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Efficacy of linseed- and tung-oil-treated wood against wood-decay fungi and water uptake

Miha Humar[a,*], Boštjan Lesar[a,b]

[a] University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, SI-100 Ljubljana, Slovenia
[b] Zimic Group, U., Bratov Komel 29, 1210 Ljubljna, Šentvid, Slovenia

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ABSTRACT

Most European wood species do not have durable wood. In order to be used in outdoor conditions, non-durable material must be protected. Non-biocidal solutions for wood protection have been attracting a lot of attention, particularly in class 2 and 3 applications. One non-biocidal technique is treatment of wood with water repellents, such as wax emulsions and oils. Linseed oil and tung oil are frequently used water repellents. This research reports on the performance of linseed- and tung-oil-treated Norway spruce and beech wood against wood-decay fungi. Additionally, short-term hydrophobic properties were determined (with a tensiometer), as well as long-term hydrophobic properties (by soaking in water) in laboratory and outdoor conditions (electrical resistance measurements). Wood treated with tung oil and linseed oil is protected against brown- and white-rot fungi; however, tung oil was found more effective. Not only did the oils tested prove efficacious against wood-decay fungi, but also they worked against short-, medium-, and long-term water uptake as well. Oil treated wood takes up less water during laboratory tests, as well as during outdoor testing.

1. Introduction

Environmental concerns in recent years have resulted in renewed interest in non-biocidal solutions for wood protection, such as water repellents (Palanti et al., 2011; Thybring, 2013). They reduce the rate of water uptake into the capillaries. The rate of water uptake can be considerably reduced either by providing a water barrier, or by rendering the wood hydrophobic; although, actually, very few materials are truly hydrophobic, with a water/solid contact angle of more than 90° (Rowell and Banks, 1985). Depending on the amounts used, water repellents are applied to wood fill in the cell lumina or they are deposited on the pore surfaces and affect the hydrophobic properties of the material surface (Rowell and Banks, 1985; Hyvönen et al., 2006). Since the wood capillaries are at least partially blocked, water cannot penetrate the wood by capillary action and the rate of water absorption is thus limited (Banks and Voulgaridis, 1980). These hydrophobic treatments only slow down water penetration; they do not fully prevent it. After a long period of soaking in water, wood treated with water repellents usually retains similar amounts of water and swells to the same extent as untreated wood (Thybring, 2013). However, most wood in use class 2 applications (above ground covered) and use class 3 (above ground uncovered) (European Committee for Standardisation, 2006) is exposed to weathering for limited periods only, and water repellents perform well in such conditions. One of the most important advantages of water repellents is that they do not generally seal the surface of the wood and therefore they allow the wood to dry after precipitation (Williams and Feist, 1999). The reduction of the average moisture content is sufficient to slow down the rate of fungal attack (Feist and Mraz, 1978; Lesar and Humar, 2011).

The most important water repellents used in wood preservation are waxes (wax emulsions) (Lesar and Humar, 2011), organosilicon compounds (De Vetter et al., 2009), and drying oils (Schultz et al., 2007). They are used alone or are incorporated into aqueous wood preservatives to reduce checking and improve the appearance of treated wood exposed outdoors (Evans et al., 2009). Tung oil is a drying oil obtained by pressing seeds from the nut of the tung tree (*Vernicia fordii*; *Vernicia montana*). As a drying oil, tung oil dries on exposure to air, forming a transparent film. Tung oils consist of the following fatty acids: palmitic acid (5.5%), oleic acid (4.0%), linoleic acid (8.5%), and alpha-eleostearic acid (82.0%) (Anonymous, 2012). The second oil that was included in this research was linseed oil. This is a clear to yellowish oil obtained from dried ripe seeds of the flax plant (*Linum usitatissimum*). Linseed oil is also a drying oil. It consists of the following acids:

* Corresponding author. Tel.: +386 1 320 3638; fax: +386 1 423 5035.
E-mail address: miha.humar@bf.uni-lj.si (M. Humar).

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unsaturated α-linolenic acid (from 51.9% to 55.2%), saturated palmitic acid (about 7%) and stearic acid (from 3.4 to 4.6%), monounsaturated oleic acid (18.5–22.6%) and double unsaturated linoleic acid (4.2–17%). Several studies have reported that impregnation of wood with linseed oil improves resistance against wood-decay fungi but not to the level required to fulfil the requirements of the EN 113 standard (Spear et al., 2006). Furthermore, the results presented by Edlund and Jermer (2007) clearly indicate that the durability of linseed-oil-treated wood in ground use could be significantly improved if sufficient retentions of oils are applied (Weight Percent Ggain (WPG) between 68% and 88%). However, use of linseed oil in outdoor applications is limited due to the poor surface appearance. There have not been many reports on the performance of tung-oil-treated wood, either in outdoor conditions or in the laboratory.

2. Materials and methods

2.1. Treatment solutions used

Three types of drying oils were used for impregnation: linseed, rustikal, and tung oil of two concentrations—50% and 100%. The lower concentration of tung oil was prepared by dilution with hexane. Those oils are commercially available from Samson (Slovenia). Concentrations of wax emulsion and oil are shown in Table 1 (100% is commercially available solution). Rustikal oil is a commercially available hydrophobic treatment, composed of linseed oil, esters of colophony, palm wax, citrus oils, siccative, etc. (Samson, 2011).

2.2. Wood decay test

The fungicidal properties of wood impregnated with different oils were determined according to the EN 113 procedure (European Committee for Standardisation, 2004), on Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) wood samples (A) (Table 1) of dimensions 0.8 mm × 15 mm × 40 mm. Prior to fungal exposure, specimens were treated with the oils (vacuum 70 mbar, 20 min; pressure 8 bar, 60 min; vacuum 70 mbar, 10 min), as shown in Table 1. After impregnation, specimens were conditioned for three weeks. Steam-sterilized impregnated and non-impregnated wood specimens were exposed to three brown-rot (*Antrodia vaillantii*, *Serpula lacrymans*, and *Gloeophyllum trabeum*) and three white-rot (*Trametes versicolor*, *Pleurotus ostreatus*, and *Hypoxylon fragiforme*) fungi. Beech wood specimens were exposed to white rot, Norway spruce ones to brown-rot fungi. There were five replicate specimens used. After 12 wk of fungal exposure, specimens were isolated and mass losses were gravimetrically determined and expressed in percentages of the initial mass.

2.3. Short-term water uptake (tensiometer)

Samples for determination of the uptake of oils and water were prepared from Norway spruce only. The dimensions of the samples were: 25_T mm × 25_R mm × 50_A mm (B) (Table 1). Conditioned samples were impregnated (vacuum 70 mbar, 30 min; pressure 8 bar, 90 min; vacuum 70 mbar, 10 min) with the respective oils, as shown in Table 1. Ten samples were prepared for each treatment. The samples were conditioned for an additional 3 wk prior to testing. The measurements were carried out at room temperature, 20 °C, at an RH of (50 ± 5)% on a Krüss Processor Tensiometer K100MK2. Axial surfaces of the specimens were positioned to be in contact with the test liquid and their masses were subsequently measured continuously every 2 s for 200 s. Other parameters used were: velocity before contact 6 mm/min, sensitivity of contact 0.005 g, and depth of immersion 0.5 mm.

2.4. Long-term water uptake tests

Samples (C) (Table 1) (25 mm × 25 mm × 50 mm) of Norway spruce (*Picea abies*) and beech (*F. sylvatica*) were vacuum/pressure impregnated with various preservative solutions according to the full cell process (vacuum 70 mbar, 20 min; pressure 8 bar, 90 min; vacuum 70 mbar, 10 min). After impregnation, the retention of the preservative solution was determined gravimetrically. The samples were then conditioned in room conditions (21 °C and 65% RH) for 2 wk; they were then dried for 3 days at 40 °C.

Long-term water uptake testing was performed according to a slightly modified standard EN 927-5 (European Committee for Standardisation, 2000) procedure on Norway spruce samples (C) (Table 1) measuring 70 mm × 20 mm × 150 mm. Prior to impregnation, specimens were coated with epoxy coating (EPOLOR, Color) on five sides, leaving the test surface uncoated (70 mm × 150 mm). After three days of drying in room conditions, half of the specimens were vacuum/pressure impregnated according to the full cell process (vacuum 70 mbar, 30 min; pressure 8 bar, 90 min; vacuum 70 mbar, 10 min) with oils, as shown in Table 1. The samples were then conditioned in room conditions (21 °C and 65% RH) for 3 wk, until a constant mass was reached. Samples were thereafter placed with the test surface in distilled

Table 1
Uptake of preservative solution and retention of different oils by Norway spruce and beech wood samples used in fungicidal and sorption tests.

Treatment solution	Conc. (%)	Type of samples*	Spruce wood		Beech wood	
			Uptake of preservative solution (kg/m^3)	Retention (kg/m^3)	Uptake of preservative solution (kg/m^3)	Retention (kg/m^3)
Control	0	A	0	0	0	0
Linseed oil	100	A	485 (49)	442 (83)	426 (24)	348 (18)
Rustikal oil	100	A	256 (89)	231 (87)	417 (34)	374 (29)
Tung oil A	50	A	462 (60)	268 (36)	361 (22)	206 (13)
Tung oil B	100		327 (107)	311 (94)	416 (23)	383 (22)
Control	0	B	0	/	/	/
Linseed oil	100	B	159 (58)	/	/	/
Rustikal oil	100	B	79 (13)	/	/	/
Tung oil A	50	B	203 (77)	/	/	/
Tung oil B	100	B	116 (50)	/	/	/
Control	0	C	0	/	/	/
Linseed oil	100	C	27 (5)	/	/	/
Rustikal oil	100	C	15 (2)	/	/	/
Tung oil B	100	C	20 (5)	/	/	/

*A – Fungicidal test: 0.8 mm × 15 mm × 40 m. B – Short term water uptake: 25 mm × 25 mm × 40 mm. C – EN 927-5 long term water uptake test: 70 mm × 20 mm × 150 mm.