Damage and Loss Due to *Ceratocystis fimbriata* in *Eucalyptus* Wood for Charcoal Production

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Eucalyptus plantation area has been increasing in Brazil, with 29% of the total plantation area being located in Minas Gerais state, which currently is being utilized primarily for charcoal production. However, diseases often increase the production costs of *Eucalyptus*. The objective of this study was to evaluate the effect of the fungus *Ceratocystis fimbriata* Ellis & Halsted on *Eucalyptus* wood for charcoal production. The basic density, volume, extractives, lignin, and holocellulose content of the wood were determined, as well as the gravimetric yield, volatile matter, fixed carbon, ash, and gross calorific values of charcoal. The introduction of the fungus *C. fimbriata* to *Eucalyptus* decreased the wood production and holocellulose content, but it also increased the wood's lignin and extractives content. The chemical changes in the wood did not affect the charcoal produced. Volume of wood losses due to *C. fimbriata* can result in a loss of up to 3478.43 US$/ha.

Keywords: Disease; Extractives; Gravimetric yield; Lignin

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INTRODUCTION

The *Eucalyptus* genus is widely used in planted forest in Brazil. Investments in research as well as favorable climate and soil have increased the average productivity of wood, reaching 40.7 m^3/ha·year (ABRAF 2013). Brazil is the only country that uses charcoal on an industrial scale, with 40% of the iron produced in the country using charcoal material as a heat source. The production of charcoal was 17.8 million cubic meters, which represents 21% of the eucalyptus wood produced in Brazil (ABRAF 2013). Minas Gerais state is the main eucalyptus producer in Brazil, accounting for 29% of the total planted area in the country (ABRAF 2013).

The timber plantations for charcoal production generate jobs and taxes in Brazil. The yield and quality of charcoal depends on both the raw material and the production process used by the manufacturer (Pereira *et al*. 2013; Protásio *et al*. 2013; Rousset *et al*. 2011, 2013). The charcoal production sector has shown overall increases above the national average, but problems related to production, such as damage by the fungus *Ceratocystis fimbriata* Ellis & Halsted, can affect productivity.

The fungus *C. fimbriata* has wide geographic distribution and various host-associated forms are native from Latin America and Asia (Harrington 2000). This fungus *C. fimbriata* has economic importance because of its ability to damage xylem (Baker *et al*. 2003). Symptoms of this disease are characteristically defined by radial stripes in cross sections of the wood (Harrington 2000). The fungus has been reported to affect such woody and herbaceous plants as *Coffea arabica* L.; *Eucalyptus* spp., *Ficus carica* L., *Gmelina arborea* Roxb, *Hevea brasiliensis* Muell. Arg., *Ipomoea batatas* Lam., *Mangifera indica* L., and *Theobroma cacao* L. (Baker *et al*. 2003).

Ceratocystis fimbriata damages wood crops, but studies on changes in wood quality and economic losses due to the fungus are scarce. Thus, the objective of this study was to evaluate the effect of *C. fimbriata* on production and quality of both wood and charcoal, as well as to estimate losses caused by this disease.

EXPERIMENTAL

Materials

The experiments were performed on seven-year-old plants of the VM3 clone (*Eucalyptus urophylla*), considered susceptible to *C. fimbriata*, in the municipalities of Paraopeba (19º 18'S, 44° 30'W), João Pinheiro[1] (17º 13'S, 46° 06'W), João Pinheiro[2] (17º 26'S, 46° 05'W), and Bocaiúva (17º 20'S, 43° 44'W), all located in Minas Gerais state, Brazil. Six healthy and six diseased trees were selected per location, totaling 48 trees.

Methods

The volume of the trees was determined using the Smaliam formula according to Leon and Valencia (2013). The volume obtained was extrapolated *per* hectare, using a basis of 3 × 3-m spacing between plants. In total, there were 1,111 plants *per* hectare.

Two 10-cm disks were removed from each tree at a height of 1.3 m from the soil. The first disk was triturated in a Wiley mill, and the fraction retained between 40- and 60-mesh sieves was used to obtain the total extractives content (TAPPI 204 om-88 1998) and lignin content (Goldschimid 1971; Gomide and Demuner 1986). The holocellulose content was obtained by subtracting the total lignin and extractives from 100. The second disk was used to determine the basic density in accordance with NBR 11941 (ABNT 2003). These parameters were performed in triplicate.

Fifty-centimeter samples were removed at the base, as well as at 50 and 100 percent of the commercial height of each tree, for carbonization. These logs were kept at 100 °C for drying. To obtain wood in a dry condition, the wood was weighed and carbonized in an electric furnace at a heating rate of 0.5 °C/min, a maximum temperature of 450 °C, and a residence time of 30 min, totaling 15 h and 30 min of carbonization time, similar to that reported by Pereira *et al.* (2013). The gravimetric yield was determined in triplicate, according Rousset *et al.* (2011), with Eq. 1,

$$\text{GY (\%)} = (\text{DMC}/\text{DMW}) \times 100 \quad (1)$$

where GY (%) is the gravimetric yield, DMC is equal to the dry mass of charcoal (kg), and DMW is the dry mass of wood.

To determine the density, the charcoal was placed in a box with internal dimensions of 40 x 40 x 40 cm. To avoid any effects of particle size distribution, the charcoal granules was standardized, adapted from NBR 6922 (ABNT 1983c). The density was determined in triplicate according to Eq. 2,

$$D = \text{MS} / 40^3 \quad (2)$$

where *D* is the density (g/cm^3), and MS is the mass of charcoal (g). The volatile matter, ash, and fixed carbon were determined according to NBR 8112 (ABNT 1983b). The gross calorific value of the charcoal was determined according to NBR 8633 (ABNT 1983a).

Both qualitative and quantitative data for wood and charcoal were subjected to the t test at 5% probability using R 2.15.1 software (R Project). The economic impact of *C. fimbriata* was based on the volumetric losses in timber production *per* hectare considering a price of 45.00 R\$/m^3, a measurement commonly used the in regions where the study was conducted. To provide prices in U.S. dollars, one dollar was considered 2.158 R\$, the average exchange rate recorded in 2013.

RESULTS AND DISCUSSION

The introduction of *C. fimbriata* to *Eucalyptus* reduced timber volumetric production in three of the four regions. Meanwhile, the overall content of lignin and extractives increased, while that of holocellulose decreased in three of the four areas evaluated (Table 1).

The basic wood density was not affected by the incidence of the disease (Table 1). The values obtained were consistent with other species of eucalyptus, between 0.442 and 0.648 g/cm^3 for *Eucalyptus benthamii*, *Eucalyptus camaldulensis*, *Eucalyptus grandis*, *Eucalyptus nitens*, and *Eucalyptus urophylla* (Couto *et al*. 2013; Inagaki *et al*. 2012; Martins *et al*. 2013; Medhurst *et al*. 2012; Zanuncio *et al*. 2013).

Table 1. Data for Healthy Plants and Plants Infected by *Ceratocystis fimbriata* in the Four Locations

Location	Condition	Vol. Prod.	Bas. Den.	Tot. Lig.	Extract.	Holoc.
Paraopeba	Healthy	485.31 $^{(44.8)a}$	0.475 $^{(0.42)a}$	29.85 $^{(1.2)a}$	2.88 $^{(0.2)a}$	67.27 $^{(2.8)a}$
	Infected	463.12 $^{(46.7)a}$	0.475 $^{(0.48)a}$	31.53 $^{(1.2)b}$	4.36 $^{(0.3)b}$	64.11 $^{(2.4)b}$
João Pinheiro[1]	Healthy	411.81 $^{(38.7)a}$	0.454 $^{(0.39)a}$	29.50 $^{(1.5)a}$	2.98 $^{(0.2)a}$	68.58 $^{(3.3)a}$
	Infected	366.31 $^{(32.4)b}$	0.470 $^{(0.41)a}$	31.08 $^{(0.8)b}$	4.13 $^{(0.3)b}$	64.79 $^{(3.7)b}$
João Pinheiro[2]	Healthy	569.31 $^{(55.8)a}$	0.474 $^{(0.4)a}$	30.90 $^{(0.7)a}$	2.40 $^{(0.2)a}$	66.7 $^{(2.8)a}$
	Infected	402.5 $^{(38.9)b}$	0.479 $^{(0.42)a}$	31.13 $^{(1.1)a}$	3.31 $^{(0.2)a}$	65.56 $^{(3.2)a}$
Bocaiúva	Healthy	449.12 $^{(43.2)a}$	0.511 $^{(0.51)a}$	29.06 $^{(0.7)a}$	4.03 $^{(0.4)a}$	66.91 $^{(3.5)a}$
	Infected	371 $^{(35.8)b}$	0.508 $^{(0.54)a}$	31.03 $^{(0.5)b}$	6.08 $^{(0.4)b}$	62.89 $^{(3.6)b}$

Consider each region separately; means followed by the same letter per column do not differ by the t test at 5% probability, standard deviation in parenthesis.
Volume Produced (m^3/ha) (Vol. Prod.), Basic Density (g/cm^3) (Bas. Den.), Total Lignin (%) (Tot. Lig.), Extractives (%) (Extract.), and Holocellulose (%) (Holoc.)

According to Table 1, the extractives content in infected trees in João Pinheiro[2] did not increase. In this area, the incidence of *C. fimbriata* caused a higher volume loss of 29.3%; meanwhile, the extractives in trees from Paraopeba increased by 51.38%, and no wood volume loss due to disease was reported, showing resistance to the fungus at the last location. The regions of Bocaiúva and João Pinheiro[1] showed intermediate numbers, with wood volume losses of 11.05 and 17.39% and an increase in extractives content of 50.86 and 38.59%, respectively. The results show variation in the extractive production according to environmental conditions, such as different soil and climate, among materials with the same genetic composition, similar to that reported for *Quercus pyrenaica*, *Eucalyptus urophylla* x *Eucalyptus grandis*, and *Eucalyptus globulus* (Alañón *et al*. 2011; Freire *et al*. 2005; Zanuncio *et al*. 2013b).

The decreased wood production in infected trees may be related to the increased desire to produce compounds that have high energy expenditure, such as lignin, whose biosynthesis requires more energy than holocellulose (Sjöströn 1981). Lignin has a similar function to extractives, in that it exhibits resistance to pathogens (Fengel and Wegener 1984), which explains its increase with the introduction of *C. fimbriata* in three of the four areas evaluated.

The holocellulose content, which has no role in resistance against pathogens, decreased in three of the four areas evaluated, reflecting the increase in lignin and extractives (Sjöströn 1981).

The charcoal gravimetric yield ranged from 28 to 40%, the bulk density ranged from 0.167 to 0.211 g/cm^3, the volatile matter ranged from 18.8 to 24.3%, the ash ranged from 0.4 to 0.7%, the fixed carbon ranged from 75 to 78.8%, and the gross calorific value ranged from 31,952 to 33,486 J/g (Table 2).

Table 2. Data for Charcoal from Healthy and Diseased Wood

Location	Type	Grav. yield	Bulk Density	Vol. Mat.	Ash	Fix. Carb.	Cal. Val.
Paraopeba	Healthy	40 (3.3) a	0.195 (0.02)a	24.3 (2.3)a	0.7 (0.09)a	75 (5.8)a	33030 (2145)a
	Infected	38 (3.1) a	0.201 (0.02)a	24.1 (2.2)a	0.6 (0.08)a	75.3 (5.1)a	32591 (2347)a
João Pinheiro[1]	Healthy	30 (2.8) a	0.190 (0.02)a	20.7 (2.2)a	0.8 (0.10)a	78.5 (6.3)a	33486 (2856)a
	Infected	28 (2.5) a	0.180 (0.02)a	19.9 (2.1)a	0.7 (0.10)a	79.4 (6.9)a	31952 (2568)a
João Pinheiro[2]	Healthy	34 (3.2) a	0.197 (0.02)a	22.8 (2.1)a	0.7 (0.09)a	76.5 (6.9)a	32989 (2743)a
	Infected	36 (3.1) a	0.187 (0.01)a	20.8 (1.9)b	0.4 (0.07)b	78.8 (6.4)b	31960 (2167)a
Bocaiúva	Healthy	40 (3.8) a	0.204 (0.03)a	22.0 (2.2)a	0.5 (0.08)a	77.5 (7.1)a	33127 (2287)a
	Infected	39 (3.1) a	0.211 (0.03)a	21.7 (2.3)a	0.5 (0.07)a	77.8 (7.3)a	33223 (2478)a

Consider each region separately; means followed by the same letter per column do not differ by the t test at 5% probability, standard deviation in parenthesis.
Gravimetric yield (%) (Grav. yield), Density (g/cm^3), Volatile Matter (%) (Vol. Mat.), Ash (%), Fixed Carbon (%) (Fix. Carb.), and Gross Calorific value (%) (Cal. Val.)

The cellulose and hemicellulose, rich in oxygen, have degradation range below the carbonization temperature used in this work. The lignin and extractives degrade in temperatures higher than that used in this work. Thereby, wood with high lignin and extractives content results in a high gravimetric yield of charcoal and materials with high calorific value (Shebani *et al*. 2008; Swithenbank *et al*. 2011; Zanuncio *et al*. 2014). However, the introduction of *C. fimbriata* increased the lignin and extractives content to a maximum at 2.03 and 2.05%, respectively, which was not sufficient to increase the gravimetric yield and calorific value of the charcoal. Accordingly, in the production chain, the incidence of *C. fimbriata* affects only the volumetric timber production.

The highest timber production was found for healthy trees in the João Pinheiro[2] area, with a volume of 569.31 m^3 per hectare after seven years. The João Pinheiro[2] area consequently had a gain of US$ 10,119.98 /ha, using an average price of R$ 45.00 m^3/wood and considering one dollar as 2.158 R$. However, the *C. fimbriata* reduced the production to 402.5 m³ per hectare after seven years, with a gain of US$ 8393.19 /ha, totaling a difference of US$ 3478.43/ha lower in comparison to health plants (Table 3).

Table 3. Area Evaluation Based on the Introduction of *Ceratocystis fimbriata* in Eucalypt Plantations

Location	Type	Wood Vol. (m^3)	Price (R$)	Price (US$)	(Losses/Hec.)* R$	(Losses/Hec.)* US$
Paraopeba	Healthy	485.31 ᵃ	21838.95 ᵃ	10119.98 ᵃ	998.55	462.72
	Infected	463.12 ᵃ	20840.4 ᵃ	9657.28 ᵃ		
João Pinheiro[1]	Healthy	411.81 ᵃ	18531.45 ᵃ	8587.33 ᵃ	2047.5	948.79
	Infected	366.31 ᵇ	16483.95 ᵇ	7638.53 ᵇ		
João Pinheiro[2]	Healthy	569,31 ᵃ	25618.95 ᵃ	11871.61 ᵃ	7506.45	3478.43
	Infected	402.5 ᵇ	18112.5 ᵇ	8393.19 ᵇ		
Bocaiúva	Healthy	449.12 ᵃ	20210.4 ᵃ	9365.34 ᵃ	3515.4	1629.01
	Infected	371 ᵇ	16695 ᵇ	7736.33 ᵇ		

Consider each region separately; means followed by the same letter per column do not differ by the t test at 5% probability
*Difference between gains from healthy and diseased trees per hectare. Calculations are as follows: Wood Volume Produced (Wood Vol.), Wood Price per Hectare (Price) and Losses per Hectare (Losses/Hec.)

The presence of *C. fimbriata* can reduce the wood production in *Eucalyptus* cultivated in Brazil. *C. fimbriata* has the potential to affect charcoal production with *Eucalyptus* wood. *C. fimbriata's* ability to affect charcoal production shows the need for studies to select resistant eucalyptus progenies to reduce the incidence of this disease.

CONCLUSIONS

1. Damage by *C. fimbriata* occurred, and its intensity varied according to region. The presence of *C. fimbriata* decreased timber production, increased lignin and extractives content, and reduced the holocellulose content in three of the four areas evaluated.
2. The chemical changes in the wood infected by *C. fimbriata* were not significant enough to change the gravimetric yield and properties of charcoal.
3. The reduction of timber production due to the presence of *C. fimbriata* can reach losses of US$ 3478.43/ha.

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