Department of **Employment, Economic Development and Innovation**

Wood properties and processing outcomes for plantation grown African mahogany (*Khaya senegalensis*) trees from Clare, Queensland (18- and 20-year-old) and Katherine, Northern Territory (14-year-old)

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Cover Plate: *Khaya senegalensis*, 18-years-old in Burdekin Agricultural College close to Clare, site number 19

Table of Contents

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Executive Summary

Khaya senegalensis, African mahogany, a high-value hardwood, was introduced in the Northern Territory (NT) in the 1950s; included in various trials there and at Weipa, Q in the 1960s-1970s; planted on ex mine sites at Weipa (160 ha) until 1985; revived in farm plantings in Queensland and in trials in the NT in the 1990s; adopted for large-scale, annual planting in the Douglas-Daly region, NT from 2006 (Nikles et al. 2008); and is to have the planted area in the NT extended to at least 20,000 ha (S. Penfold, AMA, 2010, *pers. comm.*).

The recent serious interest from plantation growers, including Forest Enterprises Australia Ltd (FEA), has seen the establishment of some large scale commercial plantations. FEA initiated the current study to process relatively young plantation stands from both Northern Territory and Queensland plantations to investigate the sawn wood and veneer recovery and quality from trees ranging from 14 years (NT – 36 trees) to 18-20 years (North Queensland – 31 trees).

Field measures of tree size and straightness were complemented with log end splitting assessment and cross-sectional disc sample collection for laboratory wood properties measurements including colour and shrinkage.

End-splitting scores assessed on sawn logs were relatively low compared to fast grown plantation eucalypts and did not impact processing negatively. Heartwood proportion in individual trees ranged from 50% up to 92 % of butt cross-sectional disc area for the visually-assessed dark coloured central heartwood and lighter coloured transition wood combined. Dark central heartwood proportion was positively related to tree size ($R^2 = 0.57$). Chemical tests failed to assist in determining heartwood – sapwood boundary. Mean basic density of whole disc samples was 658 kg/m^3 and ranged among trees from 603 to 712 kg/m^3.

When freshly sawn, the heartwood of African mahogany was orange-red to red. Transition wood appeared to be pinkish and the sapwood was a pale yellow colour. Once air dried the heartwood colour generally darkens to pinkish-brown or orange-brown and the effect of prolonged time and sun exposure is to darken and change the heartwood to a red-brown colour. A portable colour measurement spectrophotometer was used to objectively assess colour variation in *CIE* L*, a* and b* values over time with drying and exposure to sunlight. Capacity to predict standard colour values accurately after varying periods of direct sunlight exposure using results obtained on initial air-dried surfaces decreased with increasing time to sun exposure. The predictions are more accurate for L* values which represent brightness than for variation in the a* values (red spectrum). Selection of superior breeding trees for colour is likely to be based on dried samples exposed to sunlight to reliably highlight wood colour differences.

A generally low ratio between tangential and radial shrinkages was found, which was reflected in a low incidence of board distortion (particularly cupping) during drying. A preliminary experiment was carried out to investigate the quality of NIR models to predict shrinkage and density. NIR spectra correlated reasonably well with radial shrinkage and air dried density. When calibration models were applied to their validation sets, radial shrinkage was predicted to an accuracy of 76% with Standard Error of Prediction of 0.21%. There was also a strong predictive power for wood density. These are encouraging results suggesting

that NIR spectroscopy has good potential to be used as a non-destructive method to predict shrinkage and wood density using 12mm diameter increment core samples

Average green off saw recovery was 49.5% (range 40 to 69%) for Burdekin Agricultural College (BAC) logs and 41.9% (range 20 to 61%) for Katherine (NT) logs. These figures are about 10% higher than compared to 30-year-old *Khaya* study by Armstrong et al. (2007) however they are inflated as the green boards were not docked to remove wane prior to being tallied. Of the recovered sawn, dried and dressed volume from the BAC logs, based on the cambial face of boards, 27% could potentially be used for select grade, 40% for medium feature grade and 26% for high feature grades. The heart faces had a slightly higher recovery of select (30%) and medium feature (43%) grade boards with a reduction in the volume of high feature (22%) and reject (6%) grade boards. Distribution of board grades for the NT site aged 14 years followed very similar trends to those of the BAC site boards with an average (between facial and cambial face) 27% could potentially be used for select grade, 42% for medium feature grade, 26% for high feature grade and 5% reject.

Relatively to some other subtropical eucalypts, there was a low incidence of borer attack. The major grade limiting defects for both medium and high feature grade boards recovered from the BAC site were knots and wane. The presence of large knots may reflect both management practices and the nature of the genetic material at the site. This stand was not managed for timber production with a very late pruning implemented at about age 12 years. The large amount of wane affected boards is indicative of logs with a large taper and the presence of significant sweep. Wane, knots and skip were the major grade limiting defects for the NT site reflecting considerable amounts of sweep with large taper as might be expected in younger trees.

The green veneer recovered from billets of seven *Khaya* trees rotary peeled on a spindleless lathe produced a recovery of 83% of green billet volume. Dried veneer recovery ranged from 40 to 74 % per billet with an average of 64%. All of the recovered grades were suitable for use in structural ply in accordance to AS/NZ 2269: 2008. The majority of veneer sheets recovered from all billets was C grade (27%) with 20% making D grade and 13% B grade. Total dry sliced veneer recovery from the logs of the two largest logs from each location was estimated to be 41.1%.

Very positive results have been recorded in this small scale study. The amount of colour development observed and the very reasonable recoveries of both sawn and veneer products, with a good representation of higher grades in the product distribution, is encouraging. The prospects for significant improvement in these results from well managed and productive stands grown for high quality timber should be high. Additionally, the study has shown the utility of non-destructive evaluation techniques for use in tree improvement programs to improve the quality of future plantations.

A few trees combined several of the traits desired of individuals for a first breeding population. Fortunately, the two most promising trees (32, 19) had already been selected for breeding on external traits, and grafts of them are established in the seed orchard.

Introduction

Khaya senegalensis, African mahogany, a high-value hardwood, was introduced in the Northern Territory (NT) in the 1950s; included in various trials there and at Weipa, Q in the 1960s-1970s; planted on ex mine sites at Weipa (160 ha) until 1985; revived in farm plantings in Queensland and in trials in the NT in the 1990s; adopted for large-scale, annual planting in the Douglas-Daly region, NT from 2006 (Nikles et al. 2008); and is to have the planted area in the NT extended to at least 20,000 ha (S. Penfold, AMA, 2010, *pers. comm.*). Over the last few decades small trial plots have been established leading to recent serious interest from plantation growers, including Forest Enterprises Australia Ltd (FEA), to invest in large scale commercial plantations.

An early provenance trial in the Northern Territory was sampled in 2004 (Armstrong *et al.* 2007) for a sawing and timber utilization study and provided results for 32-year-old trees as part of a selection and tree improvement program (Nikles *et al.* 2008). In 2009 FEA initiated the current study to process logs from younger plantation stands from both Northern Territory and Queensland plantations to investigate the sawn wood and veneer recovery and quality from trees ranging from 14 years (NT) to 18-20 years (North Queensland).

Study objective

To determine selected tree, log and wood parameters of African mahogany (*Khaya senegalensis*) and relate these to processing properties including recoveries and values of products from sampled resources on individual- and pooled-log bases with tree identity kept.

Materials and Methods

Site location details

Two sites were selected for this study, a Burdekin Agricultural College (BAC) plantation site close to Clare (Figure 1) and a plantation site near Katherine (Fox Road) in the Northern Territory. Detailed descriptions of both sites are outlined in Table 1.

Tree selection and harvesting

Trees were selected and harvested in July 2009. At the Burdekin Agricultural College (BAC) site, the initial intention was to select 40 – 50 suitable stems for harvesting. Tree selection was based on tree size, clear bole length, estimated butt log SEDUB and sweep as well as a general visual assessment of tree health and sawmill specifications. Based on these criteria, 32 trees were selected for assessment and harvesting. In the Northern Territory (N.T.), 36 trees were selected and harvested. Each tree was measured for over bark diameter at breast height (DBHOB), and assessed for standing sweep and straightness. Appendices A and B provide details of individual tree data of all selected trees. Each tree was assigned a unique number from 1 to 32 for BAC logs (tree # 30 was later rejected) and numbers 81 to 116 for NT logs. Of 31 selected trees from BAC site, based on size and availability of clear wood, seven trees were allocated for rotary peeling and the two largest trees for sliced veneer. From the N.T. site, the two largest logs were allocated for slicing and all other logs were sawn.

Each tree was felled at a stump height of approximately of 20cm from the ground to encourage coppice production. The sample trees were merchandised into a single log of length of either 1.4m for rotary peeling or 3.0m to 3.6m length for sawing and slicing logs, with the final log length determined by the presence of large branches and/or pruning scars in combination with rapidly reducing DOB after crown break. The bark was not removed from the logs to minimize drying and cracking during transport. Each log was labeled with its unique number before removal to the loading area where identification templates were applied.

Table 1. Location details of *Khaya senegalensis* plantations.

	Site number 19	**Site number 20**	**Northern Territory**
Location	Burdekin Agricultural College, 4km north-west of Clare. 19.8˚S 147.2˚E	Burdekin Agricultural College, 4km north-west of Clare. 19.8˚S 147.2˚E	Fox Rd, Venn Horticultural Area, South of Katherine 14.4˚S 132.3˚E
AMG coordinates	520708E, 7814703N	520675E, 7814602N	UTM 53L 225775E ,83 92000N GDA94
Altitude (asl)	30m	30m	195m
Annual rainfall	940mm	940mm	1133mm
Soil type	Yellow sodosol	Yellow sodosol	Kandasol, deep red sandy loam
Date of planting	March 1989	March 1991	1995
Planted espacement and stocking	8.5 × 7.5m = 157 spha	8.5 × 9.0m = 130 spha	2 × 5 m = 1000 spha
Plantation size	0.5 ha	0.5 ha	0.7 ha
Stand management	Not thinned, pruned to 3.0m at about age 12-13 years; early irrigation.	Not thinned, pruned to 3.0m at about age 10-11 years; early irrigation.	Some irrigation at establishment, probably some fertilizing, otherwise nil.

Diameters over and under bark were measured at both log ends. Logs were moved to loading area and each face of the rotary peeling logs was painted with an emulsion wax sealant to minimize log-end splitting due to rapid moisture loss. Log end templates were glued with Bond-Crete water proofing adhesive to each log end (Figure 2) to ensure accurate tracking of identity of position of individual board within the single log (Smith *et al.*, 2003). The sawing logs were transported to the TARMAC sawmill at Wyan, near Rappville in northern New South Wales, for further processing. The rotary peeling and slicing logs were transported to the DEEDI Salisbury Research Centre (SRC), Queensland for processing (rotary peeling) and transfer to Proveneer (slicing).

In addition to sawing and veneering studies, logs and wood discs from the BAC site were also analyzed for a range of wood physical properties which are described below. No wood property assessment was undertaken for trees from the N.T. site as collecting extra wood disc samples would have compromised log size and length.

Log volume

Log volumes were calculated using Smalian’s formula (Equation 1) which uses log large and small under-bark diameters and log length for volume calculations. These were calculated for all merchandised logs and were further used in sawn and veneer recovery calculations.

$$V = [\frac{(LEDUB + SEDUB)}{2} \times \frac{1}{2}]^2 \times \pi \times L \quad (1)$$

Where: V = log volume (m^3); LEDUB = large end diameter under-bark (m); SEDUB = small end diameter under-bark (m); L = log length (m).

Figure 1. One of the two landcare forestry plantation plot of *Khaya senegalensis* at Burdekin Agricultural College, Clare, Queensland at the time of sampling in July 2009 (there had been no thinning).

Log end splits

Log end-splitting is caused by the release of growth stresses within the log and shrinkage induced stresses as the wood dries. Excessive end-splitting in green logs can reduce recovery and indicate that further stress release related problems might be encountered during processing and utilization. End splitting may develop or be exacerbated by drying that occurs between felling and processing particularly if haul distances are long, weather conditions are hot and dry and/or logs are not covered or end-sealed after felling and during transport.

Log end-splits were assessed within 3 hours of felling and about 16 hours after felling. Further assessment of splitting/cracking on log ends was not practical due to the logistical need to apply log end templates (see Figure 2) which required at least 24 hours to dry before loading and transport.

Log end-splits were scored using a method developed by Knapp *et al.* (2000). This method calculates a splitting value for a log end containing splits as follows: A split receives a score of 0.5 for each half radius it extends radially across the cross-section. If a split reaches the periphery, it gets a score value of 1. For each 1 mm opening of a split at the periphery a score of 1 is added to the score value. A splitting value for each log is given as the sum of score values from both log ends – refer to Figure 3 for an example of the scoring method and Figure 4 for a picture of a log end which displayed a higher than average level of cracking for the logs harvested in this trial.

Figure 2. Harvested *Khaya* logs from the Burdekin Agricultural College site with log end paper templates applied to enable return to log study data capture.

Log Sweep

Butt log sweep was measured at up to tree points in each standing trees using a tape measure at the point of maximum deviation from a straight piece of timber about 2.0m long held against the tree at any points of visually obvious sweep.

Prior to sawing, sweep measurements were taken on each log at up to three points with the logs rolled to detect sweep deviations. A string line was held along the log from the end to the point in the log that defined the sweep and a small ruler used to measure the maximum deviation from the string line.

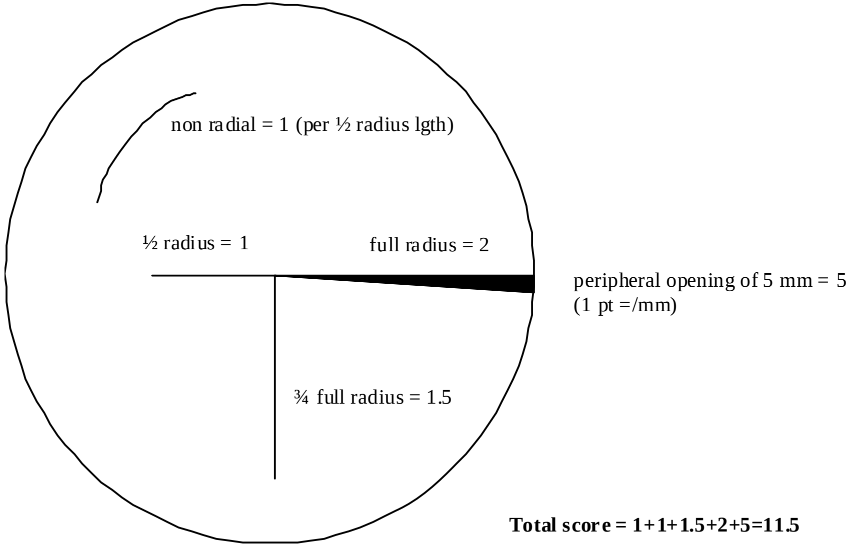

Figure 3. Example of the Knapp et al. (2000) log end split scoring system applied to a log end.

Figure 4. The large end of tree number 19 from the 18-year-old plot at Burdekin Agricultural College showing end-splitting and pen numbers and radial measure points marked at initial assessment and at the second assessment when the crack had propagated further.

Sampling of wood discs

From each tree at the BAC site, two defect-free discs were extracted from the bottom part of the butt log (exact sampling heights are listed in Appendix A). In limited cases, an additional two discs were also taken from the top of the butt log although this was not possible for all trees due to the presence of large knots or branch scars. One set of discs was used for evaluation of basic density and heartwood/sapwood proportion; another set was used for colour assessment and shrinkage. In this study, only results from discs sampled at the bottom of the sawlog are discussed as these provide a full set of comparisons among all trees at the site. Wood properties of discs sampled at the top of sawlogs from 11 trees were also analysed and are provided in Appendix H.

Heartwood/sapwood (HW/SW) proportion

There was no clear distinction between heartwood and sapwood. At first, methyl orange spray was applied to enhance this demarcation however there was no response to this chemical solution, which is commonly successfully used for eucalypts. After testing several more chemical reagents, which consequently failed to highlight heartwood, visual assessment was performed. As seen in Figure 5, there were three zones discernable on the discs: a darker heartwood zone, a lighter transition wood zone and a very light coloured sapwood zone. Measures of these three zones were recorded. Sapwood was measured as the width in radial direction while heartwood and transition wood proportions were calculated as a percentage of disc basal area under bark.

Figure 5. Transverse face of a *Khaya* log end soon after felling with distinctive heartwood, transition wood and sapwood zones (the small numbers - 1, 2, 3 and 4 - denote small end splits that were measured). Such distinctiveness was not observed in all log ends.

Basic density

Basic density was measured on two wedge samples cut from opposite positions from a single disc and positioned to minimise the inclusion of tension wood or other defects. Each wedge sample was further sectioned into two pieces representing the sapwood and heartwood zones (heartwood included transition wood). Basic density was determined by the water displacement method and is referred to here as un-extracted basic density as no attempt was made to extract heartwood extractives.

Shrinkage and Unit shrinkage

Shrinkage (green to air dry) and unit shrinkage were measured using a standard sample holding jig mounted with a point dial gauge. From each bottom disc three block samples were extracted representing true heartwood, intermediate wood and sapwood. They were sawn to cubic dimensions 25mm in each direction and had true radial and tangential faces.

Due to sample size restrictions it was not possible to obtain samples of standard size to assess longitudinal shrinkage along a 100 mm long sample length. Samples were weighed and their dimensions measured at regular intervals during drying in an oven with forced airflow, until approximately 12% moisture content had been reached. Samples were then reconditioned and re-dried with measurements taken at 12% and 5% moisture content before the samples were oven dried to a constant dry weight. The measured unit shrinkage is presented as the percentage change in dimension with each one percent change in moisture content.

Near-infrared spectroscopy

All 124 shrinkage block samples were conditioned to 12% moisture content. NIR diffuse reflectance spectra were acquired using an NIR Bruker MPA multi purpose analyzer spectrometer in integration sphere mode. NIR spectra were collected from the radial-longitudinal (RL) and radial-tangential (RT) faces. Two spectra were taken from each surface, which were further averaged to provide a single spectrum per surface. Background corrections using a reference ceramic sample were conducted at 60-minute intervals. A Partial Least Squares (PLS) regression analysis using OPUS software (Bruker MPA) was utilized to relate laboratory generated shrinkage characteristics for all samples with their corresponding NIR reflectance spectra. The dataset was split with a calibration set (70% of selected samples) used to develop the models. The performance of each model was then tested using an independent dataset or validation set consisting of the remaining 30% of the samples). A cross-validation method was conducted to determine the optimum number of principal components (PLS factors) required for each model. The coefficient of determination (R^2), the Standard Error of Calibration (SEC) and Standard Error of Prediction (SEP) generated from the regression were used to gauge how well the NIR model fitted the calibration data used to develop it.

Colour measurement

The samples used for colour determination were rectangular diametral strips free of defect and reaction wood and sawn from the green discs to approximately 40mm tangentially × 50mm longitudinally with the radial length determined by disc diameter. The radial-longitudinal face of each strip sample was planed to obtain a smooth surface and to highlight the colour variation. Prior to further preparation before drying, the samples were stored in a freezer.

On each sample, several surface spots were identified representing true heartwood, intermediate wood and sapwood. The spots were marked by pencil as circles of 27mm, this area being slightly larger than the aperture of the spectrophotometer. These circles were marked so the same surface area and position was scanned throughout the multiple scans taken over time. From 4 to 9 measurement spots were selected for each sample (see example in Figure 6).

A MiniScan XE portable colour measurement spectrophotometer from HunterLab was used in this experiment (Figure 6). The aperture size was 25mm diameter. Colour is expressed according to the Commission International de l'Eclairage (CIE) $L^*a^*b^*$ colour space (abbreviation CIELAB) with a standard illuminant D65 and a 10° standard observer. The L^* parameter represents lightness where the values of L^* vary from 0 (black) to 100 (white). The a^* and b^* parameters describe the chromatic coordinates on green-red (a^*) and blue-yellow (b^*) axes.

The measurements of colour were performed at regular intervals:

1. After 24 hours removed from the freezer exposed indoor away from direct sunlight
2. After 1 week removed from the freezer, exposed outdoors away from direct sunlight
3. After 2 weeks removed from the freezer, exposed outdoors away from direct sunlight

4. Condition 3 plus 3 days exposed to direct sunlight
5. Condition 3 plus 7 days exposed to direct sunlight
6. Condition 3 plus 14 days exposed to direct sunlight
7. Condition 3 plus 21 days exposed to direct sunlight
8. Condition 3 plus 25 days exposed to direct sunlight
9. Condition 3 plus 35 days exposed to direct sunlight

In addition a picture of the surface was also taken using a NIKON digital camera each time the colour was measured for qualitative analysis of the colour development.

Effect of surface finish on wood colour

After 14 days exposure to direct sunlight, surface finishing was applied on a single radial surface of each sample leaving the other half of the diameter untouched. An oil based finish (Danish oil) was applied on one set of samples whereas a lacquer based finish (Clearlac) was applied on every alternate sample.

Figure 6. MiniScan XE portable spectrometer in use. Note the circular spots marked on the wood sample representing heartwood, transition wood and sapwood assessment points.

Processing studies

Sawing

All logs were transported to the TARMAC Pty Ltd Wyan sawmill (near Rappville, northern NSW) within one week of felling. This sawmill has a Vislander linear breakdown line (Figure 7a) utilizing chipper canters and single arbor circular saws in several machine centres. The headrig has a pair of chipper-canters followed by four circular saws. Sideboards go to an edger, the cant is turned down and proceeds through a pair of chipper-canter heads and then through a twinsaw with scribing saws on each side (to cut boards narrower than the cant width from the outer parts of the cant). The remaining section of the cant then passes through a multi rip saw. All sawing is straight-line and the parallel breakdown sawing pattern is well suited to minimizing any growth stresses that may be encountered in sawing plantation hardwood logs. The sawing process was similar to usual commercial practice.

The logs were sawn into boards of uniform thickness of 28 mm with a variety of dimensioned board widths, depending on the log sizes (Figure 7b). Only full board lengths were recovered. Boards with excessive wane or other defects were not docked. Once all logs were sawn, all boards were sorted by size and assembled into stacks, wrapped in plastic and dispatched to the FEA Ltd sawmill at Bell Bay, Tasmania for seasoning, finishing and grading.

Figure 7. Vislander sawmill headrig (a); the final sawn product (b).

Seasoning

Boards were hand racked for drying in a small kiln at the University of Tasmania's Timber Research Unit laboratory. A concrete weight was placed on top of the stack to restrain distortion during drying (Figure 8). The drying schedule applied is shown in Table 2; air velocity was approximately 1 m/sec.

Table 2. Drying schedule for African Mahogany used in the present study – adapted from Armstrong *et al.* 2007

Moisture content (average of 4 sample boards) %	Temperature °C	Relative humidity %
Above 60	35	75
60-40	35	60
40-35	40	50
35-30	40	40
30-25	45	30
25-20	40	30
20-15	55	30
15-10	55	30

Figure 8. Timber loaded in kiln with concrete weight for restraint.

Moisture content during kiln drying was monitored by weighing sample boards. Final moisture content was measured using a calibrated resistance meter (Delmhorst DCR22) and species correction from Australian Standard AS1080.1 on two boards cut from the outer heartwood of each log. Shrinkage in width (tangential) and thickness (radial) directions was measured at location approximately 1m from the butt end of each of these boards.

Figure 9. Moulding boards to final dimensions.

Dried and dressed graded recovery

Following drying, all boards were machined to final dimension (Figure 9) using a conventional 6-head moulder. Each board face was graded to Australian Standard AS2796 rules. If a section of the face 900 mm or longer met Select grade requirements, that section was noted. Any remaining sections of board were recorded by grade and length, with grade limiting defect(s) noted. If sapwood was evident (by colour) on that face, it was noted.

The boards that had previously been measured for MC and shrinkage then had Janka hardness measured at two random points on the pith side of the board, approximately 300mm from the top end of the board. Radius of this board face from the pith, as determined from the portion of the log end template adhering to the board end, was noted. A short section adjacent to the hardness test specimen was used for determination of MC using the oven dry method of Australian Standard AS1080.1.

Rotary Veneering

Of the 31 stems harvested from BAC, 7 billets approximately 1.4m in length were sampled from the butts of trees that could not provide a 3.0m sawlog but had a shorter straight section available that met veneering specifications for straightness, size and absence of defect. The billets were processed at the DEEDI Salisbury Research Centre (SRC) Composite Research Facility.

Before peeling, the *Khaya* billets were heat treated to obtain core temperatures of 90^0C. Core temperature elevation was achieved by exposing the billets to full steam conditions for 24 hours prior to peeling. After heat treatment the billets were docked to 1300mm in length and processed on an Omeco spindleless lathe to produce veneer with a target green thickness of 2.7 to 2.8mm (Figure 10).

Figure 10. Processing of Khaya billets into veneer sheet using Omeco spindleless lathe.

After peeling the ribbon was trimmed to 2.6 m lengths and dried by a commercial veneer company, Austral Ply (Brisbane), using a Jet box dryer with 180 ^{0}C infeed and 150 ^{0}C outfeed temperatures, with a transit time of approximately 9 minutes and a target final moisture content of less than 10%. The veneer was then returned to SRC for grading in accordance to Australian/New Zealand Standard AS/NZ 2269: 2008.

Sliced veneer processing

Four logs, the two largest available from BAC and from the NT, were processed into sliced veneers (Figure 11) at the Proveneer timber company (Redbank, Queensland). Two of the logs were soaked in boiling water for 4 days prior to slicing and the other 2 were processed/sliced un-soaked.

Figure 11. Processing of *Khaya* logs into sliced veneer.

The veneers were processed to a nominal 1mm thickness and the total recovery was calculated using the product of the length × width × number of sheets per log (Appendix G) and subtracting this from the log volume estimate before processing.

Results and Discussion

Log end-split

Overall, end-splitting was not a significant problem in this study. The mean log end-split value 16 hours after felling was 7.14 (Appendix C). However this value was the sum of both log ends and the log average score was about 3.6. This end-split value compares well with the results of Armstrong *et al.* (2007) where their measured end-split value for larger more mature logs (about 30 years old) was 4.2 at about 72 hours after felling. When benchmarked to eucalypts, which are renowned for splitting problems - average values commonly range from 10 to 16 - the splitting value for these *Khaya* logs was relatively low.

Heartwood proportion and sapwood width

Wood of mahogany species is valued for its distinctly coloured heartwood. Higher heartwood proportion will consequently increase the financial value of the timber. Also, *Khaya senegalensis* is lyctus borer susceptible, so increased sapwood volume will increase timber treatment costs.

Results of heartwood proportion together with transition wood proportion estimated for individual sampled trees are presented in Figure 12 and in Table 3. Heartwood proportion ranged from 12% up to 55% of cross-sectional disc area for the central dark coloured zone. When the paler pinkish coloured transition wood is also considered as a part of heartwood, these figures increased to 50 - 92%. Sapwood width ranged from 5.5 mm up to 45 mm.

As seen from Figure 13, heartwood proportion is strongly influenced by tree size ($R^2 = 0.57$). As expected, larger trees contain more heartwood than smaller trees. On the other hand, transition wood is indirectly related to the tree radius. When combined (heartwood with transition wood) there is no association with tree size (results not shown).

Compared to a previous study by Armstrong *et al.* (2007), true heartwood in this report was found to be lower (on average 70% compared to 33%), which is to be expected given the age differences between the two studies (32-year-old vs. 18-20-year-old). However, it is likely that there will have been differences in determination of the heartwood - sapwood boundary between the two studies as this boundary was indistinct in the current study compared to the earlier study on older trees.

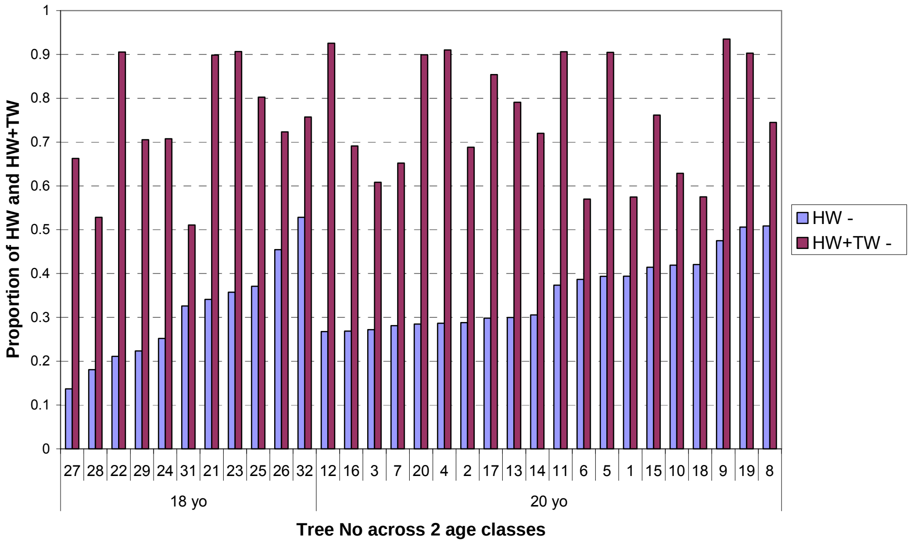

Figure 12. Heartwood (HW) and heartwood combined with transition wood (HW+TW) proportions across two age classes for individual tree from Burdekin Agricultural College. Note: values charted in ascending order based on heartwood proportion.

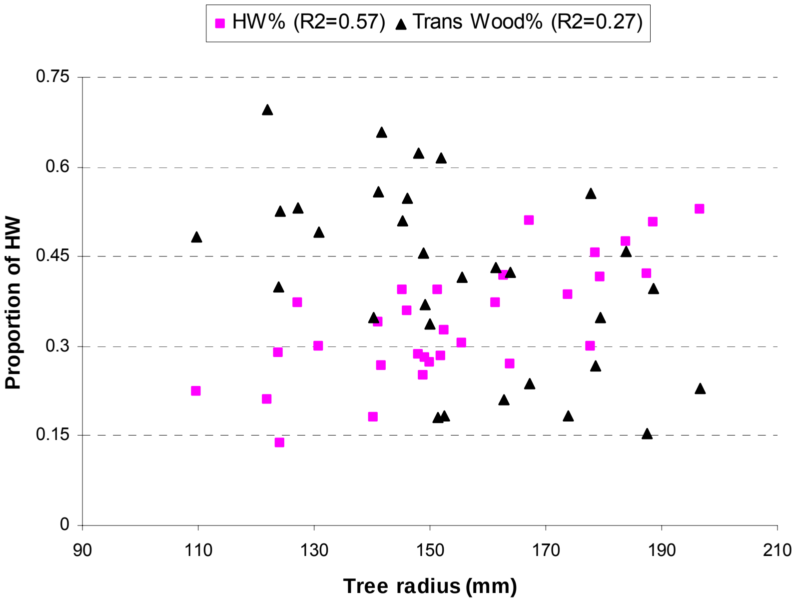

Figure 13. Scatter plot showing influence of tree size on HW and transition wood proportions **(**r^2 indicated for a straight line of best fit).

Table 3. Summary of heartwood and transition wood proportions, and sapwood width measured on disc samples from Burdekin Agricultural College.

Property	Age	Average	Minimum	Maximum	Std. deviation
Heartwood (%)	18	30.7	13.7	52.8	12.1
Transition wood (%)		42.9	18.5	69.5	15.7
Sapwood width (mm)		21.4	5.9	43.5	12.3
Heartwood (%)	20	35.7	26.7	50.8	8.7
Transition wood (%)		40.5	15.4	65.8	15.5
Sapwood width (mm)		20.7	5.4	45.3	13.0

Basic density

The results for basic density are graphically illustrated in Figure 14 and also presented in Table 4 and Appendix C. Overall mean basic density of whole disc samples was 658 kg/m^3 and ranged from 603 to 712 kg/m^3. These results compare well to figures obtained by Armstrong *et al.* (2007) for 32-year-old *Khaya* from the Northern Territory (mean value 637 kg/m^3). ANOVA results on the BAC trees found significantly higher density for the 20-year-old trees when compared to the 18-year-old trees (results not shown).

As expected, sapwood had a significantly higher density compared to the heartwood.

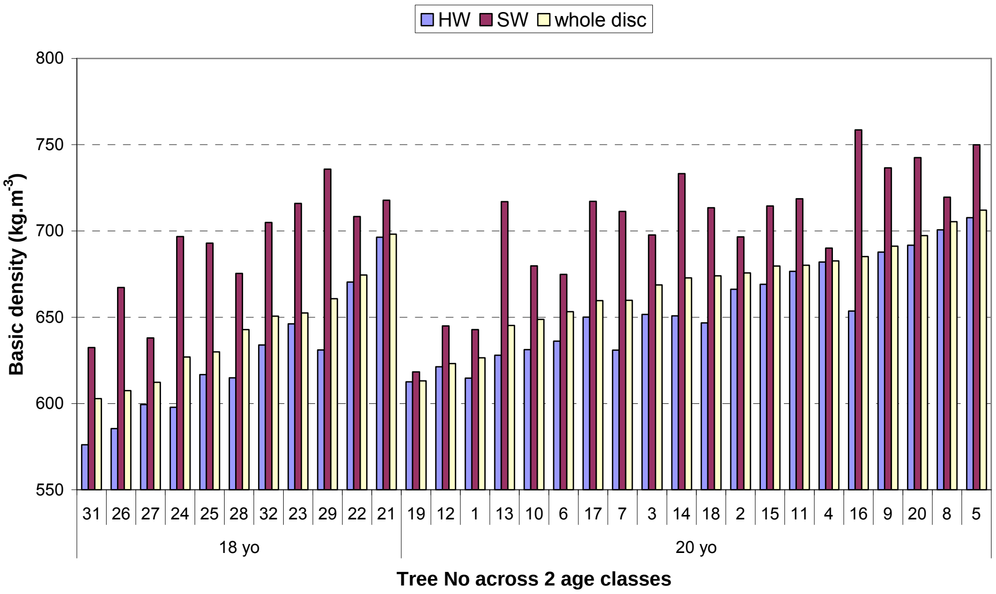

Figure 14. Basic densities of heartwood (HW), sapwood (SW) and whole disc across two age classes of individual trees from Burdekin Agricultural College. Note: values charted in ascending order based on whole-disc basic density.

Table 4. Basic density results from 17 and 14 trees (20- and 18-year-old respectively) sampled at Burdekin Agricultural College.

Segment	Age	Average (kg/m^3)	Minimum (kg/m^3)	Maximum (kg/m^3)	Std. Deviation (kg/m^3)
Whole disc	18	641	603	698	29.5
Heartwood		624	576	696	36.4
Sapwood		689	632	736	33.1
Whole disc	20	667	613	712	26.8
Heartwood		655	613	708	28.7
Sapwood		704	618	759	36.9

Wood colour assessment

When freshly sawn, the heartwood of African mahogany in the BAC samples was orange-red to red. Transition wood appeared to be pinkish and the sapwood was a pale yellow colour (Figure 15a). Once air dried the heartwood colour generally darkens to pinkish-brown or orange-brown (Figure 15b). The effect of prolonged time and sun exposure is to darken and change the heartwood colour to red-brown colour (Figure 15c).

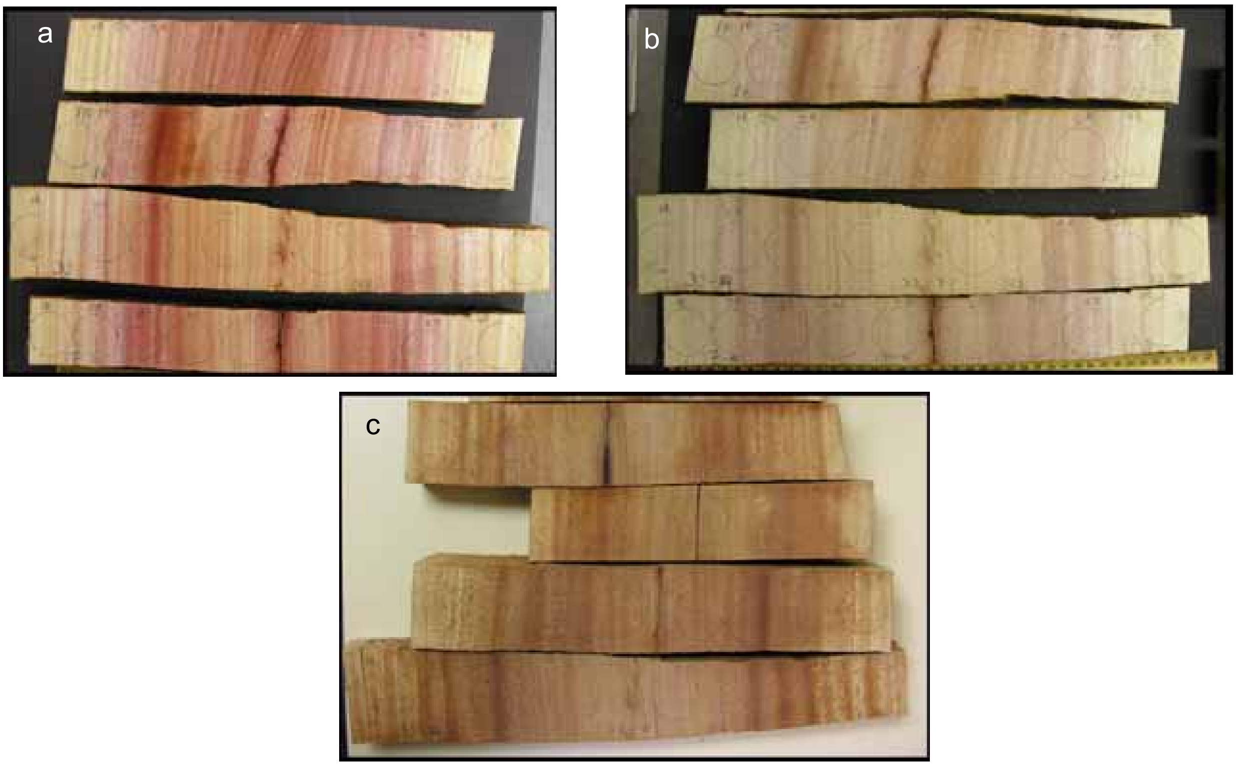

Figure 15. Examples of colour development in African mahogany wood: a) freshly cut samples; b) samples after one week drying without sun exposure; c) samples after 35 days exposed to direct sun.

Figures 16, 17 and 18 illustrate the changes in L* value (which represent the overall lightness of colour); a* value (higher values represent richness in red) and b* value (higher numbers represent richness in yellow) after a timed exposure to direct sunlight for heartwood, transition wood and sapwood. The results show that lightness dropped sharply at the beginning of the experiment when samples were exposed to sun for the first three days (Figure 16). With further sun exposure, the L* value fluctuated slightly, initially decreasing but then increasing slightly. There is a clear significant difference between sapwood and heartwood in L* value confirming that sapwood is paler than heartwood. It is also interesting to observe the differences between heartwood and transition wood. Initially there was a significant difference in L* value between HW and TW however it gradually disappeared with increasing length of sunlight exposure. This indicates that the initial clear differences in brightness between these two types of wood gradually fade away. The same trend was also observed when closely inspecting changes in a* values (Figure 17) which represent changes in red colour. On the other hand, differences in b* values between HW and TW gradually increase with increasing sun exposure time (Figure 18).

Contrary to L* value, the a* and b* values increased rapidly after being exposed to sun, during which time the colour of the samples shifted to reddish and yellow-orange respectively. Then the values decreased slightly as the intensity of the colour faded.

Figure 16. Changes in L* value (lightness) over the time after exposure to sun for heartwood, transition wood and sapwood; and after application of oil or lacquer surface treatments.

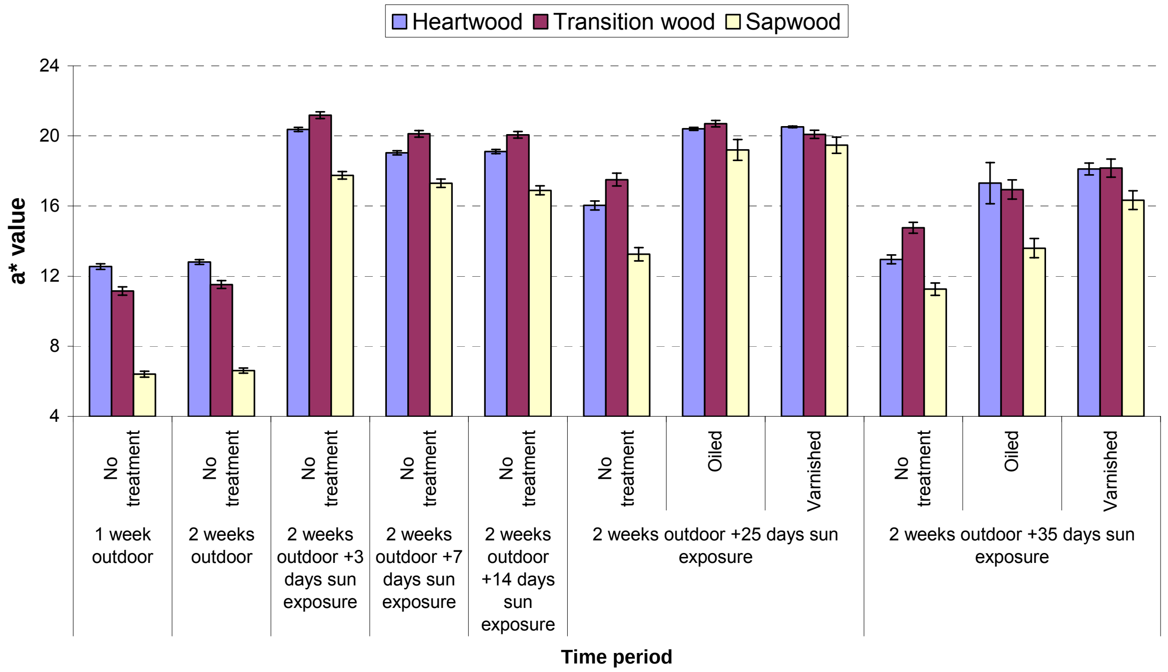

Figure 17. Changes in a* value (intensity in red colour) over the time after exposure to sun for heartwood, transition wood and sapwood; and after application of oil or lacquer surface treatments.

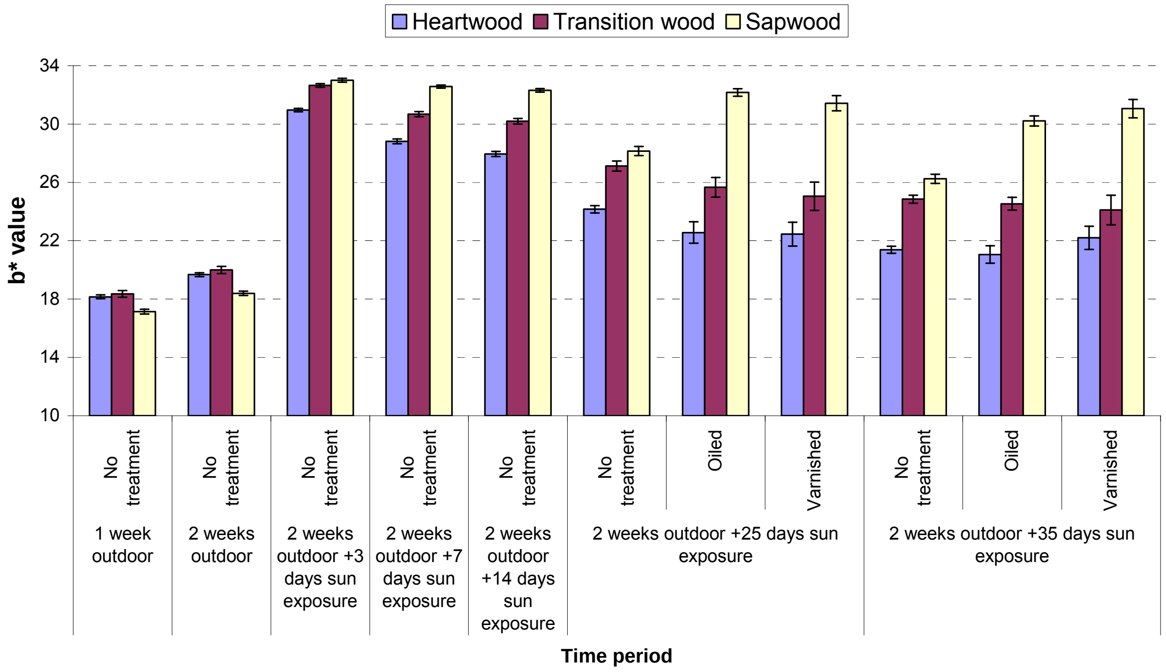

Figure 18. Changes in b* value (intensity in yellow colour) over the time after exposure to sun for heartwood, transition wood and sapwood; and after application of oil or lacquer surface treatments.

In terms of colour change when different surface finishes were applied to wood samples (previously exposed to sunlight for 14 days), there were no significant differences in L*, a* and b* values between Danish oil and lacquer treatments. Visual assessment of those two treatments however showed more intense glossiness for lacquered surfaces than surfaces sealed with Danish oil (Figure 19). Compared to the untreated surfaces, an application of either lacquer or oil caused lowered L* values (darker surface). Furthermore, heartwood exhibited more intense reddish colour and sapwood showed a higher intensity in yellow colour.

Figure 19. Two samples coated with different surface finish treatments - right-hand halves of both samples are untreated; lacquer finishing was applied to the left-hand side of the upper sample and Danish oil was applied to the left-hand side of the bottom sample. Further details are provided in the text above.

Prediction of L* a* b* values over time

Correlation coefficients were calculated in order to predict values of L*, a* and b* values after sun exposure from data obtained from the surface of air dried samples (without sun exposure). It would be desirable to be able to rapidly and non-destructively screen the best individuals for colour from measurements on air-dried core samples. For African mahogany, dark red-brown colour of heartwood is desirable and is reflected in low L* values and high a* values.

Capacity to predict CIE *L*a*b** values accurately after varying periods of direct sunlight exposure from data obtained on air-dried surfaces (1 week drying indoor; not in direct sunlight) decreases with an increasing time to sun exposure. The predictions are more accurate for brightness (L* values) than for a* values (redness). The b* values, which are of less interest) provided little capacity for prediction after sunlight exposure.

Table 5. Correlation coefficients of prediction of L*, a* and b* values over the time predicted from data collected from air dry sample surfaces (one week; no direct sunlight exposure).

Time period	L*	a*	b*
2 weeks outdoor-no sun exposure	0.99	0.99	0.95
2 weeks outdoor+3 days sun exposure	0.93	0.76	-0.04
2 weeks outdoor+7 days sun exposure	0.89	0.61	-0.18
2 weeks outdoor+14 days sun	0.89	0.64	-0.16
2 weeks outdoor+25 days sun	0.77	0.49	-0.18
2 weeks outdoor+35 days sun	0.71	0.32	-0.19

Shrinkage and Unit shrinkage

The shrinkage results are presented in Table 6 below and also listed in Appendix D at individual tree level. Shrinkage value trends are very similar to those observed in a previous study of *Khaya* by Armstrong *et al.* (2007). Unit shrinkage was moderate compared to many commercial timbers. A generally low ratio between tangential and radial shrinkages was found, which was reflected in a low incidence of board distortion (particularly cupping) during drying. Some samples exhibited higher shrinkage in the radial direction compared to the tangential direction, which is quite an uncommon occurrence in other timber species.

There was an increase in transverse shrinkage with cambial age, which follows similar trends for other properties such as wood density.

Table 6. Shrinkage (%) and Unit shrinkage (% dimensional change per 1% MC change) summaries across two age classes from Burdekin Agricultural College.

Age	Property	Segment		
		Inner heartwood	Outer heartwood	Sapwood
18	Radial shrinkage – green to 12%	1.42	1.44	1.95
	Radial shrinkage – green to 5%	2.64	2.86	3.75
	Tangential shrinkage – green to 12%	2.05	2.15	3.11
	Tangential shrinkage – green to 5%	3.66	3.58	5.06
	Radial Unit shrinkage – 12 to 5%	0.19	0.21	0.23
	Tangential Unit shrinkage – 12 to 5%	0.25	0.24	0.26
	T:R Shrinkage green to 12% ratio	1.40	1.42	1.61
20	Radial shrinkage – green to 12%	1.20	1.42	1.99
	Radial shrinkage – green to 5%	2.27	2.93	3.81
	Tangential shrinkage – green to 12%	1.78	2.09	2.93
	Tangential shrinkage – green to 5%	3.29	3.83	5.15
	Radial Unit shrinkage – 12 to 5%	0.17	0.21	0.24
	Tangential Unit shrinkage – 12 to 5%	0.24	0.24	0.29
	T:R Shrinkage green to 12% ratio	1.52	1.46	1.47

NIR calibration models

A preliminary experiment was carried out to investigate the quality of NIR models when spectra were collected either from RL or RT surfaces. In general, the calibration model based on NIR spectra taken from the RL surface provided the better correlations with higher R^2 and lower Standard Error of Cross-Validation (SECV). These results not shown but based on these findings only results from spectra collected on the RL face are reported (Table 7) and discussed.

NIR spectra correlated reasonably well with radial shrinkage and air dried density. The measured coefficient of determination was 0.81 and 0.89 respectively with a SECV of 0.17% for shrinkage and 24 $kg.m^{-3}$ for wood density. When the calibration models were applied to their validation sets, radial shrinkage was predicted to an accuracy of 76% with Standard Error of Prediction (SEP) of 0.21%. There was also a strong predictive power for wood density. Calibration and validation statistics were lower for tangential shrinkage and Unit Shrinkage.

These are encouraging results suggesting that NIR spectroscopy has good potential to be used as a non-destructive method to predict shrinkage and wood density using 12mm diameter increment core samples.

Table 7. Summary statistics of partial least squares regression models for shrinkage characteristics and air dried density in the calibration set and validation set (using spectra from solid wood samples).

Constituent	**Calibration set**			**Validation set**	
	PLS Factors	**R^2**	**SECV**	**R^2_p**	**SEP**
Radial shrinkage – green to 12%	5	81	0.17	76	0.21
Tangential shrinkage – green to 12%	6	68	0.44	72	0.46
Unit radial shrinkage – 12 to 5%	2	53	0.02	55	0.03
Unit tangent shrinkage – 12 to 5%	3	59	0.02	49	0.03
Air dried density	6	89	24	75	34.9

Sawing results

Green-off saw (GOS) recovery

Butt logs from 21 trees sampled from the Burdekin Agricultural College plots and 34 trees from the Northern Territory were sawn to board products. Table 8 presents the number of boards produced in various dimension classes. Due to a higher number of bigger logs from the BAC site a larger number of wider boards was recovered from these logs.

Table 8. Green-off saw board tally for 21 logs from Burdekin Agricultural College (age 18 and 20 years) and 34 logs from Northern Territory (age 14 years).

Location	Nominal board dimension (mm)	Count from centre cant	Count from wings
Burdekin Agricultural College (BAC)	100 × 25	29	31
	100 × 50		13
	150 × 25	118	
	75 × 50		2
	BAC Total	147	46
Northern Territory (NT)	100 × 25	160	24
	100 × 50		5
	200 × 50		1
	75 × 25	6	18
	75 × 50		1
	NT Total	166	49

Green off saw (GOS) recovery indicates the proportion of potentially saleable sawn timber recovered from a batch of logs or a single log before drying and finishing. It is calculated based on nominal sawn dimensions such as those listed in Table 8; which are the finished sizes that boards are expected to reach after drying. Actual sawn green dimensions are larger to allow for shrinkage. GOS recovery at individual log level is presented in Figure 20 and Appendices E and F. On average, GOS recovery was 49.5% from the BAC site, and 41.9% from the NT site. GOS recovery ranged from 40% to 69% for BAC logs and from 20%

to 61% for NT logs. Compared to a previous study of 32-year-old NT *Khaya* (Armstrong *et al.*, 2007) the recoveries from this study are up to 10% higher. However, the previous study was conducted using a single blade sawing system and may have sampled logs with higher levels of sweep – both factors that are likely to reduce GOS recovery. Additionally, the current boards were not docked to remove wane prior to being tallied, therefore inflating the recovered timber volume and consequently increasing the overall GOS recovery.

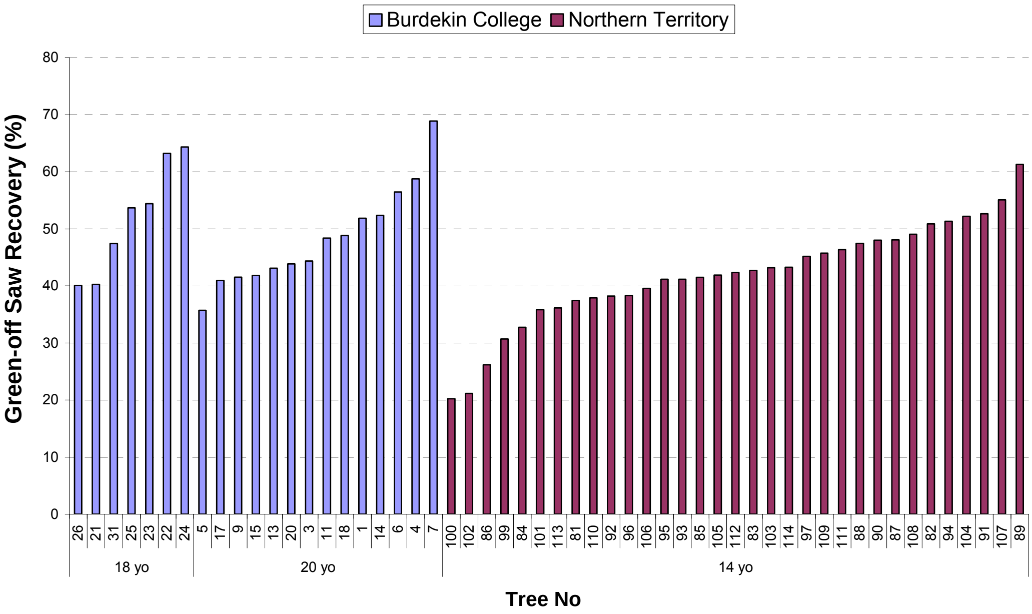

Figure 20. Green off saw recovery for individual trees from Burdekin Agricultural College and Northern Territory sites.

It would be expected that recovery is proportionally related to tree volume in a positive manner. There was however a weak negative correlation between GOS and DBHOB indicating that there are other confounding drivers affecting the recovery in this study. Sweep appears to be the most important one, and significantly contributed to low GOS recovery numbers (Table 9). Additionally, the presence of some very large bumps resulting from the very late pruning of the BAC trees and the diversion of the four largest trees/logs to slice veneering may have abnormally skewed the GOS and log volume relationship in this study. Given these factors this negative correlation is not regarded as a reliable reflection of the more probable positive relationship likely to be found in a larger complete sample from a stand that has been commercially well-managed for timber production.

Table 9. The most important factors affecting green off saw recovery from logs sawn from the Burdekin Agricultural College and Katherine sites with their correlation coefficients.

Variable	BAC	NT
Log volume	-0.38	-0.21
DBHOB	-0.29	-0.1
Standing tree sweep	-0.44	-0.21
Max log sweep	-0.27	-0.23

Seasoning

The sawn timber was transported to Launceston, Tasmania, where it was kiln dried from green condition in approximately eleven days. Logged kiln conditions are shown in Figure 21; note that the kiln failed mechanically twice during the drying process, at approximately 80 hours and 120 hours drying time. Final mean moisture content was11.1% with a standard deviation of 2.4%.

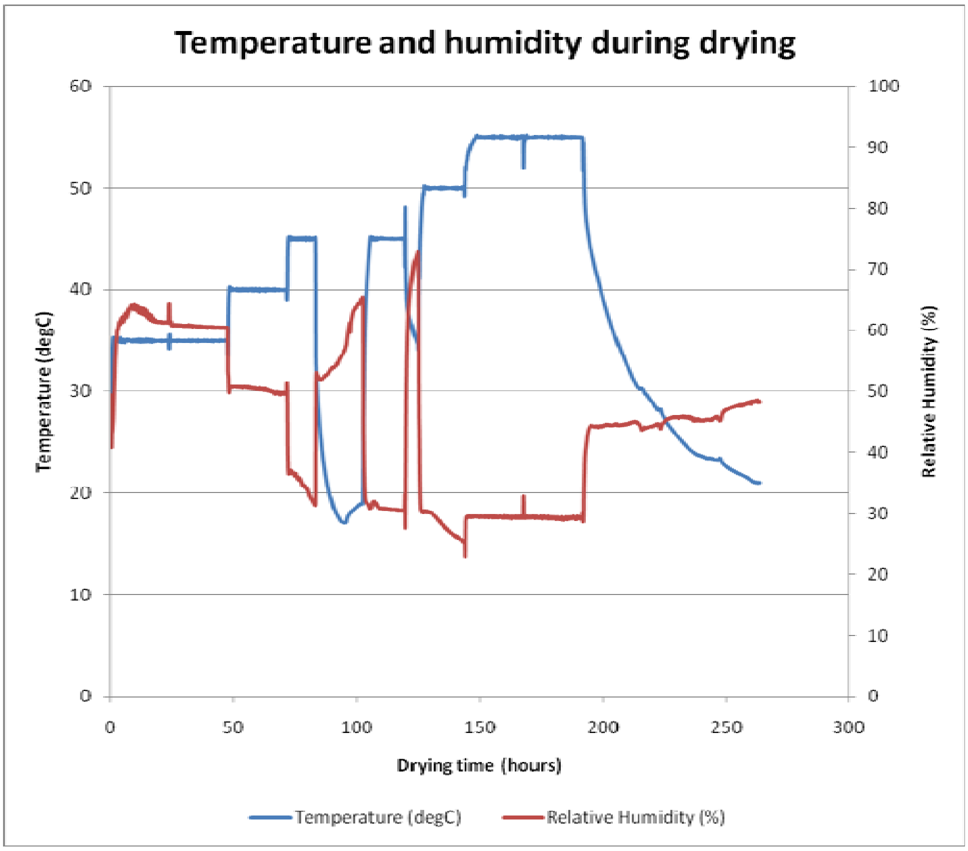

Figure 21. Kiln drying conditions in the University of Tasmania's Timber Research Unit laboratory kiln used to dry the *Khaya* boards.

Dried and dressed graded recovery

The total green volume of logs sourced from the Burdekin Agricultural College (BAC) sites was 4.64m^3 (Appendix A) with 3.93m^3 (Appendix B) from the Northern Territory (NT) for a combined volume of 8.57m^3. The conversion into sawn, dried and dressed boards resulted in a recovery of approximately 32% for BAC with a range of between 8 to 49% for individual logs. Conversion was less efficient for the logs from the younger NT site with an average recovery of 29% with a range of 13 to 41% for individual logs. The recovery for the combined sites was 30%. Detailed recoveries for each of the grade categories are provided in Table 10.

Of the recovered sawn, dried and dressed volume from the BAC logs, based on the cambial face of boards, 27% could potentially be used for Select grade, 40% for Medium Feature grade and 26% for High Feature grades (Figure 22). The heart faces had a slightly higher recovery of select (27 to 30%) and medium feature (40 to 43%) grade boards with a reduction in the volume of high feature (26 to 22%) and reject (7 to 6%) grade boards. ANOVA however showed no significant differences between cambial and heart faces for all grades at BAC and NT sites. Cambial faces would normally produce less recovery due to inclusion of wane in outer boards. Also there is a tendency to get more surface checking than when cupping is constrained which causes higher tension stress on that face.

Table 10. Percentage grade recovery based on log volume.

	Cambial Face				Heart Face			
Site	Select (%)	Medium Feature (%)	High Feature (%)	Reject (%)	Select (%)	Medium Feature (%)	High Feature (%)	Reject (%)
BAC	9	13	8	2	9	14	7	2
NT	8	11	8	2	7	12	9	1
Both	8	12	8	2	8	13	8	2

Distribution of grades for the NT site followed very similar trends as for the BAC site boards with the highest proportion of recovery being in the Medium Feature grade (Figure 22). ANOVA test revealed that there are no significant differences between BAC and NT sites for all grades.

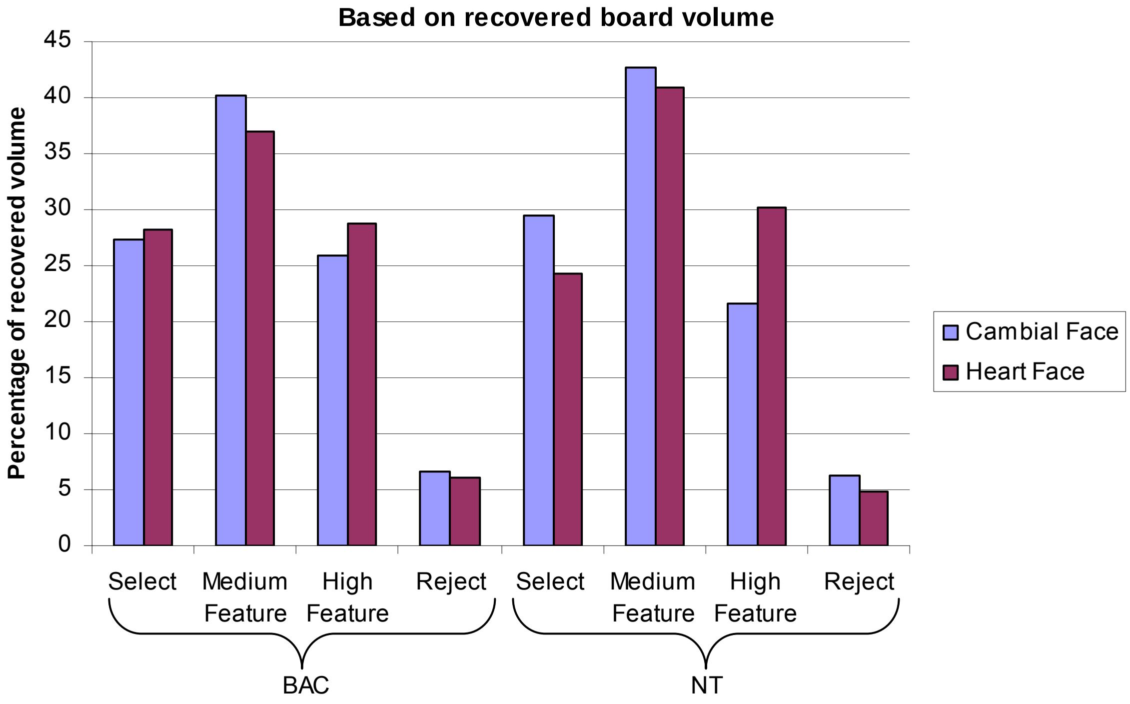

Figure 22. Comparison of cambial and heart face grade recoveries based on the volume of recovered sawn, dried and dressed boards from Burdekin Agricultural College (BAC) and Katherine, Northern Territory (NT) sites.

The sawn board grade limiting defect for the BAC and NT sites are presented in Figures 23 and 24. Note that when there was more than one defect that limited grade it was recorded as a combination defect.

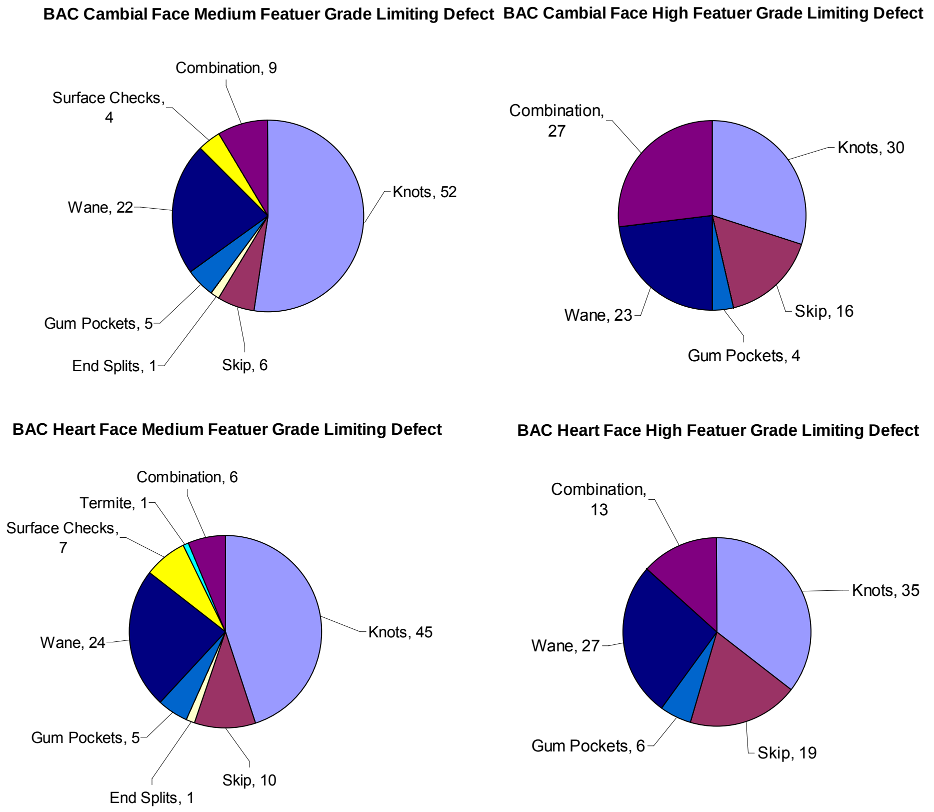

Figure 23. Burdekin Agricultural College site grade limiting defect based on percentage of recovered sawn board volume.

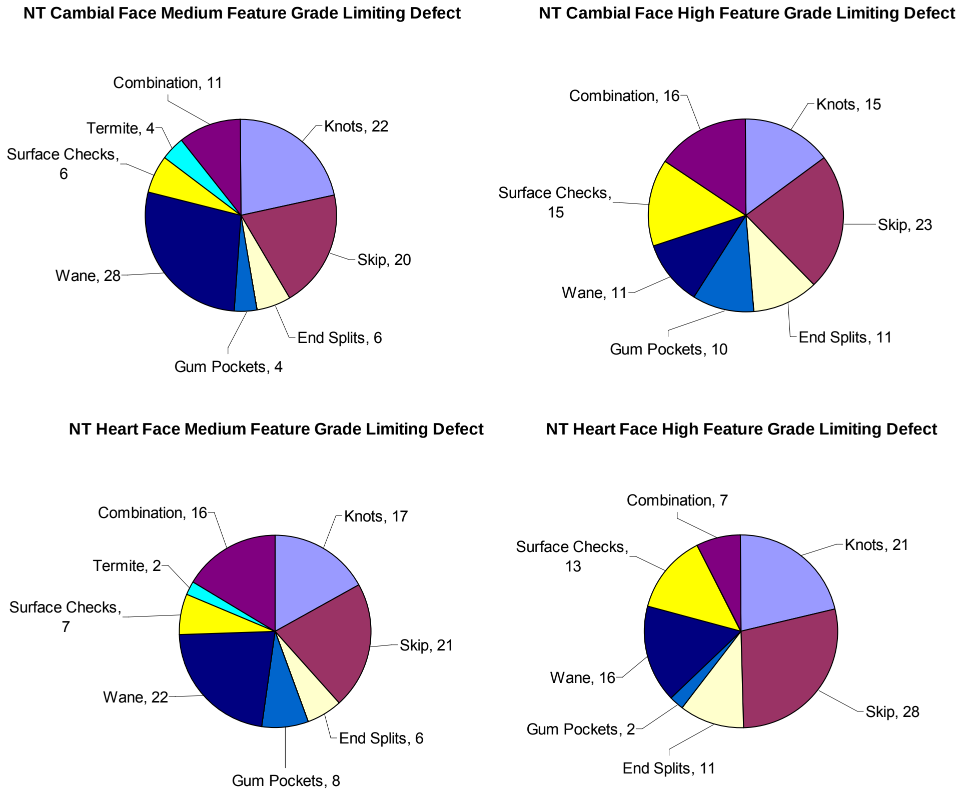

Figure 24. Northern Territory site grade limiting defect based on percentage of recovered sawn board volume.

The major grade limiting defects for both medium and high feature grade materials recovered from the BAC site were knots and wane. The presence of large knots may reflect both management practices and the nature of the genetic material at the site. In this case the stand was not managed for timber production so the late pruning at about age 12 years has had a large impact on the grade recovery. The influence of large knots in timber plantations may be reduced by using (i) higher initial stockings to achieve early competition and crown rise, (ii) a timely, staged and high-lift pruning regime, and/or (iii) the selection of superior genetic material that produces smaller branches with shallower angle. The large amount of wane affected boards is indicative of logs with a large taper and the presence of significant sweep.

Wane, knots and skip were the major grade limiting defects for the NT site. The increased influence of wane on grade recovery at this site suggests that the logs had considerable amounts of sweep with large taper as might be expected in younger stands. Sawing pattern optimisation or application of curve-sawing may have improved grade recovery.

Other issues such as surface checking, skip and end splits reflect processing issues rather than resource quality and their influence on grade recovery could be reduced by implementing processing techniques that have been optimised for *Khaya*. In particular skip is a result of under-sizing, resulting from either sawing accuracy or insufficient over-cut; therefore, if boards downgraded for skip alone are assumed to make select grade, the increase in grade recovery can be seen by comparing Figures 22 and 25.

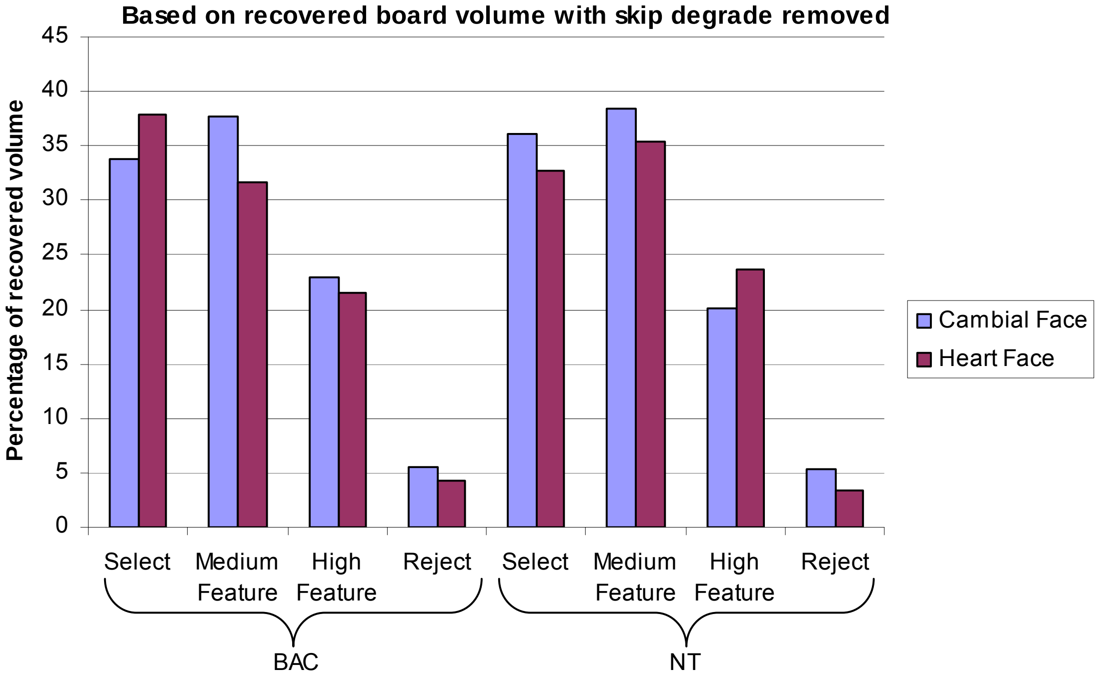

Figure 25. Increased grade recovery by assuming that boards affected by skip alone made select grade.

The potential to improve grade recovery by reducing the amount of skip is evident at both sites. Based on the cambial face, for the BAC material an increase in the volume of select grade (27 to 34%) and a reduction in volumes of medium feature (40 to 38%), high feature (26 to 23%) and reject grade (7 to 5%) may be achievable. The material from the NT showed the same trend with the potential to increase the volume of select grade (28 to 38%) combined with a consequent reduction in the volumes of medium feature (37 to 32%), high feature (29 to 21%) and reject grade(6 to 4%) likely to result from improved sawing.

Shrinkage and Janka hardness of sawn boards

Shrinkage during drying was measured on two outer heartwood boards from each log. Results are shown in Table 11. As already reported earlier, the tangential to radial shrinkage ratio was close to one, which was reflected in a low incidence of distortion during drying.

Table 11. Radial and tangential shrinkage measured on boards from BAC and NT sites.

	Tangential (Width)		Radial (Thickness)	
	BAC	NT	BAC	NT
Mean	4.5%	3.8%	4.3%	4.3%
Standard deviation	2.5%	1.1%	4.2%	2.6%

Janka hardness of the BAC material averaged 6.5 kN with a standard deviation of 1.2 kN, a little higher than the younger NT material, which averaged 6.1 kN with a standard deviation of 1.2 kN. These results are comparable to previous study (Armstrong *et al.* 2007) where average results for to 32-year-old *Khaya* samples were around 6.4 kN. As a comparison to other species, hardness of *E. pellita* ranges around 7 kN (Bailleres *et al.* 2008), *E. cloeziana* has hardness around 11 kN (Bailleres *et al*. 2009).

Peeling results

Rotary veneer recovery

The total volume of green veneer recovered from the seven *Khaya* billets peeled using the Omeco spindleless lathe at the DEEDI Composites Research facility at Salisbury was 0.42m^3, which represents a recovery of 83% of green billet volume (Table 12). This is excellent compared to current industry expectations of around 40 to 45% for regrowth *Eucalyptus* species and is comparable to the results of Hopewell *et al.* (2008) which recorded gross billet recoveries of 89 and 83% for similar aged plantation grown *E. cloeziana* and *E. pellita* respectively.

Table 12. *Khaya* rotary peeled veneer recovery from 7 BAC logs.

Billet No.	Billet volume (m^3)	Recovered green volume (%)	Recovered dry volume (%)	Total grade recovery* (%)
2	0.072	76	64	73
8	0.091	79	70	69
10	0.101	92	40	24
12	0.074	87	74	77
27	0.053	87	74	74
28	0.067	79	60	56
29	0.050	72	62	67
Total/Average	0.420	83	62	60

*proportion of in-grade veneer recovered from dry veneer

Veneer grade recovery

Dried veneer recovery ranged from 40 to 74 % with an average of 64%. The specific grade recovery for each of the billets is shown in Figure 26.

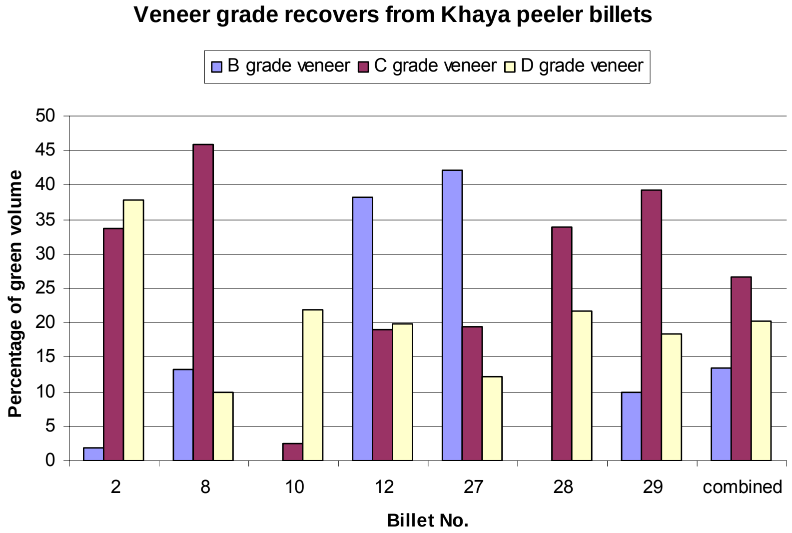

Figure 26. *Khaya* veneer grade recovery according to AS/NZ 2269: 2008.

All of the recovered grades are suitable for use in structural ply in accordance to AS/NZ 2269: 2008. The billets 12 and 27 produced a high percentage of higher value B grade veneers while billet 10 produced none. The majority of veneer sheets recovered from all billets was C grade (27%) with 20% making D grade and 13% B grade. The major grade limiting featuers can be seen in Figure 27.

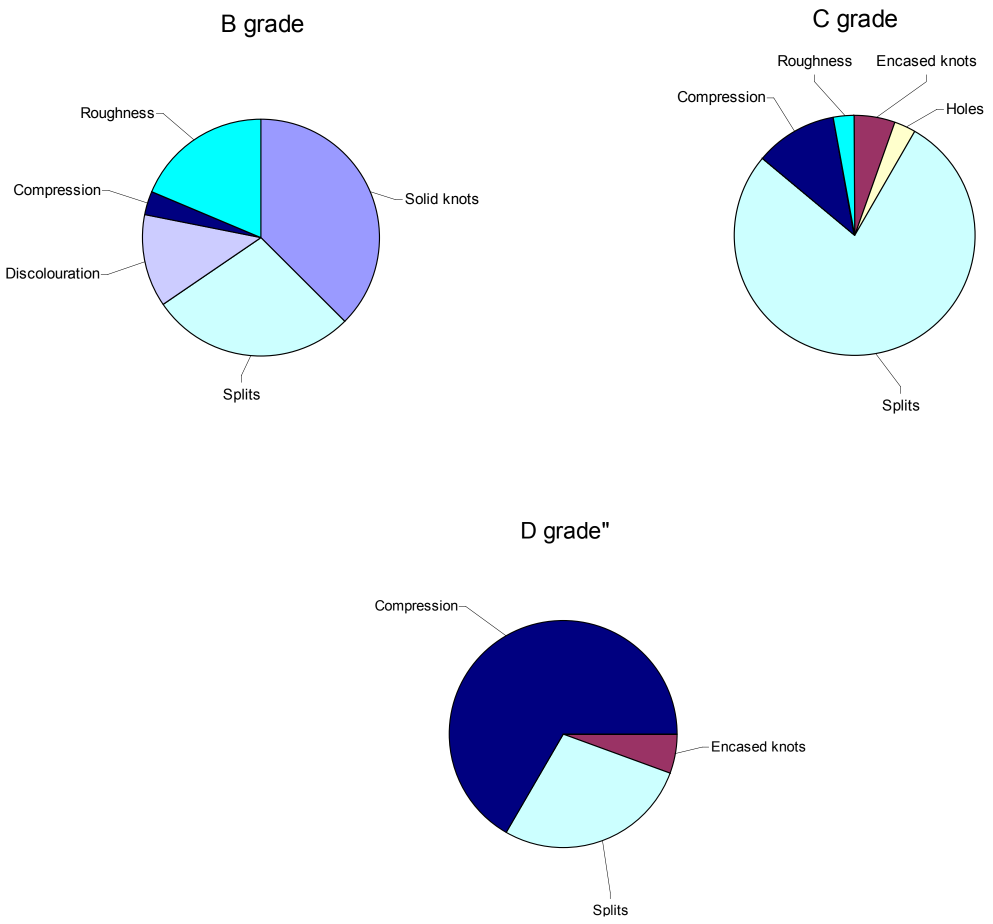

Figure 27. Grade limiting features combining assessments of veneers from all 7 billets.

Splits and compression are limiting features in all grades. They can share a common cause of non-uniform shrinkage which can result from some areas of veneer drying quicker than others, causing differential shrinkage and associated differential stresses. The most likely explanation for the occurrence of splits and compression is that they were a result of incorrect veneer peeling techniques including imperfect peeler knife alignment. If the horizontal opening between the knife and the pressure bar of a lathe is narrower at the centre of the log than near the ends, the veneer comes from the lathe with buckles in the centre. If the horizontal opening is wider towards the centre of the log, the opposite develops and the veneer comes from the lathe with a tendency to end buckle. Imperfect manual alignment of the peeler knife in this research lathe is a likely significant cause of splitting and compression in this trial.

Sliced veneer processing results

Total dry veneer recovery was estimated to be 41.1% (Appendix G). Unfortunately during the processing of these billets, all veneers were mixed together so that a calculation of recovery at individual tree level was not possible.

Promising phenotypes for breeding purposes

Within the 31-tree BAC sample, tree 32 seems promising on phenotype across a number of growth, form and wood property traits. It had been selected previously for the breeding population on the bases of growth and form. Data from the present study shows it had large diameter, moderate sweep, among only 4 trees scoring 6 for straightness, above average sawlog length, highest heartwood proportion, about average levels of shrinkages and probably would have had high GOS% recovery had it been sawn because of its good external log qualities.

Similarly, tree 19 seems promising. It also had been chosen previously for the breeding population.

Conclusions

End-splitting was not a significant problem in this study with log average scores of about 3.6. comparing well with the results of Armstrong *et al.* (2007) where their average measured end-split value of 4.2 was assessed on larger more mature logs (ranging 30 - 32 years old). When benchmarked to fast grown eucalypts that are renowned for splitting problems the splitting scores for these *Khaya* logs were relatively low.

Heartwood proportion ranged from 12% up to 55% of butt cross-sectional disc area for the visually-assessed central dark coloured heartwood. When lighter coloured transition wood was added to the heartwood proportion values increased to 50 - 92%. Sapwood width ranged from 5.5 mm up to 45 mm. Heartwood proportion was positively related to tree size (R^2 = 0.57). Chemical tests were unsuccessfully trialled to determine heartwood – sapwood boundary and visually this boundary was indistinct.

Mean basic density of whole disc samples was 658 kg/m^3 and ranged from 603 to 712 kg/m^3. These results compare well to those obtained by Armstrong *et al.* (2007) for 30-32-year-old *Khaya* from the Northern Territory (mean value 637 kg/m^3). ANOVA results showed significantly higher density for the 20-year-old trees when compared to the 18-year-old trees from the Burdekin Agricultural College suggesting that density and its related timber properties such as hardness, stiffness and strength are still maturing at these ages.

A MiniScan XE portable colour measurement spectrophotometer was used in this study to objectively assess colour variation over time with drying and exposure to sunlight. Colour was expressed according to Commission International de l'Eclairage (CIE) *L*a*b** colour space standards that provide an *L** parameter for degree of lightness where the values of *L** vary from 0 (black) to 100 (white) and *a** and *b** parameters describe the chromatic coordinates on green-red (*a**) and blue-yellow (*b**) axes. When freshly sawn, the heartwood of African mahogany is orange-red to red. Transition wood appears to be pinkish and the sapwood is a pale yellow colour. Once air dried the heartwood colour generally darkens to pinkish-brown or orange-brown and the effect of prolonged time and sun exposure is to darken and change the heartwood colour to a red-brown colour. Capacity to predict CIE *L*a*b** values accurately after varying periods of direct sunlight exposure from data obtained on air-dried surfaces decreases with an increasing time to sun exposure. The predictions are more accurate for light colours (L* values) than for a* values (redness) with low accuracy for b* values. Therefore, selection of breeding trees for colour is likely to be based on dried samples exposed to sunlight to reliably highlight wood colour differences.

Shrinkage value trends were very similar to those observed by Armstrong *et al.* (2007) with unit shrinkage being moderate compared to many commercial timbers. A generally low ratio between tangential and radial shrinkages was found, which was reflected in a low incidence of board distortion (particularly cupping) during drying. A preliminary experiment was carried out to investigate the quality of NIR models to predict shrinkage and density. NIR spectra correlated reasonably well with radial shrinkage and air dried density. When calibration models were applied to their validation sets, radial shrinkage was predicted to an accuracy of 76% with Standard Error of Prediction of 0.21%. There was also a strong predictive power for wood density. These are encouraging results suggesting that NIR spectroscopy has good potential to be used as a non-destructive method to predict shrinkage and wood density using 12mm diameter increment core samples

Green off saw recovery was 49.5% from the BAC site and 41.9% from the NT site and ranged from 40% to 69% for BAC logs and from 20% to 61% for NT logs. However, the green boards in this study were not docked to remove wane prior to being tallied, which will have inflated these GOS recovery percentages. Of the recovered sawn, dried and dressed volume from the BAC logs, based on the cambial face of boards, 27% could potentially be used for select grade, 40% for medium feature grade and 26% for high feature grades. The heart faces had a slightly higher recovery of select (30%) and medium feature (43%) grade boards with a reduction in the volume of high feature (22%) and reject (6%) grade boards. Distribution of board grades for the NT site followed very similar trends as for the BAC site boards with the highest proportion of recovery being in the medium feature grade.

The major grade limiting defects for both medium and high feature grade boards recovered from the BAC site were knots and wane. The presence of large knots may reflect both management practices and the nature of the genetic material at the site. This stand was not established and managed for timber production having been planted at much wider espacements than those currently in use in industrial plantings and with a very late pruning implemented at about age 12 years. The large amount of wane affected boards is indicative of logs with a large taper and the presence of significant sweep. Wane, knots and skip were the major grade limiting defects for the NT site. The increased influence of wane on grade recovery at this site suggests that the logs had considerable amounts of sweep with large taper as shown in the data gathered and might be expected in younger stands.

The green veneer recovered from seven *Khaya* billets rotary peeled on a spindleless lathe produced a recovery of 83% of green billet volume. This is an excellent recovery compared to current industry expectations of around 40 to 45% for regrowth *Eucalyptus* species and is comparable to the results of Hopewell *et al.* (2008) who recorded gross billet recoveries of 89 and 83% for similar aged plantation grown *E. cloeziana* and *E. pellita* respectively. Dried veneer recovery ranged from 40 to 74 % with an average of 64%. All of the recovered grades are suitable for use in structural ply in accordance to AS/NZ 2269: 2008. The majority of veneer sheets recovered from all billets was C grade (27%) with 20% making D grade and

13% B grade. Total dry sliced veneer recovery from the two largest study logs from each location was estimated to be 41.1%.

In summation, this small scale study has produced some very encouraging results. The older Queensland material (18-20 years) had not been established or managed for timber production and the younger (14-year-old) Northern Territory was at the low end of the possible commercial harvest age range. The amount of colour development observed and the very reasonable recoveries of both sawn and veneer products with a good representation of higher grades in the product distribution is very positive. The prospects for significant improvement in these results from well managed and productive stands grown for high quality timber should be high. Additionally, the study has provided opportunities to develop non-destructive evaluation techniques for use in tree improvement programs to improve the quality of future plantations.

A few trees combined several of the traits desired of individuals for a first breeding population. Fortunately, the two most promising trees (32, 19) had already been selected for breeding on external traits, and grafts of them are established in the seed orchard.

In order to gain a better understanding of the genetic and environmental effects on processing and wood properties, these factors should be considered in planning follow-up studies. There is also a need to further develop non-destructive methods of tree sampling.

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Appendix A. Data collected in the field and calculated volume for 31 trees from two stands at the Burdekin Agricultural College, Queensland (*trees from 1 to 20 aged of 18-year-old, trees from 21 to 32 aged of 20-year-old).

Tree No*	Product	DBHOB (cm)	Max merchantable log length (m)	Height to log butt (cm)	Standing sweep (mm)	Straightness score	Sawlog length	LEDOB (mm)	LEDUB (mm)	SEDOB (mm)	SEDUB (mm)	Log volume (m^3)
1	Saw	36.0	6	122	100	3	3.6	365	333	275	243	0.235
2	Ply	28.9	3	50	10	3	1.4	300	275	258	225	0.069
3	Saw	33.8	5.2	104	60	4	3.6	354	330	248	232	0.223
4	Saw	29.1	3.4	44	35	5	3	341	306	269	245	0.179
5	Saw	32.5	3.9	47	65	3	3.6	367	324	230	210	0.202
6	Saw	35.4	3.3	73	50	3	3.6	401	365	230	207	0.231
7	Saw	32.9	4.6	65	25	5	3	367	331	235	213	0.174
8	Ply	32.8	2.3	70	30	5	1.4	375	334	303	290	0.107
9	Saw	37.1	4.3	70	70	4	3	407	375	325	292	0.262
10	Ply	33.6	2.8	48	45	5	1.4	378	346	329	310	0.118
11	Saw	27.1	4.9	54	55	4	3	303	270	216	189	0.124
12	Ply	30.3	4	75	20	6	1.4	321	280	289	260	0.080
13	Saw	26.7	6.1	59	50	3	3.6	296	259	200	176	0.134
14	Saw	34.4	4.9	69	50	3	3.6	358	319	279	254	0.232
15	Saw	37.9	6.1	60	65	5	3.6	412	382	297	271	0.301
16	Saw	32.6	3	46	25	4	3	382	359	290	260	0.226
17	Saw	39.3	3.9	51	60	3	3	437	409	276	251	0.257
18	Saw	38.9	5.8	54	75	5	3	437	387	319	279	0.261
19	Slice	39.9	5.2	60	50	6	3.6	440	390	334	290	0.327
20	Saw	32.8	4.9	53	45	4	3	367	320	257	219	0.171
21	Saw	28.3	4.1	46	20	6	3	340	302	233	201	0.149
22	Saw	26.8	4.1	51	30	4	3	301	260	216	200	0.125
23	Saw	32.0	4.1	57	40	2	3.6	361	315	260	215	0.199
24	Saw	31.3	5.4	64	40	4	3	369	324	263	230	0.181
25	Saw	32.4	5.3	43	40	4	3	387	331	271	235	0.189
26	Saw	37.4	7.1	63	60	4	3.6	422	392	310	275	0.314
27	Ply	26.9	3.4	90	25	5	1.4	282	252	243	217	0.060
28	Ply	30.4	2.4	77	20	5	1.4	333	304	269	241	0.082
29	Ply	24.5	4.2	51	10	5	1.4	287	253	236	208	0.058
31	Saw	34.0	5.6	57	50	4	3.6	375	352	267	250	0.256
32	Slice	42.4	7.2	63	30	6	3.6	473	444	347	317	0.409
Mean		**32.9**	**4.5**	**62.5**	**43.5**	**4.3**	**2.9**	**365**	**329**	**270**	**242**	**0.191**
Minimum		**24.5**	**2.3**	**43.0**	**10**	**2**	**1.4**	**282**	**252**	**200**	**176**	**0.058**
Maximum		**42.4**	**7.2**	**122**	**100**	**6**	**3.6**	**473**	**444**	**347**	**317**	**0.409**

Appendix B. Data collected in the field and calculated volume for 36 trees from 14-year-old stand near Fox Road, Katherine are, Northern Territory.

Tree No	Product	DBHOB (cm)	Standing sweep (mm)	Sawlog length	LEDOB (mm)	SEDOB (mm)	Log volume (m^3)
81	Saw	19.8	50	2.9	260	186	0.095
82	Saw	18.6	34	3.1	242	166	0.081
83	Saw	25.5	37	3.0	300	230	0.140
84	Saw	17.5	23	2.9	233	155	0.069
85	Saw	19.1	5	2.9	234	163	0.072
86	Saw	28.6	30	3.0	329	254	0.172
87	Saw	19.5	25	3.0	238	166	0.078
88	Saw	23.1	25	3.0	276	220	0.122
89	Saw	21.2	14	3.0	252	202	0.101
90	Saw	21.4	15	3.0	256	183	0.094
91	Saw	18.2	23	3.0	223	156	0.068
92	Saw	23.9	40	3.0	320	207	0.137
93	Saw	21.9	15	3.0	270	191	0.105
94	Saw	23.9	28	3.0	293	218	0.116
95	Saw	19.9	30	3.0	242	182	0.087
96	Saw	31.8	12	2.9	395	292	0.235
97	Saw	23.1	20	3.0	275	202	0.112
98	Saw	17.6	10	3.0	212	159	0.065
99	Saw	28.3	17	2.9	373	249	0.196
100	Saw	19.5	30	2.9	269	155	0.083
101	Saw	20	14	3.0	267	184	0.100
102	Saw	17.9	30	3.0	255	156	0.080
103	Saw	23.4	39	3.0	230	183	0.083
104	Saw	22.2	28	3.0	238	175	0.086
105	Saw	23.5	40	3.0	296	200	0.121
106	Saw	31.3	25	3.0	360	273	0.209
107	Saw	21.2	43	3.0	201	195	0.075
108	Saw	21.4	2	3.0	243	193	0.092
109	Saw	25	35	3.0	300	215	0.131
110	Saw	25.5	15	3.0	317	245	0.158
111	Saw	20.2	2	3.0	253	175	0.089
112	Saw	21.3	5	3.0	256	192	0.097
113	Saw	22.2	40	3.0	279	220	0.125
114	Saw	33.3	37	2.9	417	300	0.260
AM2	Slice	34.9	36	2.9	433	351	0.315
AM3	Slice	33.5	70	2.9	401	315	0.260
Mean		**23.3**	**26**		**284**	**209**	**0.065**
Minimum		**17.5**	**2**		**201**	**155**	**0.186**
Maximum		**34.9**	**70**		**433**	**351**	**0.113**

Appendix C. Log and wood properties data for the Burdekin Agricultural College sample (*trees from 1 to 20 aged of 18-year-old, trees from 21 to 32 aged of 20-year-old).

Tree No*	End-split score (after 3 hours)	End-split score after 16 hours)	Ratio Max/Min Radius (LE)	Ratio Max/Min Radius (SE)	Heartwood proportion (%)	Transition wood proportion (%)	Sapwood width	Basic density heartwood (kg.m^{-3})	Basic density sapwood (kg.m^{-3})	Basic density whole-disc (kg.m^{-3})
1	6.80	9.70	1.17	1.17	39.4	18.1	36.6	615	643	627
2					28.8	40.0	21.1	666	697	676
3	6.97	8.56	1.14	1.1	27.2	33.6	33.0	652	698	669
4	4.37	8.78	1.14	1.29	28.6	62.4	6.8	682	690	683
5	7.56	11.09	1.19	1.36	39.4	51.1	7.1	708	750	712
6	6.30	11.87	1.1	1.28	38.7	18.3	42.6	636	675	653
7	5.97	8.16	1.29	1.59	28.1	37.1	28.7	631	711	660
8					50.9	23.6	22.9	701	720	705
9	7.51	12.01	1.09	1.46	47.5	46.0	6.1	688	737	691
10					41.9	21.0	33.7	631	680	649
11	4.78	7.68	1.13	1.11	37.3	53.3	6.1	677	719	680
12					26.8	65.8	5.4	621	645	623
13	6.28	8.81	1.08	1.39	30.0	49.1	14.5	628	717	645
14	5.40	6.19	1.51	1.4	30.6	41.4	23.6	651	733	673
15	2.20	8.02	1.14	1.1	41.5	34.7	22.8	669	714	680
16	4.15	5.95	1.27	1.24	26.9	42.3	27.7	654	759	685
17	4.68	6.44	1.19	1.13	29.8	55.6	13.5	650	717	660
18	3.57	4.37	1.33	1.34	42.1	15.4	45.3	647	714	674
19	7.04	8.28	1.06	1.11	50.6	39.7	9.4	613	618	613
20	3.95	5.06	1.14	1.13	28.5	61.5	7.9	692	742	697
21	3.97	5.22	1.57	1.19	34.1	55.8	7.4	696	718	698
22	3.79	4.04	1.03	1.08	21.1	69.5	5.9	670	708	674
23	1.92	3.30	1.09		35.8	54.9	7.0	646	716	652
24	3.60	4.26	1.16	1.3	25.2	45.6	23.6	598	697	627
25	3.94	4.62	1.1	1.11	37.1	43.1	16.8	617	693	630
26	4.32	5.18	1.15	2.1	45.5	26.8	26.7	586	667	607
27					13.7	52.6	23.1	599	638	612
28					18.1	34.7	38.4	615	675	643
29					22.3	48.2	17.6	631	736	661
31	4.12	5.29	1.09	2.13	32.6	18.5	43.5	576	632	603
32	5.82	8.50	1.09	1.21	52.9	22.9	25.6	634	705	651
Mean	**4.96**	**7.14**	**1.18**	**1.32**	**34.0**	**41.4**	**21.0**	**644**	**699**	**658**
Min	**1.92**	**3.30**	**0.15**	**0.15**	**13.7**	**15.4**	**5.4**	**576**	**618**	**603**
Max	**7.56**	**12.01**	**1.57**	**2.13**	**52.9**	**69.5**	**45.3**	**708**	**759**	**712**

Appendix D. Shrinkage data for Burdekin Agricultural College sample (IH - inner heartwood, OH – outer heartwood, SW – sapwood) - (*trees from 1 to 20 aged of 18-year-old, trees from 21 to 32 aged of 20-year-old).

Tree No*	Radial shrinkage – green to 12%			Tangent shrinkage – green to 12%			Radial Unit shrinkage – 12 to 5%			Tangential Unit shrinkage – 12 to 5%			T:R Shrinkage green to 12% Ratio		
	IH	OH	SW	IH	OH	SW	IH	OH	SW	IH	OH	SW	IH	OH	SW
1	1.29	1.08	1.52	1.39	1.40	2.26	0.16	0.17	0.19	0.21	0.21	0.26	1.08	1.30	1.48
2	1.52	1.60	1.99	2.74	2.77	3.10	0.20	0.22	0.23	0.29	0.30	0.30	1.80	1.73	1.55
3	1.03	1.22	1.22	1.29	1.48	1.78	0.15	0.20	0.17	0.22	0.23	0.23	1.26	1.22	1.46
4	1.07	1.08	1.81	1.98	2.38	2.74	0.15	0.19	0.23	0.24	0.28	0.30	1.85	2.20	1.52
5	1.07	1.45	1.71	1.79	2.01	2.68	0.16	0.23	0.21	0.23	0.27	0.30	1.68	1.39	1.57
6	0.76	0.82	1.59	2.14	1.39	2.75	0.13	0.15	0.20	0.21	0.20	0.28	2.84	1.70	1.73
7	0.99	1.60	1.95	2.65	2.35	2.78	0.14	0.25	0.25	0.23	0.30	0.30	2.67	1.47	1.42
8	1.06	1.21	2.21	1.42	1.00	2.78	0.17	0.27	0.27	0.26	0.23	0.30	1.34	0.82	1.26
9	1.24	1.82	2.31	1.87	2.45	2.58	0.17	0.27	0.26	0.25	0.30	0.29	1.52	1.35	1.12
10	0.98	1.15	1.51	0.94	1.27	1.76	0.15	0.21	0.20	0.21	0.19	0.22	0.96	1.10	1.17
11	1.00	1.40	1.86	1.49	2.09	2.77	0.17	0.22	0.24	0.23	0.27	0.31	1.49	1.50	1.49
12	0.94	0.99	1.84	2.06	1.66	2.44	0.15	0.16	0.24	0.27	0.23	0.27	2.18	1.67	1.32
13	1.18	1.35	2.03	1.30	2.28	3.02	0.16	0.19	0.23	0.24	0.29	0.31	1.10	1.69	1.49
14	1.66	2.16	2.51	3.18	3.55	2.89	0.19	0.24	0.28	0.27	0.30	0.30	1.92	1.64	1.15
15	1.46	1.74	2.62	1.79	2.08	2.83	0.21	0.25	0.29	0.21	0.24	0.27	1.22	1.20	1.08
16	1.24	1.60	1.73	0.96	2.23	3.07	0.17	0.20	0.21	0.22	0.20	0.28	0.77	1.39	1.77
17	1.50	1.78	2.47	1.93	2.23	3.25	0.18	0.23	0.28	0.25	0.26	0.33	1.29	1.26	1.32
18	1.41	1.49	2.64	1.61	2.34	4.69	0.20	0.23	0.29	0.23	0.21	0.35	1.14	1.57	1.78
19	1.28	1.20	2.01	1.36	0.86	3.69	0.18	0.16	0.26	0.22	0.18	0.33	1.07	0.72	1.84
20	1.22	1.74	2.43	1.57	4.03	4.66	0.18	0.22	0.25	0.28	0.23	0.32	1.28	2.32	1.92
21	1.10	1.27	2.17	1.29		2.55	0.19	0.23	0.25	0.24	0.21	0.20	1.18		1.18
22	1.40	1.94	2.33	1.58	3.42	3.32	0.19	0.23	0.26	0.24	0.27	0.29	1.12	1.76	1.43
23	1.52	1.33	1.95	3.33	2.22	3.35	0.18	0.22	0.23	0.28	0.26	0.31	2.19	1.67	1.72
24	1.38	1.13	2.15	1.50	0.74	3.44	0.17	0.17	0.23	0.21	0.18	0.27	1.09	0.66	1.60
25	1.23	1.21	2.07	0.90	1.54	3.39	0.18	0.19	0.22	0.22	0.21	0.26	0.73	1.28	1.64
26	1.49	1.28	1.42	2.12	1.95	3.35	0.18	0.21		0.26	0.27	0.17	1.42	1.53	2.37
27	1.40	1.09	2.12	2.02	1.55	2.95	0.20	0.17	0.22	0.24	0.22	0.24	1.44	1.42	1.39
28	1.56	2.17	2.05	4.13	3.66	3.53	0.21	0.24	0.24	0.28	0.29	0.33	2.64	1.69	1.72
29	1.74	1.73	2.11	2.93	3.26	3.96	0.20	0.20	0.23	0.27	0.28	0.28	1.68	1.88	1.88
31	1.21	1.34	1.05	1.10	1.44	1.62	0.17	0.21	0.15	0.21	0.22	0.22	0.91	1.07	1.54
32	1.61	1.35	2.12	1.69	1.73	2.72	0.22	0.21	0.29	0.26	0.23	0.31	1.05	1.28	1.28
Mean	**1.28**	**1.43**	**1.98**	**1.87**	**2.11**	**2.99**	**0.18**	**0.21**	**0.24**	**0.24**	**0.24**	**0.28**	**1.48**	**1.45**	**1.52**
Min	**0.76**	**0.82**	**1.05**	**0.90**	**0.74**	**1.62**	**0.13**	**0.15**	**0.15**	**0.21**	**0.18**	**0.17**	**0.73**	**0.66**	**1.08**
Max	**1.74**	**2.17**	**2.64**	**4.13**	**4.03**	**4.69**	**0.22**	**0.27**	**0.29**	**0.29**	**0.30**	**0.35**	**2.84**	**2.32**	**2.37**

Appendix E. Green-off saw recovery, dried dressed recovery and proportion of grade categories at cambial and heart faces for the Burdekin Agricultural College sample (*trees from 1 to 20 aged of 18-year-old, trees from 21 to 32 aged of 20-year-old).

Tree No*	Green-off saw recovery (%)	Dried dressed recovery (%)	Cambial Face				Heart Face			
			Select Volume (%)	Medium Feature Volume (%)	High Feature Volume (%)	Reject Volume (%)	Select Volume (%)	Medium Feature Volume (%)	High Feature Volume (%)	Reject Volume (%)
1	52	36	27	28	33	13	24	32	37	7
3	44	29	50	21	28	1	30	55	14	1
4	59	40	26	50	14	10	59	28	11	2
5	36	24	26	3	46	25	34	13	48	6
6	56	37	25	58	11	6	35	52	11	3
7	69	49	37	43	7	12	25	62	0	12
9	42	26	10	59	31	0	19	56	24	2
11	48	34	43	52	0	5	25	74	0	1
13	43	29	19	15	56	10	33	22	40	6
14	52	35	38	37	21	5	19	47	22	12
15	42	27	24	72	0	4	16	48	33	3
16	13	8	0	0	100	0	24	0	76	0
17	41	29	12	62	17	10	22	52	15	11
18	49	34	12	50	35	3	45	28	24	3
20	44	31	40	29	30	0	38	42	21	1
21	40	29	17	48	35	0	44	11	32	13
22	63	42	42	58	0	0	28	57	15	0
23	54	36	28	58	0	14	28	61	0	11
24	64	44	21	45	33	1	23	47	20	10
25	54	42	28	26	46	0	40	41	20	0
26	40	27	24	22	54	0	20	47	32	1
31	47	32	40	5	34	21	25	19	30	25
Mean	**49**	**33**	**27**	**38**	**29**	**6**	**30**	**41**	**24**	**6**
Min	**13**	**8**	**0**	**0**	**0**	**0**	**16**	**0**	**0**	**0**
Max	**69**	**49**	**50**	**72**	**100**	**25**	**59**	**74**	**76**	**25**

Appendix F. Green-off saw recovery, dried dressed recovery and proportion of grade categories at cambial and heart faces for the Northern Territory 14-year-old sample.

Tree No	Green-off saw recovery (%)	Dried dressed recovery (%)	Cambial Face				Heart Face			
			Select Volume (%)	Medium Feature Volume (%)	High Feature Volume (%)	Reject Volume (%)	Select Volume (%)	Medium Feature Volume (%)	High Feature Volume (%)	Reject Volume (%)
81	37	26	22	35	43	0	3	54	43	0
82	51	36	31	68	0	1	10	88	0	1
83	43	26	49	45	0	7	33	14	44	9
84	33	24	41	59	0	0	52	48	0	0
85	41	41	36	48	16	0	28	72	0	0
86	26	16	55	30	0	15	47	33	20	0
87	48	33	13	66	21	0	14	86	0	0
88	47	32	34	2	20	44	15	23	32	30
89	61	36	24	62	0	15	11	75	0	15
90	48	32	17	21	20	42	25	28	36	10
91	53	35	21	40	19	20	23	46	23	8
92	38	28	28	58	14	0	35	50	14	1
93	41	29	17	33	50	0	22	25	52	0
94	51	34	40	26	34	0	37	27	36	1
95	41	28	35	43	22	0	37	23	40	0
96	38	26	8	42	50	0	31	17	52	0
97	45	34	36	52	11	1	29	50	11	10
98	58	37	25	50	0	25	11	46	22	20
99	31	22	14	38	37	10	22	44	21	13
100	20	13	8	59	33	0	9	24	67	0
101	36	25	26	32	42	0	29	29	42	0
102	21	14	8	59	33	0	34	32	33	0
103	43	23	3	50	47	0	30	50	21	0
104	52	37	35	31	34	0	25	39	34	3
105	42	28	30	29	41	0	34	32	24	10
106	40	27	43	19	38	0	36	11	45	9
107	55	38	28	72	0	0	11	89	0	0
108	49	35	32	19	49	0	6	44	50	0
109	46	33	37	39	25	0	15	50	35	0
110	38	24	17	32	51	0	23	21	54	2
111	46	32	36	2	56	5	11	8	75	5
112	42	29	21	29	31	18	18	64	19	0
113	36	26	19	68	14	0	12	58	31	0
114	43	33	32	10	54	3	29	41	28	2
Mean	**42**	**29**	**27**	**40**	**27**	**6**	**24**	**42**	**30**	**4**
Min	**20**	**13**	**3**	**2**	**0**	**0**	**3**	**8**	**0**	**0**
Max	**61**	**41**	**55**	**72**	**56**	**44**	**52**	**89**	**75**	**30**

Appendix G. Sliced veneer dry recovery data for the bulked material of the 4-tree sample from the Burdekin Agricultural College and Northern Territory.

Un-soaked					**Soaked**				
Veneer pack No.	Length (mm)	Width (mm)	No. Sheets	Dry Volume (m³)	Veneer pack No.	Length (mm)	Width (mm)	No. Sheets	Dry Volume (m³)
21	2490	120	20	0.005976	34	1985	240	24	0.011434
3	2495	147	23	0.008436	2	2040	145	23	0.006803
40	2506	142	19	0.006761	24	2345	148	21	0.007288
11	2520	150	20	0.00756	6	2500	149	24	0.00894
12	2520	185	20	0.009324	26	2535	252	22	0.014054
13	2520	135	20	0.006804	14	2560	150	24	0.009216
17	2525	182	25	0.011489	36	2570	190	25	0.012208
1	2540	150	24	0.009144	38	2575	260	24	0.016068
29	2546	143	18	0.006553	37	2580	265	24	0.016409
19	2555	145	24	0.008891	15	2620	145	24	0.009118
23	2560	198	24	0.012165	25	2653	172	23	0.010495
18	2635	185	17	0.008287	28	2874	227	24	0.015658
7	2796	190	24	0.01275	31	2875	230	22	0.014548
9	2803	142	22	0.008757	39	2875	168	13	0.006279
4	2805	160	28	0.012566	22	2880	273	22	0.017297
16	2815	198	24	0.013377	27	2880	239	24	0.01652
10	2820	150	24	0.010152	35	2880	192	23	0.012718
5	2845	148	18	0.007579	30	2890	174	23	0.011566
20	2850	162	25	0.011543	32	2890	150	24	0.010404
8	2915	179	23	0.012001	33	2895	190	23	0.012651
Total				**0.1901**					**0.2397**

Total log volume (m³)	**1.047**
Total sliced veneer volume (m³)	**0.43**
% recovery	**41.1**

Appendix H. Wood properties data collected on 11 discs sampled at the top of sawlogs from Burdekin Agricultural College (IH- inner heartwood, OH – outer heartwood, SW – sapwood) - (*trees from 1 to 20 aged of 18-year-old, trees from 21 to 32 aged of 20-year-old).

Tree No*	Heartwood proportion (%)	Transition wood proportion (%)	Sapwood width (mm)	Basic density heartwood (kg.m^{-3})	Basic density sapwood (kg.m^{-3})	Basic density whole-disc (kg.m^{-3})	Radial Unit shrinkage – 12 to 5%		
							IH	OH	SW
1	11.2	28.0	39.7	605	623	616	0.17	0.22	0.22
3	20.7	35.1	25.5	644	665	654	0.21	0.25	0.24
7	10.3	36.8	30.7	586	641	614	0.22		0.21
11	17.3	39.2	22.0	661	710	682	0.20	0.19	0.20
13	13.1	45.9	19.0	653	676	662	0.21		0.24
14	29.1	20.6	33.8	610	696	652	0.18	0.18	0.21
15	14.7	28.0	42.7	620	675	650	0.17	0.18	0.23
17	7.2	45.4	31.7	598	673	632	0.22	0.23	0.25
19	10.2	41.0	38.1	573	585	579	0.22	0.17	0.18
20	17.2	62.7	10.7	672	764	690	0.21	0.18	0.22
23	26.5	58.3	9.5	606	698	623	0.20	0.19	0.22

Tree No	Tangential Unit shrinkage – 12 to 5%			T:R Shrinkage green to 12% Ratio		
	IH	OH	SW	IH	OH	SW
1	0.22	0.27	0.26	1.74	1.48	1.53
3	0.30	0.32	0.32	1.71	1.27	1.51
7	0.28		0.27	1.54		1.40
11	0.30	0.24	0.29	1.46	1.43	1.57
13	0.30		0.30	1.70		1.36
14	0.27	0.27	0.27	1.52	1.75	1.25
15	0.23	0.25	0.26	1.22	1.51	1.32
17	0.27	0.27	0.29	1.57	1.71	1.45
19	0.26	0.24	0.25	1.36	1.23	2.18
20	0.30	0.25	0.31	1.66	2.98	2.33
23	0.27	0.26	0.28	1.40	1.41	1.47