# DAMAGE BY DEFOLIATING INSECTS AND ITS EFFECT ON THE QUALITY OF WOOD FOR CHARCOAL PRODUCTION

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The objective of the present work has been to evaluate the impact of damage caused by defoliating insects on wood quality and charcoal production, and to quantify the losses per hectare according to the charcoal produced. Seven-year-old *Eucalyptus grandis* × *Eucalyptus urophylla* (clone A) and *Eucalyptus saligna* (clone B) trees, both in healthy condition and damaged by defoliating insects, were selected, with five trees to be used per treatment. Wood disks were removed from the trees at 0, 25, 50, 75 and 100% of the commercial height for analyzing the properties of the wood and for preparing and characterizing the charcoal. Damage by defoliating insects decreased the basic density of the trees at all axial positions by up to 23 kg m$^{-3}$. Also, the extractives and lignin contents increased, while the holocellulose content decreased in the attacked plants. Changes in the wood characteristics led to increased fixed carbon content and gravimetric yield, and a decrease in density. The charcoal productivity from the plants damaged by defoliating insects was lower, mainly because of the decrease in volumetric production.

*Keywords*: bioenergy, *Eucalyptus*, forestry, integrated pest management, wood products

## INTRODUCTION

Forest plantations are the main source of raw material for charcoal production in Brazil.[1,2,3,4] However, defoliating insects, such as leaf-cutting ants,[5] caterpillars[6,7] and beetles,[8,9] may limit the productivity of these plants.[10] These insects have been found to have a high economic impact, as they can consume up to 100% of the leaf area and even cause tree death.[11]

The reduction of the leaf area decreases the production of photoassimilates in trees, resulting in lower growth and wood production.[11,12] Damage by defoliating insects may affect the wood quality,[13,14] and, consequently, its use for charcoal production. However, the estimation of the losses caused by defoliating insects takes into account only the volumetric wood losses.

Carbonization is a process of wood thermal decomposition, carried out in the absence of oxygen or in a controlled atmosphere, whose main product is charcoal, mainly intended for use in steel production. The quality of the raw material, such as the basic density[15] and chemical composition[16,17] of the wood, may affect the quality of the charcoal produced.

The objective of the present investigation has been to evaluate the quality of wood destined for charcoal production as affected by the attack of defoliating insects, and to estimate the losses caused by the damage incurred by defoliating insects, in terms of charcoal mass produced per hectare.

## EXPERIMENTAL

### Collection of wood samples

*Eucalyptus grandis* × *Eucalyptus urophylla* (clone A) and *Eucalyptus saligna* (clone B) trees, both

healthy and damaged by defoliating insects, were harvested in the municipality of Jaguairaiva, Paraná state, Brazil (24° 15' 04" S; 49° 42' 21" W). All the wood samples were collected within a radius of 4 km, presenting similar soil and climate conditions. Five 7-year-old trees were harvested per treatment, for a total of four treatments in the study. The wood volume produced in all stands was provided by the producer, based on their forest inventory.

The damage by defoliating insects occurred when the trees were 28 months old, with 100% of the leaf area being consumed by *Gonipterus platensis* Marelli (Coleoptera: Curculionidae), without the occurrence of other xylophagous organisms until the trees were harvested.

After harvesting, wood disks were removed from the base and at 25, 50, 75 and 100% of the commercial tree height, and the wood and charcoal produced were characterized (Fig. 1).

**Physical properties of the wood**
Wood basic density was determined in one disk of each of those removed at 0, 25, 50, 75 and 100% of the commercial tree height, using the ratio between the dry mass and the saturated volume, according to NBR 11941.[18] The mean density of the tree was determined with the weighted average of the basic densities obtained from the disks taken from the different tree heights.

**Chemical and energetic analysis of the wood**
Wood disks removed from the base and at 25, 50, 75 and 100% of the commercial tree height of the eucalyptus plants were ground in a Wiley mill and then sieved. The fraction retained between the 40- and 60-mesh screens was used to determine the total extractives according to ASTM D-1105;[19] soluble lignin was determined according to the method described by Gomide and Demuner;[20] insoluble lignin was determined according to the method of Goldschmidt;[21] and total lignin was calculated by the sum of the soluble and insoluble lignin. Holocellulose content was obtained by subtracting the lignin, ash and extractives content from 100%.

**Wood carbonization and charcoal characterization**
Wood disks removed from the base of the trees and at 25, 50, 75 and 100% of the commercial height were cut into small pieces, mixed and then carbonized at 450 °C, with residence time of 30 min and a heating rate of 1.67 °C min$^{-1}$. The gravimetric yield after carbonization was calculated by the ratio between the charcoal produced and the original dry wood mass.

The contents of fixed carbon, volatile matter and ashes were analyzed according to NBR 8112,[22] the gross calorific value was measured according to NBR 8633,[23] and the apparent relative density was analyzed according to NBR 9165.[24]

**Statistical analysis**
The data were submitted to tests for homogeneity of variances (Bartlett test, 5% of significance) and normality (Shapiro-Wilk test, 5% of significance) prior to variance analysis. The contrast between the means of the parameters evaluated was determined by the Scott-Knott test at 5% significance level.
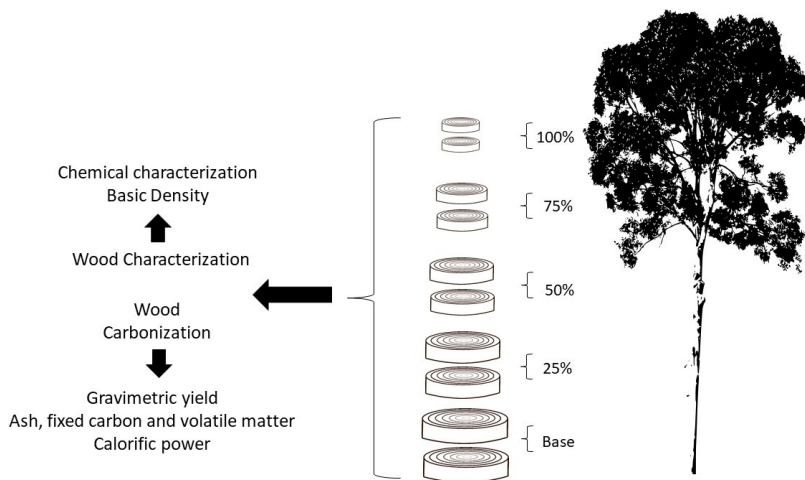


Figure 1: Simplified diagram of the process of tree sampling for evaluating wood quality and produced charcoal

**Economic analysis of damage caused by defoliating insects**
The charcoal mass produced per hectare was obtained by multiplying the wood volume produced per hectare by the wood's basic density and the gravimetric yield after carbonization, according to the following Equation 1:

$$CPH = WV \times WDB \times CGY \qquad (1)$$

where CPH = charcoal produced per hectare; WV = wood volume per hectare, WBD = wood basic density and CGY = charcoal gravimetric yield.

## RESULTS AND DISCUSSION

The basic density of clone A (*Eucalyptus grandis × Eucalyptus urophylla*) was higher than that of clone B (*Eucalyptus saligna*), and this variable was lower in the trees that were damaged at all of the axial positions sampled and, consequently, in the tree as a whole (Table 1). The reduction in the production of photosynthetic compounds, through the decrement in the leaf area, limited the cambium activity, reducing the basic density of the wood produced. This loss is not usually accounted for by planted forest producers, who only consider the wood volume produced. The wood density of healthy plants or those damaged by insects varied between 440 and 473 kg m$^{-3}$, and these values were similar to those of 413 to 571 kg m$^{-3}$, for *Eucalyptus benthamii*, *Eucalyptus dunnii*, *Eucalyptus grandis* and *Eucalyptus grandis × Eucalyptus urophylla* with ages between 5 and 7 years old.[25,26]

Damage incurred by defoliating insects altered the wood's chemical composition (Table 2), increasing the extractives and lignin content, and decreasing the holocellulose content, but it did not affect the ash content of the two clones evaluated.

The extractives and lignin content increased up to 54% and 6.6%, respectively, while holocellulose content reduced up to 3.9%, because of the attack of defoliating insects. The content of extractives and lignin may also vary with the environmental conditions.[27,28] The extractives and lignin have a protective function against xylophagous agents and, therefore, their increase is a plant defense mechanism against damages caused by defoliating insects. Meanwhile, holocellulose has no protective function in the plant and, therefore, its biosynthesis is not so necessary.

The increase in the lignin and extractives contents in the wood damaged by *Ceratocystis fimbriata* was also reported previously for *Eucalyptus grandis* and *Eucalyptus urophylla*.[29,28] This shows that the trees have similar defense strategies against damage by bacteria or insects and for direct damage to the wood or leaves.

Changes in wood chemistry caused by the attack of defoliating insects affected the charcoal production and the quality of the obtained product (Table 3). The attacked trees showed higher carbonization gravimetric yield, the charcoal produced showed higher content of fixed carbon, and lower volatile matter and apparent relative density.

Table 1

Basic density of *Eucalyptus grandis × Eucalyptus urophylla* (clone A) and *Eucalyptus saligna* (clone B) trees, healthy or damaged by defoliating insects, and means per tree (MTree)

| Sample | Comercial height | | | | | MTree |
|---|---|---|---|---|---|---|
| | 0% | 25% | 50% | 75% | 100% | |
| Clone A healthy | 481$^{3.2}$a | 468$^{3.8}$a | 477$^{4.2}$a | 471$^{4.1}$a | 455$^{4.5}$a | 473$^{3.2}$ a |
| Clone A damaged | 464$^{3.4}$b | 455$^{3.8}$b | 440$^{4.7}$b | 445$^{4.5}$b | 436$^{4.7}$b | 451$^{3.8}$ b |
| Clone B healthy | 462$^{4.0}$a | 454$^{4.5}$a | 464$^{4.2}$a | 468$^{4.8}$a | 452$^{4.5}$a | 463$^{4.2}$ a |
| Clone B damaged | 442$^{4.2}$b | 440$^{4.3}$b | 439$^{4.1}$b | 441$^{4.6}$b | 438$^{3.7}$b | 440$^{4.0}$ b |

Means per clone, followed by the same letter per column, do not differ by the t test at 5% probability. Values in superscript represent the coefficient of variation

Table 2

Extractives (Ext.), soluble lignin (Lsol.), insoluble lignin (Lins.), total lignin (Ltot), ashes (A) and holocellulose (Hol.) for *Eucalyptus grandis × Eucalyptus urophylla* (clone A) and *Eucalyptus saligna* (clone B) trees, healthy or damaged by defoliating insects

| Sample | Ext. (%) | Lsol. (%) | Lins. (%) | Ltot. (%) | A (%) | Hol. (%) |
|---|---|---|---|---|---|---|
| Clone A healthy | 2.14$^{6.2}$a | 4.03$^{5.1}$a | 23.6$^{5.6}$a | 27.2$^{5.1}$a | 0.14$^{22.4}$a | 70.52$^{3.6}$a |
| Clone A damaged | 3.11$^{6.1}$b | 4.11$^{5.3}$a | 25.1$^{5.8}$b | 29.0$^{5.4}$b | 0.17$^{18.4}$a | 67.7$^{4.5}$b |
| Clone B healthy | 2.09$^{7.1}$a | 3.95$^{5.6}$a | 24.2$^{3.4}$a | 28.3$^{5.1}$a | 0.17$^{17.7}$a | 68.31$^{4.6}$a |
| Clone B damaged | 3.22$^{3.4}$b | 4.64$^{6.1}$a | 25.6$^{3.1}$b | 29.9$^{4.7}$b | 0.20$^{20.3}$ a | 66.68$^{4.8}$b |

Means per clone, followed by the same letter per column, do not differ by the t test at 5% probability. Values in superscript represent the coefficient of variation

Table 3

Wood calorific value (WCV), charcoal calorific value (CCV), gravimetric yield (GY),
fixed carbon (FC), volatile matter (VM), ash content (A) and apparent relative density (ARD) of wood and charcoal
from *Eucalyptus grandis* × *Eucalyptus urophylla* (clone A) and five healthy *Eucalyptus saligna*
(clone B) trees damaged by defoliating insects

| Sample | WCV (Mj Kg$^{-1}$) | CCV (Mj Kg$^{-1}$) | GY (%) | FC (%) | VM (%) | A (%) | ARD (Kg m$^{-3}$) |
|---|---|---|---|---|---|---|---|
| Clone A healthy | 19.6$^{3.2}$a | 31.12$^{4.3}$a | 32.52$^{4.9}$a | 75.37$^{4.3}$a | 24.02$^{4.9}$a | 0.62$^{20.2}$a | 313$^{4.6}$a |
| Clone A damaged | 19.2$^{4.8}$a | 32.02$^{5.3}$a | 33.79$^{3.6}$b | 77.66$^{5.4}$b | 22.15$^{3.9}$ b | 0.52$^{22.3}$a | 302$^{6.3}$b |
| Clone B healthy | 19.3$^{5.4}$a | 31.85$^{4.9}$a | 32.02$^{4.2}$a | 76.07$^{4.9}$a | 21.91$^{5.7}$ a | 0.66$^{18.9}$a | 305$^{5.3}$a |
| Clone B damaged | 19.5$^{5.3}$a | 31.92$^{5.0}$a | 33.03$^{4.9}$b | 77.23$^{5.5}$b | 23.46$^{5.1}$ b | 0.51$^{21.7}$a | 295$^{4.4}$b |

Means per clone, followed by the same letter per column, do not differ by the t test at 5% probability. Values in superscript represent the coefficient of variation

The damage incurred by defoliating insects increased the gravimetric yield from 32.52 to 33.79% for clone "A" and from 32.02 to 33.03% for clone "B". In addition, the fixed carbon content increased in both clones, from 75.35 to 77.66% in clone "A" and from 76.07 to 77.23% in clone "B". The changes in the fixed carbon content reduced the volatile matter content, but did not affect the ash content. These changes show the impact of the attack of defoliating insects on the chemical characteristics of the wood. Thus, the increase in the lignin content as a response to their attack results in materials with higher resistance to thermal degradation, increasing the gravimetric yield and the fixed carbon content.[16,30] The increase in the wood extractives may also have contributed to an increase in the gravimetric yield, as reported for eucalyptus and pine species.[17]

The apparent relative density of the charcoal was lower in trees damaged by defoliating insects (Table 3). The reduction of the wood's basic density in trees affected by defoliating insects decreases the apparent density of the charcoal[31] and, consequently, the energy density[32] and mechanical resistance[33] of the charcoal, making it difficult to use in the steel industry.

The calorific value and ash content of charcoal from both healthy trees and those damaged by defoliating insects were similar, but these parameters were higher in charcoal than in wood (Table 3). The calorific value ranged from 19.2 to 19.6 Mj kg$^{-1}$ for wood and from 31.12 to 32.02 Mj kg$^{-1}$ for the charcoal, this increase occurred due to the degradation of the hemicelluloses and cellulose during the carbonization. The high oxygen content of these compounds negatively influenced the energy release during carbonization. The increased ash content with carbonization is due to the minerals, which are not degraded at the carbonization temperature.[34]

Table 4

Wood volume per hectare (WV), wood basic density (WBD), charcoal gravimetric yield (CGY) and charcoal produced
per hectare (CPH) from healthy and damaged trees by defoliating insects per clone

| Sample | WV (m$^3$ ha$^{-1}$)* | WBD (kg m$^{-3}$) | CGY (%) | CPH (t) |
|---|---|---|---|---|
| Clone A healthy | 239 | 473.6 | 32.52 | 36.81 |
| Clone A damaged | 217 | 451.8 | 33.79 | 33.13 |
| Clone B healthy | 307 | 463.4 | 32.02 | 45.55 |
| Clone B damaged | 249 | 440.2 | 33.03 | 36.20 |

Wood volume per hectare was provided by the producer based on the forest inventory

The charcoal production per hectare from healthy trees was higher than when using trees damaged by insects, reducing the wood volume production per hectare by 9.2 and 18.9% for clones A and B, respectively (Table 4). Damage caused by defoliating insects reduced the wood basic density and consequently the mass of wood produced per hectare. However, the higher lignin content in plants with insect damage increased their gravimetric yield. Therefore, the charcoal production of clone A in healthy stands and those attacked by defoliating insects was 36.81 and

33.13 tons per hectare, respectively, and in stands of clone B the production was 45.55 and 36.20 tons, respectively. The lower apparent density of

**CONCLUSION**

Damage caused by defoliating insects altered wood quality and, consequently, charcoal production. The basic density of damaged trees resulted in lower biomass produced per hectare. The lignin and extractives contents were higher, holocellulose was lower and wood ash was similar in both healthy trees and those affected by defoliating insects. The chemical changes in the wood increased the carbonization gravimetric yield and the fixed carbon, but reduced the volatile matter. The charcoal production per hectare from trees damaged by insects was lower because of the decrease in the volumetric production of the wood. The basic density reduction was compensated by the increase in the gravimetric yield, thus, the wood quality did not affect the charcoal productivity per hectare. However, the changes in charcoal quality may affect its use in steel production.

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