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RADIAL CLUSTER OF *Eucalyptus grandis* BOARDS SUBMITTED TO THE CONVENTIONAL DRYING PROCESS

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Resumo

Agrupamento radial de tábuas de eucalyptus grandis submetidas ao processo de secagem convencional. O gênero *Eucalyptus* sp. apresenta defeitos naturais, de desdobro e secagem que acarretam perdas significativas de madeira. Por isso, conhecer a região de ocorrência dos defeitos pode ser uma ferramenta útil para quem beneficia madeira. Sendo assim, este trabalho objetivou agrupar radialmente tábuas de *Eucalyptus grandis* com base nos defeitos naturais e de secagem. Seis árvores foram desdobradas em tábuas e separadas em duas regiões: central (C) e externa (E). As tábuas centrais (C) apresentavam maior proporção de madeira da região próxima à medula; e as externas (E), maior proporção de madeira da região próxima à casca. Os defeitos ocorridos nas tábuas secas em estufa convencional, a 10 % de umidade foram avaliados por meio de análise multivariada e variaram no sentido medula-casca. A análise de agrupamento separou a madeira em duas regiões (central e externa) e a análise de componentes principais destacou quais defeitos foram dominantes para cada região. As tábuas externas (E) apresentram maior intensidade de encurvanento e encanoamento. As centrais (C) apresentaram maior intensidade de arqueamento, nós, bolsas de resina ou kino, colapso e rachaduras superficiais. Essas informações podem ser importantes para quem industrializa madeira, pois, sabendo em qual região o defeito mais ocorre, uma peça de madeira pode deixar de ser utilizada. No entanto, o fator operacional deve ser levado em consideração, pois características da madeira, o tipo e condições do equipamento de corte, método de desdobro, layout da serraria, pode inviabilizar a separação da tora em duas regiões.
Palavras-chave: Análise de cluster; análise de componentes principais (PCA); defeitos.

Abstract

The *Eucalyptus* sp. genus presents natural debarking and drying defects that lead to significant wood losses. For this reason, knowing the region where the defects occur may be a useful tool for those who process wood. Thus, this work aimed to radially group *Eucalyptus grandis* boards based on natural and drying defects. Six trees were split into boards and separated into two regions: central (C) and external (E). The central boards (C) had a higher proportion of wood from the region near the pith; and the external boards (E) had a higher proportion of wood from the region near the bark. The defects occurring in the boards dried in conventional kiln at 10% humidity were evaluated using multivariate analysis and varied in the pith-to-bark direction. The Cluster analysis separated the wood into two regions (central and external) and the principal components analysis highlighted which defects were dominant for each region. The external boards (E) presented higher bow and cupped intensity. The central boards (C) presented higher crook intensity, knots, gum or kino bags, collapse, and superficial cracks. This information may be important for those who industrialize wood, because by knowing in which region the defect most occurs, a piece of wood may no longer be used. However, the operational factor should be taken into account, because wood characteristics, the type and conditions of the cutting equipment, pitsawing method, and sawmill layout may make it unfeasible to separate the log into two regions.
Keywords: Cluster analysis; Principal Component Analysis (PCA); defects.

INTRODUCTION

Eucalyptus wood is a potential alternative for the supply of raw material for timber industries (ELEOTÉRIO *et al*., 2015). However, it can present natural defects such as knots, gum bags, cracks and growth stresses (HASELEIN *et al*., 2004; CASTRO SILVA, 2001). Defects caused by growth stresses and drying (top cracking, surperficial cracking, warping and collapse), constituting an additional obstacle to its use, resulting in significant wood loss (SOUZA *et al*., 2012).

Most of the defects that occur in eucalyptus wood and significantly contribute to the limitation of its use are related to growth and drying stresses. The identification of species and the adoption of pitsawing and drying methods that aim to reduce the amount of defects on the wood surface is a good strategy to increase the yield and productivity of timber industries (ELEOTÉRIO *et al*., 2014).

One way to reduce the amount and type of defect is to produce wood pieces with only one type of wood, that is, pieces containing wood only from the region near the pith or the region near the bark. This is because the wood located near the pith presents different anatomical, strength and stiffness (JESUS; SILVA, 2020), shrinkage, swelling and drying (CASTRO SILVA, 2001, LOURENÇON *et al*., 2013; CALONEGO *et al*., 2014) properties than that located near the bark. According to Palermo *et al.* (2013), the separation of different types of wood is fundamental to standardize wood properties and a positive characteristic in the transformation of wood into other products. For example, wood pieces with uniform growth ring width, similar adsorption and desorption properties, and anisotropy coefficient between 1.5 and 2.0 have fewer defects such as cracking, warping, and twisting during water outflow.

For industries that use eucalyptus wood, information about the behavior and the variation of defects that occur in the pith-bark direction during the drying process can be a very important tool to define the best way to industrialize and apply the wood.

Thus, the objective of this study was to group the natural defects and the defects occurring in *Eucalyptus grandis* boards in the pith-to-bark direction after their conventional drying.

MATERIAL AND METHODS

Material collection and preparation

Six trees of *Eucalyptus grandis* W. Hill Ex-Maiden, 23 years old, with mean diameter of 45 cm and mean commercial height of the trunk of 12 m, were collected from a plantation located in Barra do Piraí/RJ/Brazil (geographical coordinates: 22º43'23" South latitude and 44º08'08" West longitude).

These trees, before being felled, at a height of 1.30m, were girdlined with a chainsaw. After felling, to reduce cracking at the ends of the logs, girdling (continuous incisions with 1/3 depth of its radius) was also performed along the trunk at heights corresponding to 3.70, 6.10 and 8.70 m, according to the methodology described by Latorraca *et al*. (2015). These logs were transported and stored in the sawmill park and cut into 2.0 m long short logs, eliminating 20 cm of wood located around each girdling. The 18 short logs had their ends colored to identify two radial regions, i.e., yellow and a small proportion of bege-pink central region (C) and pink the external region (E), (Figure 1A and 1F).

The logs with the colored ends were unfolded in a vertical band saw, first eliminating the two opposite parallel sides (Figure 1B y 1C) and then cut in half to obtain two 150 mm thick planks (Figure 1C y 1D). Each plank was sawn with a two-axis multiple circular saw generating 331 boards with a length of 200 cm, a nominal thickness of 25 mm, and a width of 150 mm (Figure 1E). Central and external boards (Figures 1E and 1F).

Figure 1. Delimitation of different regions and sawing of wood. A, painting in the cross section of the logs; B, removal of the slabs; C: splitting log on planks; D, planks; E: splitting logs in multiple circular saw; F, boards with painted ends.

Figura 1. Delimitação de diferentes regiões e desdobro da madeira. A, Toras com a seção transversal colorida; B, Remoção das costaneiras; C, Divisão das toras em pranchões; D, Pranchões; E, Desdobro dos pronchões em serras circulares múltiplas; F, Tábuas com extremidades coloridas.

The 331 boards were stacked and conveyed to the conventional drying chamber, Leogap, maximum capacity of 4.0 m^3, with top ventilation and reversible motor. The fans worked with RPM rotation around 50% of its total capacity and an average air velocity of around 3 m/s was estimated. The chamber has a humidification system by sprinklers and heating by electrically heated finned heat exchangers. The drying program adopted was gentle and ended when the wood had an average moisture content of 10% (Table 1). The drying was carried out with green wood until it reached 10% of final moisture content.

Table 1. Drying program applied to *Eucalyptus grandis* boards.
Tabela1. Programa de secagem aplicado às tábuas de *Eucalyptus grandis*.

Calefacción	TU (%)	TBS	TBU	UR	UE	PS
		40	39	94	22	-
Hasta 50	50	40	37	83	16	3,1
50 – 40	40	40	36,5	80	15	2,7
40 – 30	30	40	36	77	14	2,2
30 – 25	25	46	40	69	11	2,2
25 – 20	20	53	45	61	9	2,2
20 – 15	15	59	46	47	7	2,2
15 – 10	10	65	46	35	5	2,2
Uniformización		65	54	57	8	***
Acondicionamiento		65	61	83	14	***

Legend: TU - moisture content (%); TBS - dry bulb temperature; TBU - moist bulb temperature; UR - relative moisture; UE - equilibrium moisture of the wood; PS - drying potential.

Of the 331 boards removed from the conventional drying chamber, 132 boards were selected and separated into two regions based on the end coloration of each board (yellow, beige pink and pink): external region (E) composed of 80 boards with pink colored ends and central region (C) composed of 52 boards with ends presenting a mixture of yellow and beige pink colors.

In the 132 boards, the natural defects were evaluated qualitatively and the drying defects were evaluated quantitatively, based on the methodology described by Latorraca *et al*. (2015) and Lópes *et al.* (2016).

The crook intensity (I_AT), was determined by measuring the greatest distance (Y_1) existing between the curved face of the wood board and a horizontal plane joining the two ends in relation to its total length (L_r), according to the following equation:

$$IAT = \frac{Y_1}{L_r}$$

The bow intensity (IET) was determined by measuring the greatest distance (Y_2) existing between the curved face of the wood board (smallest dimension of the cross section - width) and a horizontal plane joining the two ends in relation to its total length (Lr), according to the following equation:

$$IET = \frac{Y_2}{L_r}$$

The cupped intensity (ENCAN), was determined by measuring the maximum deflection (Y_3) existing between the concave edge and the transverse plane (L_1) joining the longitudinal edges of the board.

The number of knots (N) was determined by counting them on the face of greatest occurrence. Additionally, superficial cracking (SR), collapse (COLAP), and gum bags (BR) defects were visually classified as absent or present.

Cluster analysis and principal component analysis (PCA) were applied to segregate the drying defects that occurred in the boards from different regions of the log (pith-bark).

RESULTS

Evaluation and Cluster of defects in the pith-bark direction

The cluster analysis of the boards was performed including all 132 boards, based on the *Wards* method (minimum variance), using the Euclidean distance as a measure of dissimilarity and is represented in the form of an "inverted tree crown", containing the different clusters in two dimensions and is represented graphically by a dendrogram, with the position of each board (Figure 2).

To separate the boards according to the defects of each region, the criterion mentioned by Scheeren et *al.* (2000) was applied to the dendrogram of Figure 2. Plotting the cut-off line at distance 15 on the y-axis resulted in the formation of two clusters (the green cluster composed of boards with wood from the external region and the orange cluster composed of boards from the central region).

After the cluster analysis, of the 52 total boards classified as central (C), 49 showed similar defects for this group and of the 80 boards classified as external (E), 79 showed similar defects for this group, proving that there was the formation of two groups (central and external), Figure 2.

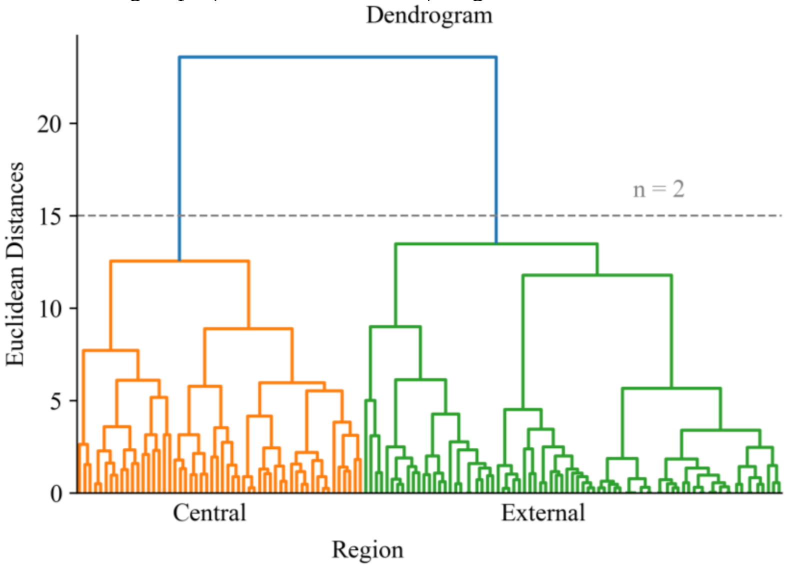

Figure 2. Dendrogram of the 132 boards, grouped in the pith-bark direction, based on *Wards* linking.
Figura 2. Dendrograma das 132 tábuas, agrupadas no sentido medula-casca, pelo método de ligação de *Wards*.

To determine which defects were important for the segregation of the two groups, the data were submitted to principal component analysis (PCA), retaining those factors whose eigenvalue explained 50% or more of the total variation. The total variance explained from the extraction of two components was 60.5%, where principal component 1 (PC1) contributed 38.9% and the second (PC2) contributed 21.6%, (Figure 3).

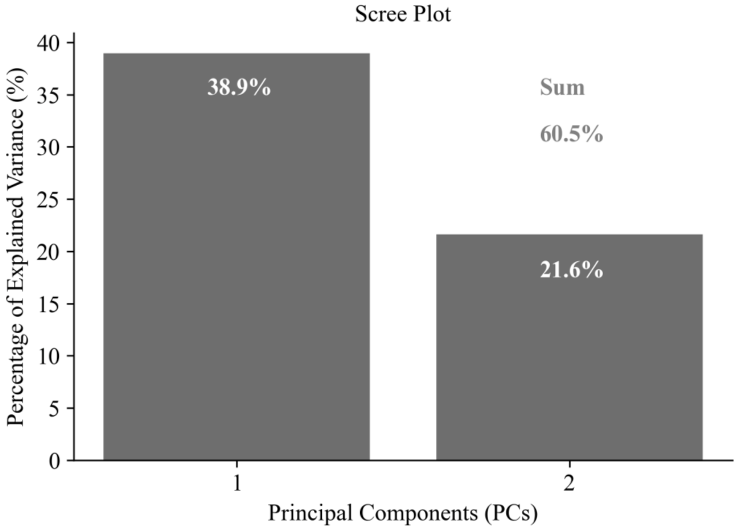

Figure 3. The cumulated variability from PC1 and PC2.
Figura 3. Variabilidade acumulada de PC1 e PC2.

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The principal component 1 (PC1) with 38.9% of the total variance explained, presented as dominant defects: crook intensity, knots, gum bags and superficial cracks (Figure 4).

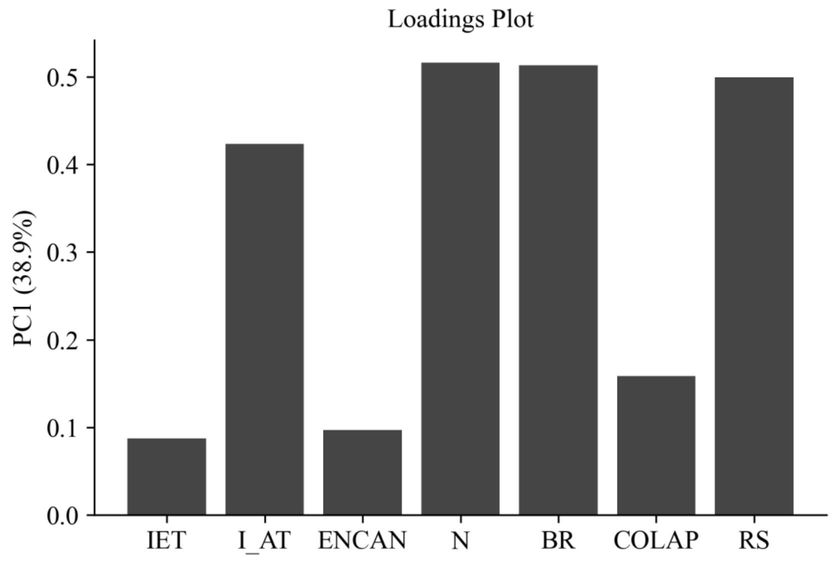

Figure 4. Eigenvectors of each defect for the principal component 1 (PC1). Bow Intensity (IET), Crook Intensity of (I_AT), cupped intensity (ENCAN), knots (N), gum bags (BR), collapse (COLAP) and superficial cracks (RS).
Figura 4. Autovetores de cada defeito para o componente principal 1 (PC1). Intensidade de encurvamento (IET), intensidade de arqueamento (I_AT), intensidade de encanoamento (ENCAN), nós (N), bolsas de resina (BR**),** colapso (COLAP) e rachaduras superficiais (RS).

The principal component 2 (PC2), with 21.6%, presented as dominant defects: bow intensity and cupped intensity (Figure 5).

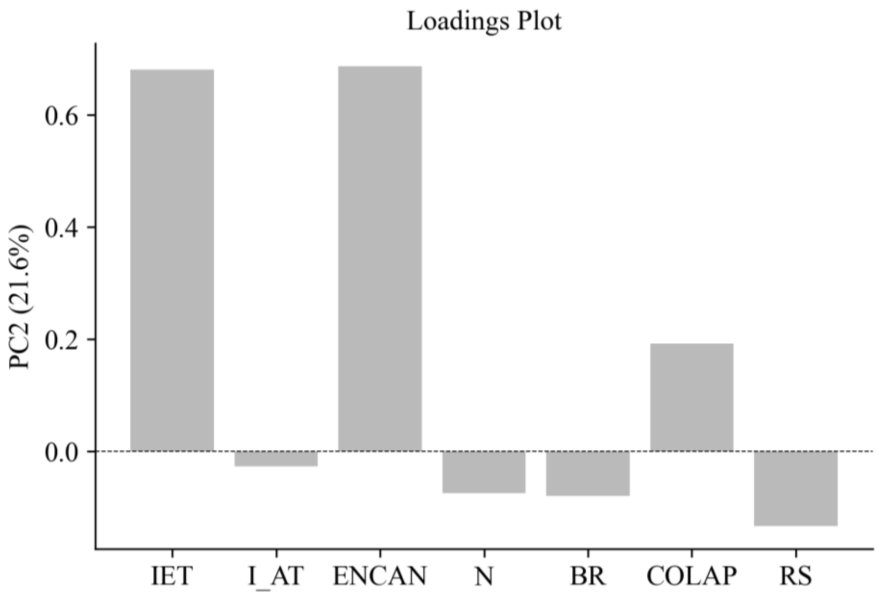

Figure 5. Eigenvectors of each defect for the principal component 2 (PC2). Bow Intensity (IET), Crook Intensity of (I_AT), cupped intensity (ENCAN), knots (N), gum bags (BR), collapse (COLAP) and superficial cracks (RS).
Figura 5. Autovectores de cada defeito para o componente principal 2 (PC2). Intensidade de encurvamento (IET), intensidade de arqueamento (I_AT), intensidade de encanoamento (ENCAN), nós (N), bolsas de resina (BR**),** colapso (COLAP) e rachaduras superficiais (RS).

A confrontation between the data of dispersion of the scores and eigenvectors of the principal components resulted in a two-dimensional graph, where the same separation of the cluster analysis by the *Ward* method was verified (Figure 6).

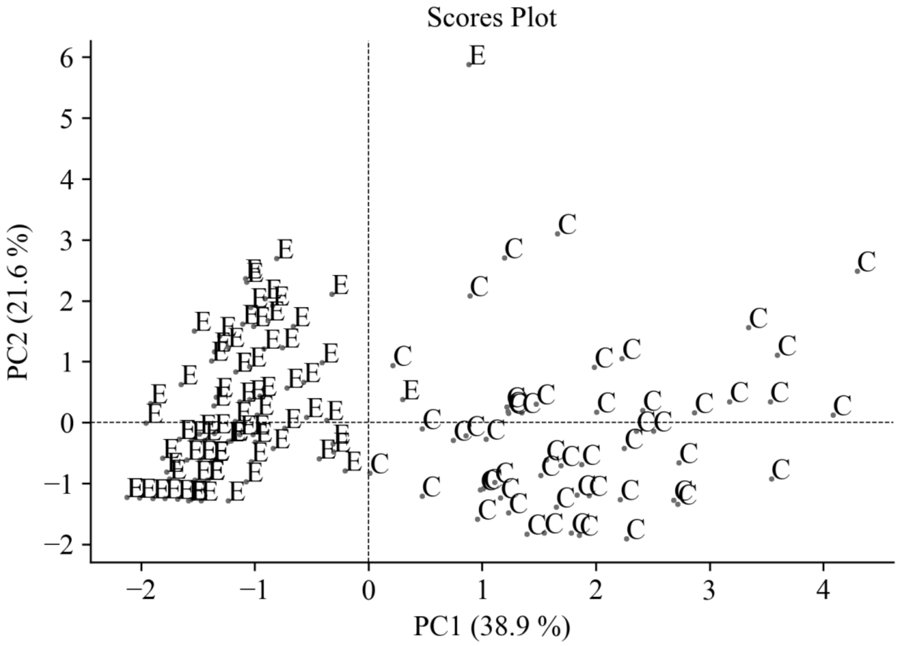

Figure 6. Graphical dispersion of the scores of the defects that occurred on the boards in relation to the principal component 1 (PC1) and 2 (PC2).

Figura 6. Dispersão gráfica dos scores de defeitos ocorridos nas tábuas em relação ao componente principal 1 (PC1) e 2 (PC2).

Table 2 shows the average values of each defect, according to the region where the boards were removed. It can be seen that the bow (IET) and cupp (ENCAN) intensity were higher in the boards from the external region. The crook intensity (I_AT), knots, gum bags (BR), collapse (COLAP), and superficial cracks (RS) were higher in the central boards. For the central boards 91% of them presented gum bags, 35% presented collapse, and 70% superficial cracks.

Table 2. Average values of the defects, in the pith-bark direction. Bow Intensity (IET), Crook Intensity of (I_AT), cupped intensity (ENCAN), knots (N), gum bags (BR), collapse (COLAP) and superficial cracks (RS).

Tabela 2. Valores médios dos defeitos, no sentido médula-casca. Intensidade de encurvamento (IET), intensidade de arqueamento (I_AT), intensidade de encanoamento (ENCAN), nós (N), bolsas de resina (BR**),** colapso (COLAP) e rachaduras superficiais (RS).

Cluster	**IET (mm/m)**	**I_AT (mm/m)**	**ENCAN mm**	**NÓS Nº**	**BR %**	**COLAP %**	**RS %**
Central	1,31	4,55	0,57	3,91	91	35	70
External	1,52	2,51	0,87	0,32	5	25	1

DISCUSSION

As can be seen in Figures 2 and 6 of this study, the cluster analysis and PCA showed the formation of two groups, which may favor wood separation, depending on the intensity of occurrence of a defect in the stem cross section. In the case of the crook intensity, this was higher in the central wood and the result is similar to that found by Touza (2001) who found in tangential cutting system of *Eucalyptus globulus* logs higher crook indices in pieces removed from the center of the stem and lower in those removed near the bark. Lima and Stape (2017) found similar results for sawn wood from *Eucalyptus* sp. clones. According to them, crook and the number of knots decrease in the pith-to-bark direction, while bow increases.

For the defects of bow (IET) and cupped (ENCAN), it was observed that these occur more frequently in the boards taken from the external regions (E). This result is in agreement with that found by Calonego and Severo (2007), who recorded that pieces containing pith presented low cupp, with a maximum increase in the intermediate region. A similar result was found by Touza (2001) who observed that cupp was lower in boards coming from the central region of the stem and higher in boards taken near the periphery of the trunk.

Superficial cracking, which appears due to the rapid drying of the wood surface while its interior is still moist, promotes the formation of tensions, which, by exceeding the perpendicular tensile strength of the fibers, causes the appearance of this type of cracking (SOUZA *et al*., 2015). They usually appear at the beginning of drying and may disappear as the wood dries. However, if the evaporation of water on the surface is intense, they remain. Vidaurre *et al*. (2011) point out that regardless of age, genetic material and density, surface cracks are most frequent at a distance between 7 and 9 cm from the pith. In this study, it was observed that these were greater in the boards in the central region.

The low permeability of *Eucalyptus* sp. contributes to the appearance of collapse. This defect arises due to the formation of a high capillary tension during the exit of free water or capillarity, which forces the wall to rupture, because it has no resistance, and thus the crushing of the cells occurs. According to Jankowsky *et al*. (2003) while superficial cracking occurs due to the moisture gradient, collapse in eucalyptus wood occurs due to the low permeability of the wood. It also occurs due to the use of high drying rates, during free water removal (above PSF), high drying potential and high temperature.

With respect to collapse, in this study, its highest occurrence was in the boards considered central, contrary to that found by Ananías *et al*. (2014) who observed in *Eucalyptus nitens* a 50% lower incidence of collapse in the wood of the central region when compared to wood in the transition region (between the center and the periphery).

In addition to drying defects, others such as knots and gum bags significantly affect wood quality. Knots in a piece of wood is what decreases its strength the most. According to Mohan and Venkatachalapathy (2012) knots are the most common defects observed in wood and their manual selection and classification is tedious and time consuming and they suggest using a sensor equipped device for identification. In this study, knots and gum bags were greater in the boards in the central region of the stem.

Knowledge about the pattern of defect distribution, that is, where they occur in greater or lesser proportion in the cross section of the trunk, will contribute to decision making and may be useful information during wood processing. For example, if in the wood located around the bark, the occurrence of knots and bowing is lower, the person processing the wood can rotate the log so that a greater amount of boards without the presence of this defect are produced.

CONCLUSIONS

- Cluster analysis allowed grouping the boards into two regions (central and external).
- The principal component analysis allowed to verify which defects were dominant for each region.
- Depending on the region where the piece of wood is taken in the stem cross section, the defects studied in Eucalyptus grandis vary in the pith-bark direction. This information may be important for those who industrialize and use wood, because by knowing which type of defect occurs more in each region, the piece of wood may or may not be used as raw material in the manufacturing of a certain product. For example, in products that require resistance and rigidity, the wood from the central region can be excluded, because it has a high index of cracks and knots. Moreover, this information can provide subsidies for decision making regarding the type of pitsawing and drying to be adopted in order to minimize the occurrence of defects and increase the quality of the final product.

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