# POTENTIAL USE OF PLANTED FAST-GROWING SPECIES FOR PRODUCTION OF PARTICLEBOARD

**R Trianoski*, S Iwakiri & JLM de Matos**

*Federal University of Paraná, Paraná, Prefeito Lothário Meissner Street, 632, Botanical Garden, Curitiba, Paraná, Brazil, 80210-170*

*Received August 2010*

**TRIANOSKI R, IWAKIRI S & DE MATOS JLM. 2011. Potential use of planted fast-growing species for production of particleboard.** The present study evaluated the potential of using planted fast-growing species in Brazil for the manufacturing of particleboard. The species used in the experiment were *Acrocarpus fraxinifolius, Melia azedarach, Grevillea robusta, Schizolobium parahyba* and *Toona ciliata*. They were collected from an 18-year-old experimental forestry plantation located in Corupá, Santa Catarina, Brazil. *Pinus taeda* was used as reference species. Particleboard with final thickness 15 mm and nominal density 0.80 g cm$^{-3}$ were produced using urea-formaldehyde resin under pressing temperature of 160 °C, specific pressure 40 kgf cm$^{-2}$ and press time 8 min. The board was evaluated for physical and mechanical properties based on the European Standards (EN) for particleboard. When compared with panels of *P. taeda* and with requirements of EN, the final results showed satisfactory physical and mechanical properties in all treatments, except for the particleboard made from *G. robusta*. Thus, this study demonstrated that species *A. fraxinifolius, M. azedarach, S. parahyba* and *T. ciliata* were potentially useful for the production of particleboard.

Keywords: Wood particles, alternative forestry species, *Acrocarpus fraxinifolius, Melia azedarach, Grevillea robusta, Schizolobium parahyba, Toona ciliata*

**TRIANOSKI R, IWAKIRI S & DE MATOS JLM. 2011. Potensi penggunaan spesies yang tumbuh cepat untuk penghasilan papan serpai.** Kajian ini menilai potensi menggunakan spesies yang cepat tumbuh di Brazil untuk menghasilkan papan serpai. Spesies yang digunakan ialah *Acrocarpus fraxinifolius, Melia azedarach, Grevillea robusta, Schizolobium parahyba* dan *Toona ciliata*. Semua spesies ini diambil dari ladang hutan yang berusia 18 tahun di Corupá, Santa Catarina, Brazil. *Pinus taeda* diguna sebagai spesies rujukan. Papan serpai yang mempunyai ketebalan akhir 15 mm serta ketumpatan nominal 0.80 g cm$^{-3}$ dihasilkan menggunakan resin urea formaldehid pada suhu 160 °C, tekanan spesifik 40 kgf cm$^{-2}$ dan tempoh tekanan selama 8 min. Papan dinilai berdasarkan ciri-ciri fizikal dan mekanik mengikut Standard Eropah (EN) bagi papan serpai. Apabila papan yang dihasil dibandingkan dengan panel *P. taeda* dan keperluan EN, keputusan menunjukkan ciri-ciri fizikal dan mekanik yang memuaskan dalam semua ujian kecuali papan serpai yang dibuat daripada *G. robusta*. Oleh itu, kajian ini menunjukkan bahawa spesies *A. fraxinifolius, M. azedarach, S. parahyba* dan *T. ciliata* berpotensi untuk digunakan dalam penghasilan papan serpai.

## INTRODUCTION

The forest-based industry has notably grown in the past few years and it continues in rapid technological expansion both in procedures and products. Within this context, the industry of reconstituted wood panels has stood out and, consequently, shown great relevance once it is able to supply the quantity and quality that the market demanded.

Among reconstituted wood panels, particleboard is of great importance as it does not require high quality raw materials (Maloney 1993). It also has a high rate of demand due to the wide diversity of products, flexibility in application and, mainly, the huge growth of the furniture industry, which is the main consumer of this type of panel.

In the production of particleboards, there are several interconnected variables that influence the properties of the final product, namely, wood density, pH, wood extractives, panel density, geometry of particles, types and amount of adhesives and method of mat formation and pressing parameter (Iwakiri 2005). The control of these variables affects directly the mechanical properties and dimensional stability of the board (Tsoumis 1991). Within such variables, of great importance is the employed species which represents a great variability in its anatomic

---

**E-mail: rosillani@gmail.com*

structure (Tsoumis 1991) and influences the wood density, chemical properties and reactions of the polymerisation of adhesive (Sjöstrom 1981). The species will also determine the type of particle to be produced, the pressing parameter and the final properties of the panel.

Since species of wood influences the production process, and in view of the ever increasing demand for raw materials, it becomes necessary to expand plantation areas not only with common species that are already being used but also with other fast-growing species that can contribute in quantity and quality to meet the needs of industries. In addition, these fast-growing species can also play a part in the development and creation of new products.

Therefore, due to the need of research on non-conventional species, and to obtain information about their characteristics and behaviour, this work was aimed at evaluating the potential use of fast-growing alternative forest species grown in forest plantations for the production of particleboard.

## MATERIALS AND METHODS

### Materials

The species used in this study were *Acrocarpus fraxinifolius*, *Melia azedarach*, *Grevillea robusta*, *Schizolobium parahyba* and *Toona ciliata*. The trees were 18 years old and were collected from experimental forest plantations located in Corupá, Santa Catarina, Brazil. *Pinus taeda*, traditionally used by particleboard industries, was taken as control to compare results obtained in this study.

Urea formaldehyde resin type E2 (solid contents 67.5%, Brookfield viscosity 538 cP, pH 8.22, density 1.29 g $cm^{-3}$, gelatinisation time 1.12 min, 1% paraffin wax based on the dry weight of the particles) was used for the production of experimental panels.

### Methods

Five trees per species were collected and processed according to the COPANT regulation 458 (Pan-American Standards Commission 1972a). Particles of *P. taeda* were collected from a mill in Araucária, Paraná, Brazil.

For the determination of wood density, sample discs were cut from the stem at every 0.40 m in compliance with COPANT regulation 461 (Pan-American Standards Commission 1972b). Chemical analyses were conducted using sampled particles obtained after wood chips were produced following the sampling procedure recommended by the TAPPI 257 (TAPPI 2002b) and 264 (TAPPI 1997b) regulations. The chemical properties analysed were extractives in ethanol–toluene (TAPPI 280:1999), total extractives (TAPPI 204:1997a) and pH (TAPPI 252:2002a).

The experimental design comprised seven treatments in homogeneous composition, with three panels in each treatment. Six of the treatments were produced with 100% particles per species, including *P. taeda* as control treatment, while one treatment was a mixture of the five alternative species in the ratio of 20% per species.

Wood chips were produced in a disc flaker and later dried in a conventional drying kiln at moisture contents between 4 and 10%. Wood chips for *S. parahyba* could not be produced under green moisture condition, so the wood had to be dried before undergoing such process. After drying, wood chips were processed in a hammer mill to produce sliver particles. These particles were then automatically classified through sieves of sizes 14 and 30 mesh. The particles that remained on the 14-mesh sieve and those that passed through the 30-mesh sieve were discarded. Thus, only particles between 14- and 30-mesh size were used for the manufacture of the panels. These were then dried once more until a moisture content of about 3% was obtained.

Paraffin wax and catalysed resin with ammonium chloride (1 and 8% based on the oven-dry weight of particles) were subsequently sprayed over the particles by aspersion in a rotary bounding mixer. The matrix panels were randomly modelled in a 50 × 50 cm tray. The amount of materials was then calculated for panels with approximately 0.80 g $cm^{-3}$ nominal density with dimensions of 50 × 50 × 1.5 cm.

The panels were consolidated by adopting the following pressing guideline: 160 °C temperature, specific pressure of 40 kgf $cm^{-2}$ and press time of 8 min. After panels had been manufactured, they were transferred into a climatic chamber under controlled temperature and relative humidity (20 ± 3 °C and 65 ± 5% relative humidity) until an equilibrium moisture condition was reached.

The quality of panels was evaluated in accordance to the methodology proposed by the European Standard. Physical properties evaluated were density (EN 323:2002f), moisture content (EN 322:2002e), water absorption and thickness swelling after 2 and 24 hours of immersion in water (20 ± 1°C) (EN 317:2002b), and dimensional variations related to the relative humidity (EN 318:2002c). Mechanical properties analysed were static bending (EN 310:2002a) and internal bond (EN 319:2002d). The experimental results were compared with the requirements of EN 312 (2003) standards.

A statistical treatment was made in order to verify the presence of outliers, data normality and statistical difference in each variable of the outcome. Analysis of covariance was performed on each property analysed using individual values obtained for set of tested samples. All tests were done by the Statgraphics Centurion Program (2009) at a level of 5% probability.

## RESULTS AND DISCUSSION

### Wood properties

This study showed that wood densities of all species could be classified as low and were suitable for the production of particleboard (Table 1). Species with densities lower than 0.55 g cm$^{-3}$ are recommended for the production of particleboards as they ensure satisfactory compaction ratio (Maloney 1993). In the chemical analysis, results obtained from the extraction under ethanol–toluene showed that *G. robusta* exhibited the greatest quantity of extractives.

All species, except *T. ciliata*, presented average values for the total extractive content according to the range for angiosperms, i.e. less than 10%, usually 2 ± 3% (Sjöstrom 1981). The extractive content is an important indicator of the wood line and its sharp presence can prevent the use of certain species for the production of particleboards.

The pH values that were obtained from the species used in the current analysis were adequate to the variation interval described in literature (Stamm 1964), i.e. between 3.0 and 5.5. Thus, none of the species went through an excessive high or low acidity level. However, industrial use of urea-formaldehyde resin in the bonding process requires a pH between 3.0 and 3.5 for polymerisation. Thus, if the species studied are to be used in the industry, catalysts need to be added to ease and swift the cure during the pressing procedure.

### Properties of panels

*Board density, compaction ratio and moisture content*

The average board density for different treatments varied between 0.73 and 0.78 g cm$^{-3}$ (Table 2). This indicated the need to adjust the data

**Table 1** Physical and chemical properties of the wood species used in the study

| Species | Wood density (g cm$^{-3}$) | Extraction in ethanol–toluene (%) | Total extractives (%) | pH |
|---|---|---|---|---|
| *Pinus taeda* (control) | 0.50 a<br>(4.43) | 4.06 e<br>(0.10) | 7.37 d<br>(1.52) | 4.58 e<br>(0.88) |
| *Acrocarpus fraxinifolius* | 0.46 b<br>(5.82) | 5.91 d<br>(2.99) | 9.44 b<br>(2.64) | 5.07 c<br>(0.46) |
| *Melia azedarach* | 0.49 a<br>(4.05) | 2.95 f<br>(2.85) | 4.41 e<br>(0.87) | 5.50 a<br>(0.46) |
| *Grevillea robusta* | 0.49 a<br>(5.62) | 8.17 a<br>(1.46) | 8.32 c<br>(2.42) | 5.39 b<br>(0.60) |
| *Schizolobium parahyba* | 0.26 d<br>(6.59) | 6.38 c<br>(1.95) | 8.85 c<br>(1.28) | 5.04 d<br>(0.61) |
| *Toona ciliata* | 0.37 c<br>(4.91) | 7.58 b<br>(3.73) | 10.33 a<br>(3.43) | 5.54 a<br>(0.58) |

Averages followed by the same letter in the same column are not significantly different according to Tukey's test at 5% probability; values in parentheses refer to coefficients of variation (%).

**Table 2** Average values of board density, compaction ratio and moisture content

| Species | Board density ($g\ cm^{-3}$) | Compaction ratio | Moisture content (%) |
|---|---|---|---|
| *Pinus taeda* | 0.78 ab<br>(6.77) | 1.52 f<br>(3.07) | 10.22 a<br>(4.04) |
| *Acrocarpus fraxinifolius* | 0.75 abc<br>(7.98) | 1.65 d<br>(3.53) | 9.50 bc<br>(5.47) |
| *Melia azedarach* | 0.74 bc<br>(4.65) | 1.56 e<br>(2.17) | 9.95 ab<br>(3.06) |
| *Grevillea robusta* | 0.78 ab<br>(6.42) | 1.52 f<br>(2.88) | 9.60 bc<br>(3.54) |
| *Schizolobium parahyba* | 0.73 c<br>(6.31) | 2.83 a<br>(1.59) | 9.39 c<br>(4.27) |
| *Toona ciliata* | 0.72 c<br>(6.76) | 2.02 b<br>(2.63) | 9.95 ab<br>(3.58) |
| Combination of five species | 0.79 a<br>(5.33) | 1.82 c<br>(2.00) | 9.56 bc<br>(3.13) |

Averages followed by the same letter in the same column are not significantly different according to Tukey's test at 5% probability; values in parentheses refer to coefficients of variation (%).

obtained using the analysis of covariance to additional properties.

The species with the greatest difference in nominal density were *S. parahyba* and *T. ciliata*. This difference may due to the low wood densities of these two species and greater volume of particles, resulting in a large release of compressing tension enforced during the pressing process. After pressing, a return in thickness occurred and the treatments produced with *S. parahyba* and *T. ciliata* presented an average thickness of 16.1 and 16.7 mm respectively, contributing to the low density of the panel.

With regard to the variable compaction ratio, it was observed that all species showed average values of above 1.3. This ratio indicated sufficient densification during the manufacture of panels (Moslemi 1974, Maloney 1993). However, these authors stated that the upper limit of this parameter was 1.6.

Moisture contents were low in all species indicating that hygroscopic reduction occurred when wood was being processed into wood particles and also when resins, wax and additives were being incorporated. However, the low moisture contents were mainly due to the adoption of high temperatures and pressure during compression of panels (Wu 1999) which caused the breaking or rearrangement of hygroscopic regions of wood (hydroxyl groups), resulting in the panels being less reactive to water.

### *Water absorption, thickness swelling and dimensional variations*

Water absorption following 2 and 24 hours of immersion in water varied from 7.94 to 31.22% and from 27.82 to 68.70% respectively (Table 3). It was observed that in both cases, the highest values were recorded for *S. parahyba*.

After two hours immersion, values for thickness swelling were between 12.07 and 17.06%, while after 24 hours, 16.78 and 29.76%. *Schizolobium parahyba* had the greatest swelling rates while *T. ciliata* showed the best performance with the lowest rates, i.e. even better than the control. Treatment with *Schizolobium* showed the highest value of swelling due to greater compaction ratio and low wood density which caused the release of internal panel tension during the immersion period (Moslemi 1974, Kelly 1977).

After 2 and 24-hours water absorption, *M. azedarach* was the only species that showed properties similar to the control, *P. taeda*. For thickness swelling, *T. ciliata* and the mix species were also statistically equal to *P. taeda*.

The experiment that analysed the dimensional variations associated with changes in the relative humidity revealed substantial differences only in the thickness of the panels when relative humidity was between 65 and 85%. Relative humidity at 30 to 65% did not affect all treatments studied in relation to thickness. Significant changes were

**Table 3** Average values of water absorption and thickness swelling after 2 and 24 hours and dimensional variation associated to variations in relative humidity

| Species | WA 2 hours$^1$ (%) | WA 24 hours$^1$ (%) | TS 2 hours$^2$ (%) | TS 24 hours$^2$ (%) | DVL$^3$ | | DVT$^4$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 65–30% RH | 65–85% RH | 65–30% RH | 65–85% RH |
| *Pinus taeda* | 7.94 d<br>(10.66) | 27.82 e<br>(10.24) | 13.02 c<br>(8.81) | 18.56 de<br>(7.24) | -0.77 a<br>(15.21) | 0.23 a<br>(39.29) | -3.99 a<br>(15.08) | 5.70 ab<br>(6.16) |
| *Acrocarpus fraxinifolius* | 19.17 b<br>(24.69) | 52.53 b<br>(20.93) | 14.11 b<br>(8.31) | 24.58 c<br>(10.04) | -0.61 a<br>(26.65) | 0.37 a<br>(32.54) | -3.27 a<br>(5.28) | 5.80 a<br>(13.18) |
| *Melia azedarach* | 9.92 d<br>(13.80) | 32.06 e<br>(13.88) | 12.45 c<br>(7.45) | 17.79 de<br>(6.32) | -0.73 a<br>(16.23) | 0.38 a<br>(23.58) | -3.40 a<br>(8.59) | 4.13 ab<br>(22.58) |
| *Grevillea robusta* | 10.72 c<br>(28.33) | 40.64 c<br>(14.04) | 14.44 b<br>(6.29) | 25.98 b<br>(8.29) | -0.65 a<br>(8.24) | 0.43 a<br>(42.01) | -4.42 a<br>(4.27) | 4.80 ab<br>(21.88) |
| *Schizolobium parahyba* | 31.22 a<br>(13.76) | 68.70 a<br>(9.37) | 17.06 a<br>(11.40) | 29.76 a<br>(11.13) | -0.81 a<br>(7.22) | 0.48 a<br>(20.42) | -3.89 a<br>(15.31) | 5.54 ab<br>(13.83) |
| *Toona ciliata* | 13.27 c<br>(18.87) | 37.46 d<br>(21.19) | 12.07 c<br>(6.27) | 16.78 e<br>(5.99) | -0.83 a<br>(9.36) | 0.51 a<br>(15.17) | -3.65 a<br>(20.18) | 3.39 ab<br>(25.45) |
| Mixture 5 species | 10.25 c<br>(10.69) | 32.45 d<br>(12.43) | 13.20 c<br>(8.36) | 18.82 d<br>(7.73) | -0.55 a<br>(8.81) | 0.39 a<br>(11.90) | -3.97 a<br>(8.41) | 3.17 b<br>(13.91) |

Averages followed by the same letter in the same column are not significantly different according to Tukey's test at 5% probability; values in terms with ANACOVA to board density of 0.76 g cm$^{-3}$; $^1$water absorption after 2 and 24 hours immersion in water, $^2$thickness swelling after 2 and 24 hours immersion in water, $^3$dimensional variation in length for relative humidity variations of 65 to 30% and 65 to 85%, $^4$dimensional variation in thickness for relative humidity variations of 65 to 30% and 65 to 85%; values in parentheses refer to coefficients of variation (%).

not observed in both relative humidity variations. However, *A. fraxinifolius* showed the widest expansion in thickness and was only statistically diferent when compared with the manufactured treatment, i.e. the mix of five species.

### *Bending strength and internal bond*

The average values for bending strength and internal bond are shown in Table 4. Modulus of rupture (MOR) values for *T. ciliata* and *M. azedarach* were greater than the rest of the species. *Toona ciliata* had high compaction ratio and thus resulted in the high MOR. Although it exhibited the highest extractive contents (10.33%, Table 1), it could be concluded that these types of extractives that comprised substances of low molecular weights did not exert negative influence over the adhesive polymerisation.

On the other hand, the low MOR value for *G. robusta* could be attributed to the high content of its extractives in ethanol–toluene soluble (8.17%, Table 1). Such extractives (ethanol–toluene soluble) are characterised in waxes, oils and fats. Thus *G. robusta* may interact with the adhesive and affect the polymerisation reactions.

Modulus of elasticity (MOE) was also highest in *T. ciliata* while *G. robusta* showed the lowest value. These trends are explained by the same reasons mentioned in the discussion regarding MOR.

Results of this experiment showed that *A. fraxinifolius*, *M. azedarach, S. parahyba* and *T. ciliata* exhibited MOR and MOE values higher than *P. taeda.* Panels produced using these four species exhibited higher average values than the requirements outlined in the EN 312: 2003 Standard (i.e. MOR 13 MPa and MOE 1600 MPa). However, *G. robusta* did not meet the minimum requirements.

In the experiment of the internal bond, the species showed values ranging between 0.61 (*G. robusta*) and 1.88 MPa (*M. azedarach*). The low value of internal bond in the latter was also due to the high content of its ethanol–toluene soluble extractives.

The minimum internal bond value prescribed in the EN 312:2003 Standard is 0.35 MPa. In this study, all species including control and mixed species met this minimum requirement. This indicated adequate quality of bonding between particles and also highlighted those species with

**Table 4** Average values of bending strength and internal bond

| Species | Bending strength[1] MOR (MPa) | Bending strength[1] MOE (MPa) | Internal bond[2] (MPa) |
|---|---|---|---|
| *Pinus taeda* | 11.17 d | 1.581 d | 1.05 e |
| | (17.13) | (17.00) | (13.42) |
| *Acrocarpus fraxinifolius* | 18.19 b | 2.134 b | 1.50 c |
| | (19.92) | (19.58) | (10.99) |
| *Melia azedarach* | 18.56 ab | 2.192 b | 1.88 a |
| | (22.85) | (20.32) | (9.99) |
| *Grevillea robusta* | 7.04 e | 1.475 d | 0.61 f |
| | (30.03) | (25.74) | (15.57) |
| *Schizolobium parahyba* | 15.70 c | 1.973 c | 1.34 d |
| | (22.25) | (23.45) | (11.97) |
| *Toona ciliata* | 19.83 a | 2.427 a | 1.64 b |
| | (24.31) | (23.94) | (9.98) |
| Mixture of 5 species | 15.40 c | 2.073 bc | 1.09 e |
| | (23.63) | (20.17) | (13.64) |

Averages followed by the same letter in the same column are not significantly different according to Tukey's test at 5% probability; [1]values adjusted by ANCOVA to a board density of 0.69 g $cm^{-3}$, [2]values adjusted by ANCOVA to a board density of 0.73 g $cm^{-3}$; MOR = modulus of rupture, MOE = modulus of elasticity; values in parentheses refer to the coefficients of variation (%).

viable technical potential for the production of particleboard. Taking the control treatment into consideration, except the panels that were made from *G. robusta,* panels produced from all study species were of superior quality compared with panels produced from *P. taeda,* a species which has been traditionally used in Brazilian industrial processes.

## CONCLUSIONS

*Acrocarpus fraxinifolius*, *M. azedarach*, *G. robusta*, *S. parahyba* and *T. ciliata* showed low densities and are thus suitable for the production of particleboard. The chemical analyses demonstrated that these species did not have inhibitor chemical properties that were not suitable for the production of good quality particleboards, except for *G. robusta. Grevillea robusta* exhibited high contents of soluble substances in ethanol–toluene which had negative influence on adhesive polymerisation. On the other hand, *A. fraxinifolius, M. azedarach, S. parahyba* and *T. ciliata* met the minimum requirements outlined in the EN 312:2003 Standard and produced panels which had better physical and mechanical properties compared with *P. taeda.* The use of the mixture of the five species produced panels with intermediate physical and mechanical properties and these values were higher than *P. taeda.*

Two species, *M. azedarach* and *T. ciliata,* had the best performance and thus the highest potential for the production of particleboard. It is recommended to explore the possibility of these two species for particleboard production in various proportions, in case there is a shortage of supply of any one of them.

## ACKNOWLEDGEMENTS

The authors thank B Florestal for permission to collect samples from experimental plantations and to Berneck SA Corporation for the supply of *P. taeda,* resins and additives. Thanks are also extended to CNPq for the student grant.

## REFERENCES

EN (European Standard). 2002a. *NP EN 310. Wood-based Panels—Determination of Modulus of Elasticity in Bending and of Bending Strength.* Portuguese Institute of Quality, Caparica.

EN (European Standard). 2002b. *NP EN 317: Particleboards and Medium Density Fiberboards—Determination of Thickness Swelling After Immersion in Water.* Portuguese Institute of Quality, Caparica.

EN (European Standard). 2002c. *EN 318. Wood-based Panels—Determination of Dimensional Changes Associated With Changes in Relative Humidity*. European Committee for Standardization, Brussels.

EN (European Standard). 2002d. *NP EN 319. Particleboards and Medium Density Fiberboards—Determination of the Resistance in the Face of Perpendicular Traction to Plates.* Portuguese Institute of Quality, Caparica.

EN (European Standard). 2002e. *EN 322: Wood-based panels—Determination of Moisture Content.* European Committee for Standardization, Brussels.

EN (European Standard). 2002f. *NP EN 323: Wood-based panels—Determination of Density.* Portuguese Institute of Quality, Caparica.

EN (European Standard). 2003. *EN 312. Particleboards—Specifications.* European Committee for Standardization, Brussels.

Iwakiri S. 2005. *Reconstituted Wood Panels.* Fupef, Curitiba. (In Portuguese)

Kelly MW. 1977. *A Critical Literature Review of Relationships Between Processing Parameters and Physical Properties of Particleboards.* General Technical Report FPL-10. US Forest Products Laboratory, Wisconsin.

Maloney TM.1993. *Modern Particleboard and Dry-Process Fiberboard Manufacturing.* Second edition. Miller Freeman Inc, São Francisco.

Moslemi AA. 1974. *Particleboard. Volume 1. Materials.* Southern Illinois University Press, London.

Pan-American Standards Commission. 1972a. *COPANT 458. Woods—Selection and Collection of Samples.* Pan-American Standards Commission, Caracas. (In Spanish)

Pan-American Standards Commission. 1972b. *COPANT 461. Woods—Establishment of Apparent Specific Weight.* Pan-American Standards Commission, Caracas. (In Spanish)

Sjöstrom E. 1981. *Wood Chemistry: Fundamentals and Applications.* Academic Press, New York.

Stamm A. 1964. *Wood and Cellulose Science.* The Ronald Press Company, New York.

TAPPI (Technical Association of the Pulp and Paper Industry). 1997a. *TAPPI 204. Solvent Extractives of Wood and Pulp.* TAPPI, Atlanta.

TAPPI (Technical Association of the Pulp and Paper Industry). 1997b. *TAPPI 264. Preparation of Wood for Chemical Analysis.* TAPPI, Atlanta.

TAPPI (Technical Association of the Pulp and Paper Industry). 1999. *TAPPI 280. Acetone Extractives of Wood and Pulp.* TAPPI, Atlanta.

TAPPI (Technical Association of the Pulp and Paper Industry). 2002a. *TAPPI 252. PH and Electrical Conductivity of Hot Water Extracts of Pulp, Paper, and Paperboard.* TAPPI, Atlanta.

TAPPI (Technical Association of the Pulp and Paper Industry). 2002b. *TAPPI 257. Sampling and Preparing Wood for Analysis.* TAPPI, Atlanta.

Tsoumis G. 1991. *Science and Technology of Wood: Structure, Properties and Utilization.* Van Nostrand Reinhold Inc, New York.

Wu Q. 1999. Application of Nelson's sorption isotherm to wood composites and overlays. *Wood and Fiber Science* 31: 187–191.