CHEMICAL AND EXTRACTIVES COMPATIBILITY OF EMPTY BUNCH FRUIT OF *Elaeis guineensis*, LEAVES OF *Ananas cumosos* AND TETRAPAK WITH WOOD USED IN PARTICLEBOARDS IN TROPICAL AREAS

R. MOYA[†], D. CAMACHO[†], R. SOTO[‡], J.F. MATA-SEGREDA[§] and J. VEGA-BAUDRIT[‡+]

† *Escuela de Ingeniería Forestal, Instituto Tecnológico de Costa Rica, Cartago, Costa Rica.*
rmoya@itcr.ac.cr and dicamacho@itcr.ac.cr
‡ *Escuela de Química, Universidad Nacional de Costa Rica, Apartado 86-3000 Heredia, Costa Rica*
roysoto@costarricense.cr
§ *Biorgánica Escuela de Química, Facultad de Ciencias Universidad de Costa Rica, Costa Rica*
julio.mata@ucr.ac.cr
+ *Laboratorio Nacional Nanotecnología, LANOTEC, CENAT, San Jose, Costa Rica.*
jvegab@gmail.com

Abstract— **Tropical countries produce a great variety of lignocellulosic residues from small-area planted crops. Large amount of "Tetra Pak" package are also produced without any disposal treatment. In order to give solutions for waste management, residues must be incorporated in other processes, such as the manufacture of particleboards. The main objective of this work was to evaluate chemical compositions, extractives in different solvent, chemical characterization of extracts in polar and un-polar solvent utilizing infrared spectrum analysis. A second aim of this study was to test the compatibility between chemical composition and extractives of empty bunch fruit of *Elaeis guineensis* (BPF), the leaves of *Ananas cumosos* (PL) and "Tetra Pak" packages with three timber species (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*).. Results showed that cellulose, ashes and lignin content of BPF, PL and "Tetra Pak" differ from those of the woody species. Similar result was obtained for pH and for the amount of substances extracted with different solvents. Infrared spectrum of water (polar), and ethanol-toluene (un-polar) solutions showed that the greatest differences in extracts were found in BPF and PL, this in relation to the studied woody species. Finally, HCMA showed that residues from BPF and "Tetra Pak" packages are slightly different, considering chemical compositions and extract content, to other woody species used for particleboard manufacture. Moreover, PL has the least compatibility with the woody species.**

Keywords— **Tropical species, infrared analysis, lignocellulose residues, agricultural crop.**

I. INTRODUCTION

Several tropical countries have a suitable climate for a great variety of single crops and multi-purpose crops such as coffee and timber trees. "Tetra Pak" packages are a beverage and liquid food system widely used all over the world as an aseptic packaging material.

Agricultural crops and "Tetra Pak" packages can be linked through the following disposal characteristics:

1. In crops, post-harvest residues are not being disposed or recycled appropriately (Bertsch, 2006, Ulloa *et al*., 2004).

2. Some crops have been blamed for environmental problems (Kissinger and Rees, 2010).

3. The amount of waste generated by "Tetra Pak" packaging and the low percentage of recycling.

An attractive option would be the possibility of combining the residues coming from sawmills, pineapple production, oil palm fruit processing and "Tetra Pak" waste. Although these crops are composed by lignocelluloses materials, their chemical composition is different, which reduces their compatibility. Lignocelluloses materials are formed of cellulose, lignin and extractives, and the amount and composition vary between them (John and Thomas, 2008). Extractives affect many processes where lignocellulose residues are utilized, for example pulp production or heat production (Tamaki and Mazza, 2010). They are natural substances whose chemical composition varies widely (Reddy and Yang, 2005).

Particleboards were traditionally produced from wood residues. However, in the last 20 years, a variety of raw lignocelluloses materials have been introduced as a complementary option (James, 2010). Particleboards made from pure agricultural residues or from the combination of wood residues with other materials have shown excellent physical and chemical properties (Hashim *et al*., 2010; Onurah, 2005). Chemical compatibility of these residues has been not studied previously.

The objective of the present study was to determine the chemical composition the extractives in different solvents and the chemical characterization of extracts in polar and un-polar solvent using infrared spectrum analysis. In addition, compatibility was established by means of using the chemical composition and extractives content, this for the empty bunch fruit of *Elaeis guineensis*, the pineapple leaves (*Ananas cumosos*), and the "Tetra Pak" packages. At last, lignocellulosic residues were compared with the wood of the three main timber species used for commercial plantations in Costa

Rica (*Gmelina arborea*, *Tectona grandis* and *Cupressus lusitanica*) and utilized in particleboards production.

II. METHODS

A. Abbreviations

TG: *Tectona grandis*; GA: *Gmelina arbórea*; CL: *Cupressus lusitanica*; BPF: empty bunch fruit of *Elaeis guineensis*; PL: Pineapple (*Ananas comosus*) leaves; TPP: "Tetra Pak" packages; MC: Moisture content

B. Material

A sample of oil palm fruits (BPF) were collected in from two plantations in the South Pacific Coast of Costa Rica. A sample of pineapple plants (PL) without fruit were collected from two plantations in the Central Pacific coast of Costa Rica. Wood samples of *Gmelina arborea* (GA), *Tectona grandis* (TG) and *Cupressus lusitanica* (CL) were collected from mature plantations in Costa Rica for its characterization (Moya and Muñoz, 2010). "Tetra Pak" packages (TPP) were obtained from daily consumption milk containers.

C. Sampling and materials

Two oil palm fruits were separated in samples from the bunch. Next, both fruits were cut to obtain sizes ranging from 2 to 3 cm long. Pineapple were cut in 2 cm long pieces and "Tetra Pak" boxes were cut in 1 cm wide sheets, and subsequently cut in 2 cm long pieces. The plantation wood samples came from 3 cross sections measuring 3 cm of thickness, extracted from 3 different trees and cut at a height of 1.3 m (Moya and Muñoz, 2010). In these woody species, due to the presence of sapwood and heartwood in the transversal sections, samples were taken only from the heartwood portion. The samples were ground to obtain chips of 2 cm length. From the green (non dried) material, 3 different samples were taken to measure green humidity content. The remaining material was dried until reaching close to the 12% humidity content and next it was ground. In this procedure, the pre-cut material of the different lignocellulose materials were ground to less than 0.6 mm particle size and sieved between two meshes of 0.25 mm and 0.42 mm (40 to 60 meshes respectively). The selected material for the tests was that retained between the 40 and 60 meshes.

D. Chemical analysis

Chemical analysis consisted on determining pH, moisture content in green condition, ash content, and cellulose and lignin content. The methodology proposed by Moore and Johnson (1967) was used to determine the pH and the ASTM D-4442-92 standard (ASTM, 2003a) was used to determine moisture content (MC). The ASTM D-1102-84 standard (ASTM, 2003b) was used to determine ash content and the TAPPI T222 om-02 method (Tappi, 2002) was used to quantify lignin content. Finally, the Seifert's procedure (Seifert, 1960) was used to determine the cellulose content.

E. Extractions

The extractives are substances located into the hemicellulose-cellulose-lignin tissues and are important for the establishment of compatibility with other lignocellulosic materials and chemicals compounds. The study of their amounts or quality issues allows knowing better their behavior with other materials or substances. The extractives were determined in A)water (hot and room temperature), according to D-1110-84 (ASTM, 2003c), which established extractives for such extraneous materials (tannins, gums, sugars, starches and coloring matters); B) in sodium hydroxide using the D-1109-84 standard (ASTM, 2003d) and solubility of wood was determined in a hot dilute alkali solution; C) in an ethanol-toluene solution using the D-1107-96 standard (ASTM, 2003e); D) in an ethanol-hexane (1:1) solution commonly used for determining oils, wax levels, fats, resins, tannins and other ether-insoluble components; E) in dichloromethane (CH_2-Cl_2) using the D-1108-96 standard, which is a measurement of waxes, fats, resins, oils, and similar materials (ASTM, 2003f); F) and the extractives-free residue using the D-1105-96 standard for determining the extractives that are soluble in neutral solvents and that are not a part of the wood (ASTM, 2003g). Each extractive was determined in separated samples and not carried out by succession.

F. Infrared spectrum analysis

Infrared spectrum analysis was performance using polar and un-polar extracts and cool water extracts, and ethanol extracts were selected as polar and un-polar, respectively. Analysis was performed over the cool water extract and the ethanol-toluene solution extract and two analyses were taken from each extract type. Following both extractions, the water and the ethanol-toluene solution were evaporated from their respective extracts to a Petri dish. These extractives were selected because they represent a polar and an un-polar solvent which measures the performance. Next, samples from the solid extracts were taken for the next phase of the analysis. The solid sample from the ethanol-toluene extraction was placed then on a sodium chloride (NaCl) plate; with the samples from the water extraction, a potassium bromide (KBr) pellet was made. Sample analyzed were carried out with an FT-IR Spectrometers (infrared spectrometer) of the brand Thermo Scientific. IR analysis was carried out using a KBr disk.

G. Data analysis

Statistical analysis was carried out using the SAS 8.1 software (SAS Institute, Inc., Cary, NC, USA). The normality and presence of extreme values or outliers were tested for each chemical variable. A general statistical description (average and variation coefficient) was performed for the different variables. The one-way ANOVA (analysis of variance) was used for establishing the difference between five lignocellulosic residues. Additionally, Tukey's test was applied to establish differences between chemical variable means. Finally, hierarchical clustering for multivariate analysis (HCMA) was carried out for testing the compatibility between residues. Three different HCMA were performed: (i) utilizing chemical characteristics (cellulose, lignin, moisture and ash content, pH, and extractives extracted in cool and hot water (NaOH, solution of ethanol-

toluene, ethanol-hexane, dichloromethane, and free extractives), (b) utilizing IR spectra of extracted in cold water and (c) utilizing IR spectra in ethanol-toluene extracts. The goal was to find a grouping of residues such that variation in chemical composition and IR spectra within each cluster were as small as possible, and a difference between clusters could be maximized. This similitude was tested by linking distances between groups. Statistical SAS and STATISTICA programs were used to evaluate the grouping.

III. RESULTS

A. Chemical composition

Results of chemical composition analyses are shown in table 1. The pH of TPP was the highest value and closest to neutral, and was not statistically different from the TG wood. GA and CL woods, and the BPF residue presented a pH value statistically lower than the TPP residue, but not different from the TG wood (Table 1). Finally, PL leaves presented the lowest pH value of all studied residues, with their pH of 4.5.

For MC, it was found that all residues present statistically different values, with the exception of CL and GA. PL residues have the highest MC, followed by GA and CL, while TG and BPF present intermediate humidity values (Table 1).

Wood (TG, GA and CL) residues had the lowest ash percentages, presenting values less than 1.1%. BPF ash percentage was statistically higher than PL. TPP had a higher ash percentage (Table 1). Nevertheless, TPP ash value should be interpreted with caution. This residue, added to the cellulose and polyethylene layers, has an aluminum layer which does not burn during the ash-burning test, thus producing a high amount of ashes due to the residual aluminum.

With respect to cellulose, it was found that TPP presented the highest percentage, followed by GA, which turned to be statistically different from CL, TG and PL. BPT residue had the least cellulose content (Table 1). With respect to lignin, it was found that CL residue showed the highest percentage, whereas PL residue yielded the lowest percentage. GA, TG and BPF residues showed values ranging from 25 to 30%. Once more, TPP has high lignin content; however, since this residue was evaluated with polyethylene and aluminum layers, results may be biased. It is very likely that the cellulose found in this residue is mostly lignin-free.

TPP residue comes from a beverage container for human consumption. Therefore, a neutral pH level and low humidity was assumed and later on confirmed with the tests (Table 1). On the opposite, the agricultural residues (BPF and PL) have a tendency to be slightly acid or highly humid, especially PL. BPF presented a pH similar than residues of some woody species; however, it was found that PL was statistically more acid than those of the woods (Table 1).

B. Extractives

A summary of the quantity of extractives in the different types of solvents (organic and inorganic) are shown on table 2. Cold water extractives varied from 5.9 to 27.8%, with PL having the highest statistical value. The three plantation woods had the lowest values (from 5.9 to 7.8%) and BPF and TPP residues had intermediate values. Hot water extractives were found to be higher than the cold water extractives, ranging from 7.0 to 38.3%. Moreover, they revealed a similar trend to that of the cold water extractives: PL being statistically higher, followed by BPF and TPP, and lastly, the 3 woody species presented the lowest content of cold water extractives. The amount of extractives in NaOH yielded the highest percentage of extractives, varying from 24.2 to 54.3%. BPF and PL residues showed the highest percentage with this solvent (statistically significant). The three plantation woods and the TPP residue were not statistically different. The amount of extractives from an ethanol-toluene solvent ranged from 3.8 to 11.5%, with BPF showing the highest percentage, followed by PL and GA; while CL, TG and TPP accounted for the lowest values (statistically significant). The content of extractives in an ethanol-toluene mixture was, in general, lesser than that normally found in an ethanol-hexane mixture. Values varied from 0.3 to 7.5%. BPF, with PL and CL residues having the highest percentages, followed by GA and TG, while TPP showed the lowest percentages, all statistically significant (Table 2). The extractives from dichloromethane yielded a lower percentage than the other tested substances, ranging from 0.5 to 8.4%. The statistically highest percentage was for BPF, followed by PL residues. On the opposite, CL, GA and TG residues yielded intermediate values and without statistical significance. Ground TPP presented the lowest statistical value. Lastly, extractives-free were statistically equal in BPF, PL, CL and TG. No statistical differences were found between CL and GA; TPP yielded the lowest percentages (statistically different).

Table 1. Chemical characteristics of oil palm fruit sections of *Elaeis guineensis*, *Ananas comosus* leaves, "Tetra Pak" packages and three wood species growing in plantations.

Parameters	*Elaeis guineensis* (BPF)	*Ananas comosus* (PL)	"Tetra Pak" package (TPP)	*Cupressus lusitánica* (CL)	*Gmelina arborea* (GA)	*Tectona grandis* (TG)
pH	5.9[BA] (0.81)	4.5[C] (0.18)	7.4[D] (0.02)	4.9[A] (0.03)	5.6[AB] (0.05)	6.4[BD] (0.07)
MC (%)	39.1[C] (8.97)	88.0[D] (2.50)	7.3[E] (0.30)	58.9[A] (3.42)	65.1[A] (2.16)	51.3[B] (2.97)
Ash (%)	5.4[B] (0.98)	6.8[C] (1.67)	11.0[D] (1.36)	0.2[A] (0.04)	1.1[A] (0.08)	0.8[A] (0.13)
Cellulose (%)	37.8[C] (1.83)	39.9[A] (1.63)	66.7[D] (1.98)	39.3[AC] (0.26)	46.6[B] (1.08)	41.4[A] (1.52)
Lignin (%)	31.4[C] (9.80)	13.9[D] (4.40)	25.4[B] (1.70)	46.4[A] (1.35)	25.6[B] (0.03)	30.1[C] (1.03)

Note: Averages with equal letters do not present significant differences. Determined at P-value >0.01. The values in parenthesis represent variation coefficients.
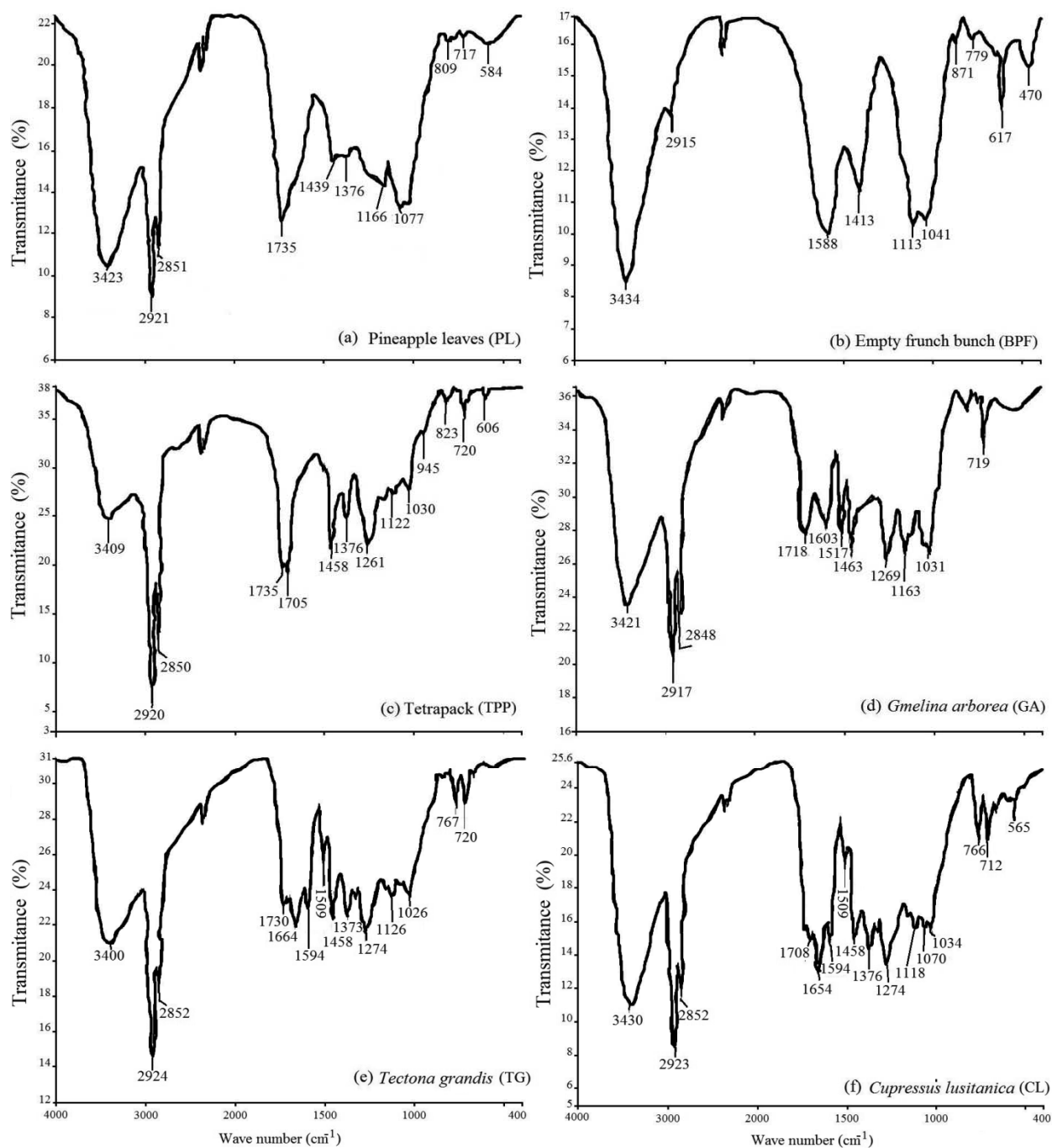
Fig. 1. IR spectra for ethanol-toluene extracts of different lignocellulosic residues.

C. Characterization of extractives

Infrared spectroscopy - FTIR for the water and ethanol-toluene extracts are shown in Figures 1 and 2, respectively, indicating the type of functional groups presented in residues of lignocellulose extracts.

A peak near 3420 cm^{-1} (corresponding to O-H groups) was obtained for all residues. Groups with stretching vibration near 2960 cm^{-1} (corresponding to C-H bond vibration), 1705-1735 cm^{-1} (C=O stretching band), 1240-1375 cm^{-1} (C-H methyl group vibrations), 1150-1300 cm^{-1} (C-O vibrations of alcohol, phenol or esters) and in the proximity of 720 cm^{-1} (corresponding to a C-O bond) were also present in all ethanol-toluene

extracts from residues (Fig. 1), with the exception of EFB (Fig. 1b). C=O groups, possibly from wax, were present in the lignocellulose residues, except for EFB in the ethanol extracts (Fig. 1b). Band at 1755 cm^{-1}, as observed in lignocellulose residues (except for EFB), suggest ester-type carbonyl groups, such as those in waxes or triacyl glycerols. Woods and TPP presented group vibrations between 1450-1460 cm^{-1} (Fig. 1c-1f), PL between 1460 and 1410 cm^{-1} (Fig. 1a), and the BPF stalk in 1440 cm^{-1} (Fig. 1b). These absorptions are associated to aromatic moieties.

The following differences were found between IR analyses of different residues:

(i) (Ethanol-toluene extracts, in BPF do not show vibration around 1603-1654 cm^{-1}. Besides, this residue did not show vibration between 1000 and 1100 cm^{-1}, which can be amide (N-H) groups (Fig. 1b). But amide groups were present in the 3 woods, TPP and PL.

(ii) The woods and PL, TPP and BPF differences were noted in vibrations ranging from 1509 to 1594 cm^{-1} in water extracts, corresponding to aromatic C=O. These groups were solely present in the three types of wood (Fig. 1d-1f).

(iii) Although low vibrations of 809 to 945 cm^{-1} did not show C-H groups in woody species, in contrast to PL (Fig. 1a), BPF (Fig. 1b) and TPP (Fig. 1c); characteristics high at 2900-2800 cm^{-1} corroborated the presence of C-H in these woody species, as well as, PL, BPF and TPP.

(iv) Only BPF and TPP showed vibrations ranging from 1130 to 1180 cm^{-1} (Figs. 2b and 2c), corresponding to C-O groups from alcohols, phenols or esters.

(v) Vibrations between 720 and 900 cm^{-1} appeared in all the woods, TPP and BPF (Fig. 2b-2f) but were not present in PL (Fig. 2a). However, these vibrations are difficult to establish because many vibrational modes that appears in this IR region.

D. Residues comparisons

The comparison of the six types of lignocellulose residues using chemical characteristics (lignin, cellulose, pH, amount of water and amount of extractives using different solvents) by hierarchical clustering multivariate analysis show a similarity between the three wood types, linkage distances were the lowest, less than 22 (Fig. 3a). While BPF residue is also similar to these three types of woods because its linkage distance with woody species was less than PL and TPP. In contrast, TPP residue was slightly different from the woods and BPF (the latter with a large linkage). PL showed the largest differences in comparison to the other studied residues (Fig. 3a). Degree of similarity was determined by evaluating the chemical characteristics. It was found that the ash of extractives using NaOH solution were highly significant for chemical aspects defining similarity (Table 3). Additionally, the humidity content, extractives obtained with water (cold and hot), ethanol-hexane solution, and a dichloromethane solution were less statistically significant (Table 3).

The evaluation of residue similarity with the infrared spectra of water extracts (Fig.3b) indicated a similar grouping than chemical components (Fig. 3a). The woody species extracted in water were closely grouped, having various similarities with BPF extracts (linkage distance being the lowest), followed by TPP extracts and lastly PL extracts, which presented the least similarity with the other residues (. they yielded close linkage distance) (Fig. 3b).

Grouping of residues using the infrared spectra on ethanol-toluene extracts revealed some differences in relation to the aforementioned groupings. BPF stalk was different than the woody species, the latter being grouped amongst similar conditions, but more similar to PL extracts. Moreover, TPP extracts have intermediate characteristics between the group of woods and the one formed by BPF and PL (Fig. 3c).

Table 2. Extractives for different oil palm fruit sections of *Elaeis guineensis*, for *Ananas comosus* leaves, for "Tetra Pak" packages, and for three species growing in plantations.

Extractives percentage	*Elaeis guineensis* (BPF)	*Ananas comosus* (PL)	*Cupressus lusitanica* (CL)	*Gmelina arborea* (GA)	*Tectona grandis* (TG)	"Tetra Pak" package (TPP)
Cold water	13.4^A (1.22)	27.8^B (0.61)	5.9^C (0.17)	7.8^C (0.08)	7.2^C (0.09)	13.0^A (0.41)
Hot water	16.4^A (1.82)	38.3^B (0.75)	7.0^C (0.07)	9.0^C (0.15)	8.5^C (0.44)	13.9^D (0.31)
NaOH at 1%	54.3^A (12.43)	53.8^A (13.14)	24.2^B (0.51)	26.1^B (0.56)	23.8^B (0.12)	25.6^B (0.07)
Ethanol toluene	11.5^A (1.06)	9.4^B (1.08)	3.8^C (0.06)	7.2^D (0.12)	4.6^C (0.14)	5.5^C (0.15)
Ethanol hexane	7.5^A (2.53)	5.7^A (1.66)	5.2^A (0.18)	1.5^B (0.24)	2.2^B (0.15)	0.3^C (0.27)
Dichloromethane	8.4^A (0.78)	3.6^B (0.73)	1.5^C (0.2)	2.2^C (0.12)	2.2^C (0.08)	0.5^D (0.03)
Extractives-free	13.0^A (2.67)	13.7^A (1.95)	10.6^{AB} (0.12)	9.2^B (2.67)	13.7^A (0.94)	0.5^C (0.03)

Note: Averages with equal letters do not present significant differences. Determined at P-value >0.01. The values in parenthesis represent variation coefficients.

Table 3. Significance of chemical characteristics for grouping for three woody species, empty fruit bunch and pineapple leaves using chemical compositions.

Chemical characteristics	Between	df	Within	df	F
pH	4.3	3	1.1	2	2.6
Moisture content	3583.8	3	95.6	2	25.0*
Ash	91.2	3	0.4	2	144.7**
Cellulose	568.0	3	28.3	2	13.4
Lignin	322.5	3	239.5	2	0.9
Extractives in cool water	308.5	3	20.4	2	10.1*
Extractives in hot water	668.9	3	17.8	2	25.0*
Extractives in NaOH at 1%	1131.9	3	2.9	2	257.8**
Extractives in ethanol toluene	40.8	3	3.5	2	7.8
Extractives in ethanol hexane	37.5	3	1.8	2	13.5*
Extractives in dichloromethane	37.4	3	1.9	2	12.9*
Extractives- free	37.5	3	90.1	2	0.3

Legend: * Statistically significant for α=0.05. ** Statistically significant for α=0.01.
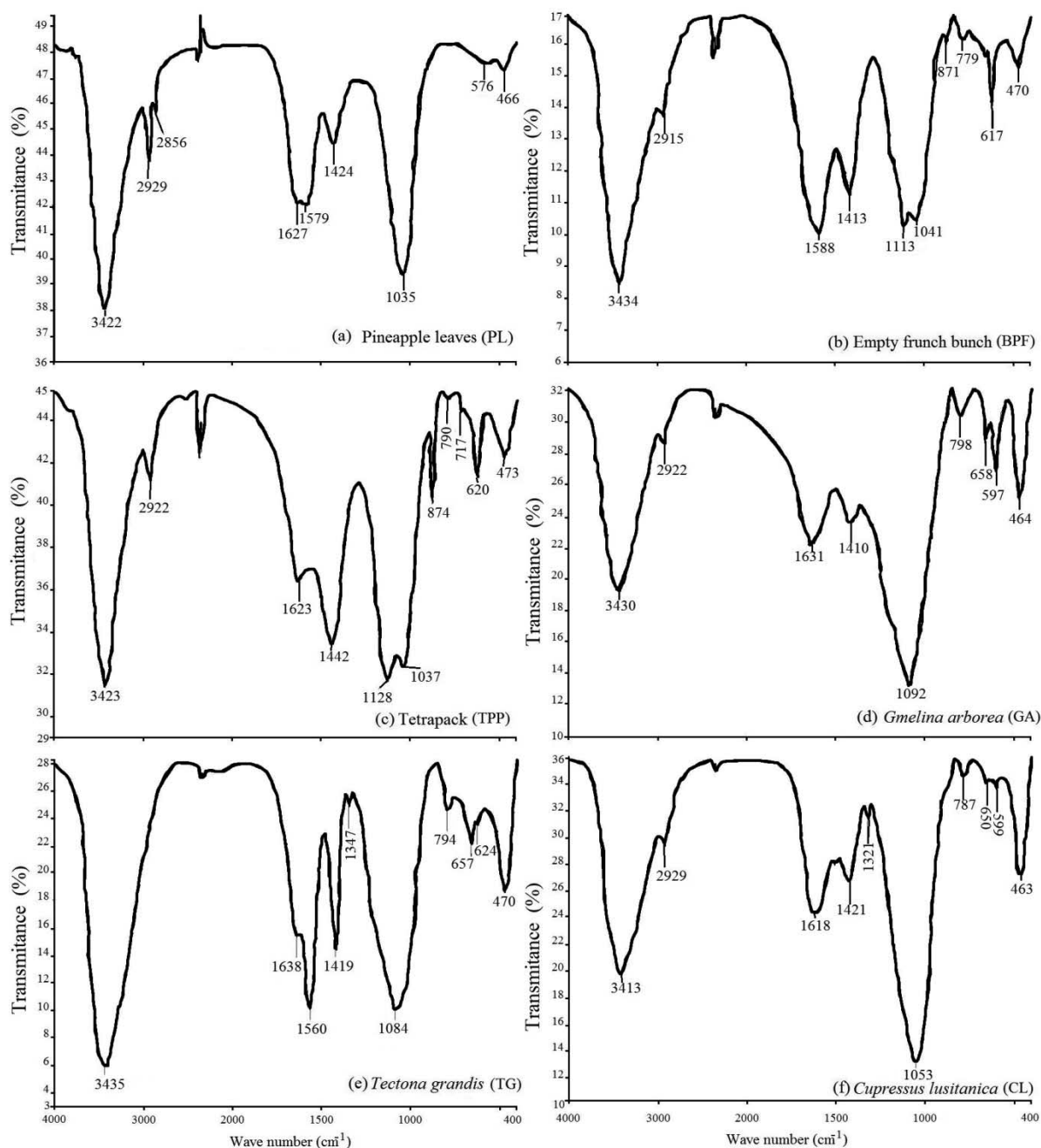
Fig. 2. IR spectra of extracts in water for three woody species, empty fruit bunch and pineapple leaves.

IV. DISCUSSION

Low pH levels on PL affect negatively some types of adhesiveswhen used as residues to manufacture particleboards. Adhesives are formulated for pH neutral materials (Xing *et al.*, 2006; Halvarsson *et al.*, 2010). Residues with low pH levels may affect curing time, by accelerating or retarding the curing process for the adhesive (Xing *et al.*, 2004). However, there are alternatives to solve the low pH problem; by adding a pH buffer when particles are being bonded (Xing *et al.*, 2004), or by treating particles with acid or alkaline substances (Munawar *et al.*, 2008).

The amount of water contained in PL may negatively affect its possible use in particleboards. In such products, an MC lower to 10% is necessary (Xing *et al.*, 2006), resulting in high energetic consumption when the material is being dried (Moya and Tenorio, 2012). Nevertheless, there are other options of mechanical nature, such as the use of mills with centrifuges, which may be implemented to dry pineapple residues, aiming at improving the efficiency in water elimination (Moya and Tenorio, 2012; Wong, 2007). BPF residue has the advantage of having a lower MC than woods commonly used in particleboards.

The ash quantity contained in both agricultural residues is higher than that in the woody residues, as these plants contain deposits of microfossils or phytolithis (Halvarsson *et al.*, 2010). High ash content has a negative effect on production processes abdon particleboards both physical and mechanical performance (Halvarsson

et al., 2010). Velázquez *et al*. (2003), mentions that when ash content is less than 1.5% it does not affect the physical and mechanical properties of particleboards made from *Miscanthus sinensis*.

Cellulose and lignin content determine the properties of future materials that may be manufactured from materials presenting a high content of these polymers (Lopes and Felisberti, 2006; John and Thomas, 2008). Particularly, in particleboards these contents determine the degree of particle cohesion and the products' mechanical performance (Westin *et al*., 2000). High structural performance in particleboards may be obtained with TPP residue due to the purification degree that this product has while manufacturing packaging material (Korkmaz *et al*., 2009). TPP and BPF residues present high lignin content but slightly less than woody species commonly used to manufacture particleboards. Pineapple has the disadvantage of having low lignin content, which may result in low structural performance of these types of products.

The amount of lignin in some derived products may have negative effects, such as the high energy consumption required in case of extracting cellulose, as in pulping processes (John and Thomas, 2008). Nonetheless, in products requiring high performance for mechanical stress such as particleboards, for example, lignin confers rigidness, resistance and protection to fibers (Saheb and Job, 1999). As mentioned previously, lignin content values for TPP should be treated with caution since this value may also contain aluminum or other aggregate polymers during packaging manufacture (Korkmaz *et al*., 2009).

Extractives are non-structural or secondary components made of many lignocelluloses materials, in which a great number and variety of components may be found (Tamaki and Mazza, 2010). The effect of extractives in lignocellulosic material has become more prominent in the last years, because lignocellulose residues are a natural source of energy or source of raw material (Reddy and Yang, 2005). Moreover, the extractives percentage present in different lignocellulose residues has different effects depending on their prospective uses, being important to know their effects (Trianoski *et al*., 2011). For example, Chen *et al*. (2007) and Thammasouk *et al*. (1997) affirm that water and ethanol extractives from different lignocellulose materials may be composed of non-structural sugars, organic acids, organic material, nitrogenous material, greases and other minor compounds. Those extractives, dissolved in the aforementioned solvents; do not allow part of the lignin precipitate when using lignocellulose residues in ethanol production. These authors concluded that extractives from these kinds of residues need to be removed to attain higher efficiency. In the present study it was also found that it is necessary to eliminate the extractives, either a portion or all, for stalk or pineapple with high contents of extractives.

Specifically, tests performed with some lignocellulosic residues in the present study evidenced that mixing them does not result in producing boards with suitable properties (Moya *et al*., 2013, 2014). For example, Onuorah (2005) found that, when different wood species are combined with palm oil plant residues, boards get lower mechanical resistance values without evidencing the reason for this. It could be assumed that the low resistance found by the author could be due to the amount and type of extractives present in each of the lignocellulosic residues, which determine residue compatibility; thus affecting board performance. Nevertheless, some practices have been implemented to improve residue performance in board production. For instance, Laemsak and Okuma (2000) and Munawar *et al*. (2008) have improved performance of particleboards in different lignocellulose residue types by giving particles a pre-treatment with vaporization and explosion.

Treatments to diminish extractives effects in lignocellulose materials are based mainly on adding some kind of substance to improve the compatibility of present materials when residues are used for manufacturing particleboards, (García *et al*., 2011). For example, Halvarsson *et al*. (2009) found that in order to diminish extractives' effects on wheat straw, particles must be treated with iron chloride and hydrogen peroxide, therefore improving physical and mechanical properties of particleboards made with this lignocellulose material. Furthermore, Han *et al*. (1998) improved structural performance of particleboards using reed and wheat straw, with silane matrix as coupling agent.

The grouping results of the different residues once more confirm that woody species have similar chemical components in terms of quantity and quality (Fig. 3). In fact, chemical composition analysis (Table 1) and percentage of extractives with different solvents (Table 2) revealed few differences in the three wood types. This finding shows that fine structural and physical conditions in particleboards can be achieved by using a combination of these woods for their manufacture.

With respect to BPF and TPP, chemical composition (Fig. 3a) and infrared spectra of water and ethanol-toluene extracts are slightly different to the woods. This result may be influenced by humidity, ash content and amount of extracts that can be dissolved in a sodium hydroxide solution (Table 3). PL residue presented less compatibility with the several wood types, differing in most chemical components (Table 1) and extractives that may be extracted with aqueous solutions (Fig. 1 and 2).

Particleboard production has focused on raw material coming from woody species and in some other cases these boards have been constructed with wood blends. However, the increasing demand of forest conservation, irregularities in wood production and pressure to use lignocellulose residues from agricultural activities, favor other non-wood residue types in the process of particleboard (Kalia *et al*., 2009). Nevertheless, extractives' chemical composition results (Table 3) have shown that potential inclusion of BPF stalk or PL present high contents of different extractives and in a certain manner are
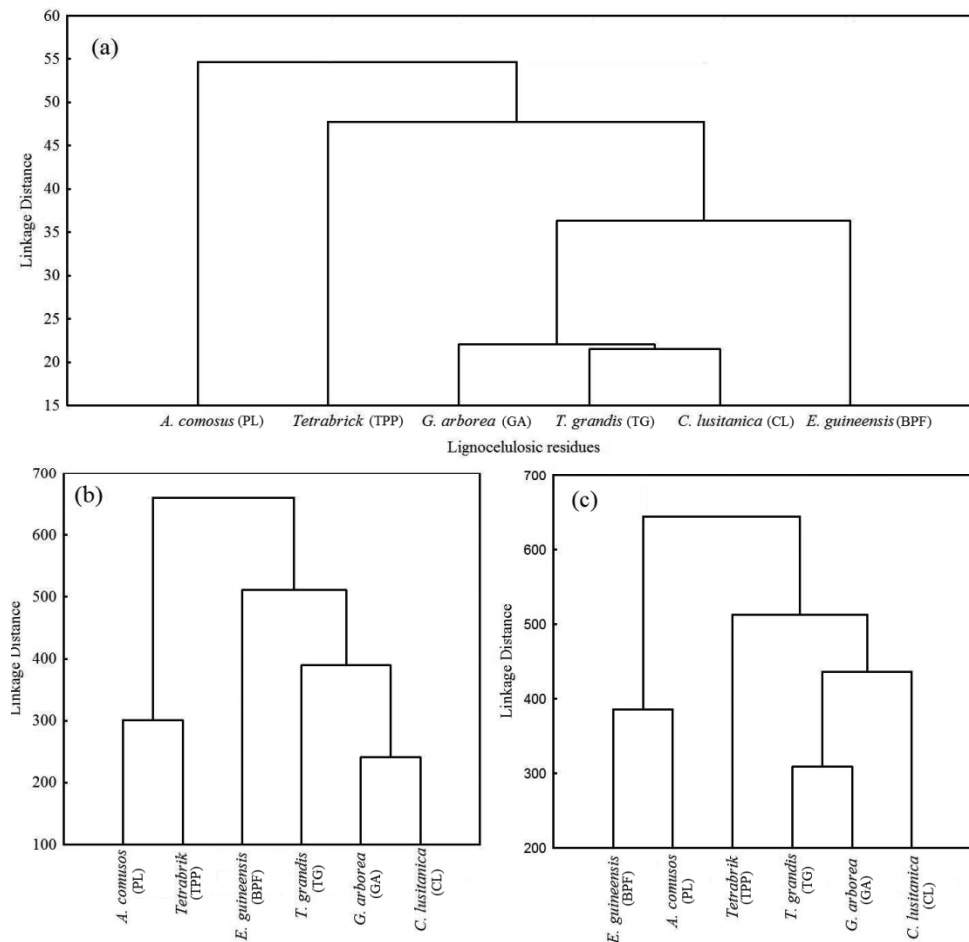
Fig. 3. Tree grouping for three woody species, empty fruit bunch and pineapple leaves. (a) Using chemical characteristics, (b) Using IR spectra of extracted in water and (c) Using IR spectra of extracted in ethanol-toluene solution.

slightly different to the woods (Fig. 3), which may affect compatibility when mixing some of the woods utilized and extractives coming from oil palm and pineapple leaves.

On the other hand, industrial TPP residue offers great advantages in relation to agro-forestal residues; it possesses low amount of dissolved extractives in all implemented solvents. Moreover, this residue is lightly acid (pH=4-5), which gives it great potential to manufacture particleboards using blends with another type of lignocellulose residue, and presents similarity with all studied residues (Fig. 3).

V. CONCLUSIONS
Chemical composition and extractives in PL are different to the composition of GA, TG and CL woods, to BPF stalk and TPP. The main differences are related to: its low pH level; initial high humidity; ash content; low lignin content; extractives dissolved in water, ethanol-toluene and dichloromethane. In addition, some extractives composition detected in IR spectroscopy differ since several compounds are not present in the woody species, BPF and PL.

Grouping results of residues confirm once more that woody species have similar quantity and quality of chemical components. Meanwhile, BPF stalk and TPP are slightly different to wood, as found in similarity comparison with woods using chemical composition and infrared spectra of water and ethanol-toluene extracts.

Consequently, particleboards manufactured with mixtures of these lignocellulose residues can differ with mixing proportions, especially with PL. On the other hand, woody species are similar to oil palm fruit bunch and TPP. The similarity of these agricultural materials could permit the mixing of wood and oil palm fruit bunch and TPP. However, although there is chemical compatibility between these materials, further studies on mechanical compatibility on real particleboards are necessary.

Although TPP present polyethylene and aluminum layers, the performance between this residues and woody species was not affected. Mechanical properties of mixtures between those residues in particleboards presented excellent compatibility with the woody species (Moya *et al*., 2013 and 2014).

REFERENCES

ASTM, *Standard test methods for direct moisture content measurement of mood and wood-base materials*, ASTM D 4442–03, **04.10**, American Society for Testing and Materials, Philadelphia, PA, USA (2003a).

ASTM, *Standard test method for ash in wood*, ASTM D1102-84, **04.10**, American Society for Testing and Materials, Philadelphia, PA, USA (2003b).

ASTM, *Standard test methods for water solubility of wood,* ASTM D1110-84, **11.06**, American Society for Testing and Materials, Philadelphia, PA, USA (2003c).

ASTM, *Standard test method for 1% sodium hydroxide solubility of wood*, ASTM D1109-96, **11.06**, American Society for Testing and Materials, Philadelphia, PA, USA (2003d).

ASTM, *Standard test method for ethanol-toluene solubility of wood*, ASTM D1107-96, **11.06**, American Society for Testing and Materials, Philadelphia, PA, USA (2003e).

ASTM, *Standard test method for dichloromethane solubles in wood*, ASTM D1108-96, **11.06**, American Society for Testing and Materials, Philadelphia, PA, USA (2003f).

ASTM, *Standard Test Method for Preparation of Extractive−Free Wood*, ASTM D 1105–96, **04.10**, American Society for Testing and Materials, Philadelphia, PA, USA (2003g).

Bertsch, F., "El recurso de la tierra en Costa Rica," *Agron. Costarricense*, **30**, 133-156 (2006).

Chen, S.F., R.A. Mowery, C.J. Scarlata and C.K. Chambliss "Compositional analysis of water-soluble materials in corn stover," *J. Agric. Food Chem.*, **55**, 5912–5918 (2007).

García, T., J. Andréu, T. Ferránndez, M. Ferránndez and C.E. Ferránndez, "Evaluation of the physical and mechanical properties of particleboard made from giant reed (*Arundo donax* L.)," *BioResources*, **6**, 477-486 (2011).

Halvarsson, S., H. Edlund and M. Norgrena, "Manufacture of non-resin wheat straw fiberboards," *Ind. Crop. Prod.*, **29**, 437–445 (2009).

Halvarsson, S., H. Edlund and M. Norgren, "Wheat straw as raw material for manufacture of medium density fiberboard (MDF)," *BioResources*, **5**, 1215-1231 (2010).

Han, G., C. Zhang, D. Zhang, K. Umemura and S. Kawaim, "Upgrading of urea formaldehyde-bonded reed and wheat straw particleboards using silane coupling agents," *J. Wood Sci.*, **44**, 282-286 (1998).

Hashim, R., N. Saari, O. Sulaiman, T. Sugimoto, M. Hiziroglu and R. Tanaka, "Effect of particle geometry on the properties of binderless particleboard manufactured from oil palm trunk," *J. Mat. Design,* **31**, 4251-4257 (2010).

James, W., "Life-cycle inventory of particleboard in terms of resources, emissions, energy and carbon," *Wood Fiber Sci.*, **42**, 90–106 (2010).

John, M.J. and S. Thomas, "Review: Biofibres and biocomposites," *Carbohyd. Polym.*, **71**, 343–364 (2008).

Kissinger, M. and M.K. Rees, "Exporting natural capital: the foreign eco-footprint on Costa Rica and implications for sustainability," *Environ. Dev. Sust.*, **12**, 547-560 (2010).

Korkmaz, A., J. Yanik, M. Brebu and C. Vasile, "Pyrolysis of the tetra pack," *Waste Manag.*, **29**, 2836–2841 (2009).

Kalia, S., B.S. Kaith and I. Kaur, "Pretreatments of natural fibers and their application as reinforcing material in polymer composites—A review," *Polym. Eng. Sci.*, **49**, 1253–1272 (2009).

Laemsak, N. and M. Okuma, "Development of boards made from oil palm fruit for properties of binderless boards from steam-exploded fibers of oil palm frond," *J. Wood Sci.*, **46**, 322-326 (2000).

Lopes, C.M.A and M.I. Felisberti, "Composite of low-density polyethylene and aluminum obtained from the recycling of postconsumer aseptic packaging," *J. Appl. Polym. Sci.*, **101**, 3183–3191 (2006).

Moore, W. and D. Johnson, *Procedures for the chemical analysis of wood and wood products,* Research Paper FLP, Forest Service, Forest Products Laboratory, Madison, WI (1967).

Moya, R., D. Camacho, J. Mata and R. Soto, "Fungal decay, coating, burning properties and change of color of particleboards manufactured with woody biomass, agricultural wastes and tetra pack residues," *J. Biomaterials Nanobiotech.*, **4,** 334-342 (2013).

Moya, R., D. Camacho, G. Oporto, R. Soto and J. Mata, "Physical, mechanical and hydration kinetics of particleboards manufactured with woody biomass (*Cupressus lusitanica*, *Gmelina arborea* and *Tectona grandis*), agricultural resources and tetra pak packages," *Waste Manag. Res.*, **32,** 106-114 (2014).

Moya, R. and F. Muñoz, "Physical and mechanical properties of eight species from fast-growth plantation in Costa Rica," *J. Trop. For. Sci.*, **22**, 317-328 (2010).

Moya, R. and C. Tenorio, "Evaluation of different methods proposal for the drying of lignocelluloses residues," *BioRecources*, **7**, 3500-3514 (2012).

Munawar, S.S., K. Umemura, F. Tanaka and S. Kawai, "Effects of alkali, mild steam, and chitosan treatments on the properties of pineapple, ramie, and sansevieria fiber bundles," *J. Wood Sci.*, **54**, 28–35 (2008).

Onuorah, E.O., "Properties of fiberboards made from oil palm (*Elaeis guineensis*) and/or mixed tropical hardwood sawmill residues," *J. Trop. For. Sci.*, **17**, 497-507 (2005).

Reddy, N and Y. Yang, "Biofibers from agricultural by-products for industrial applications," *TRENDS in Biotechnol.*, **23**, 22-27 (2005).

Saheb, N.D. and J.P. Jod, "Natural fiber polymer composited: a review," *Adv. Poly. Tech.*, **18**, 351-363 (1999).

Seifert, K., "Zur frage der Cellulose-Schnellbestimmung nach der Acetylaceton-Methode," *Papier*, **14**, 104–106 (1960).

Tamaki, Y. and G. Mazza, "Measurement of structural carbohydrates, lignins, and micro-components of straw and shives: Effects of extractives, particle size and crop species," *Ind. Crop. Prod.*, **31**, 534–541 (2010).

Tappi, *Standard test for acid–insoluble lignin in wood and pulp* TAPPI T 222 om-02 revised 2002, Parkway South Norcross, US (2002).

Thammasouk, K., D. Tandjo and M.H. Penner, "Influence of extractives on the analysis of herbaceous biomass," *J. Agric. Food Chem.,* **45**, 437–443 (1997).

Trianoski, R., S. Iwakiri and J.L.M. De Matos, "potential uses in fish feeds: the Costa Rica situation," *Waste Manag.*, **24**, 87-97 (2004).

Potential use of planted fast-growing species for particleboard," *J. Trop. For. Sci.*, **23**, 311-317 (2011).

Ulloa, J.B., J.H. Weerd, E.A. Huisman and J.A.J. Verreth, "Tropical agricultural residues and their Velásquez, J.A., F. Ferrando, X. Farriol and J. Salvadó, "Binderless fiberboard from steam exploded *Miscanthus sinensis*," *Wood Sci. Tech.*, **37**, 269-278 (2003).

Westin, M., R. Simonson and B. Östman, "Kraft lignin wood fiberboards – The effect of kraft lignin addition to wood chips or board pulp prior to fiberboard production," *Eur. J. Wood and Wood Prod.*, **58**, 393-400 (2000).

Wong, J. "Drying technology of pineapple leaf fiber," *J. Anhui Agri. Sci.*, **29**, 123-135, (2007).

Xing, C., S.Y. Zhang and J. Deng, "Effect of wood acidity and catalyst on UF resin gel time," *Holzforschung*, **58**, 408–412 (2004).

Xing C., S.Y. Zhang, J. Deng and A. Cloutier, "Medium-density fiberboard performance as affected by wood fiber acidity, bulk density, and size distribution," *Wood Sci Tech.*, **40**, 637–646 (2006).