Journal of Cleaner Production xxx (2016) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Potential of teak heartwood extracts as a natural wood preservative

Victor Fassina Brocco [a, *], Juarez Benigno Paes [a], Lais Gonçalves da Costa [a], Sérgio Brazolin [b], Marina Donária Chaves Arantes [a]

[a] Department of Forest and Wood Science, Federal University of Espírito Santo, Av. Governador Lindemberg, 316, 29550-000, Jerônimo Monteiro, Espírito Santo, Brazil

[b] Institute for Technological Research of São Paulo State – IPT, Center for Forest Resources Technology, Av. Prof. Almeida Prado, 532, 05508-901, São Paulo, SP, Brazil

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form
10 November 2016
Accepted 12 November 2016
Available online xxx

Keywords:
Decay resistance
Eco-friendly preservative
Natural extracts
Tectona grandis
Wood protection

ABSTRACT

This study aimed to evaluate the preservative potential of teak (*Tectona grandis*) heartwood extracts against decay fungi. The waste obtained in the mechanical processing of 20-year-old teak wood was used to perform extractions in hot water and absolute ethanol. To evaluate the influence of teak extracts on the natural resistance of wood, a 10-year-old teak sapwood and *Pinus* sp. were used. To determine the concentration of the treatment solutions, a toxicity test to the brown rot fungus *Postia placenta* was performed. For the impregnation, a full-cell (Bethell) treatment was conducted. Biological assays with brown, white and soft-rot fungi were performed under laboratory conditions to test the efficiency of the teak extractive solutions. The solutions containing the absolute ethanol extractives promoted the best results in the decay resistance of the treated wood and significantly changed the resistance class of the respective treated species. The resistance to soft-rot fungi was not changed.

1. Introduction

Wood is a biological material, and it is subject to variability in its properties, such as physical, mechanical, chemical and natural resistance to deterioration by biotic and abiotic agents. The natural resistance to wood-destroying organisms is one of the properties that determines the susceptibility level of the wood to these organisms (e.g., fungi, termites, beetles and marine borers), and it is most often attributed to the presence, quantity and type of extractives.

High natural durability species have a range of use and a higher added value on the market. Teak wood (*Tectona grandis* Linn. f.) is known for its high natural resistance to wood-destroying organisms depending on its age, origin, quantity and type of extractive (Bhat et al., 2005; Thulasidas and Bhat, 2007; Dungani et al., 2012). Therefore, teak wood has high commercial value because it meets the requirements for the use of naturally durable woods on the market (Dungani et al., 2012).

However, some wood species have low natural durability and require preservative treatments to improve their performance and lifespan in their different uses. Most low durability wood on the market are treated under vacuum and pressure by industrial methods with waterborne preservatives made of metallic salts, which have high efficiency in protecting wood from wood-destroying organisms (Lebow, 2010; Bolin and Smith, 2011).

According to Lin et al. (2009) and Kartal et al. (2015), these preservatives include various chemicals, such as arsenic, chromium, copper and boron. These substances make the process expensive and are harmful to humans and the environment, and they require care during and after the end of life of the treated wood, representing a hazard in the disposal and reuse of this material (Wang et al., 2016).

Due to the aforementioned facts and in accordance with the role that extractives play in wood protection, several studies have highlighted the use of substances extracted from wood of naturally durable species as potential eco-friendly preservatives (Nakayama et al., 2001; Mburu et al., 2007; Syofuna et al., 2012; Kirker et al., 2013; Tascioglu et al., 2013; Mohammed et al., 2016).

Therefore, according to the influence of extractives on the natural resistance of wood, the aim of the present study was to evaluate the potential of extractives obtained from the waste produced in the mechanical processing of teak wood to increase the natural durability of treated wood.

* Corresponding author.
E-mail address: vfbrocco@hotmail.com (V.F. Brocco).

http://dx.doi.org/10.1016/j.jclepro.2016.11.074
0959-6526/

2. Material and methods

2.1. Species, origin, collection and sampling

The waste used in this research was obtained from the mechanical processing of four teak trees (*Tectona grandis* L.f.) from a plantation of Celulose Nipo-Brasileira - CENIBRA SA company, located in Belo Oriente in the region of Vale do Rio Doce, Minas Gerais State, Brazil (19°15'00″S, 42°22'30″W). The region is characterized by elevations ranging from 200 to 1000 m, an annual precipitation of 1163 mm and a red-yellow latosol (Oxisol) soil type (Lima et al., 2008). 20-year-old teak tress were used.

The logs were converted into 7 cm thick planks, and the sapwood was removed. After being air-dried, the planks were planed, and the waste produced (shavings) were collected, dried, homogenized and then stored in plastic bags to perform the extractions.

To verify the effectiveness of the heartwood extractives as a natural preservative against wood-destroying fungi, five teak trees from a 10-year-old second thinning were collected due to their high proportion of sapwood and low biological resistance (Moya and Berrocal, 2010). These trees were collected in the city of Sooretama, Espírito Santo State, Brazil, on a plantation intercropped with coffee and located at 19°08'41″S, 40°06'17″W. The region is characterized by an average elevation of 50 m, an average annual rainfall of 1200 mm and a sandy dystrophic red-yellow latosol (Oxisol) tableland soil type (Paula and Soares, 2011).

Free from defects trees with an average diameter at breast height (DBH) of 22.00 cm were obtained, and the first two 2.50 m logs were collected from each tree. The logs were converted, and the sapwood was used for the preparation of the samples for impregnation with the preservative solutions obtained from the 20-year-old teak heartwood extractives. Boards of *Pinus* sp. were acquired from the local commerce and were also used to evaluate the influence of the teak extractives because they are widely used in wood sawmills and are a low natural resistance wood.

2.2. Quantification of extractives and production of treatment solutions

2.2.1. Quantification of teak extractives

For easier extraction, the wood shavings generated from the mechanical processing of the 20-year-old teak heartwood were transformed into sawdust in a Wiley mill using a 0.5 cm sieve. The sawdust was classified via particle sieving using a 0.30 mm (48 "mesh") sieve to retain the material to be used. The classified sawdust was stored in an air-conditioned room (25 ± 2 °C with 65± 5% relative humidity) reaching an average moisture content of 10.16%, and then it was used for the extractions.

The quantification of the teak heartwood extractives was performed using a representative sample (500 g) of all the sawdust obtained. The material was again classified, and the sawdust that passed through the 40 "mesh" sieve and was retained in the 60 "mesh" sieve was used.

The determination of the extractives was performed in hot water according to the recommendations of the "American Society for Testing and Materials" - ASTM D-1110 (2005) and in absolute ethanol as recommended by the "Technical Association of the Pulp and Paper Industry" - TAPPI T 264 om-88 (1992). For each extraction, three replications were used.

2.2.2. Obtaining the teak extractive solutions

To produce the treatment solutions to be impregnated into the wood, the sawdust classified through the 0.30 mm sieve was subjected to hot water extraction (HW) and cold extraction in absolute ethanol (AE).

In the extractions, for each 2 kg of sawdust, 10 L of solvent (water or absolute ethanol) were added. In the HW extraction, the samples were boiled without applying pressure, in an autoclave, in a cylindrical container made of stainless that had a capacity of approximately 30 L for two and a half hours.

In the case of AE extractions, cold extractions were performed in which the sawdust was subjected to extraction in a properly sealed plastic container that had a capacity of 50 L. The container containing the material was stirred four times a day, and the extractions lasted for 24 h.

In the both cases, each sample was extracted two times to remove the maximum amount of extractives present. After each extraction, the material was filtered through a 0.053 mm (270 "mesh") sieve to retain particles of sawdust and stored in a refrigerator (±10 °C) as recommended by Syofuna et al. (2012).

2.2.3. Toxicity test and final concentration of the extractive solutions

Three aliquots of 50 mL were taken from the hot water extractive solutions and dried at 103 ± 2 °C for 24 h to determine the total solids content (TSC) initially present in the extract. Equation (1) was used for TSC determinations.

$$TSC = (M_2/M_1) \times 100 \quad (1)$$

TSC: Total solids content (%);
M_1: Initial mass of the aliquot (g) and
M_2: Dry mass of the aliquot (g).

After determining the initial concentration based on TSC, seven concentrations (0.125%, 0.25%, 0.50%, 1%, 2%, 4% and 8% TSC) of the extractive solutions were prepared with the HW extracts by adding distilled water or via artificial evaporation. These solutions were used to prepare a malt:agar (2:1.5%) medium to determine the concentration for inhibition fungal growth of *Postia placenta* in Petri dishes due to the fast growth and high decay potential of this fungus.

The evaluation of the fungal growth was performed in Petri dishes when the mycelial growth filled the entire diameter of the control treatment plate (without extractives). The measurements were conducted using a 0.01 mm accuracy digital caliper to measure the diameter of fungal colonies in two perpendicular directions, and then the growth inhibition (%) was calculated.

Hot water extraction include fewer compounds and substances that generally no affect the wood natural resistance compared to the compounds obtained in ethanol (Oliveira et al., 2005). Thus, the concentration that promoted no fungal growth for the hot water extracts was also used for the absolute ethanol extracts.

The obtained extractive solutions were adjusted to the final concentration via artificial evaporation. For the concentration of the absolute ethanol solution, a 1-L capacity flat bottom flask connected to a "Liebig" condenser (30 cm) was used for ethanol recovery.

A third treatment solution consisting of a mixture of the solutions extracted in hot water and absolute ethanol (HW + AE) with a ratio of 1:1 with the same concentration was also used for the impregnation.

2.2.4. Wood treatment

The three obtained solutions were used for the preservative treatment of the 10-year-old teak sapwood and *Pinus* sp. For each