consistent with previous patterns observed for *P. radiata*^{17,18}, spiral grain angles were generally greater at 4m than at 0 m.

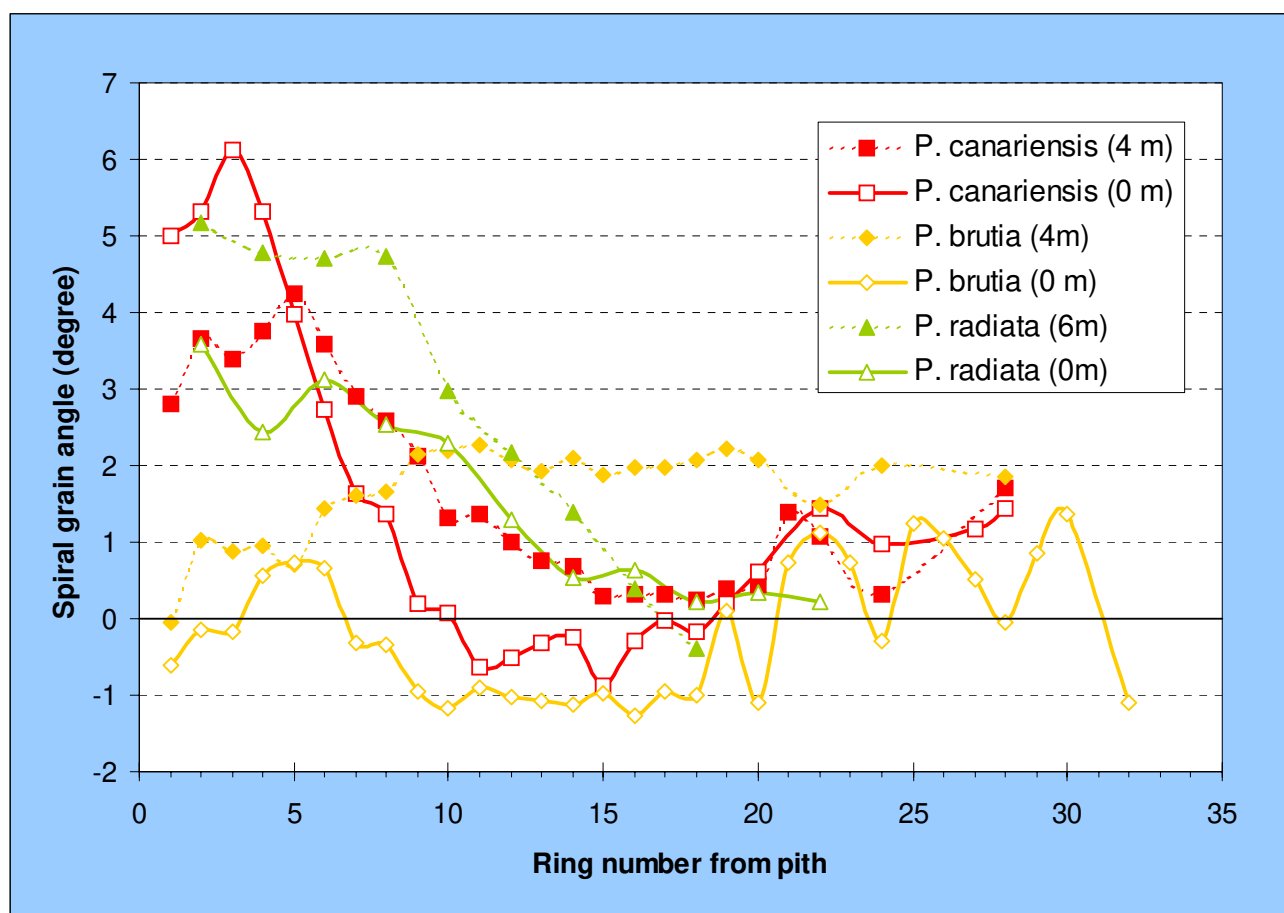


Figure 50: Mean spiral grain measurements for top and bottom strips. Data for *P. radiata*¹⁷ are also included for comparison. NB: Positive angles indicate left hand spiral.

¹⁷ Young G.D., McConchie D.L. and McKinley R.B. (1991) Utilisation of 25-year-old Pinus Radiata, Part 1: Wood properties. NZ J For Sci 21:217-227

¹⁸ Cown D.J., Young G.D. and Kimberley M.O. (1991) Spiral grain patterns in plantation-grown Pinus Radiata. NZ J For Sci 21:206-216

5. Discussion of Results

Overall the dryland conifers were comparable to *P. radiata* for sawn structural timber products and MDF manufacture but at a disadvantage for both kraft and TMP production. Both *P. canariensis* and *P. brutia* show good potential for sawn structural products. Knots are a major concern for both species. Both species are of medium to high density for exotic conifers and have comparable or better (*P. canariensis*) stiffness properties than *P. radiata*. However, the strength of both species was poor or at best marginal (*P. canariensis* was slightly better than *P. brutia*) compared with *P. radiata*, this was largely due to the size and distribution of knots.

For MDF production, the wood from the dryland pine species could be used successfully. The high pressure refining of dryland pine species was successful in producing acceptable fibre furnish with no compounds present which might interfere with the cure of urea-formaldehyde resins. Panel properties were generally found to be similar to those of panels made with a radiata pine resource currently used for the manufacture of commercial MDF.

For kraft pulp and paper production, the dryland pines are at a significant pulp yield disadvantage compared with the current *P. radiata* resource. The mainland provenance of *P. radiata* had the highest pulp yield (59.4% at Kappa number 92). *P. canariensis* had the lowest yield (54.6% at Kappa number 93) with the other four samples covering a range of only 1.1%. Results for papermaking tests appeared to be predominantly influenced by the densities of the wood samples, with *P. canariensis* exhibiting the highest bulk and tearing resistance and the lowest tensile strength, whereas *P. radiata* (Mainland) had lower bulk and tear and the highest tensile strength.

For TMP paper production, the dryland conifers would generally be considered inferior raw materials compared to the control samples of *P. radiata*. Energy is the single largest cost in producing TMP, and the control samples and *P. radiata* (Cedros) required 15% less energy to produce a sheet at a given tensile strength than the other conifers. The higher density species (*P. canariensis* and *P. brutia*) were particularly disadvantaged, with inferior pulp strength properties as well. Although the scattering coefficients of pulps produced from these two species were high, this advantage was generally at the expense of higher energy requirements.

Basic density of *P. canariensis* was almost 70 kg.m⁻³ higher than that of the next sample (*P. brutia*). Density differences of this magnitude would be considered significant and may have consequences for paper properties. Both samples were from trees 16 years older than those of the other conifers (38 years *versus* 22 years). Older trees would be expected to have higher basic density, irrespective of species differences.

In contrast, *P. radiata* (Mainland) had the lowest density; 66 kg.m⁻³ lower than the lightest ‘dryland’ pine sample (*P. radiata* Cedros). However, at 375 kg.m⁻³, the density of the Mainland *P. radiata* sample was perhaps 80 kg.m⁻³ lower than might be considered representative of the overall *P. radiata* resource, reflecting the particular genetics and growing conditions existing at the Buccleuch State Forest, near Tumut. The densities of the other samples covered a range of only 24 kg.m⁻³ and would not be considered significantly different given the sampling error likely to result from between-tree variation.

Acetone extractives content of all samples were higher than what would be considered normal for *P. radiata* and these elevated extractives levels may potentially impact on pulp and paper manufacture. However, although there was a negative trend between pulp yield and the extractives and resin acid contents (Table 207) the relationships were not strong (correlations of -0.56 and -0.27 for pulp yield with acetone extractives and resin acid contents respectively). The elevated extractives contents may however influence the economics of pulping operations if the mill is limited by the black liquor recovery furnace. The additional extractives will add to the black liquor

burden and may reduce the efficiency of the overall operation. The impact of extractives on operating efficiency of a TMP mill also requires consideration and there is potentially a build up of material on the paper machinery.

Table 20: Summarised means for acetone extractives, resin acid content and kraft pulp yield

	% acetone extractives	Resin acid (%)	Kraft pulp yield (%)
<i>P. brutia</i>	7.96	3.15	57.1
<i>P. canariensis</i>	7.29	2.1	54.6
<i>P. radiata</i> (Guadalupe)	7.04	1.54	56
<i>P. radiata</i> (Cedros)	6.24	1.17	56.7
<i>P. pinaster</i>	3.5	0.37	56.5
<i>P. radiata</i> (Mainland)	3.67	0.86	59.4

This study suffered from two major limitations: the limited range of conifer genotypes available and the fact that the sample sites were wetter than the potential future planting range for these species. The limitation in available genotypes meant that a limited range of species and provenances were available for sampling and that only a single site was sampled for each genotype. Results of this study can thus only be considered indicative of the potential of these species. To fully explore the potential of dryland conifer species in Australia, a wider range of samples would need to be tested. However, a wider study will have to wait until the required systematic trials of species and provenances are old enough to provide a reliable indication of wood quality.

The second limitation is that the sites sampled in this study were wetter than the potential future planting range for these species. As it was not possible to sample each genotype across a range of environments the results of the current study can not be extrapolated to other sites and it is impossible to predict the likely effect of drier environments on the wood quality of these species.

6. Implications

Overall the dryland conifers were comparable to *P. radiata* for sawn structural timber products and MDF manufacture but at a disadvantage for both kraft and TMP production.

7. Recommendations

Results of this study can be considered as a preliminary indication of the processing potential of the dryland conifers. Future studies will be required using a wider range of species and provenances from a range of site qualities to fully determine the processing potential of these species. However, such a study will have to wait until the required systematic trials of species and provenances are old enough to provide a reliable indication of wood quality

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Appendix 1 – KRAFT Unbleached Papermaking Properties

Beating revs	Freeness CSF mL	Drainage s	Bulk cm ³ /g	Tear index mN.m ² /g	Tensile index N.m/g	Stretch %	Burst index kPa.m ² /g	Air res. s	Comp. index N.m/.g	Ring crush N.m2/g	Brightness %ISO
<i>Pinus canariensis</i> (Canary Island pine)											
600	458	4.5	1.49	12.3	81	3.3	6.5	6			
700	352	5.2	1.44	12.7	81	3.4	6.5	17			
800	281	5.2	1.43	11.4	83	3.3	6.5	46	31	1.4	13.7
<i>Pinus brutia</i> (Brutian/Red/Turkish/Calabrian pine)											
600	475	4.6	1.27	7.5	95	3.4	7.4	21			
700	320	5.0	1.27	7.3	101	3.5	8.4	41			
800	239	5.8	1.24	6.9	103	3.4	8.5	183	38	1.4	13.1
<i>Pinus pinaster</i> (Maritime pine)											
600	470	4.3	1.37	10.1	86	3.4	6.7	13			
700	368	4.8	1.36	10.0	85	3.6	7.2	19			
800	290	5.1	1.33	9.3	93	3.6	7.1	80	35	1.7	14.5
1000	159	7.2	1.27	8.1	94	3.4	7.8	817			
<i>Pinus radiata</i> (Guadalupe)											
600	469	4.6	1.27	7.7	93	3.5	7.5	14			
700	334	5.0	1.25	7.6	99	3.5	8.1	52			
800	326	5.4	1.24	7.9	88	3.5	7.5	118	36	1.4	13.0
<i>Pinus radiata</i> (Cedros)											
600	437	4.5	1.26	7.6	92	3.6	8.3	18			
700	351	4.7	1.27	7.5	94	3.6	7.6	54			
800	277	5.3	1.23	7.0	100	3.6	7.6	195	37	1.5	13.0
<i>Pinus radiata</i> (Mainland)											
800	428	4.5	1.30	8.3	99	3.1	8.3	27			
900	361	4.9	1.27	7.7	101	3.3	8.0	130			
1000	277	5.7	1.24	7.9	103	3.6	8.4	238	35	1.6	13.6
<i>Pinus radiata</i> (reference sample), basic density 460 kg/m ³ , screened pulp yield 47.1%, Kappa number 31.0											
0	723	4.0	1.67	14.8	53	2.3	3.8				
1000	685	4.1	1.41	10.2	80	2.8	6.0				
2000	623	4.3	1.34	9.1	88	2.8	6.5				
4000	408	5.1	1.28	8.4	99	3.0	7.0				

Appendix 2 – TMP Papermaking properties

Basic density Kg/m ³	SEC KWh/t	Shive content %	LWA Fib. lgt mm	Freeness CSF mL	Bulk cm ³ /g	Tear index mN.m ² /g	Tensile index N.m/g	Stretch %	Burst index kPa.m ² /g	Air res. s	B/ness %ISO	Opacity %	Abs. coeff m ² /kg	Scatt. coeff m ² /kg
<i>Pinus canariensis</i> (Canary Island pine)														
534	1079	3		434	3.73	3.4	11.5	0.9	0.5	1	44.3	93.3	4.04	33.6
	1242	2.1		289	2.95	4.8	15.8	1.2	0.7	2	44.4	92.8	3.54	34.5
	1492	1	1.64	142	3.08	5.3	19.8	1.4	0.9	12	45.9	95.1	3.97	43.3
	1970	0.7		99	2.76	4.9	24.1	1.5	1.1	25	47.2	96.1	4.41	46.7
<i>Pinus brutia</i> (Brutian/Red/Turkish/Calabrian pine)														
465	1082	4.8		442	3.43	3.4	11.5	0.9	0.5	1	44.3	93.3	4.04	33.6
	1311	2.1		237	3.11	3.7	16.1	1.1	0.6	2	46.6	94.8	4.02	39.6
	2393	1.4	1.34	126	2.82	4.9	20.8	1.3	1	12	47.8	45.8	4.32	43.4
<i>Pinus pinaster</i> (Maritime pine)														
453	1346	1.5		436	3.48	4.4	15.4	1.4	0.6	1	49.3	90.8	2.71	34.3
	1454	1.1		278	3.28	5.5	18.4	1.4	0.9	3	50.5	91.3	2.73	36.6
	2022	0.7	1.68	191	2.90	6.4	25.1	1.6	1.2	6	51.8	92.8	2.82	39.8
	n/a	0.8		126	2.63	6.5	30.3	1.8	1.5	31	52.1	94.5	3.41	46.1
<i>Pinus radiata</i> (Guadalupe)														
444	1277	1.4		379	3.58	3.5	14.7	1.2	0.6	1	47.4	92.9	3.27	36.9
	1388	1.2		288	2.97	4.6	18.5	1.2	0.8	2	46.3	93.3	3.56	36.5
	1703	0.8	1.39	150	2.78	4.8	21.9	1.4	1.0	10	47	94.3	3.80	40.9
	2481	0.3		72	2.24	5.0	32.3	1.7	1.4	71	49.3	96.5	4.36	49.3
<i>Pinus radiata</i> (Cedros)														
441	1086	1.9		444	3.61	5.6	17.9	1.4	0.8	1	45.7	92	3.33	32.0
	1086	2.6		426	3.14	5.7	19.7	1.3	0.9	1	47.5	91.8	3.08	33.2
	2099	0.4		94	2.45	5.7	31.9	1.8	1.5	64	49.3	96.2	4.62	48.5
<i>Pinus radiata</i> (Mainland)														
375	1063	4.5		370	3.08	5.3	19.2	1.2	0.8	2	51.6	91.6	2.59	38.3
	1301	3.7		323	3.12	5.2	20.3	1.4	0.9	3	51.8	93.4	2.94	40.7
	1538	2.0		189	2.62	6.0	26.7	1.5	1.2	23	52.3	94.3	3.13	44.1
	2001	1.2	1.43	118	2.39	5.6	33.5	1.7	1.6	70	52.8	95.3	3.50	48.6
<i>Pinus radiata</i> (Commercial)														
445	1204	4.6		522	3.48	5.8	17.4	1.3	0.8	1	47.7	93.3	3.34	36.1
	1322	1.5		243	2.86	5.1	20.9	1.3	0.9	5	48.7	93.6	3.42	38.2
	1542	0.7	1.48	144	2.63	6.1	25.5	1.4	1.1	22	49.2	96	4.37	45.7
	1954	0.6		89	2.24	5.7	31.7	1.5	1.5	51	49.2	96.6	4.70	48.2

Appendix 3 - Photographs of sawmill study

- A & B: Orientation of north south Axis through the primary breakdown bandsaw.
C: Flitches collecting on the transfer deck in front of the circular re-saw showing sequential colours painted on small end face of the logs



Appendix 4 - Photographs of kiln drying

Shows structural timber (90 x 35 mm) being dried in a kiln constructed from a converted shipping container.



Appendix 5 -Weighting system of basic densities from strips for the whole disc

Eq. 1 shows the weighting system that was used to give an estimate of the mean disk basic density from the shrinkage blocks cut from the diametrical strip.

Figure 51: Weighting system used to estimate basic density of disk from the basic density of the shrinkage blocks from the diametrical strips

shows how the system works on an ideal stem, while

Figure 52: Limitation of weighting system with elliptical, off centre or out of round stems

shows the minor difficulty it has with non-ideal stems such as elliptical stems and off center pith.

$$\text{Weight} = \left[\frac{((\text{position})^2 - ((\text{position} - 1)^2))}{((\text{position max})^2)} \right] \times 0.5 \quad \text{Eq. 1}$$

$$\begin{aligned} \text{E.G. Weight (B3)} &= \left[\frac{((3^2) - (2^2))}{(5^2)} \right] \times 0.5 \\ &= [(9-4)/25]/2 \\ &= 1/10 \text{ or } 0.1 \end{aligned}$$

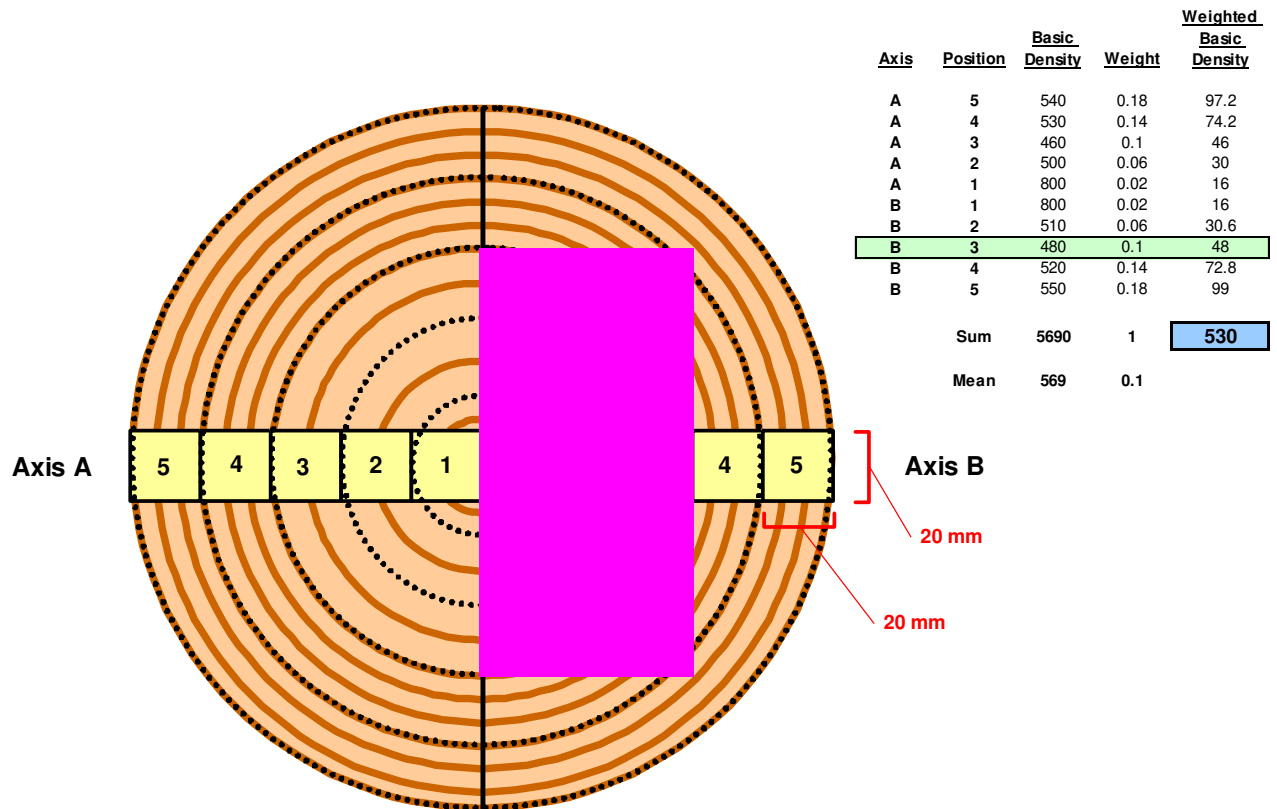


Figure 51: Weighting system used to estimate basic density of disk from the basic density of the shrinkage blocks from the diametrical strips

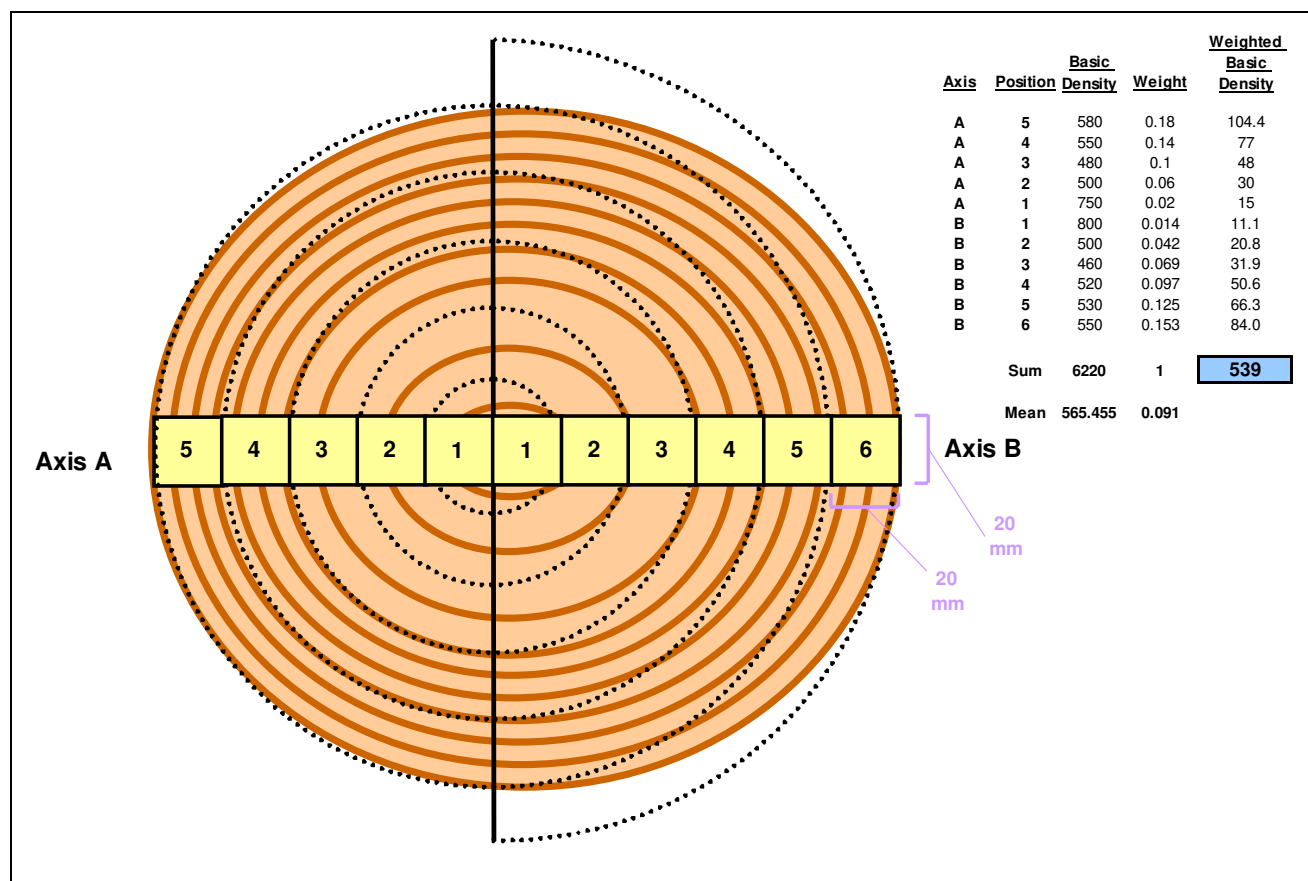


Figure 52: Limitation of weighting system with elliptical, off centre or out of round stems

Appendix 6 - Shrinkage versus MC%

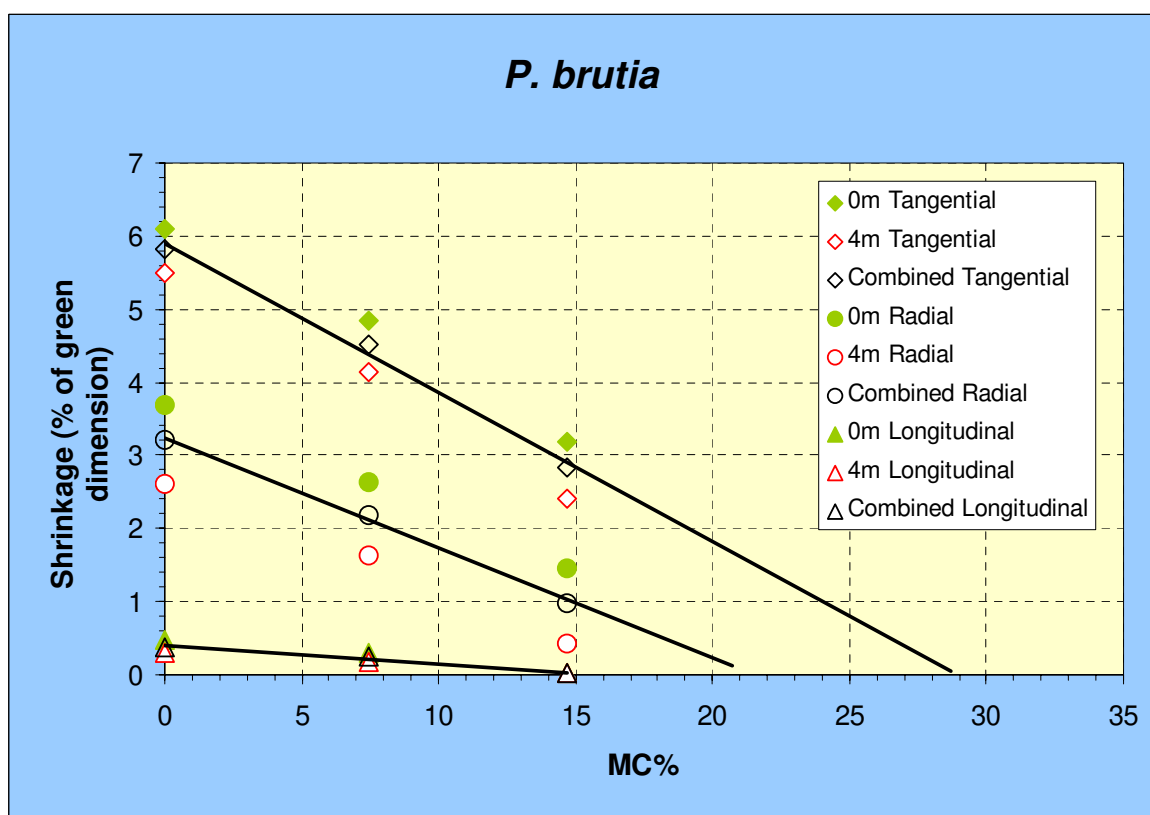
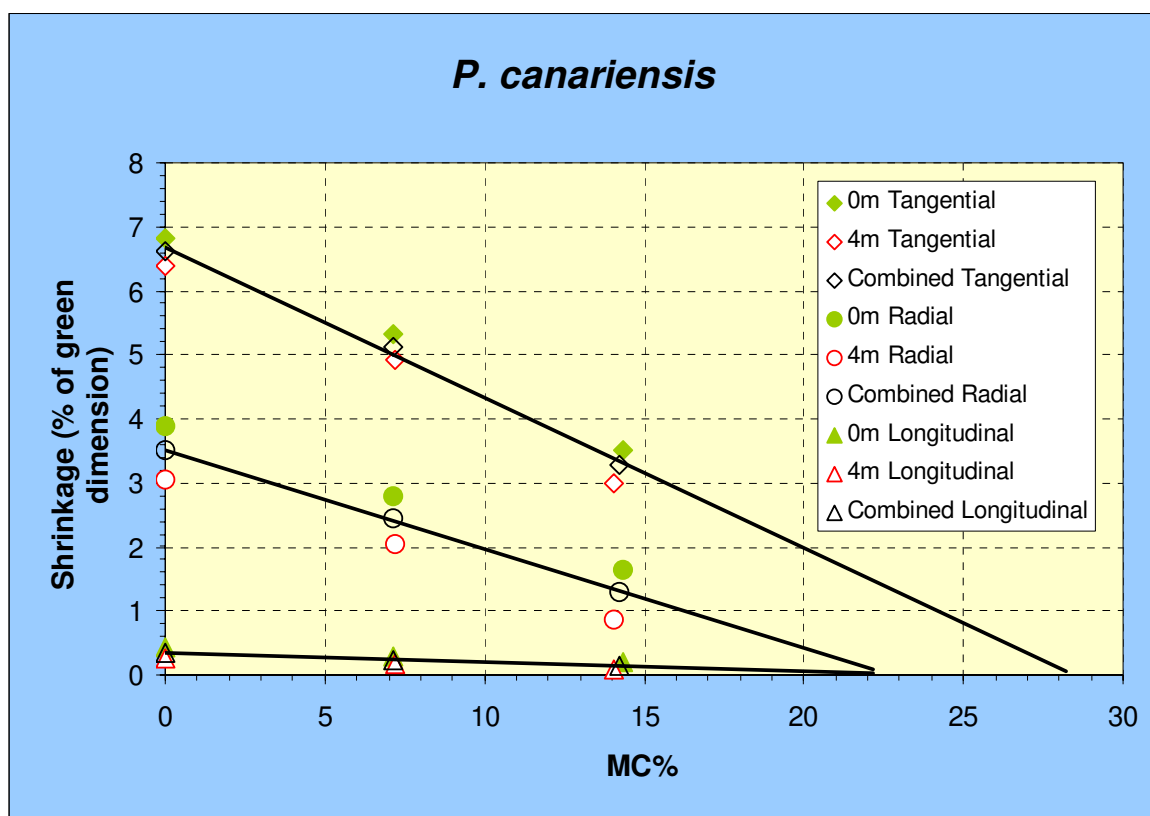


Figure 53: Shrinkage against MC%

Appendix 7 - Spiral grain measurements for individual trees.

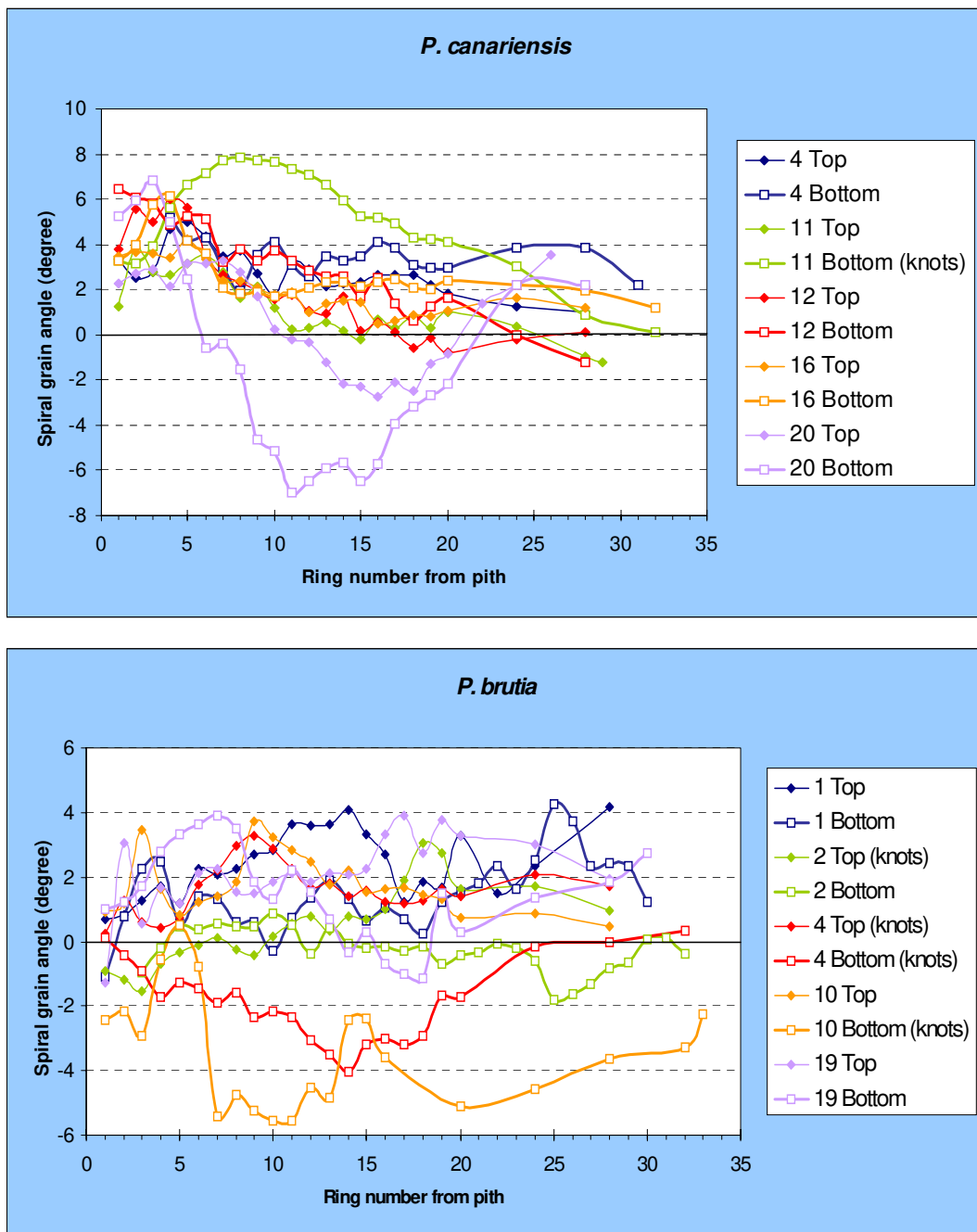


Figure 54: Plot of spiral grain for each individual strips from the top and bottom of the five randomly selected logs of *P. canariensis* and *P. brutia*

NB: comments in brackets note knots that were in or near the strips that may have affected the spiral grain measurements.

NB: Positive angles indicate left hand spiral.