Crystallinity and Chemical Structure of Amazon Wood Species in a Log Yard After Natural Degradation

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The objective of this work was to evaluate whether the chemical composition of wood and its crystallinity can help in the analysis of degradation by fungi and insects in logs of Amazonian wood species stored in a stockyard. For this study, wood from five commercial species that had been stored in an open yard for six months was used. The scale of degradation by fungi and insects, the moisture content of the logs, the total extractive content, lignin, holocellulose and the crystallinity were evaluated. It was concluded that the position of the logs in the stacks, associated with the storage time, influenced the evaluated characteristics. It was also observed that X-ray diffraction has potential for analysis of the degradation by fungi and insects in logs of Amazonian species stored in the stockyard.

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INTRODUCTION

Losses in timber industries in the Amazon can reach up to 60% due to lack of post-harvesting care, transport, and storage (Abreu *et al.* 2002). When the logs arrive at the industrial yard, a portion of them has already been sufficiently degraded by the action of xylophagous organisms. This loss is directly reflected in the final productivity of the companies, as it leads to the rejection of a large part of the material because it does not meet the ideal quality characteristics for processing the logs.

The main wood degradation agents can be classified according to their origin, which can be biotic or abiotic. Biologically, fungi and insects of biotic origin are the main organisms that deteriorate wood, causing losses in the timber industry (Vivian *et al.* 2014). According to Silva (2018), wood processing industries suffer considerable economic losses from biodeterioration, such as boreholes, that reduce log yield or color changes caused by staining fungi in wood for export.

According to Ampessan *et al.* (2015), the duration of wood storage in yards is determined by the demand for raw material and logistics. When it comes to the Amazon region, the reality is different from other regions of Brazil.

The issue of logistics for the extraction, transport, and processing of logs is one of the main obstacles to their use, considering that the transport of logs in some regions is mostly via river, and the transportation by land faces poor condition of the roads. As a result, the logs of various species of commercial interest end up being stored for much longer in yards located within the forests or even in areas that do not have the proper planning to receive this material.

Some authors have already conducted works that evaluated the quality of the wood regarding the degradation of xylophagous organisms of different species in stockyards (Abreu *et al.* 2002; Hanada *et al*. 2003). However, it appears that the numbers of works with Amazonian species related to this theme is very low, with most research focusing on wood from species of the *Pinus* and *Eucalyptus* genera under controlled conditions. Authors such as Viana *et al.* (2010) point out that forest-based industries have been encountering difficulties in controlling the quality of their products. The determination of wood properties, in most cases, is completed through a series of tests involving traditional methods that are costly and destructive. The tests generate high subjectivity of results, requiring innovation in further research. In this scenario, the use of non-conventional wood evaluation techniques can be an important tool due to the reduced cost and time spent on analyses, with a view to directing the best way to use this material.

An example of this is X-ray diffraction (XRD), a fast and practical analytical technique that uses small amounts of woody material to study atomic-level structures in substances (French 2020). The method is widely used to verify the behavior of cellulose of different species in the treatment and preservation industry, charcoal, and pulp and paper industries (Pereira 2012; Geoge and Sabapathi 2015; Lima *et al.* 2015; Silva 2020). It determines crystallinity by dividing the diffractogram into crystalline and amorphous phases, calculating their respective areas, and relating them to phase volumes. Cellulose, the most abundant polymer in nature and one of the compounds most degraded by xylophages (Awadel-Karim *et al.* 1999; Andrade *et al*. 2003; Lengowski 2012), is a crystalline component, whereas lignin and hemicelluloses are amorphous. Thus, the cellulose content is an indication of the CI of wood-derived cellulosic materials (Daicho *et al.* 2018). Traditionally, the widely-used Segal method is applied to evaluate cellulose, with the selection of a specific wavelength to assess the contribution of amorphous cellulose to the XRD signal. However, this approach may not adequately consider the potential influence of lignin, especially at the chosen wavelength for amorphous cellulose. This issue underscores the need for a more comprehensive examination of XRD methodology and its applications in cellulose analysis.

In addition to that, there is a dearth of studies related to the use of this technique to evaluate parameters related to the degradation by fungi and insects of wood stored in sawmill yards in the Amazon Forest. Most of the studies in the literature on the species traded in this region are based on qualitative analyses with old methodologies. Therefore, knowledge about the resistance of wood stored in yards to the attack of xylophagous organisms through prediction techniques, such as XRD, is important because they can become a new alternative for the analysis of degradation by fungi and insects of logs of different Amazonian species. Logs of Amazonian wood species stored in a sawmill yard were investigated through X-ray diffraction in order to evaluate their crystallinity and how this parameter can be correlated with the analysis of wood degradation by fungi and insects.

EXPERIMENTAL

Materials

The material used in this study came from the log storage yard located in the port of Rondobel Forest Services, located in the rural area of Santarém, Pará, Brazil, under the coordinates (2°39'13.1"S, 55°42'53.8"W). Santarém, Pará, Brazil, features an equatorial climate, classified as Af according to Köppen and Geiger, with annual average temperatures ranging from 24 °C to 3 2°C (27.2 °C on average) and with an average relative humidity of 86%. The region experiences a rainy season from December to June with an average annual precipitation of 2,000 mm to 2,500 mm, and a dry season from July to November. For this study, material from 5 (five) commercial species stored in piles fully exposed (without cover) to natural conditions for 6 months was used. These wood species are presented in Table 1.

Table 1. List of Species Selected for the Study

Common Name	Scientific Identification	Family
Cumaru	*Dipteryx odorata*	Leguminosae
Guajará	*Micropholis venulosa*	Sapotaceae
Garapa	*Apuleia leiocarpa*	Fabaceae
Jarana	*Lecythis lurida*	Lecythidaceae
Quaruba	*Vochysia maxima* Ouke	Vochysiaceae

The scientific identification data of the species were previously made by professionals from the Rondobel’s Company. Ten piles of each species were selected for log collection. The sampling method considered (i) the volume of existing piles in the yard, (ii) ease of access considering the availability of machinery to move the material, and (iii) state of greater degradation in loco. After the previous selection, the stacks were visually divided into three layers or extracts, and from each stack, two logs were removed from the top, one from the middle and two from the bottom. The logs were selected in the most central region of the pile to avoid the edge effect. After selection, the logs were arranged on the ground for visual analysis procedures and woody material collection.

Methods

Three wooden wedges were collected from each log at relative positions of 25%, 50% and 75% of the log's length. Two logs were selected closest to the tops (at least 50 cm away from the ends), one in the central region, aiming at the chemical analysis and a log from the base of storage piles. The wedges were removed by destructive sampling using a chainsaw. The removed wedges were stored in waterproof canvas. In each of the three collection positions, samples were also taken for later determination of the moisture content of the species. These were packed in sealed plastic bags to be sent to the laboratory along with the wedges.

The methodology used to assess the level of degradation by insects was adapted from Abreu *et al.* (2002). The evaluation was performed along the logs (above and below the bark). Analyses, such as size and quantification of holes and internal galleries, were completed in the field, through qualitative analysis, and all the evaluated parameters were filled in a spreadsheet containing the information that would be evaluated (Table 2).

Table 2. Criteria for Classifying the Level of Wood Degradation by Insects*

Level of Degradation	Degradation Index
Healthy- no attacks	4
Light or superficial attack caused by termites and coleoptera	3
Evident but moderate attack caused by termites and coleoptera	2
Intense attack by termites and coleoptera	1
Total bark/sapwood/heartwood attack	0

Note: Adapted from Abreu (2002)

The determination of the level of degradation by fungi was carried out along the entire log (above and below the bark), according to the procedure used for insect attacks and using the same logs. The degradation index was applied according to the values presented in Table 3, adapted from Lepage (1970), using trained observers to assign the scores. The attack notes were assigned by distinguishing the heartwood and sapwood of the log.

Table 3. Classification of the Level of Wood Degradation by Fungi*

Level of Degradation	Degradation Index
Healthy- no attacks	100
Mild or superficial fungal attack	90
Evident but moderate attack caused by fungi	70
Intense rot	40
Breakage, almost total loss of resistance	0

Note: Adapted from Lepage (1970)

Sawdust samples with a granulometry of 60-mesh were taken using a knife mill and a classifying sieve from the wedges taken from logs of the species located at the base, middle, and top of the piles. The samples were acclimatized in an environment with a temperature of 20 ºC and relative humidity of 65%, until mass stabilization for subsequent determination of the extractives, lignin, holocellulose, and crystallinity.

The moisture content of the wood species used was determined in accordance with the guidelines of NBR 7190. Total extractives content was determined using extraction with ethanol:toluene mixture (ASTM D1107 1996), insoluble lignin (ASTM D1106 2013), and holocellulose (by difference) of samples taken from the logs of the species in the base, middle, and top pile positions, respectively.

For the X-ray diffraction test, completely dry sawdust with a granulometry of 60 mesh was used, and the measurements for later calculation of the crystallinity index were performed using a D2 PHASER BRUKER model diffractometer and a copper anode tube with a characteristic emission line of 1.54 Å / 8.047 keV (Cu- Kα1), maximum power of 300 W (30 kV × 10 mA), a Lynxeye detector (OD CODE), and angle θ. Data were collected in step-by-step mode, with a step of 0.05° and a count time of 1.5 s per point. The method adopted to determine the crystallinity indices was suggested by Hermans and Weidinger (1948), considering that for each species, analyses of the base, middle, and top logs were made, totaling 15 values for this variable. For each position, only one sample was used without replication.

After the tests, the data were submitted to a one-way analysis of variance (ANOVA-One Way) to assess whether there were differences in the levels of extractives, lignin, and cellulose and between positions in the log pile. Data normality was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The variance homogeneity assumption was evaluated using the Levene test.

For the extractive content variable, data normality was not observed, thus bootstrapping procedures were performed (1000 resamplings; 95% of confidence interval) to obtain greater reliability of the results, to correct deviations from normality of sample distribution and differences between sizes of the groups, and to present a 95% confidence interval for the differences between the means. Considering the heterogeneity of variance, Welch correction, and *post-hoc* evaluation was requested using the Games-Howell technique.

RESULTS AND DISCUSSION

Qualitative Evaluation of the Attack of Fungi and Insects on the Wood of the Evaluated Species

It was found that all species after six months of storage in a yard without movement showed some type of fungal attack. As expected, the bark and sapwood regions were the most compromised by the action of these agents. It was also noted that species, such as guajará (*Micropholis venulosa*) and the garapa (*Apuleia leiocarpa*), classified as white wood as a function of color, had lower resistance to fungal attacks (Table 4).

Table 4. Percentage of Logs Attacked by Fungi (F%) and Insects (I%)*

Common Name	Scientific Identification	F (%)	I (%)	Comments
Cumaru	*Dipteryx odorata*	60	60	Bark compromised by fungal attack; Small insect holes in bark and sapwood
Guajará	*Micropholis venulosa.*	60	80	Bark and sapwood compromised by fungal attack; Bark, sapwood, and heartwood compromised by galleries made by beetle larvae
Garapa	*Apuleia leiocarpa*	60	80	Bark and sapwood compromised by fungal attack; Bark and sapwood compromised by galleries made by beetle larvae
Jarana	*Lecythis lurida*	60	60	Bark and sapwood compromised by fungal attack; Small insect holes in bark and sapwood
Quaruba	*Vochysia maxima* Ducke	60	60	Bark and sapwood compromised by fungal attack; Small insect holes in the bark

*Note: In the bark-heartwood direction in each species evaluated after 06 months of storage without movement and qualitative observations made in the company's storage yard

Pinheiro (2001) explains that in the bark and sapwood regions, which were the most attacked in this study, there is a higher concentration of nutrients, mainly proteins and vitamins, which are important for the development of fungi that, later, pass them on to insects, and therefore are incorporated in this way in the food chain. Thus, fungi initially consume the sapwood wood, catalyzing the loss of some extractives located in the heartwood through evaporation, leaching, and reactions caused by the environment, allowing the attack of this region later (Silva 2014).

Fungi are the main biological agents that degrade wood, causing the breakdown of its structure and affecting its physicochemical properties. The study by Barreal (1998) showed that fungal colonization can cause, in the medium/long term, a significant loss of wood weight due to degradation in the crystalline region of cellulose. These organisms can also create barriers for the drying or impregnation of wood in some preservative substances (Brito 2014), in addition to causing considerable mass loss in the wood, which directly affects the mechanical properties (Brazolin *et al.* 2014).

A high incidence of larvae and adult individuals of beetles, termites, and ants was observed in the evaluated logs. It was observed that all the logs had their aesthetic quality compromised by the attack of insects. Guajará (*Micropholis venulosa*) and garapa (*Apuleia leiocarpa)* were the species that were present in more than 80% of the attacked trees. In all species, the bark and sapwood regions were the most compromised by these attacks.

Guajará (*Micropholis venulosa*) and garapa (*Apuleia leiocarpa*) logs showed galleries made by beetle larvae in the bark and sapwood region. Among the evaluated species, only the guajará (*M. venulosa*) presented insect attacks in the heartwood region. In this species, perforations caused by beetle larvae that are known as “wood borers” were observed in the heartwood region, the region of the log of greatest interest when it comes to the timber industry.

The term “wooden drill”, which is related to the perforations found in the heartwood of guajará (*M. venulosa)*, covers several species of insects that are harmful. The damage to the wood is a result of the feeding of the larval stage, which produces circular holes between 1 mm and 10 mm in diameter. The larva feeds on the wood, leaving excrements and fine wood dust, which also ends up being a gateway for fungus to attack the core of the species. The size of the tunnels, the orientation within the wood, and the characteristics of the residues vary according to the beetle species. The type of wood can also determine the type of insect that can attack (Brochini *et al.* 2018).

The study by Costa *et al.* (2011) showed the same pattern of resistance to fungus attack presented by guajará (*Micropholis venulosa*) and garapa (*Apuleia leiocarpa*) on marupá wood (*Simarouba amara*), a species that also has white wood due to its color. It was also found that the species used in this study showed the same insect attack pattern as Abreu *et al*. (2002) in a study conducted in six timber industries in Manaus, with 19 species commercialized in the region.

Some studies show that insect attacks also cause damage to the timber industry. Data from Imazon, which is a non-profit Brazilian and Amazonian scientific institution that carries out research and projects to promote socio-environmental development and climate justice in this region, show that in the state of Pará, damage caused by insects resulted in the loss of 8% of the total volume of the log during lamination processes. In sawmills in the state, losses due to insect attacks ranged from 0% to 13%, depending on the species (Imazon 2022). The study by Gallio *et al.* (2018) verified that the deterioration caused by a group of insects caused reductions in the mechanical properties of four forest species after a food preference test.

Moisture Content

Figure 1 shows the average moisture values of the logs of the species evaluated in the stockyard. It is observed that the guajará logs (*Micropholis venulosa)* and quaruba (*Vochysia maxima Ducke)* obtained higher average moisture content, with values above 100%, which may be an explanation for the high incidence of attacks by different fungi and holes and galleries of different insects in the logs of these species. The other species presented logs with average moisture values between 20% and 70%.

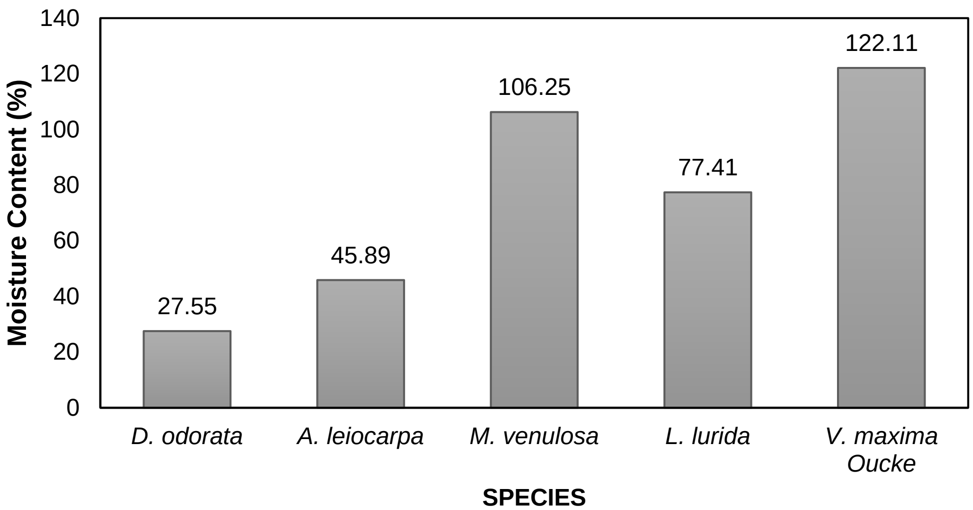

Fig. 1. Average moisture content of the species evaluated inside Rondobel's log yard

Green or freshly cut wood has moisture values ranging from 30% to 400%, depending on the characteristics of each species. The position of the logs in the piles, combined with abiotic factors and the intrinsic characteristics of each species, are possible explanations for the variation in the moisture content of the studied species, which also conditions the higher incidence of attack by fungi and insects. The variation in the moisture content in the wood, in addition to favoring the attack of biotic agents in the biodeterioration process, can also influence the deterioration of wood by abiotic agents. Among all the unfavorable conditions, a very high moisture content is one of the main factors responsible for triggering fungal and insect attacks on wood (Kumode *et al.* 2013). According to Mesquita *et al.* (2006), the most favorable wood moisture content for fungus growth is between 35% and 50%.

Chemical Analysis

For the chemical analyses, normality distribution tests showed that only the extractive content did not present a normal distribution Kolmogorov-Smirnov = 0.165, $p < 0.010$; Shapiro-Wilk = 0.95, $p < 0.010$). For the extractive content, the ANOVA showed that there was a difference between the species [Welch's F (5, 20.4865) = 110.19, $p < 0.001$]. The Games-Howell *post-hoc* test showed significant differences between the evaluated species in all evaluated parameters. It was also verified that the variables evaluated in some of the species were not influenced by the position of the logs (bottom, middle, and top) in the stockpile.

It was found that in most species there was a specific behavior of increasing the extractives content in the samples of the logs that were located in the middle of the stockpile. As for the percentage of lignin, only guajará (*Micropholis venulosa*) and jarana

(*Lecythis lurida*) showed mean values above 30%. The average holocellulose values of the species in the three evaluated positions did not show a behavior pattern similar to that of the extractives and the average values of the species were around 57 and 68%, respectively (Table 5).

Table 5. Averages per Species of the Total Extractives, Lignin, and Holocellulose Content of the Species Evaluated within Rondobel's Log Yard

Common Name	Scientific Identification	Position in the Stack	Extractives (%)	Lignin (%)	Holocellulose (%)
Cumaru	*Dipteryx odorata*	Base	10.5 C	27.7 B	61.7 A
		Middle	17.5 A	29.8 A	52.7 B
		Top	13.3 B	28 AB	58.8C
Averages			**13.77 ab**	**28.5c**	**57.73c**
Garapa	*Apuleia leiocarpa*	Base	18.6 A	16.8 A	64.6 A
		Middle	11.6 B	19.7 A	68.7 A
		Top	19.9 A	14.6 A	65.4 A
Averages			**16.7 a**	**17.03 c**	**66.23 ab**
Guajará	*Micropholis venulosa*	Base	5.80 B	34 B	60.3 AB
		Middle	12.7 A	27.3C	60.0 A
		Top	8.7 AB	36 A	55.3 B
Averages			**9.07 bc**	**32.43 a**	**58.53 c**
Jarana	*Lecythis lurida*	Base	2.16C	32.64 A	65.2 A
		Middle	8.20 B	28.23 AB	63.6 A
		Top	5.46 A	29.47 B	65.1 A
Averages			**5.27 cd**	**30.11 ab**	**64.63 b**
Quaruba	*Vochysia maxima Ducke*	Base	4.80 A	25.5 A	69.6 A
		Middle	4.30 B	30.0 A	65.7 A
		Top	4.60 B	25.8 A	69.6 A
Averages			**4.57 d**	**27.1 b**	**68.3 a**

**Averages that do not share a letter are significantly different*

The behavior of the five species evaluated in this work was probably the result of alterations in the chemical composition of the wood that occurred during storage time in concordance with the study by Brand and Muňiz (2012). Differences in average extractive content are an indication that the positions of the logs in the stockpile and the time of exposure in the yard may have influenced the behavior of this variable in most of the evaluated species. It was observed that the logs present at the base of the stockpile ended up suffering greater influence from direct contact with the ground. This ends up being more common in stockyards in the Amazon region, which most often do not have adequate conditions for storage and may have caused a greater leaching of water-soluble secondary components. The highest average values were observed in the material collected from species of most logs located in the middle of the pile, which ended up not receiving as much influence from external factors and consequently these compounds were less leached. The logs located at the top of the pile ended up suffering from a high incidence and influence of external factors, which may have caused the leaching of large amounts of some groups of highly volatile extractives present in the wood. This information corroborates data from Nzokou and Kamdem (2006), who stated that this decrease is due to the leaching of extractives by rainwater, which manages to have more incidence on the top of the piles.

Silva (2018) observed an opposite behavior to most of the species evaluated in that study in the values of total extractive content in a stockpile of the species *Manilkara elata*. In this case, higher values were observed in the ground position and lower values in the top position, ranging from 10.98 to 5.61%, indicating a loss of extractives in the top - ground direction in the piles of wood stored in a mining area located in the municipality from Paragominas – PA.

The natural durability of the wood is conferred by its secondary components that, in most cases, are present in small proportions, but can, in some species, reach high values, such as those found by Duarte *et al.* (2020), when determining the levels of *D. odorata* extractives and obtaining values of approximately 12.7%. Stangerlin *et al.* (2013) obtained percentage values of extractives that ranged between 2% and 9% in the wood of native species, such as marupá, jequitibá, and cumaru. The authors Castro *et al.* (2015) obtained values between 9% and 12% in angelim-pedra, cumarurana, jatobá, and louro-vermelho woods.

Barbosa *et al.* (2007) and Oliveira *et al.* (2005) pointed out the affinity that exists between the content of extractives with the natural durability and resistance of wood species against degradation caused by xylophagous organisms. This is because some wood species present classes of extractives that are highly attractive to xylophagous organisms. In contrast, other wood species will present classes of components that will serve as a protective barrier, repelling the action of certain degradation agents.

Based on this, it is inferred that the garapa species (*Apuleia leiocarpa*) and cumaru (*Dipteryx odorata*) have greater resistance to attack by xylophages and natural durability depending on the type and the greater amount of extractives present in the wood. The wood of species, such as Jarana (*Lecythis lurida*) and Quaruba (*Vochysia maxima*), should show greater susceptibility to attack by xylophagous organisms, mainly fungi, because these species have presented the lowest values of this variable and have white wood depending on the color. Data found by Ibama (1997 and Technological Research Institute - IPT (1989) claim that the wood of the genera *Lecythis* and *Vochysia* have low resistance to attack by xylophagous organisms, more specifically fungi and termites.

Secondary wood compounds may have their differences related to their constituent groups. Silvério *et al.* (2007) explain that while the extractives of some wood species are rich in starch and/or sugars, promoting the deterioration of this material by fungi and other xylophagous agents, those of other species may be rich in phenolic compounds or other types of compounds having biocidal action, giving them more durability in environmental conditions favorable to these deteriorating agents.

According to Oliveira *et al.* (2005), the extractives that give wood durability are normally formed during the transformation of sapwood into heartwood, being of phenolic and polyphenolic character, and they accumulate in the lumens and cell walls, resulting, in most cases, in the dark coloration of the wood's core. When it comes to Amazonian species, lignin contents can range between 24 and 35% (Santana and Okino 2007). The low lignin content presented by the garapa species (*Apuleia leiocarpa)* may be linked to the high amount of holocellulose and extractives present in the species. Hanada *et al.* (2003) studied fungal attack on 12 species of tropical wood and observed that the species with the lowest density were those with the greatest diversity and intensity of fungi. Among the possible explanations, they pointed out that the presence of lignin in high amounts is also a limiting factor for the establishment of mold and staining fungi, as these fungi cannot degrade lignin. Lignin, however, can only deteriorate to a limited extent, and a high content of lignin can still be found even in highly deteriorated wood species whose structure has been affected (Blanchette 2000).

The fungi that cause brown rot preferentially degrade cellulose and hemicelluloses without removing the surrounding lignin (Silva 2018). In this way, wood species, such as quaruba (*Vochysia maxima*), jarana (Lecythis *lurida*), and garapa (*Apuleia leiocarpa)*, that respectively presented the highest levels of holocellulose, tend to be highly susceptible to attack by these and other xylophagous organisms, when evaluating the entire set of quantified variables.

With this, it is recommended to perform more in-depth studies, mainly on the classification of the extractives present in the species to give more veracity to whether these compounds have an influence or not on the resistance of the species to the attack of xylophagous organisms.

Crystallinity Index (%)

In this study, the value of the crystallinity index of the species ranged between 53 and 71% (Table 6). All species showed a higher crystallinity index in the logs present at the top of the stockpiles. This behavior may be linked to the high incidence of attack by xylophagous organisms, mainly fungus, which degrade the wood chemical compounds, including the non-crystalline regions of the cell wall, such as amorphous cellulose, increasing the crystallinity concentration in some species studied.

The logs present at the base and in the middle of the piles showed lower crystallinity index values, which can be attributed to the limited weathering protection provided by the logs in the top of the stockpile, as the incidence of light and water is diminished in these pile regions. Bianchi (1995) mentions that this data is important, because crystallinity can be used as a quantitative tool in the evaluation of the rate of biodeterioration of species after a long time of storage and attack by xylophagous organisms.

Table 6. Crystallinity Index (CI) of the Wood Species by Position in the Stockpile

Common Name	Scientific Identification	Position	CI (%)
Cumaru	*Dipteryx odorata*	Base	63.30
		Middle	62.28
		Top	63.88
Garapa	*Apuleia leiocarpa*	Base	60.29
		Middle	62.99
		Top	65.39
Guajará	*Micropholis venulosa*	Base	56.14
		Middle	62.44
		Top	71.77
Jarana	*Lecythis lurida*	Base	53.48
		Middle	59.93
		Top	60.90
Quaruba	*Vochysia maxima Ducke*	Base	56.37
		Middle	55.03
		Top	63.67

Results different from those of this study were found by Silva (2020) in four native species, timborana (*Pseudopiptadenia suaveolens*), pau-amarelo (*Euxylophora paraensis Huber*), tamanqueira (*Aegiphila integrifolia*), and parapará (*Jacaranda copaia*), after five weeks of a natural resistance bioassay with soil termites (*Nasutitermes* sp.), with CI values ranging between 44 and 59.9%.

Silva (2020) mentions that over time, the decrease in the crystallinity index could be related to the beginning of consumption of crystalline regions, causing degradation of cellulose by fungi and insects, or to the concentration of non-cellulosic components. According to Winandy and Rowell (2005), cellulose is the polymer that most contributes to the mechanical strength of wood. Cellulose chains are extremely resistant to tensile and compressive stresses, due to the hydrogen bonds within them. The authors Chand and Hashmi (1993) and Greenberg *et al.* (1989), mention that the variation of the tensile strength and the modulus of elasticity of the wood are directly related to the variation of the degree of crystallinity of the wood itself. That is, when the fibers contain a greater proportion of crystalline regions, the mechanical resistance increases. Therefore, cellulose is the only component present in the fiber that crystallizes. The crystallinity index is an important parameter to be quantified, considering that it exerts a direct influence on the technological properties of wood. Analysis of the crystallinity index is a promising tool to help understand the behavior of cellulose after attack by xylophagous organisms and over a long period of exposure of logs to external agents and the possible influence of these factors on the technological properties of the wood. It is recommended to carry out studies with this variable in the wood of more species of commercial interest, at different time intervals, to further emphasize the information presented for this variable.

CONCLUSIONS

1. The position of the logs in the piles associated with the storage time influences the quantitative and qualitative chemical characteristics of the wood in logs stores outdoors in tropical conditions. However, this effect is species dependent.
2. The X-ray diffraction technique showed potential for analysis of degradation by fungi and insects in logs of Amazonian species stored in a stockyard.
3. The study can generate support for a better resizing of the storage time of wood from different species using information of chemical properties in order to reduce the damage that can be caused by xylophagous organisms.
4. It is recommended to carry out in-depth studies of the chemical composition of extractives (identification of their components) of these and other species of commercial interest, since they show different behaviors within the species studied.

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