SOME ANATOMICAL FEATURES OF AN *ACACIA* HYBRID, *A. MANGIUM* AND *A. AURICULIFORMIS* GROWN IN INDONESIA WITH REGARD TO PULP YIELD AND PAPER STRENGTH

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YAHYA R, SUGIYAMA J, SILSIA D & GRIL J. 2010. Some anatomical features of an *Acacia* hybrid, *A. mangium* and *A. auriculiformis* grown in Indonesia with regard to pulp yield and paper strength. The objectives of this study were to compare anatomical wood properties, chemical composition and wood density between an *Acacia* hybrid and its parents, namely, *Acacia mangium* and *Acacia auriculiformis*. The strength of the relationship between these anatomical properties or wood density and chemical composition as a way to predict the pulp yield and paper strength was studied. Three seven-year-old trees per species were randomly selected from an experimental plantation. Compared with both parents, the *Acacia* hybrid had longer fibre, and higher slenderness ratio, fibre proportion and holocellulose content but smaller proportions of vessels, parenchyma cells and extractives. In addition, the hybrid tended to have thinner cell wall, and lower proportion of ray cells, rigidity and lignin content but higher flexibility coefficient and wood density than *A. mangium*. Holocellulose, α-cellulose and lignin contents were all reliably predicted by fibre length. Slenderness ratio was a better predictor of extractives content than fibre length. Both fibre length and slenderness ratio were better predictors of chemical composition than wood density. Therefore, fibre length and slenderness ratio could be good predictors of pulp yield and paper strength for acacias.

Keywords: Fibre dimensions, derived values, proportions of cell types, chemical composition, pulp yield

YAHYA R, SUGIYAMA J, SILSIA D & GRIL J. 2010. Beberapa ciri anatomi *Acacia* hibrid, *A. mangium* dan *A. auriculiformis* yang ditanam di Indonesia yang mempengaruhi hasil pulpa dan kekuatan kertas. Kajian ini bertujuan untuk membandingkan ciri-ciri anatomi kayu, komposisi kimia dan ketumpatan kayu *Acacia* hibrid dengan induknya iaitu *Acacia mangium* dan *Acacia auriculiformis*. Kekuatan perhubungan antara ciri anatomi atau ketumpatan kayu dengan komposisi kimia dikaji sebagai cara untuk menjangka hasil pulpa dan kekuatan kertas. Tiga pokok berusia tujuh tahun daripada setiap spesies dipilih secara rawak daripada ladang eksperimen. *Acacia* hibrid mempunyai gentian yang lebih panjang serta nisbah kelangsingan, peratusan gentian dan kandungan holoselulosa yang lebih tinggi daripada kedua-dua induk. Namun, peratusan vesel, sel parenkima dan hasil ekstraktifnya adalah lebih rendah. Di samping itu, *Acacia* hibrid mempunyai dinding sel yang lebih nipis, peratusan sel ruji, ketegaran dan kandungan lignin yang lebih rendah daripada *A. mangium*. Namun, *A.* hibrid mempunyai koefisien kelenturan dan ketumpatan kayu yang lebih tinggi daripada *A. mangium*. Kandungan-kandungan holoselulosa, α-selulosa dan lignin dapat dijangka berasaskan panjang gentian. Nisbah kelangsingan lebih baik daripada panjang gentian dalam menjangka kandungan ekstraktif kayu. Kedua-dua panjang gentian dan nisbah kelangsingan lebih baik daripada ketumpatan kayu dalam menjangka komposisi kimia kayu. Oleh itu panjang gentian dan nisbah kelangsingan boleh digunakan untuk menjangka penghasilan pulpa daripada acasia dan kekuatan kertas yang dibuat daripada pulpanya.

INTRODUCTION

Areas of timber forest plantation in Indonesia have increased to fulfil the demands of the timber and pulp industries, and to increase pulp export. *Acacia mangium* was selected to be planted in plantations (Wahyudi *et al.* 2000, Sumiarsi *et al.* 2006) because it was the most promising species in terms of adaptability and growth (Hardiyanto & Supriyadi 2005). Based on estimates by Firmanti and Kawai (2005), *A. mangium* plantations in Indonesia reach one million hectares in the year 2010.

Acacia auriculiformis was also selected as alternative for *A. mangium* by Musi Hutan Persada (MHP), a private forest timber plantation in

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South Sumatra, Indonesia, at the beginning of its plantation programme. Spontaneous hybrids of *A. mangium* and *A. auriculiformis* were grown in the MHP plantation. The first natural hybrids of the two species were recorded by Hepburn and Shim in Sabah, Malaysia in 1972 (Pinso & Nasi 1991).

Now, the hybrids have been reproduced in the clonal propagation area by MHP. Compared with *A. mangium*, the hybrid generally looks alike, but has lighter branches and better self-pruning ability. It has a straighter stem than *A. auriculiformis*. The most obvious advantage of *Acacia* hybrids is their rapid growth. Growth of the hybrid trees is significantly faster than that of the two parent species (Kha 1999). Growth of hybrid is under strong genetic control, with a clonal mean heritability ranging from 0.76 to 0.82. Stem straightness is also under genetic control (clonal mean heritability of 0.78–0.79), while the genetic control in axis persistence is low to moderate (clonal mean heritability of 0.32–0.53) (Hardiyanto & Supriyanto 2002).

These properties show that the *Acacia* hybrid is promising and tends to be better than its parents as a raw material for pulp and papermaking. However, to date there is no information on wood density, wood anatomy and chemical composition of the hybrid in Indonesia, and international publications are very limited and difficult to access (Kha 1999, Kim *et al.* 2008). To promote the establishment of timber forest plantations using *Acacia* hybrids, the aspects of wood quality related to pulp properties should be included in the assessment. Assessment of the mentioned properties is, therefore, a key factor in evaluating the success of *Acacia* hybrids as a pulpwood resource in Indonesia. In this paper, we compared wood of *A. mangium* × *A. auriculiformis* hybrids and its parents for pulpwood based on density, some anatomical cell properties and chemical composition.

Although these wood properties can predict pulp yield and paper strength, no predictor alone can explain/predict both pulp yield and paper strength. Fibre dimensions and derived values have been discussed only in relation to paper strength (Dinwoodie 1965). Kraft pulp yield has generally been found to correlate negatively with extractives and lignin but positively with holocellulose and α-cellulose contents (Amidon 1981, Wallis *et al.* 1996). On the other hand, the relationship between density and pulp yield or quality is still debatable. Horn (1978) mentioned that apparent density indirectly measured pulp flexibility. Heavy hardwood fibres are stiffer, so they do not easily fill the gap in the sheet compared with light hardwood fibres (Horn 1978). However, low density will result in a lower kraft yield (Casey 1952, Haygreen & Bowyer 1996).

Thus, the best way to predict both pulp yield and paper strength is to evaluate all wood properties. However, this is costly and time consuming. Direct pulping trials are slow, expensive and require a relatively large quantity of wood chips. Anatomical measurements (in terms of fibre dimensions and derived values) are more rapid and cost effective than chemical composition analysis. They provide more types of data than wood density.

The main objective of this work was to discuss the advantage of an *Acacia* hybrid over its parents for pulping, as well as to search for some anatomical predictors of pulp yield and paper strength applicable to this species.

MATERIALS AND METHODS

Three trees each of *Acacia* hybrid, *A. mangium* and *A. auriculiformis*—all seven years old—were randomly selected from a trial area of MHP plantation for this study. One 10 cm thick disc was collected from each tree trunk at mid-height between 0.1 m above the ground and a vertical position of the tree where the diameter equals 8 cm. All the discs were used to determine cell proportions, fibre dimensions, chemical compositions and density of wood.

From each disc, one cube of 2.5 × 2.5 × 2.5 cm for measuring chemical composition and three cubes of 2 × 2 × 2 cm for measuring cell proportion and fibre dimension were prepared. The three cubes were taken from three different radial positions: near the pith, near the bark and mid-way. Each cube was further divided by transverse sectioning into two samples—one kept for cell proportion (1 × 1 × 1 cm) and one for fibre dimensions (1 × 0.2 × 0.2 cm).

All specimens for the cell proportion were sectioned with a sliding microtome. The sections were washed in alcohol, stained in safranin and then mounted in Canada Balsam. The cell proportions were obtained by the weighing method.

The specimens for fibre dimension were macerated in 1:1 solution of glacial acid and 30% hydrogen peroxide at 60 °C for 48 hours. After maceration, the fibres were washed in water, finally in alcohol and mounted on slides. For each radial position, the length of 15 macerated fibres and the total fibre width and lumen width at mid-length were measured using a micrometer through a microscope. Cell wall thickness was calculated as (fibre width – lumen width)/2. The results were averaged arithmetically.

From the anatomical data, derived values were calculated according to the formulae:

$$RR = \frac{FWT^2}{FLD}$$ (Runkel 1949)

$$MR = \frac{FD^2 - FLD^2}{FD^2}$$ (Tamolang & Wangaard 1961)

$$SR = \frac{FL}{FD}$$ (Varghese *et al.* 1995)

$$CR = \frac{FWT}{FD}$$ (Tamolang & Wangaard 1961)

$$FC = \frac{FLD}{FD}$$ (Wangaard 1962)

where

RR = Runkel ratio
MR = Muhlsteph's ratio
SR = Slenderness ratio
CR = Coefficient of rigidity
FC = Flexibility coefficient
FL = Fibre length
FD = Fibre diameter
FWT = Fibre wall thickness
FLD = Fibre lumen diameter

The one cube per disc used for the measurement of chemical composition was located at the borderline between heartwood and sapwood so that the proportions in both tissue equal that of the whole disc. The heartwood/sapwood ratio was on average 1.13 for the *Acacia* hybrid, 1.44 for *A. mangium* and 0.92 for *A. auriculiformis*. The oven-dried weight of specimen was measured and divided by its volume to obtain the oven-dried density which was referred to as density. Content of alcohol–benzene extracts, lignin, holocellulose and α-cellulose of the samples were determined according to TAPPI T 204, T 222, T 9 and T 203 respectively (TAPPI 1994).

Analysis of variance was used to determine if significant differences were present in the wood properties between the three acacias. If significant differences were present, Duncan's multiple range test was used to determine which of the means were significantly different from one another. Relationships between anatomical properties and chemical composition or wood density were calculated using simple regression analysis.

RESULTS AND DISCUSSION

Fibre dimensions

Fibres of the hybrid were significantly longer than those of both parents (Table 1). Hybrid fibres were 8.8 and 21.5% longer than *A. mangium* and *A. auriculiformis* respectively. A hybrid producing longer fibres is expected to produce stronger paper because of the positive correlation between fibre length and e.g. burst strength (Casey 1952, Miyake 1968, El-Hosseiny & Anderson 1999, Ona *et al.* 2001), tensile strength (Casey 1952, Miyake 1968), tear strength (Casey 1952, Haygreen & Bowyer 1996) and folding endurance (Dinwoodie 1965, Ona *et al.* 2001).

The cell walls of *Acacia* hybrid tended to be thinner than those of both parents. Thick-walled fibres produce paper with low burst and tensile strength (Casey 1952, Haygreen & Bowyer 1996). Biermann (1993) mentioned that paper made from thick-walled cells resulted in low folding endurance.

Derived values

Acacia hybrids were significantly different from both *A. mangium* and *A. auriculiformis* in slenderness ratio (Table 1). Furthermore, the coefficient of rigidity of the hybrids tended to be smaller compared with *A. auriculiformis* and their flexibility coefficient higher. However, both these values in hybrids were not significantly different from those of *A. mangium*. There is a positive correlation between slenderness ratio and folding endurance (Dinwoodie 1965, Ona *et al.* 2001), and between flexibility coefficient and burst (Ona *et al.* 2001), breaking length and tear resistance (Mabilangan & Estudillo 1996). Fibre flexibility influences the number of interfibre

Table 1 Fibre dimension and derived values of *Acacia* hybrid and its parents

Species	FL (µm)	FD (µm)	FLD (µm)	FWT (µm)	RR	MR	SR	CR	FC	PF (%)	PR (%)	PP (%)	PV (%)
Acacia hybrid	1068	18.76	13.74	2.51	0.37	46.17	57.4	0.13	0.73	72.65	8.51	9.39	9.45
A. mangium	982**	19.39	14.29	2.55	0.37	45.85	51.29*	0.13	0.73	62.46**	9.77	15.66*	12.11**
A. auriculiformis	879**	16.74*	11.13*	2.81	0.55	55.00	52.65*	0.17	0.67	68.18*	9.07	11.23	11.55**

FL = fibre length, FD = fibre diameter, FLD = fibre lumen diameter, FWT = fibre wall thickness
RR = Runkel ratio, MR = Muhlsteph's ratio, SR = slenderness ratio, CR = coefficient of rigidity, FC = flexibility coefficient
PF, PR, PP, PV = Proportions of fibre, ray cells, parenchyma cells and vessels respectively
** Significantly different at the 0.01 level, * = at 0.05 level

bonds because more flexible fibres have more interfibre contact (Amidon 1981).

Proportions of cell types

Proportion of ray cells in the hybrid tended to be lower than in the parent species (Table 1). The vessel (Figure 1a) and parenchyma cell (Figure 1b) proportions of the hybrid were statistically lower than those of *A. mangium*. The ray proportion in *Eucalyptus camaldulensis* was negatively correlated with pulp yield, burst factor, breaking length, kappa number and unbleached brightness, while the proportion of axial parenchyma cells was negatively correlated with pulp yield, tear factor, folding endurance, kappa number and unbleached brightness (Ona *et al.* 2001). Parenchyma cells were detrimental to burst and tensile strength (Horn 1978). On the other hand, Haygreen and Bowyer (1996) explained that during processing, vessels were more likely to break and because of that wood containing a high proportion of vessels would produce a lower pulp yield than wood with higher fibre content. Vessel proportion and the number of vessels per mm^2 were negatively correlated with pulp yield and paper strength properties (Amidon 1981).

Statistically, the proportion of fibres in *Acacia* hybrid was significantly higher than that of the two parents (Table 1 and Figure 1c). Positive correlation between proportion of fibres and tear factor or folding endurance was reported (Ona *et al.* 2001).

Chemical compositions

The lignin content of the *Acacia* hybrid was slightly lower than that of *A. mangium* and *A. auriculiformis*, although statistically there was no significant difference (Table 2). A higher proportion of lignin results in lower pulp yield (Batchelor *et al.* 1971, Haygreen & Bowyer 1996) as well as lower pulp strength (Fengel & Wegener 1989) and requires more bleaching chemicals (Sjostrom 1993, Ona *et al.* 2001).

Table 2 shows that the lowest extractives content was found in the *Acacia* hybrid, followed by *A. mangium* and *A. auriculiformis*. The extractives content in the hybrid was significantly different from that of the two parents. Materials with low extractives content are preferable for pulp and paper (Ona *et al.* 2001, Kube & Raymond 2002). Eklund and Lindstrom (1991) stated that in kraft pulping, most of the resins and extractives were removed while about 50% remained after sulphite pulping. The remaining substances can give rise to considerable problems during paper manufacturing. Large amounts of extractives in pulps used for food packaging may give taste and odour to the foodstuffs (Bergelin & Holmbom 2008). Deposits from resin adhere to different parts of the paper machine or may appear as dirt spots on the paper.

The α-cellulose content of the hybrid was similar to *A. mangium*; the holocellulose content was significantly higher than in both *A. mangium* and *A. auriculiformis* (Table 2). For kraft pulping of hardwood, the pulp yield has generally been found to be positively correlated with holocellulose and α-cellulose contents (Amidon 1981). Holocellulose represents the total content of carbohydrate materials and a high holocellulose content, therefore, is desirable for the pulp and paper industry because it is correlated with a higher pulp yield (Mabilangan & Estudillo 1996). The high holocellulose content of the hybrid can be expected to produce higher pulp yield.

Table 2 Chemical compositions and wood density of *Acacia* hybrid and its parents

Species	Alcohol–benzene extractives (%)	Holocellulose (%)	α-Cellulose (%)	Lignin (%)	Density (g cm^{-3})
Acacia hybrid	2.9	82.88	45.45	30.91	0.49
A. mangium	5.38**	80.43**	45.71	31.30	0.46
A. auriculiformis	5.96**	71.33**	40.57*	34.10	0.52

** Significantly different from *Acacia* hybrid at the 0.01 level, * = at the 0.05 level

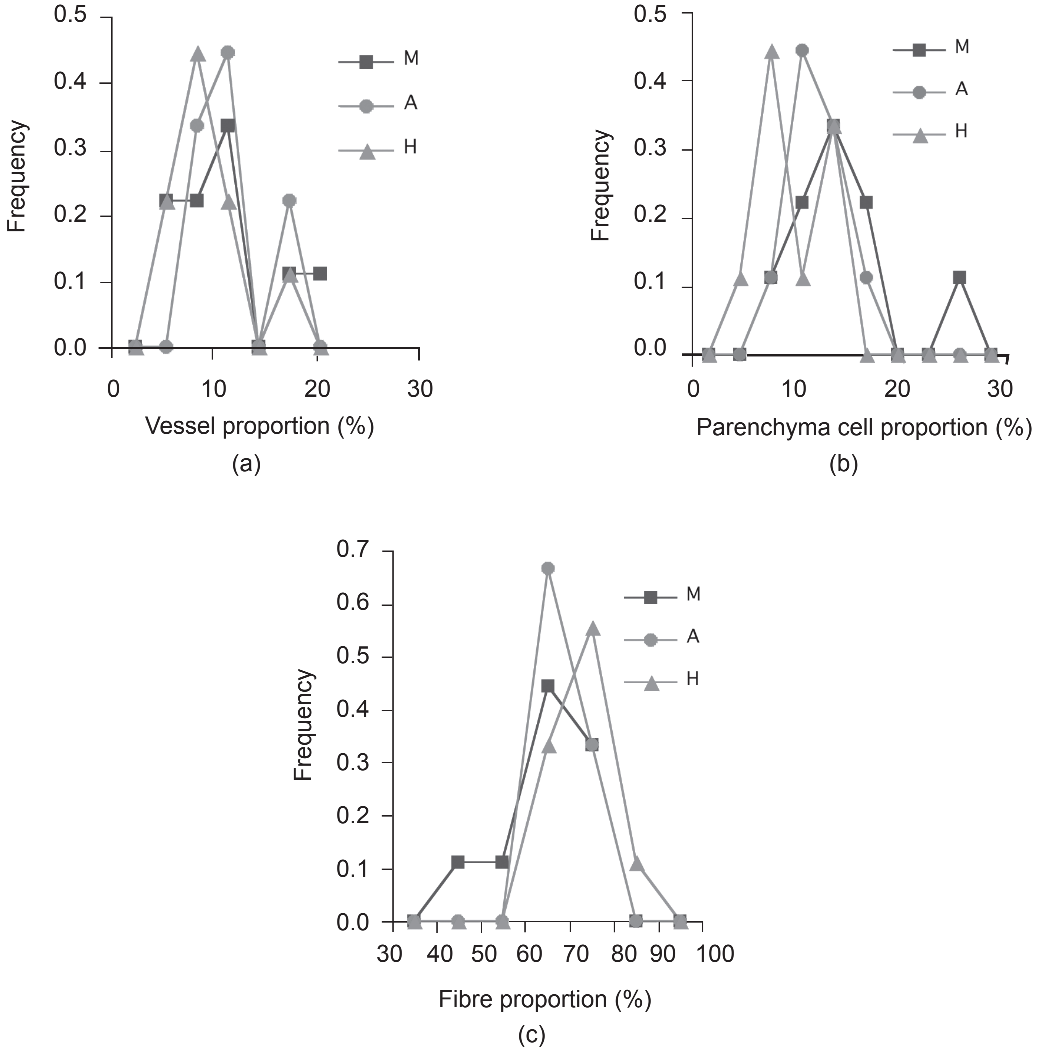

Figure 1 Cell proportions in *A. mangium* (M), *A. auriculiformis* (A) and *Acacia* hybrid (H): (a) vessel, (b) parenchyma cell and (c) fibre

Wood density

The highest wood density was found in *A. auriculiformis,* followed by the hybrid and *A. mangium* (Table 2). Statistically there was no difference in wood density between the hybrid and both *A. auriculiformis* and *A. mangium.* Low wood density will result in lower kraft yield (Casey 1952, Haygreen & Bowyer 1996). Greaves and Borralho (1996) stated that the increase of wood density and pulp yield decreased the cost of converting green roundwood into unbleached pulp per oven-dried tonne of bleached pulp produced.

Prediction of chemical compositions using fibre length and density

Regression coefficients for the correlation of fibre length with holocellulose, cellulose and lignin contents are shown in Figure 2. The fibre length strongly correlated with holocellulose (r = 0.92), α-cellulose (r = 0.82) and lignin (r = -0.70). Thus, it appears as a reliable predictor of these chemical compositions. Fibre length contributed 85, 68 and 49% of variations in the holocellulose, α-cellulose and lignin contents respectively. The slenderness ratio was a better predictor of the extractives content compared with fibre length (Figure 3). Variations in the extractives content were 74 and 66% by slenderness ratio and fibre length respectively. The correlation coefficients of slenderness ratio and fibre length with extractives content were -0.86 and -0.81 respectively. Density was strongly correlated with holocellulose (r = 0.92) and α-cellulose (r = 0.82) and it explained 85 and 68% of variations in holocellulose and α-cellulose respectively (Figures 4a, b). However, as shown by the comparison between Figures 2a and 4a, based on the observed regression, density would not have correctly predicted the ranking between *A. mangium* and the hybrid. Moreover, density is not correlated with lignin and extractives content.

As mentioned earlier for kraft pulp of hardwood, pulp yield is positively correlated with holocellulose and cellulose contents (Amidon 1981). On the other hand, materials with high amounts of lignin (Batchelor *et al.* 1971, Fengel & Wegener 1989, Sjostrom 1993, Haygreen & Bowyer 1996, Ona *et al.* 2001) and extractives (Eklund & Lindstrom 1991, Ona *et al.* 2001, Kube & Raymond 2002) decrease pulp yield.

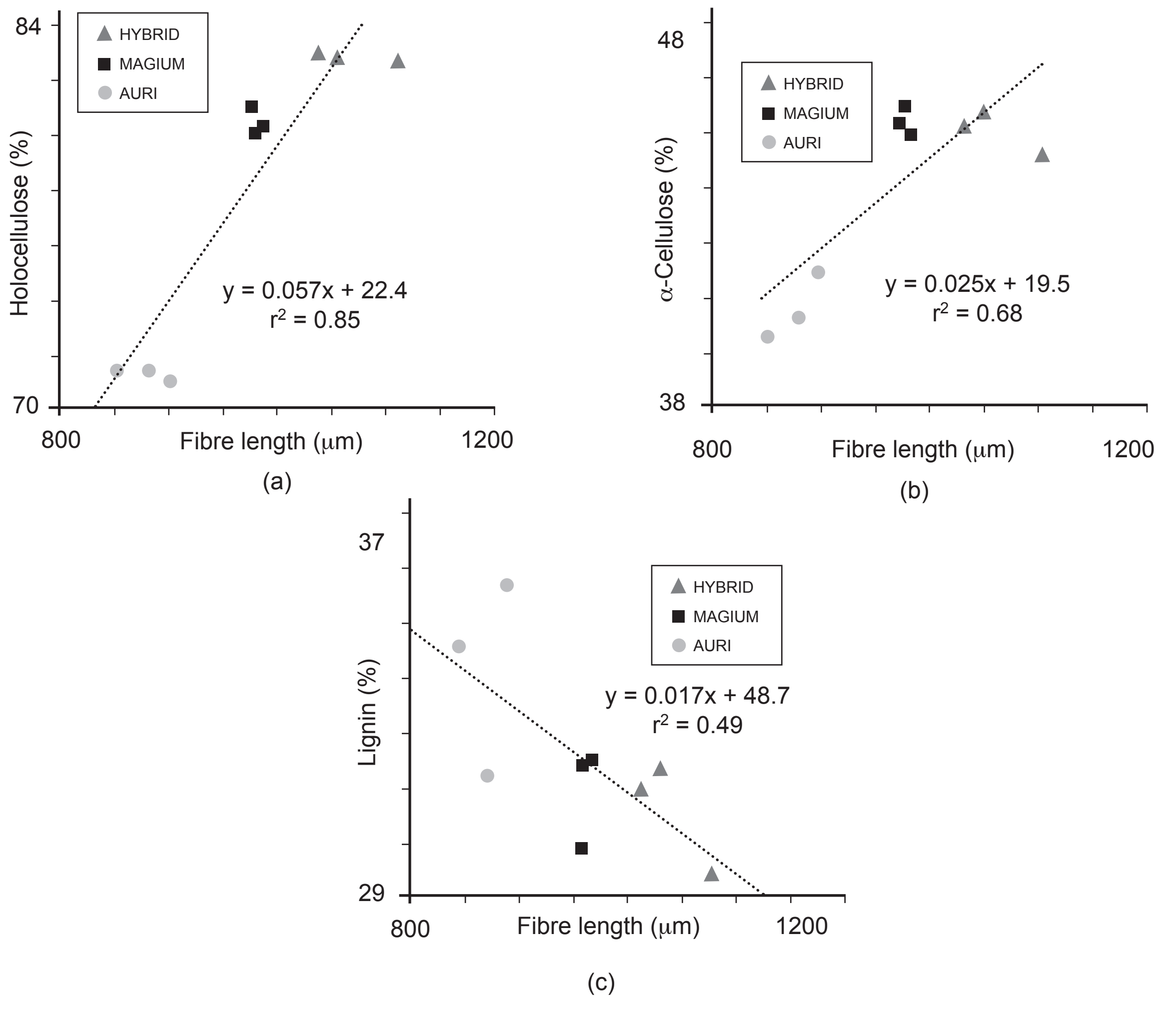

Figure 2 Relationships between chemical compositions and fibre length in acacias: (a) holocellulose, (b) α-cellulose and (c) lignin content

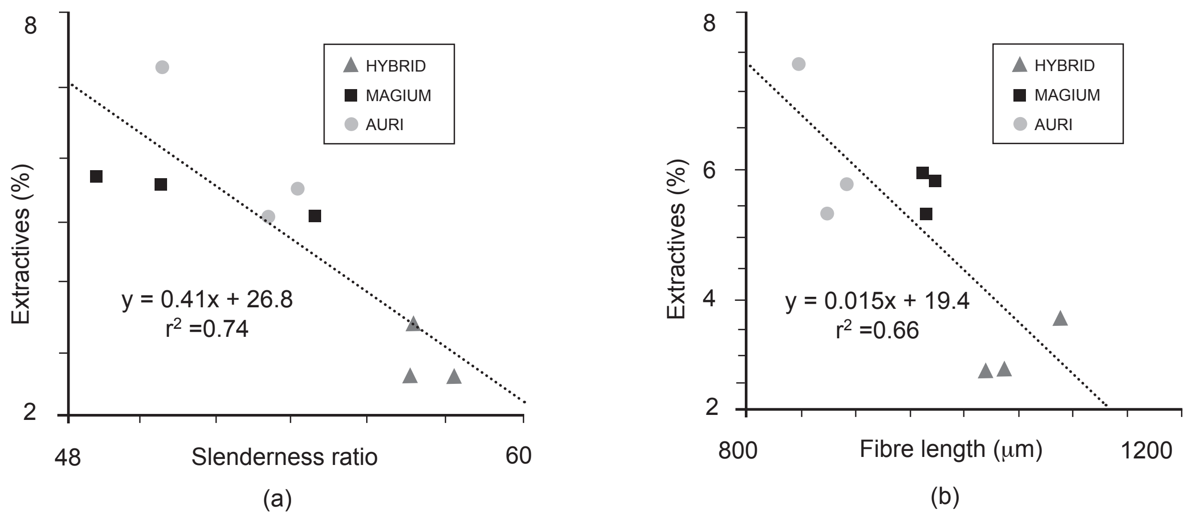

Figure 3 Relationship between extractives content and anatomical properties in acacias: (a) slenderness ratio and (b) fibre length

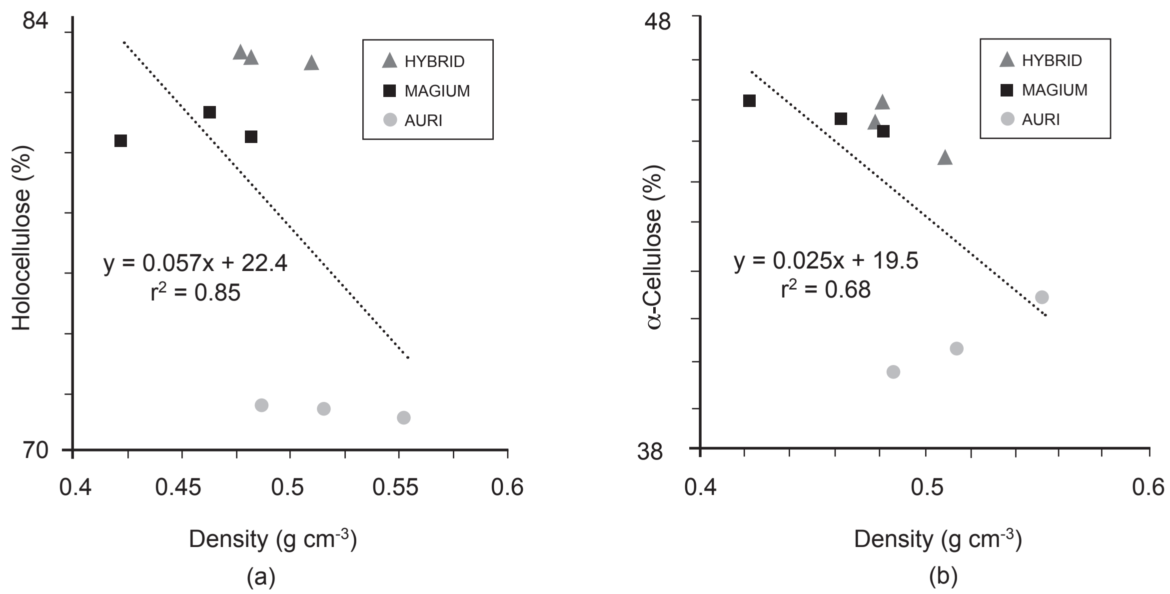

Figure 4 Relationships between chemical compositions and density in acacias: (a) holocellulose and (b) α-cellulose

This study showed that fibre length and slenderness ratio seemed the best potential indexes for establishing a strong correlation with pulp yield and paper strength, rather than density.

CONCLUSIONS

Statistically, the *Acacia* hybrid had longer fibres, higher slenderness ratio, higher proportion of fibres and holocellulose content than *A. mangium* and *A. auriculiformis*. It also had lower proportions of vessels, parenchyma cells and extractives. In addition, the hybrid tended to have thinner cell walls, smaller proportion of ray cells, smaller coefficient of rigidity and lignin content, and higher flexibility coefficient and wood density than *A. mangium.*

Based on these properties, the hybrid should produce a higher pulp yield and give better paper strength than *A. mangium* and *A. auriculiformis.* Additionally, holocellulose, α-cellulose and lignin contents were all reliably predicted by fibre length in this study. Slenderness ratio was a better predictor for extractives content compared with fibre length. Density, to some extent, could predict holocellulose and α-cellulose but not lignin and extractives content. Therefore, fibre length and slenderness ratio could be used as predictors for pulp yield and paper strength of acacias.

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