Mycobiology 30(1): 37-40 (2002)

Sapstain and Mold Control on Radiata Pine Lumber: Laboratory and Field Tests of Selected Fungicides

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(Received January 29, 2002)

The susceptibility of radiata pine sapwood to fungal attack and the ability of selected fungicides to control colonization of sapstain and mold fungi on green radiata pine sapwood were evaluated. Radiata pine sapwood was highly susceptible to fungal staining, suggesting that prompt application of fungicides after sawing is essential for preventing fungal colonization. The ability of commercial fungicides to prevent fungal discoloration on radiata pine sapwood was assessed using an accelerated 6-week test on small samples in the laboratory, and in field tests using bulk-piled boards exposed outdoors for 6 weeks during summer rainy season. In laboratory tests, Hylite extra provided excellent protection against fungal discoloration even at the lowest concentrations. Hylite clear, Britewood S, and NP-1 Plus provided good short-term protection (2 to 4 weeks), but higher chemical loadings were required for long-term protection (6 weeks). Woodguard produced little or no protection over the test periods. In field tests, Kathon 893 provided markedly superior protection at the concentration of 0.5 percent or higher. NP-1 Plus provided relatively good protection at all concentrations evaluated. Hylite extra was effective only for short-term protection (2 to 4 weeks) at all concentrations tested, but higher solution strengths were needed for long-term protection.

KEYWORDS: Fungal discoloration, Fungicides, Mold, Radiata pine, Sapstain

Radiata pine (*Pinus radiata* D. Don), currently being imported from New Zealand, Chile, and Australia, is the most important lumber source in Korea, and accounts for approximately 60 percent of the nations lumber production (Korea Forest Service, 2000). However, green radiata pine sapwood is highly susceptible to attack by sapstain and mold fungi, particularly during warmer weather. Preventing fungal staining will be essential for the production of clean lumber, thereby reducing the increased losses in revenue due to fungal discoloration. Fungal discoloration can be prevented by rapid kiln drying the wood below the fiber saturation point or surface application of fungicides (Zabel and Morrell, 1992). Although the immediate kiln drying can effectively control fungal discoloration, majority of lumber produced in Korea is air-dried because of the added costs associated with kiln drying. Therefore, chemical treatments must be employed for effective protection from fungal staining.

A variety of fungicides have been developed and tested for control of sapstain and mold (Cassens and Eslyn, 1983; Cserjesi and Johnson, 1982; Drysdale, 1987; Hayward *et al.*, 1984; Kim *et al.*, 1999; Morrell *et al.*, 1998; Presnell and Nicholas 1990; Wakeling and Maynard, 1997; Wakeling *et al.*, 1999), but efficacy of these compounds can vary with wood species and the form in which the wood is treated (Miller and Morrell, 1989; Miller *et al.*, 1989; Tsunoda and Nishimoto, 1985). In this study, the susceptibility of radiata pine sapwood to fungal staining was assessed using fungi isolated from stained radiata pine, and the ability of selected fungicides to prevent fungal staining was evaluated on radiata pine sapwood in both laboratory and field tests.

Materials and Methods

Stain susceptibility tests. Sapstain and mold fungi isolated from stained radiata pine lumber were inoculated on 2 percent malt extract agar in petri dishes and incubated at 25°C. The fungi tested were *Acremonium killiens*, *Fusarium* spp., *Geotrichum candidum*, *Gliocladum viride*, *Graphium putredinis*, *Leptographium* sp., *Monillia americana*, *Penicillium* spp., *Rhinocladiella atrovirens*, *Sporothrix* sp., and *Trichoderma* spp. The inoculum for each fungus was kept separately for block application. After incubation for 7 to 14 days, a plate of each organism was flooded with sterilized distilled water and the agar surface was scraped lightly with a rubber rod to dislodge spores and mycelial fragments. Radiata pine sapwood blocks (5 by 10 mm in cross section and 50 mm long), cut from freshly sawn boards and sterilized using ethylene oxide gas, were dipped into selected fungal inoculum for 30 seconds and then laid on U-shaped glass rod over moistened filter papers in glass petri dishes. Fifteen replicates were used for each fungus. The dishes were sealed

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with parafilm to prevent moisture loss and incubated at 25°C. The degree of discoloration on block surface was visually estimated 2, 4, and 6 weeks after incubation using a scale from 0 (no discoloration) to 100 (complete discoloration).

Laboratory tests. The ability of selected fungicides to control fungal discoloration was assessed by dipping green radiata pine blocks (7 by 20 mm in cross section and 70 mm long) for 1 minute in a solution of diluted fungicide. Six concentrations (Table 2) were formulated for each fungicide, and each concentration was tested on seven blocks. The tested fungicides included: Britewood S, a formulation containing sodium ortho-phenylphenate (Contechem Inc.); Hylite clear, a formulation containing ortho-phenylphenate, carbendazim, and 3-iodo-2-propynyl butyl carbamate (Osmose New Zealand); Hylite extra, a formulation containing carbendazim and copper-8-hydroxyquinolate (Osmose New Zealand); NP-1 Plus, s formulation containing didecyl dimethyl ammonium chloride and 3-iodo-2-propynyl butyl carbamate (Kopcoat Inc.); and Woodguard, a formulation containing 3-iodo-2-propynyl butyl carbamate (Hanchem Inc.). Blocks dipped in distilled water served as untreated controls. After dip treatment, the blocks were allowed to drain, then place on plastic mesh over moistened paper towels in an aluminum pan. The blocks were sprayed to runoff with a fungal inoculum cocktail prepared by combining the inoculum for each of the fungi as described earlier and pans were covered with aluminum foil to retard moisture loss. Following the inoculation, the blocks were incubated at 25°C for 6 weeks. The blocks were resparayed with the inoculum cocktail at 1-week intervals until the surfaces of the untreated control blocks were overgrown with sporulating fungi. After 2, 4, and 6 weeks of incubation, each block was visually scored on the upper surface for degree of fungal discoloration as described earlier.

Field tests. Twenty freshly sawn radiata pine sapwood boards (45 by 90 mm in cross section and 1,000 mm long), free of knots, wane, resin pockets, visible fungal discoloration, and any other defects, were given an agitated dip for 1 minute in test solutions (Table 3). Of the fungicides evaluated in laboratory tests, Hylite extra and NP-1 Plus were included because the former chemical gave the best performance under laboratory conditions and the latter chemical is the fungicide that most often used in western U.S. (Hansen and Morrell, 1997) regardless of laboratory test results. Kathon 893, a formulation containing 2-n-octyl-4-isothiazolin-3-one (Rohm and Hass Co.) was tested because of its markedly superior performance for controlling fungal discoloration in radiata pine log study (Kim, 2000). Untreated boards served as control. Following dipping, boards were block-stacked (four boards high and five boards wide) with best face for testing upturned on a pair of bearer placed on an asphalt-sealed surface. Treated packets were stored in a drying shed at a local sawmill to prevent rain wetting. The tests commenced in early July, with the onset of rainy season and were completed by mid August 2001. Mean temperature, mean relative humidity, and total rainfall of a test site during field tests were 26.6°C, 80.4%, and 219 mm, respectively (Korea Meteorological Administration, 2000). After 2, 4, and 6 weeks of storage, the packets were opened. Each board was examined visually for the extent of fungal discoloration over its upturned surface as described earlier.

Results and Discussion

Stain susceptibility tests. The degree of fungal discoloration on radiata pine sapwood is presented in Table 1. Discoloration was more intense with exposure time, although the increase varied depending on fungus. *Graphium putredinis*, *Leptographium* sp., *Penicillium* spp., and *Rhinocladiella atrovirens* showed predominant staining ability, suggesting the importance of these fungi in staining of radiata pine sapwood. These fungi produced very heavy discoloration even at 2 weeks of exposure and complete stain over the entire block surface after 4 weeks. *Fusarium* spp. *Gliocladum viride*, *Monillia americana*, and *Trichoderma* spp. produced moderate to heavy discoloration after 4 weeks. However, *M. americana* and *Trichoderma* spp. produced slight discoloration in 2 weeks, suggesting they were not fully functional on the wood substrate in 2 weeks. *Penicillium* secies produced spores over the entire block surface, but *Trichoderma* species produced spores more sporadically. *Acremonium killiens*,

Table 1. The degree of discoloration of untreated radiata pine sapwood exposed to pure cultures of sapstain and mold fungi isolated from stained radiata pine lumber

Fungus	Incubation period (weeks)		
	2	4	6
Acremonium killiens	0.0 (0.0)[a]	0.0 (0.0)	0.0 (0.0)
Fusarium spp.	56.0(25.1)	89.0 (7.0)	89.5 (6.4)
Geotrichum candidum	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Gliocladium viride	55.0(24.5)	73.0(29.7)	77.0(28.2)
Graphium putredinis	82.5(13.2)	99.0 (2.1)	99.5 (1.6)
Leptographium sp.	84.7 (8.3)	100.0 (0.0)	100.0 (0.0)
Monillia americana	6.0 (4.8)	46.7(28.7)	54.3(27.1)
Penicillium spp.	94.0 (6.0)	100.0 (0.0)	100.0 (0.0)
Rhinocladiella atrovirens	97.7 (3.2)	100.0 (0.0)	100.0 (0.0)
Sporothrix sp.	5.5 (2.2)	5.9 (3.3)	6.4 (4.7)
Trichoderma spp.	17.7(11.0)	49.7(19.4)	65.0(14.0)

[a]The degree of discoloration is based on ratings from 0 (no stain) to 100 (completely stained); values are means of 15 replications per fungus (values in parentheses represent one standard deviation).

Table 2. Ability of selected chemicals to inhibit fungal stain of radiata pine sapwood in small-scale laboratory evaluations

Chemical (trade name)	Concentration (% total a.i.)	Incubation period (weeks) 2	4	6
Control	0.00	93.9 (6.3)[a]	98.9 (2.1)	100.0 (0.0)
(water treated)	0.50	2.1 (3.9)	15.7 (7.3)	30.7(14.9)
Britewood S	1.00	2.1 (5.7)	15.7 (9.2)	21.4(10.8)
	2.00	0.0 (0.0)	7.1 (9.9)	14.3 (7.2)
	3.00	0.0 (0.0)	9.3 (7.1)	28.6(11.8)
	3.50	0.0 (0.0)	0.0 (0.0)	7.9 (6.4)
	4.00	0.0 (0.0)	0.0 (0.0)	9.3 (9.3)
Hylite clear	0.52	1.4 (2.4)	17.1 (7.5)	28.6 (7.4)
	0.77	1.4 (2.4)	10.7 (6.8)	22.1(10.9)
	1.03	0.0 (0.0)	2.9 (3.9)	4.3 (3.1)
	1.29	0.0 (0.0)	6.4 (4.5)	12.1 (6.2)
	1.55	0.0 (0.0)	3.6 (3.8)	11.4 (8.5)
	2.06	0.0 (0.0)	1.4 (2.4)	7.9 (4.0)
Hylite extra	0.08	0.0 (0.0)	0.7 (1.9)	1.4 (2.4)
	0.15	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	0.23	0.0 (0.0)	0.7 (1.9)	0.7 (1.9)
	0.30	0.0 (0.0)	0.0 (0.0)	0.7 (1.9)
	0.38	0.0 (0.0)	0.0 (0.0)	0.7 (1.9)
	0.45	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
NP-1 Plus	0.25	18.6(10.3)	26.4(11.4)	44.3(21.1)
	0.50	13.6 (6.0)	27.1(12.3)	39.3(15.4)
	0.75	6.4 (7.0)	11.4 (8.0)	18.6(14.3)
	1.00	5.7 (8.4)	14.3(10.1)	21.4(14.1)
	1.25	3.6 (4.6)	7.9 (6.1)	10.0 (6.2)
	1.50	0.7 (1.9)	4.3 (3.3)	7.1 (4.9)
Woodguard	0.13	73.6(23.1)	77.9(30.4)	96.4 (5.6)
	0.25	51.4(18.5)	64.3(13.7)	90.7 (9.8)
	0.50	25.0 (7.7)	61.4(11.4)	72.1(11.0)
	0.75	25.0 (9.4)	63.6(12.3)	75.0(18.7)
	1.00	3.6 (5.6)	30.0 (7.9)	47.9(12.6)
	1.25	1.4 (2.4)	11.4 (5.5)	46.4(13.6)

[a]The degree of discoloration is based on ratings from 0 (no stain) to 100 (completely stained); values are means of 7 replications per fungus (values in parentheses represent one standard deviation).

Geotrichum candidum, and *Sporothrix* sp. produced none or little stain because of nonpigmentation of fungal hyphae on wood blocks. These results provide that radiata pine sapwood is highly susceptible to fungal staining, and treatment with proper fungicide must be applied to freshly sawn lumber after sawing unless the lumber can be immediately kiln-dried.

Laboratory tests. Table 2 gives laboratory test data for five commercial fungicide formulations tested at a range of concentrations. For the purpose of the tests, stain ratings of 20 or less were considered to have an acceptable stain control. Four of the five fungicides produced effective control of stain and mold fungi for at least one concentration for 6 weeks. Hylite extra provided excellent protection even at the lowest concentration tested. Hylite clear, Britewood S, and NP-1 Plus provided intermediate protection to fungal discoloration at concentration of about 1.0 percent or higher. Woodguard produced unacceptable protection at any concentrations evaluated after the 6-week period. However, Woodguard gave good-to-excellent protection against sapstain and mold fungi on Korean pine sapwood (our unpublished data), indicating that the efficacy of fungicides can vary with wood species as reported by Tsunoda and Nishimoto (1985). Also, Oh *et al.* (1999) reported Woodguard was effective in controlling fungal staining on radiata pine sapwood, suggesting that the efficacy of fungicides can vary with fungi used in tests. For a reference, they used test fungi (*Aspergillus niger*, *Aurebasidium pullulans*, *Gliocladium virens*, *Penicillium funiculosum*, and *Rhizopus stolonifer*) specified in Japanese Wood Preserving Association (1992) while we used fungi isolated from stained radiata pine sapwood (Table 1).

Table 3. Ability of selected chemicals to inhibit fungal stain of radiata pine lumber in field trials

Chemical (trade name)	Concentration (% total a.i.)	Exposure period (weeks) 2	4	6
Control		73.4(18.5)[a]	86.6(9.1)	92.8 (6.8)
(water treated)	0.05	5.0 (0.0)	14.7(4.2)	57.5(19.7)
Hylite extra	0.08	3.1 (3.6)	17.5(4.3)	51.6(14.8)
	0.13	0.9 (2.0)	9.4(2.3)	35.3 (8.7)
NP-1 plus	0.50	3.8 (3.9)	5.0(3.7)	21.9 (7.0)
	0.75	11.9 (4.4)	17.8(5.3)	18.8 (8.6)
	1.00	10.6 (3.5)	14.4(4.5)	18.4 (5.2)
Kathon 893	0.25	3.4 (3.0)	12.2(4.9)	37.2(14.6)
	0.50	1.6 (2.4)	4.7(5.3)	7.8 (5.2)
	1.00	0.3 (1.3)	1.9(3.0)	3.8 (3.2)

[a]The degree of discoloration is based on ratings from 0 (no stain) to 100 (completely stained); values are means of 20 replications per fungus (values in parentheses represent one standard deviation).

Freshly sawn lumber normally requires chemical treatment for short-term protection when there are delays before kiln drying, especially in summer rainy season. All fungicides except for NP-1 Plus and Woodguard were effective at all concentrations after 2 or 4 weeks of exposure. NP-1 Plus controlled fungal growth at all concentrations tested for 2 weeks, but the protection decreased after the additional 2 weeks of exposure. Woodguard provided protection at the concentrations higher than 1.0 percent at 2 weeks, but at the concentration of 1.25 percent for 4 weeks.

Field tests. The efficacy of fungicides in field tests is summarized in Table 3, and any treatments with stain ratings of 20 or less were deemed effective. Severe surface discoloration developed on untreated boards even after 2 weeks of storage, indicating that fungal activity was high during the test period. After 6 weeks of outdoor storage, Kathon 893 provided excellent protection at the concen-

tration of 0.5 percent or higher. NP-1 Plus provided relatively good protection at all concentrations evaluated. The better performance of NP-1 Plus in field tests in comparison with in laboratory tests was not surprising because conditions for fungal discoloration was different between in the laboratory and field, suggesting that the effectiveness of fungicides must be evaluated by field trials. Extensive staining was observed on boards treated with Hylite extra regardless of concentrations tested. Hylite extra was effective for short-term protection (2 to 4 weeks) at all concentrations tested, but higher solution strengths were needed for long-term protection.

Acknowledgement

This research was supported by Korea Research Foundation Grant (KRF-2000-G00071).

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