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CHARACTERIZATION OF ANATOMICAL, CHEMICAL, AND BIODEGRADABLE PROPERTIES OF FIBERS FROM CORN, WHEAT, AND RICE RESIDUES

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ABSTRACT

Anatomical, chemical, and biodegradation properties of fibers from wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and corn (*Zea mays* L.) plant residues and from rice hull were characterized to generate scientific and technical knowledge to support decision making regarding their use. The anatomical and chemical properties were determined following standard procedures. The degree of biodeterioration was analyzed from growth of white rot fungus *Pleurotus ostreatus* (Jaq.) Quél. in 30 d under favorable conditions. Afterwards, weight loss was evaluated for each residue. Three replicates were used, plus a control of radiata pine (*Pinus radiata* D. Don) woodchips. The greatest proportion of α-cellulose was found in residues of rice plants (45.1%), with a high amount of extractable (non-structural components, that confer organoleptic characteristics), followed by rice hull (22.78%), which is explained by the presence of silica in their cells. Ash content was higher in wheat residues, reaching up to 18.34%. Anatomical characteristics were studied to corroborate potential use in industrial processes. Fiber length and wall thickness were similar to those of latifoliate wood fibers, although possibly less resistant because of lower lignification. The largest weight loss was from rice plant (32%), followed by rice hull (27%), and corn plants (26.6%). The most resistant was wheat plant (15.8%). All these materials had greater weight losses than the control sample (3.8%). Thus, given their anatomical and chemical properties, the use of plant residue fibers in industrial processes is technically possible, though with concern about their biodegradability.

Key words: agriculture fibers, biodeterioration, crop residues, *Pleurotus ostreatus*, white rot.

INTRODUCTION

There has been increasing interest in recent years in the use of lignocellulosic matter (together with matter originating from forestry, agriculture and urban life). The use and application of these materials has gained attention in important areas such as generating animal feed, producing particle boards, obtaining biocompounds and chemical and energy products, among others. Potentially they could be sources of renewable energy that partially or totally substitute fossil fuels (Barba, 2000). Lignocellulose is used directly to obtain secondary energy products through processes of pyrolysis, gasification or catalytic steam-reforming, chemical or enzymatic hydrolysis and ethanol fermentation. These are products of low added value that are profitable owing to the cost of conventional fuels.

Obtaining polymeric fractions and chemical derivatives is highly important in terms of utilizing residues from forests and crops, as well as industrial wood, mainly polymers composed of lignocellulosic matter; cellulose, lignin and hemicellulose that are separated by fractioning and subsequently purified to be used individually. A wide range of added value products can be obtained from these fractions, such as cellulose for textiles, food or pharmaceuticals, fibers, paper production, wood panels, lignin derivatives used as adhesives and hemicellulosic derivatives such as xylose, mannose or furfural (Barba, 2000).

Wood has traditionally been the most widely used lignocellulosic matter in the production of pulp, furniture and boards of diverse types, as well as being a source for energy (FAO, 1973). Increasing demand for these raw materials, together with economic and environmental factors, makes it necessary to research alternative sources of lignocellulosic matter (Garay, 2002a; 2002b).

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Each year 11 million hectares of forestland is lost globally, which is equivalent to the loss of one hectare every 4 seconds. Among the reasons for this decline are notably the production of wood for industrial and fuel uses and deforestation because of the expansion of pastures, croplands and urban development (Departamento de Medio Ambiente, Gobierno de Aragón, 2000). Globally forests are estimated to cover 3.87 billion hectares, 95% of which are natural forests and the remaining 5% are planted forests. Tropical deforestation and degradation of forests in many parts of the world are negatively affecting the availability of forestry goods and services. While forest areas have stabilized in developed countries and overall has experienced a slight increase, deforestation continues in developing countries (FAO, 2001).

Residues are mainly the stems or stalks of cereal plants such as wheat, corn or rice, left after harvesting the grain. In the case of wheat (*Triticum aestivum* L.) residues are an important source of fibrous biomass after harvest. The United States produces approximately 10 million tons annually. Residues can be converted into paper, particleboards, fuel and other products (Fiber Futures, 2007). Rice residue (*Oryza sativa* L.) is the major source of agricultural residue fiber in the world and is particularly important in the development of Asian countries. It can be converted into a variety of useful products, including paper and construction materials. The main obstacle in the clean processing of rice is its high silica content (FAO, 1973; Potivarai, 2005; Fiber Futures, 2007). New technologies may soon overcome this obstacle. Corn (*Zea mays* L.) is the major source of agricultural residues in the United States, with more than 250 million tons per year. The fiber lends itself to paper production and many studies have been undertaken to investigate the commercial use of this fiber (Fiber Futures, 2007).

Fields are cleared after harvest by burning residues, which causes severe air pollution. For example, 200 thousand hectares of rice produces 1.5 million tons of residues that are traditionally burned in fields in California, which in turn generates 50 thousand tons of carbon monoxide every year. The harmful effects of this practice to human health are evident. On the other hand, the quantity of wheat residues available in the United States exceeds 100 million metric tons per year, sufficient to fully supply the production of medium density particleboard (Davis, 2001).

Wheat, corn and rice producers confront the same problem, namely what to do with residues. Silva and Acevedo (2005) provide harvest indices (ratios between harvested biomass and total biomass) of 0.46 for corn and 0.42 for wheat. Residues can be collected and sold for animal feed, but such markets are often unprofitable for producers (Klee *et al*., 2000). Residues can be incorporated into the soil, but the process can cost US$ 16 to 20 per hectare (Fiber Futures, 2007). They can also be left in the field to reduce erosion and provide nutrients for beneficial microbes in the soil. However, this can also favor organisms that cause diseases and could destroy the harvest in the following year. In fact, the additional labor costs for preparing the soil and the threat of diseases are the main motives for rice producers in California to burn their fields after harvest, although burning is increasingly prohibited except in cases of infected fields. This activity has a major impact on air quality. The quantity of residues produced each year is enormous. In California alone, the annual rice and wheat harvests respectively generate more than 300 and 400 thousand tons of residues (Davis and Dhingra, 2001; Fiber Futures, 2007).

In Thailand and many other Asian countries, where rice harvesting is concentrated, burn-off of rice residues is common. This practice emits large quantities of contaminants into the air and can have serious effects on air quality, public health and the climate (Xinwu Xu *et al.*, 2004).

Rice and wheat residues are good sources of cellulose as a base for obtaining resistant and biodegradable fibers that can replace wood fiber or plastic derived from petroleum. Many products can be developed using pulping processes to obtain fibers and produce compounds that mix fibers with other plastic or inorganic materials (Xinwu Xu *et al*., 2004; Boonlert, 2005). Since 1973 there have been references to the use of diverse types of fibers for production of cellulose and panels, among the most important being wheat and bagasse (*Ambelania acida* Aubl.) China (Lee *et al*., 2004), which represent at least 50% of cellulose production in these Asian countries. Bagasse and flax (*Linum usitatissimum* L.) are cited as important raw materials for panel industries (FAO, 1973).

There is increasing demand for biodegradable products and experts estimate that renewable resources will be incorporated into 10% of production in the United States by 2020 and 50% by 2050. Increased use of agricultural fibers is a way to offer consumers more options of environmentally friendly products (Fiber Futures, 2007).

Table 1 shows the chemical compositions of rice and cereal residues and compares them to those of latifoliate wood.

Cellulose is the main component responsible for the structure and rigidity in particleboard. The cellulose content is slightly lower in plant residue than in wood. The type of hemicellulose in plant residue is less pure than that of wood. Lignin is the natural cementing agent that holds material together. For certain construction materials, the chemical components must be removed through a refining process.

Table 1. Chemical composition of cereal and rice straw.

Type	Cereal	Rice	Latifoliate
		%	
Cellulose	45-55	43-49	57
Hemicellulose	26-32	23-28	23
Lignin	16-21	12-16	25
Ash	2-9	15-20	1
Silica	2-8	9-14	0.5

Source: Fiber Future, 2007.

The main difference, which is also a disadvantage in some industrial processes, is that rice residue and hulls have higher silica content than wood does. This means that particleboards made from residues more resistant to cutting and results in greater wear on cutting tools. This factor should be considered in the context of the costs of removing residues from agricultural fields.

Among the main uses of rice hulls that are being studied are notably as an energy source and diverse industrial applications of silica such as the ceramic industry. Numerous investigations have been conducted in Japan and India on possible uses of rice hulls and residues. It is estimated that annual global rice production is 550 million tons, close to 20% of this is rice hull, that is to say, 100 million tons. In Thailand alone around 4 million tons of rice hull is generated annually. These figures encourage interest in research, as well as environmental and political considerations (Wada, 2005).

Hetz *et al*. (2006) analyzed the quantities of wheat residues and estimated the quantities of residue left after harvesting that could be gathered with a baler. The quantities of residue fluctuated between 1.6 and 5.1 t ha^{-1}, and the total left in the field averaged 6.4 t ha^{-1}. This is projected as a total for the country of 2.7 million tons.

The most important crop in Chile is wheat, with 420 thousand ha planted per year. Corn production occupies 135 thousand ha and rice production covers 25 thousand ha (INE, 2006). Cultivation of these crops is rising owing to the increasing need to provide food for the country and the world (Calderón, 2008). There have been studies of using stubble for energy (FAO 1973; 2001), and as a compliment to animal feed (Manterola *et al.,* 1999).

Rice had the highest increase of cereals in the 2005-2006 agricultural season, with 37.2% annual variation and an average output of 5.73 t ha^{-1}, a record figure that represents a 22.7% increase over the 2004-2005 season. 78% of national rice production is concentrated in the Maule Region and specifically in Linares Province (INE, 2006).

The objective of this work was to characterize the anatomical, physical, chemical and biodegradable properties of four types of residues, of wheat corn and rice plants and rice hulls, with the aim of generating information to facilitate the incorporation of residual material in industrial processes.

MATERIALS AND METHODS

Raw materials

Agricultural plant residues remaining after harvests were used. The residues were from rice plants (PA) and rice hulls (CA) obtained from the area of San Javier, Maule Region, Chile; wheat plant residues (PT) obtained from the Southern Campus of the Universidad de Chile, La Pintana Commune, Metropolitan Region, and corn plant residues (PM) obtained near Llallauquén, Libertador General Bernardo O'Higgins Region. Pine radiata (*Pinus radiata* D. Don) wood chips were used as a control (MA).

Anatomical characterization of the fibers

Maceration. The material was macerated using the Franklin method (Normand, 1972). The pieces of fiber were cut with a scalpel and placed in test tubes in a solution of 1:1 acetic acid and oxygenated water of 30 volumes. The samples were dried in a stove at 60 ºC for approximately 1 week. The disaggregated particles were washed in water, stained with aqueous safranin at 1% for 3 min, dehydrated with alcohol at 96% and xylol. Subsequently, the fibers were dried, placed on slides and fixed with Canada balsam.

Biometric measurements. The length, total diameter and wall thickness of the fibers were measured in the macerations with a reticulated eyepiece and classified according to the List of Microscope Features for Hardwood Identification (IAWA Committee, 1989). Twenty-five length-wise measurements were made according to the following ranges: ≤ 900, 900-1600 and ≥ 1600 µm. Fifteen fiber diameters were measured per species and wall thickness was determined according to the following categories: very thin-walled fibers, thin-walled to thick-walled fibers and very thick-walled fibers. Observation of the cellular components of each fiber was made with a binocular optical microscope (Intraco Micro, model 9707556, Prague, Czech Republic) with an integrated video camera (GKB mod. CC8306, Prague, Czech Republic) connected to a Compaq Presario 4814 computer (New York, USA). Digital images were obtained with a digital camera (Olympus C-700 Ultra zoom camera, Tokyo, Japan).

Chemical composition of the fibers

TAPPI methods (Technical Association of the Pulp and Paper Industry, 1999) were used for determining chemical composition. Firstly, samples representative of the fibers were submitted to granulometry according to established norms. To do this, residue samples were ground (Model L40, Thomas-Wiley, Mexico City, Mexico), then sieved, separating the material that passed through filter No. 40 and was retained by filter No. 60. The components that did not form part of the cell walls, termed the non-structural components, were then determined. To determine the inorganic compounds (ashes) three aliquots of 4 to 7 g of ground and sieved material from corn and wheat stubble were placed in 30 mL previously tared porcelain crucibles and calcinated in an oven (ProLabo, Pyrolabo model, Paris, France) gradually increasing the temperature until 580-600 ºC for 4 h to reach complete oxidation. The crucibles were placed in a stove at 103 ± 2 ºC and then cooled in a vacuum desiccator. After cooling, the samples were weighed with an analytical scale (model JK-180, Chyo, Tokyo, Japan), expressing the residues (ashes) as a percentage of anhydrous fiber.

A second aliquot of ground and sieved material was used to determine the organic fraction, termed extractables, of the soluble fibers in neutral solvents by extracting them in Soxhlet extractor, using three solvent systems separately and sequentially: an ethanol-toluene mixture in a 2:1 ratio; etilic alcohol at 95% and distilled water, with an approximate velocity of four siphonings per hour for 4 h. Completing the extraction period, the excess solvent was removed by filtering in a kitazato flask, and continued with the following solvent until the removal of extractables was complete. These were determined by concentration of the extracts obtained from each solvent in a rotavapor at low temperature and pressure. Subsequently, the concentrated extract was dried in aluminum plates in a stove at 103 ± 2 ºC. The sum of anhydrous mass of the residues obtained in each extract, the extractables, was expressed as a percentage of total extractables in relations to the initial anhydrous mass.

Of the structural components, holocellulose was determined in four aliquots of each fiber free from extractables, treated in acetic acid and sodium chlorite for 1 h in precipitated 250 mL vessels in a thermal bath at 70 º C. The oxidated residues were filtered with a No. 1 porous plate that had previously been tared, exercising a mild suction with a vacuum pump, washed with warm distilled water and then cold water to remove excess chlorine and acid. The samples were placed in a stove to dry holocellulose residue, which is expressed in percentage of the initial anhydrous mass free of extractables.

To determine α-cellulose, the residues of holocellulose for each fiber were used, which were treated with a sodium hydroxide solution (17.5 ± 0.1%) to remove the less crystallized fractions of polysaccharides and then were filtered with porous plate that had previously been tared, placed in a kitazato flask and with the aid of a vacuum pump the residue resistant to the alkaline treatment was washed with a 100 mL solution of sodium hydroxide (8.3%), and then with acetic acid (10%) to eliminate excess alkali.

Finally, lignin was determined in two aliquots of material free of extractables of 1 g of each fiber. They were treated in precipitation vessels with 15 mL of sulfuric acid at 72% for 2 h at room temperature and subsequently the solution was diluted at 3% with distilled water until a volume of 560 mL and treated for 20 to 30 min in an autoclave at 120 ºC. When the hydrolysis of the polysaccharides was completed, the solid residue was recovered in a previously weighed porous plate filter, dried to the anhydrous weight in a stove and then cooled in a desiccator and finally weighed in an analytic scale, expressing the weight of the anhydrous residue as a percentage of the original anhydrous mass free of extractables.

Biodeterioration study

Fungus is used to evaluate the degree of biodeterioration of a species. In this case, the white rot fungus *Pleurotus ostreatus* (Jaq.) Quél., which was obtained from the micoteca of the Biodeterioration and Preservation Laboratory of the Wood Engineering Department, Faculty of Forestry Sciences, Universidad de Chile, Santiago. Other materials used were agar at 2%, malt extract at 3%, 500 mL flasks, precipitation vessels, combed cotton, tweezers, burners, Litmus paper (0-14), alcohol at 98% purity, autoclave, incubation chamber, laminar flow hood and a microscope. The fiber samples were chopped and dried and the initial mass was registered. The culture medium was prepared with agar-malt for the nutrition of the fungus, at 2 and 3%, conditioned at pH 5.5. The flasks were sterilized in an autoclave at saturated steam pressure at 1.05 kg cm^{-2} and 120 ºC for 20 min, after which they were placed in the culture chamber at 25 ºC for 7 days to obtain fungal growth. The inoculation was carried out in a laminar flow hood**.** Once the fungus was developed, the fibers were incorporated into the procedure. Fungal growth was registered on average twice a week under controlled conditions at 25 ºC for 32 days in an incubation chamber. Finally, the weight loss of the fibers was determined.

Experimental design and statistical analysis

The experimental design established as a treatment that each residue (rice, corn and wheat plants and rice hull) was submitted to action by white rot fungus. The statistical design was bifactorial of fixed completely randomized effects, which evaluated the residues and compared them to wood for the variable of weight loss provoked by fungal action.

The experimental design is described in the following model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij}$$

where, Y_{ij} is the variable response of weight loss, μ is the global mean, α_i is the factor of the type of residue ($i = 5$), β_j is the factor type of fungus ($j = 1$), $\alpha\beta_{ij}$ are the effects of the combinations of previous factors on the global mean μ, and ε_{ij} is the component of random error associated with factors of divergence among the assays.

A variance analysis was made to establish the influence of each factor and the differences were quantified through the Duncan test ($p \leq 0.05$). For the analysis of chemical and anatomical properties, the determination of the mean and standard deviation of the determined values were considered.

RESULTS AND DISCUSSION

Anatomic characterization

The fiber lengths obtained in this study were similar to those of latifoliate fibers (Table 2), according to the categories of the IAWA Committee (1989). Corn plant residues presented the greatest average fiber length (1.63 mm), very similar to species such as oak (*Nothofagus obliqua* (Mirb.) Blume) and rauli beech (*Nothofagus alpina* (Poepp. & Endl. Oerst.)), whose fiber lengths vary between 0.30 and 1.10 mm; olivillo (*Aextoxicon punctatum* (Ruiz et Pav.)), with 0.70 to 2.00 mm (Díaz-Vaz, 2003), and *Eucalyptus globulus* Labill., with 0.93 to 1.17 mm (Saavedra, 2004). The residues of rice plants and hulls and wheat plants had fiber lengths that fluctuated between 0.59 and 0.85 mm.

The thickness of the fiber walls (Table 2) was similar to those of hardwoods fibers. According to these results, the sample fibers are classified as thin to thick-walled fibers (IAWA Committee, 1989). Corn plant residues and rice hull presented the thickest cellular walls (2.0 to 2.2 µm), which is similar to those found in fibers of *E. globulus* (2.38 to 2.94 µm; Saavedra, 2004). The cellular elements, fibers and vessels observed in the macerations are shown in Figure 1 (a-h).

Chemical composition

In general terms at the level of the structural components of lignocellulosic wall of the fibers, the chemical composition is similar to that of wood, with percentages of α-cellulose, lignin and holocellulose within the usual ranges obtained (Table 3). Higher values were obtained for lignin than those observed by other authors (Wood, 2002), 22.86% was found in wheat straw, while Ballesteros *et al*. (2004) found only 16.7%. This difference could be attributed in part to the fact that the two studies did not use the same methods. There were no significant differences in total polysaccharides and cellulose from the values determined by other authors.

An important difference was observed at the level of the non-structural components, particularly in the percentage of ashes, where the fibers showed higher values (6.47 to 18.34%) than those normally found in angiosperm species from temperate zones (0.2 to 0.9%). This result concurs with those obtained by other authors with rice straw and other agricultural residues (Fiber Futures, 2007) and in sorghum bagassse (4.8%) and wheat straw (11.3%) (Ballesteros *et al.,* 2004). This is important in milling these materials, given that their high silica content makes them abrasive for the blades of cutting instruments. As well, in relation to using these raw materials as fuels, a high percentage of ashes has the double effect of lowering calorific power and, depending on the nature of the material, can cause the "syntherization" or fusion of the same to the grill and tubes of the combustion chamber, causing problems of encrustation.

Extractables are also higher. Nevertheless, it is possible to find wood with similar values to those obtained. This does not present problems in combustion given its organic nature, and depending on the type of compound, this can contribute to greater or lesser susceptibility to the biodeterioration of these materials.

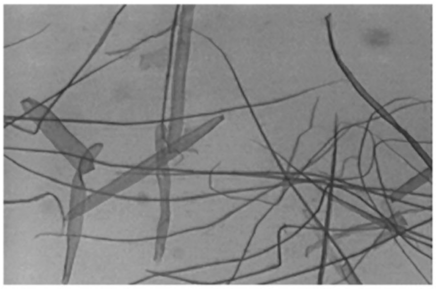
Biodeterioration study

All the fibers were affected by the fungus, but the rice plant residues were the most susceptible to

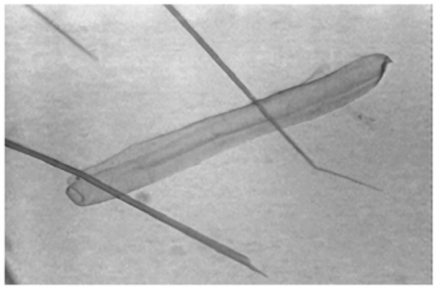
Table 2. Length of the fibers and fiber cell wall diameter and thickness.

Sample	Length	Range		Lumen diameter	Wall thickness
	mm	mm	µm	µm	µm
Corn residues	1.52 ± 0.491	0.900 - 1.600	8.4	4.4	2.0
Rice residues	0.663 ± 0.239	≤ 0.900	4.9	1.9	1.5
Rice hulls	0.594 ± 0.262	≤ 0.900	6.7	2.4	2.2
Wheat residues	0.851 ± 0.166	≤ 0.900	9.9	6.8	1.6

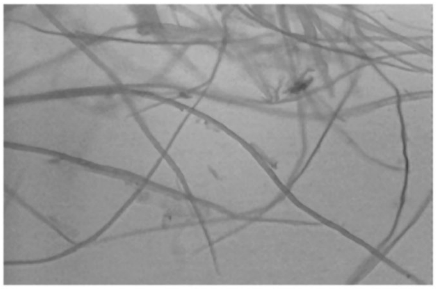
± Standard deviation.



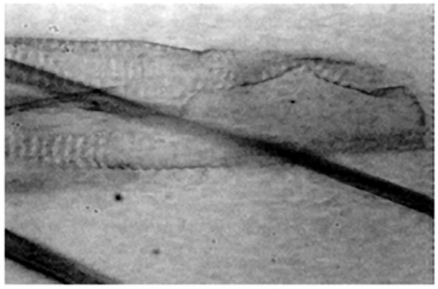
a) Fibers and vessels in residues of corn plants (100x).



b) Vessel in residue of corn plants (400x).

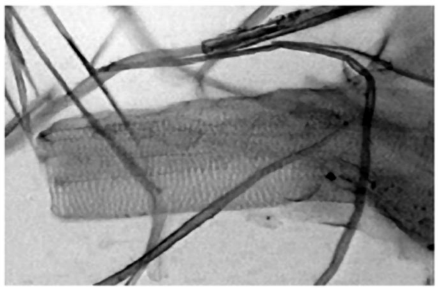


c) Fibers in residues of rice plants (100x).

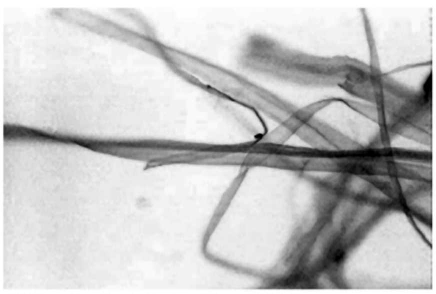


d) Vessel in residues of rice plants (400x).

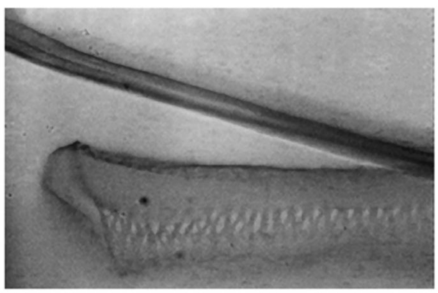
e) Fibers in rice hull residues (100x).



f) Vessel in rice hull residues (400x).



g) Fibers in wheat plant residues (100x).



h) Vessel in wheat plant residues (400x).

Figure 1. Anatomical characteristics of the fibers.

biodeterioration under the established conditions of humidity and temperature. The second most susceptible was rice hull, then corn plant residues and finally wheat plant residues (Table 4).

The variance analysis indicated that there is a statistical difference of 95% of confidence for the evaluated weight loss. According to the Duncan test, the weight loss of all the studied fibers was higher than that of the pine radiata woodchips, among these fibers, the most resistant to degradation came from wheat plants, while the most susceptible came from rice plants (Figure 2).

Garay *et al*. (2000) used the loss of mechanical properties to evaluate the lignivorous action of white rot the fungus *Ceriporiopsis subvermispora* (Pilát) Gilb.

Table 3. Fiber chemical composition.

Identification	Ashes (inorganic)	Total extractables	α-Cellulose	Lignin	
	%				
Corn residues	6.5	14.7	41.2	18.3	78.4
Rice residues	14.8	10.9	45.1	23.4	84.0
Wheat residues	18.3	6.3	35.2	22.9	79.2
Rice hulls	14.91	22.78	41.29	37.01	71.8
Wood[1] (angiosperm)	0.2-0.6	2-15	40-45	18-22	74-80

[1]General values for hardwoods (angiosperms), taken from USDA Forest Service (1974) Res. FPL-091.

& Ryvarden to facilitate wood softening. Mechanical determinations were made of flexure, compression and shear, as well as chemical determinations of cellulose, lignin, hemicellulose and extractables. The results confirm that this fungus causes physical and mechanical deterioration to the wood, with loss of resistance, static flexure, dynamic and parallel compression, as well as 43.4% decrease in cellulose in the control and 24.8% in the wood with fungus, which is expected given that the fungus attacks the chemical components of the wood, mainly the lignin, but also continues attacking cellulose. At the level of the internal structure, the microfibrils are affected because the cellulose chain has lost part of the lignin that maintains the molecular structure (Rodríguez, 1998). Based on the results of fiber deterioration in this work, it can be assumed that weight loss leads to chemical modifications and this in turn changes the mechanical properties of the fibers, such that the greater the weight loss, the lower the mechanical resistance of the fibers.

Méndez (2003) found that weight loss in wood of *E. globulus* by the fungus *Pleurotus ostreatus* was higher in lower density woods, 0.56 to 0.75 g cm^{-3}, at 40, 60 and 80% humidity. At 80% humidity, the weight loss was ~3% and 4% for the other humidity levels evaluated, after 45 days of damage. Méndez (2003) used a solid piece of 1 x 3 x 0.5 cm, while fibers and woodchips were studied in this study. Less aggregation facilitates fungal action. The present results indicate an important weight loss in the fibers (32% in rice plant residues). All the samples evaluated presented higher levels of weight loss than those of the woodchips, which for their part presented values similar to those of Méndez (2003). If this weight loss is associated with the chemical composition of the fiber, cellulose loss can be deduced.

Gálvez (2001) studied the chemical composition of wood from *P. radiata* affected by *P. ostreatus*, at 40 days the α-cellulose in the control was 40.59%, and 37.52% in the affected wood. Weight loss indicates that irreversible chemical modifications in the wood had been produced. Because the chemical composition determined for the

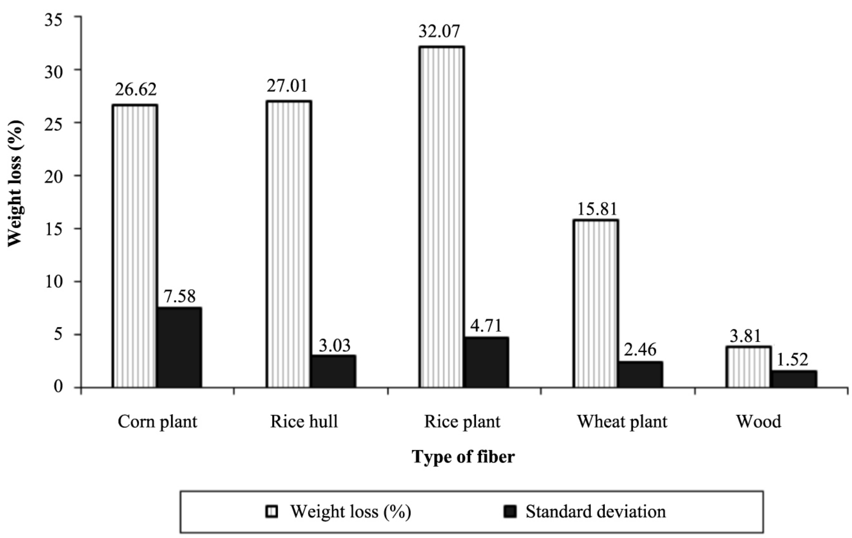


Figure 2. Fiber weight loss during incubation (32 days at 25 ºC).

Table 4. Observations in biodegradation in incubation (25 ºC for 32 days).

Observation number	Day	Observations
1	4	Fungal growth reached 75% of the rice hull residue substrate and ~50% in the other residue substrates. There were no appreciable signs of damage in the control. No contaminating agent was observed.
2	6	Fungal growth was observed in 100% of the rice hull substrate, in 85% of the corn residue substrate and in 50% of the other two substrates. There were no appreciable signs of damage in the control. No contaminating agent was observed.
3	8	The fungus reached 90 to 95% of the substrate of the corn plant residue. Similar fungal growth was observed with the other substrates, reaching 70% of each substrate. There were no appreciable signs of damage in the control. No contaminating agent was observed.
4	11	Fungal growth was observed in 80% of the wheat residue. The fungus grew in 100% of the other substrates. There were no appreciable signs of damage in the control. No contaminating agent was observed.
5	15	The fungus grew to 90% of the wheat residue. By this date there was growth in 100% of the other substrates. There were no appreciable signs of damage in the control. No contaminating agent was observed.
6	19	Fungal growth reached 100% of the wheat plant residue. A slight invasion of hyphae was observed in the control, appearing as small dark spots. No contaminating agent was observed.
7	22	The fungus continued growing on the substrates, most notably on corn and rice residues. An increase in the diameter of the spots in the control was observed. No contaminating agent was observed.
8	26	The fungus continued growing, most notably with rice plant residue. There was an incipient proliferation of hyphae on the surface of the control. No contaminating agent was observed.
9	30	All the substrates had hyphae on the surfaces; the invasion was more intense in rice and corn residue than in residue of rice hull and wheat and light in the control. No contaminating agent was observed.
10	32	There was a major effect of fungus in corn fiber, which presented an increase in fungal volume compared to the other fibers. Fungal attack was observed in the control, but less severe than in the residues. No contaminating agent was observed.

fibers was similar to that of the wood, it is possible to compare the results between the weight loss of rice and wheat plant residues. Rice plant residues presented 45.1% of α-cellulose and those of wheat presented 35.2% (Table 4), which indicates a greater effect on rice plant residues owing to its greater availability of α-cellulose for the fungus. An additional fact is that rice hulls contain approximately 20% of silica, which should be considered when selecting the tools for chopping and/or milling (Boonlert, 2005).

The study of biodeterioration seeks to establish the magnitude of the damage that a rot fungus can cause to fiber. This allows for taking the necessary for protecting fibers and establishing the requisites for adequate collection and storage.

García de Cortázar *et al*. (2003) made a field evaluation of a predictive model of the effect of temperature and humidity on the decomposition of wheat stubble and found that the temperature to which the stubble was subjected had a significant effect on the quantity of decomposed material in the first, second and third month of the study. Humidity only caused differences in stubble decomposition between the driest and the other treatments.

Apart from the aspects of biodeterioration and chemical composition, the dimensions of the fibers are a significant factor for the yields of the process and the mechanical resistance properties of the products obtained. Thus, anatomical study provides information for comparing the characteristics of these fibers to those of wood more commonly used in Chile.

CONCLUSIONS

Greater damage was observed by the test fungus on the studied agricultural fibers than on the control sample of wood shavings. The rice plant residues presented the highest weight loss (32%), followed by rice hulls (27%) and corn plant residues (26.6%). The most resistant material was wheat plant residue (15.8%), although the materials had higher weight loss than the control (3.8%).

According to the basic chemical composition determined, the studied fibers can be used as replacements of or as complement to wood in pulp and paper and construction board production. Likewise, the fibers presented similar morphological and biometric characteristics to those of latifoliate fibers, which also support their incorporation into production processes.

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RESUMEN

Caracterización de propiedades anatómicas, químicas y de biodegradación de fibras provenientes de residuos de maíz, trigo y arroz. Se caracterizaron las propiedades anatómicas, químicas y biodegradación de fibras de residuos de plantas de trigo (*Triticum aestivum* L.), plantas de arroz (*Oryza sativa* L.), plantas de maíz (*Zea mays* L.), y cáscara de arroz, con el objetivo de generar información y tomar decisiones de uso con bases científicas y tecnológicas. Las propiedades anatómicas y químicas se determinaron utilizando procedimientos estándares. El biodeterioro se estudió analizando el crecimiento del hongo de pudrición blanca *Pleurotus ostreatus* (Jaq.) Quél. durante 30 días bajo condiciones favorables; y la consiguiente pérdida de peso de cada residuo. Con tres repeticiones, más testigo de viruta de *Pinus radiata* D. Don. Mayor proporción de α-celulosa se encontró en arroz (45,1%), con alta cantidad de extraíbles (compuestos no estructurales que aportan características organolépticas) seguido por cáscara de arroz (22,78%), que posee sílice en sus células; el contenido de cenizas fue mayor en trigo (18,34%). Las características anatómicas corroboran las posibilidades de uso en procesos industriales, pues poseen longitud y espesor de pared similar a las fibras de maderas latifoliadas, aunque posiblemente menos resistentes por su menor lignificación. Las plantas de arroz presentaron mayor pérdida de peso (32%), seguida de cáscara de arroz (27%) y plantas de maíz (26,6%); las más resistentes fueron las plantas de trigo (15,8%). Todos los materiales tuvieron pérdidas de peso mayores que la madera (3,8%). Entonces, dada sus propiedades anatómicas y químicas, es técnicamente posible su empleo en procesos industriales, aunque se debe cautelar la biodegradación.

Palabras clave: biodeterioro, fibras agrícolas, residuos agrícolas, *Pleurotus ostreatus*, pudrición blanca.

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