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# Chemical analyses of lignocellulosic materials residue for cement panels reinforcement

P.F.P. Ferraz[1,*], R.F. Mendes[2], G.A.S. Ferraz[1], G. Rossi[3], L. Conti[3] and M. Barbari[3]

[1]Federal University of Lavras, Department of Agricultural Engineering, Campus Universitário, PO Box 3037, Lavras, Minas Gerais, Brazil
[2]Federal University of Lavras, Department of Engineering, Campus Universitário, PO Box 3037, Lavras, Minas Gerais, Brazil
[3]University of Firenze, Department of Agriculture, Food, Environment and Forestry (DAGRI), Via San Bonaventura 13, IT50145 Firenze, Italy
[*]Correspondence: patricia.ponciano@ufla.br

**Abstract.** The use of lignocellulosic material residue in cement composites is on the rise as sustainable building materials in most developing countries. Besides, this alternative is seen as a good option for new cement panels formulations for indoor applications. Thus, the current paper aims to evaluate de chemical properties of five potential lignocellulosic materials residues to be used for cement panels reinforcement: Eucalyptus, sugarcane bagasse, coconut fibre, coffee rusk, and banana pseudostem. The following physical properties of the lignocellulosic materials were evaluated: lignin, extractives, ash, and holocellulose. To evaluate the similarity of the chemical composition of the lignocellulosic materials, Hierarchical Cluster Analysis (HCA) was used identified by using Ward's method of cluster analysis. These compositions were grouped by dendrograms in which the similarity of these data was qualified. It was observed that there were statistical differences among all types of lignocellulosic materials related to the chemical composition. Coconut showed the smallest amount of extractives, and sugar cane the most significant amount. Eucalyptus and coffee husk presented the most similar chemical composition. All of the evaluated materials could be used in fibre cement production for indoor applications.

**Key words:** cementitious composites, chemical properties, dendrograms, hierarchical cluster analysis.

## INTRODUCTION

The use of residues lignocellulosic materials as cement-based reinforcement is on the rise as sustainable building materials in most developing countries (Sudin & Swamy, 2006; Teixeira et al., 2018). Many studies have been focused on the use of natural materials in buildings materials since these materials present high sustainability (Conti et al., 2017). Besides, the residues lignocellulosic materials can be abundant in the environment in many parts of the world and relatively inexpensive (Castro et al., 2019).

The lignocellulosic residues can be considered as potential alternatives for rural and civil buildings, given their ecological friendliness and ready availability in fibrous form and also, since they can be extracted from plant leaves at low cost, in the most of cases (Silva et al., 2008). The engineering design of rural and civil buildings must take the availability of the local materials into account, encouraging wherever possible the use of natural materials that can be regenerated (Bambi et al., 2019).

The use of lignocellulosic material residues to produce cement composites to be used in building constructions is considered as a good option for new lignocellulosic cement formulations. However, one of the challenges for the production of cementitious composites reinforced with lignocellulosic materials is reinforcement/matrix interaction (Teixeira et al., 2018). Thus, to use adequately, the lignocellulosic materials is mandatory to know the chemical composition of these materials. The chemical concentrations may influence the cement composites' mechanical properties, the bond behaviour, and degradation of natural fibres in composites components (Onuaguluchi & Banthia, 2016).

To compare the difference of chemical composition of the lignocellulosic residues, techniques of Hierarchical cluster analysis (HCA) can be used. HCA, also known as hierarchical clustering, is a popular method for cluster analysis in big data research and data mining, aiming to establish a hierarchy of clusters (Muntaner et al., 2012). HCA attempts to group subjects with similar features into clusters (Ferraz et al., 2019).

Thus, this paper aimed to evaluate the chemical properties of lignocellulosic materials residue to produce cement panels using agglomerative hierarchical clustering.

## MATERIAL AND METHODS

The experiment was developed at the Federal University of Lavras (UFLA), Lavras, Brazil. To evaluate the chemical properties of five potential lignocellulosic materials residues to be used for cement panels reinforcement a sample of the following materials were collected: sugarcane bagasse (*Saccharum officinarum*), eucalyptus (*Eucalyptus grandis*), banana pseudostem (*Musa acuminata*), coconut shell (*Cocos nucifera*) and coffee husk (*Coffea arabica* L.).

Eucalyptus wood tree and banana pseudostem were obtained from local experimental cultivations at Federal University of Lavras - UFLA. Sugar cane was obtained in a commercial cachaça distillery for the production of sugar-cane liquor (cachaça) in Lavras - Minas Gerais state (MG), Brazil. The coconut shell was taken from local floriculture in Lavras - MG, Brazil. Coffee husk was obtained from a farm in the municipality of Santo Antônio do Amparo - MG, Brazil.

Eucalyptus and sugar cane passed through a laminator for delaminating. Coconut shell, coffee husk, and banana pseudostem were processed in a hammer-mill. The material particles were selected through a sieve, and the fraction retained between 20 (0.841 mm) and 40 (0.420 mm) mesh was used to the experimental chemical analyses as established in the NBR 14853 (2010) Standards.

Panels were produced following the methodology suggested by Latorraca (2000), and Lopes (2004), and described by Mendes et al. (2017).

To evaluate the chemical properties of the lignocellulosic materials to produce cement panels, the following analyses were carried out: lignin, total extractives, ash, and holocellulose.

Holocellulose content was calculated by extracting lignin with sodium chlorite and acetic acid, according to the procedure reported in Browning (1963). Total extractive content was measured as established in the NBR 14853 (2010) Standards.

The insoluble lignin content was measured according to the NBR 7989 (2010) Standards. An oven was used to obtain the mineral content of ashes, according to the NBR 13999 (2017) Standards.

The data of chemical properties lignocellulosic materials analysis was performed using Hierarchical cluster analysis (HCA). The basic idea of this technique is to put in the same group objects that are similar according to some predetermined criterion (Linden, 2009). Within each cluster, the objects are similar to each other, while objects located in other clusters are different from one another (Dominick et al., 2012). The results of the HCA method were described using a dendrogram, which is a similarity diagram, quantified using Ward's method and Euclidean distance, described by Ferraz at al., (2014).

According to Dominick et al. (2012), the Euclidian distance (DE) is described by Eq. 1:

$$DE = \left[\left(\frac{Dlink}{Dmax} \times 100\right)\right] \tag{1}$$

where *Dlink* is the connection or linkage distance, and *Dmax* is the maximum distance. To standardize the bond distance represented by the y-axis, the ratio is usually multiplied by 100.

As the initial cluster, the Ward method considers individuals who provide the lowest sum of squares of deviations (Melo Júnior et al., 2006).

The HAC analysis and the dendrograms of the chemical properties were performed using the statistical computer system R (R Development Core Team, 2019), and the cophenetic correlation coefficient fit was also estimated using the same software.

Internal bonding (IB) analyzes were performed according to the American Society for Testing and Material - ASTM D1037 (2016).

## RESULTS AND DISCUSSION

Fig. 1 indicates de chemical composition of the lignocellulosic materials evaluated. It is possible to observe that there is a big variation in the chemical composition of the lignocellulosic materials. According to Onuaguluchi & Banthia (2016), the concentrations of the chemical components in a raw material depend on factors such as fibre type, growth condition, dimension, age, cultivation site, extraction, and processing method. Besides, the amount of these components (lignin, total extractives, ash, and holocellulose) can affect the properties of the cement composite reinforced with these materials. Chemical composition of lignocellulosic materials can affect the mechanical properties of the panels (Onuaguluchi & Banthia, 2016).

To evaluate the chemical properties of the lignocellulosic materials, the agglomerative hierarchical clustering (HCA) was used. HCA separates the lignocellulosic materials into groups, based on the characteristics of their chemical composition. These materials are separated using classification criteria in such a way that there is homogeneity within the group and heterogeneity between the groups. The results of the HCA method were described using dendrograms (Fig. 2, a, b, c, and d), which is a similarity diagram, quantified using Ward's method and Euclidean distance. Fig. 2 shows the chemical composition of every evaluated lignocellulosic residue materials hierarchically clustered separated a) lignin (%), b) total extractives (%), c) ash (%), d) holocellulose (%). In the dendrogram, the level of similarity is indicated on the horizontal scale, and the evaluated lignocellulosic materials are represented on the vertical axis in convenient order for grouping. The horizontal axis displays the distance between observations and/or clusters. The horizontal bars indicate the point at which two clusters/observations are merged. It means that smaller values of the horizontal axis indicate more similarity between the groups.

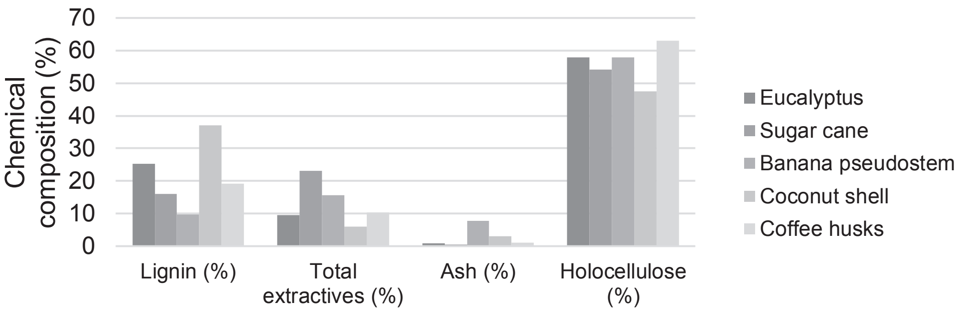


**Figure 1.** Chemical composition of the lignocellulosic materials: a) lignin (%), b) total extractives (%), c) ash (%), d) holocellulose (%) of eucalyptus, sugar cane, banana pseudostem, coconut shell and coffee husk.

In Fig. 2, a is evident that sugar cane and coffee husks presented a similar amount of lignin. It is indicated because the distance scale (horizontal axis) is closer to 0. Sugar cane and coffee husk presented a similar amount of lignin, 16.0%, and 19.2%, respectively. The distance scale of the other materials presented bigger values, which indicates that they are not similar. It means that coconut shell, sugar cane, and eucalyptus presented statistical differences related to the amount of lignin in their composition. Eucalyptus presented a smaller amount of lignin (9.7%).

Fig. 2, b shows the groups formed based on the total extractives composition. This Figure indicates that eucalyptus and coffee husk are in the same group of similarity, with a scale distance of 0.1. Both materials presented an intermediate amount of total extractives (9.5 and 10.3% for eucalyptus and coffee husk, respectively). Coconut shell is the material with the smaller amount of total extractives (5.9%). Sugar cane and banana pseudostem presented the bigger dissimilarity, and they presented the bigger values of the scale distance in comparison with the other materials (> 1.8).

According to Angles et al. (1997) the ash fraction is formed by most of the inorganic substances present in the native substrate. All the materials presented a similar amount of ash, around (1%, Fig. 1, c), except banana pseudostem that presented 7.8%. In Fig. 2, c, it is possible to observe that banana pseudostem presented the bigger dissimilarity in comparison with the other materials. Banana pseudostem showed a scale distance of the other materials bigger than 2.0, while the other materials presented the distance scale smaller than 0.5. It indicates that coffee husk, eucalyptus, and sugar cane can be part of the same group because they have a similar amount of ash, with a distance scale smaller than 0.2. While coconut shell is alone in a different group (distance scale of 0.5) and banana pseudostem is the lignocellulosic material most different than the others with a distance scale bigger than 2.0.

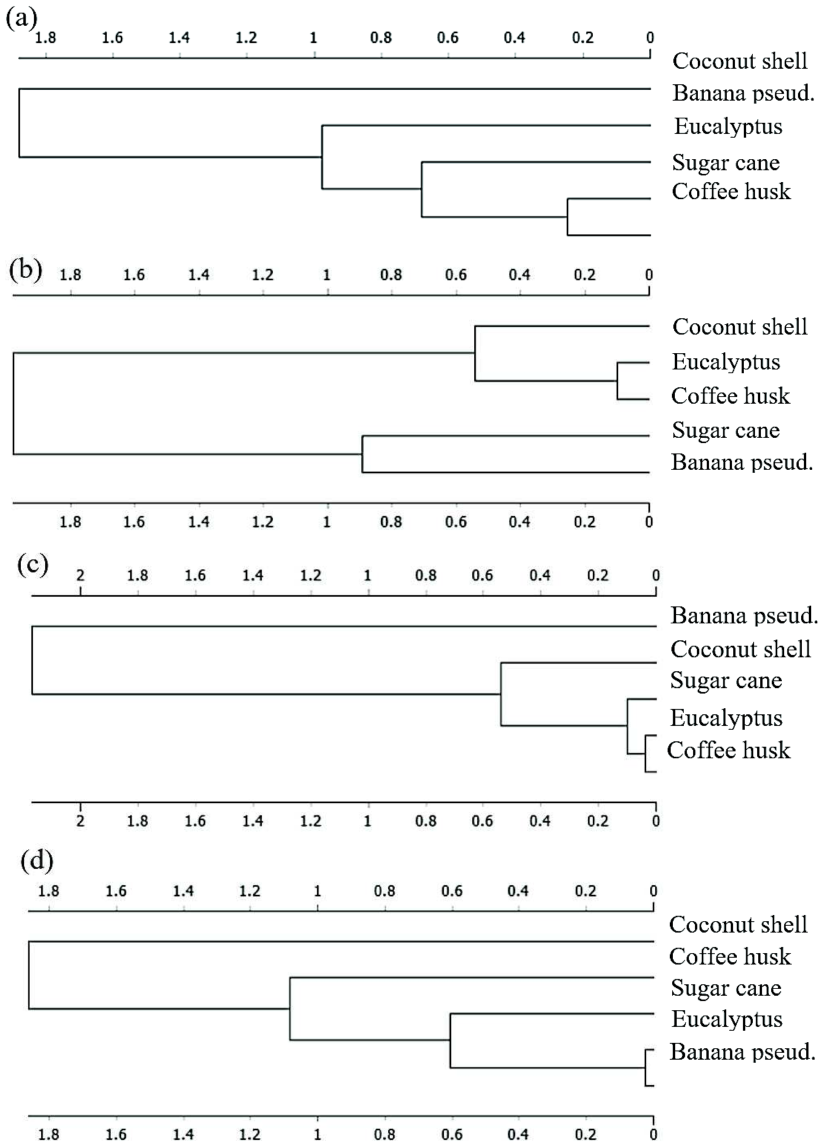


**Figure 2.** Dendrograms of the chemical properties of lignocellulosic materials: a) Lignin (%), b) total extractives (%), c) ash (%), d) holocellulose (%) of eucalyptus, sugar cane, banana pseudostem, coconut shell and coffee husk.

Based on the amount of holocellulose (Fig. 2, d) eucalyptus and banana pseudostem presented a similar amount of this element, around 58%, which means that they are in the same group. The other materials presented dissimilarities concerning the amount of holocellulose. It means that there is a significant variation in the composition of holocellulose of these materials. According to Fig. 1, coffee husk presented the biggest amount of holocellulose of the evaluated materials. Holocellulose has a significant influence on the cement composite properties. This chemical component can be one of the responsible for the mechanical resistance of the composites (Teixeira et al. (2018).

While in Fig. 2 is possible to see the lignocellulosic materials grouped based on each chemical component separately, In Fig. 3, the lignocellulosic materials are grouped based on all chemical components at the same time. Based on Fig. 3, it is possible to observe that none of the evaluated material presented a similar chemical composition. The materials that presented the most similar chemical composition were eucalyptus and coffee husk. These materials presented the smaller values of the distance scale. Eucalyptus and coffee husk presented intermediate values of lignin, total extractives, and ash. However, on the other hand, coconut shell was the material that presented the most different composition concerning the other evaluated materials. It can be explained because the coconut shell showed the biggest amount of lignin and the smaller values of total extractives and holocellulose.

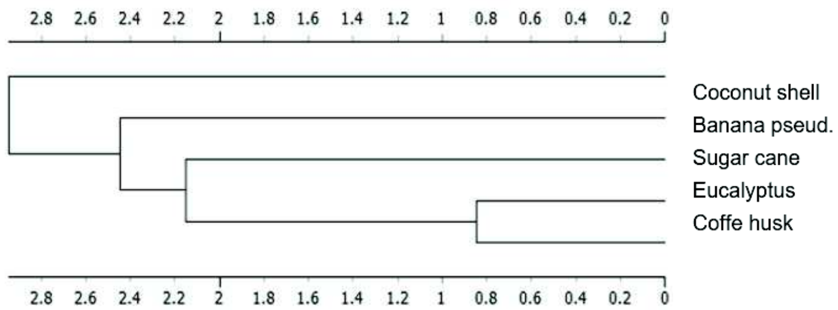


**Figure 3.** Dendrograms of the chemical properties of lignocellulosic materials.

Internal bonding (IB) is related to the transmission of the stress that occurs between lignocellulosic and cement particles, which is affected by factors such as the content of extractives, interaction between particle and cement matrix, and cement matrix and particle dimensions (Mendes et al., 2017).

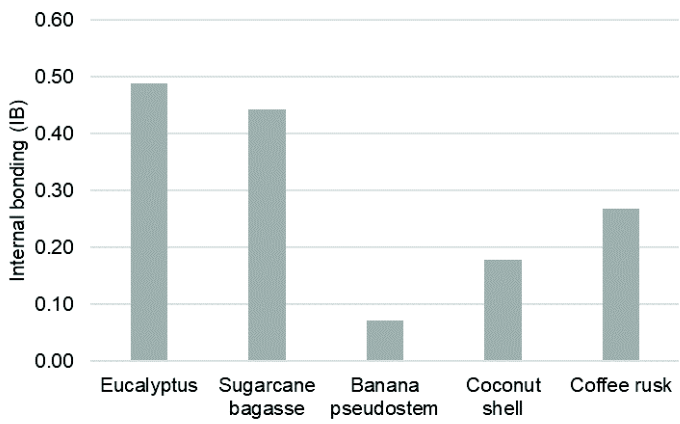


**Figure 4.** Internal bonding (IB) of the lignocellulosic composites.

Fig. 4 shows that the chemical content of the lignocellulosic materials affected the mechanical properties of composites. The Eucalyptus composites can be highlighted because they presented the best results of internal bonding (IB). This higher IB may be related to the lower extractives content (Fig. 1), which may affect the cement cure and to prejudice the interaction of the lignocellulosic particles with the cement matrix (Mendes et al., 2017).

Panels with banana pseudostem presented the lower values of IB. Despite not having the highest amount of extracts, banana pseudostem presented low values of lignin, which affects the fiber union and, consequently, the mechanical resistance of the material used in the production of cement-based panels (Asasutjarit et al., 2009). In general, the lower values of resistance to the IB are related to the small adhesion of matrix fiber in the composite (Kochova et al., 2020).

## CONCLUSION

It was possible to investigate the chemical properties of the five potential lignocellulosic materials residues to be used for cement panels reinforcement using Hierarchical Cluster Analysis.

According to the results of the current work, eucalyptus and coffee husk presented the most similar chemical composition. These materials presented the smaller values of the distance scale. Eucalyptus and coffee husk presented intermediate values of lignin, total extractives, and ash.

The coconut shell was the material that presented the most different composition concerning the other evaluated materials. It can be explained because the coconut shell showed the biggest amount of lignin and the smaller values of total extractives and holocellulose.

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