Resistance of eastern redcedar panels to damage by subterranean termites (Isoptera: Rhinotermitidae)

Brad Kard
Salim Hiziroglu*
Mark E. Payton

Abstract

This study investigated resistance of experimental particleboard-chip panels manufactured from eastern redcedar (*Juniperus virginiana* L.) to feeding by the wood-destroying eastern subterranean termite, *Reticulitermes flavipes* (Kollar). Eastern redcedar raw chips with or without foliage, and 2.5 by 2.5 by 1.3-cm rectangular blocks of single-layer or triple-layer particleboard-chip panels with or without foliage were exposed to foraging termites. Chips and blocks sustained some damage by feeding termites but were not equally preferred. In choice tests, where all chips and panel blocks plus controls were simultaneously available to foraging termites, radiata pine sustained 44.6 percent weight loss compared with 2.1 to 6.1 percent weight loss for chips and blocks. In no-choice feeding tests, where termites received only one type of food resource, raw redcedar chips and panel blocks sustained less feeding damage compared with radiata pine sapwood, and termite worker survival was less than 24 percent after 12 weeks, compared with more than 84 percent survival in radiata pine controls. Additionally in no-choice tests, chips and blocks lost 4.9 to 6.3 percent weight, whereas radiata pine controls sustained 9.2 percent weight loss. Based on these findings, redcedar panels tested exhibited moderate resistance against termite damage.

Subterranean termites are widespread pests of wood structures and wood products in North America and cause extensive damage annually (Sharma 1993). These wood-destroying pests are a continuous threat to wood composite materials in residential and commercial structures. Wood composite panels used extensively in building construction are found in millions of homes in the United States and abroad. However, manufactured particleboard and other wood-based panel products are seldom evaluated for resistance to attack by subterranean termites. Because termites are cryptic, and severe damage often occurs but remains undetected until structural wood components are beyond repair, it is important to know the susceptibility or resistance of these materials to damage by termites. If panels made from eastern redcedar (*Juniperus virginiana* L.) are resistant to termite damage, a beneficial use of this pest tree species could result.

Natural resistance of wood to termite attack is due in part to chemicals deposited during heartwood formation (Carlsson et al. 1952, Erdtman and Topliss 1957, Kumar 1971, Carter and Beal 1982, Sims 1988). Concentrations of biologically active chemicals usually differ among trees within a species, and can vary among locations in individual trees (Rudman and Gay 1967). A specific chemical that causes resistance to insects may occur only in wood of one tree species, and not others. Woods containing different chemicals can be expected to differ in their ability to resist wood-destroying insects (Beal et al. 1974, Carter and Smythe 1974, Carter and Mauldin 1981, Grace and Yamamoto 1994).

Heartwood is generally more resistant to insects than sapwood, and termites readily survive on sapwood but not on heartwood because of the latter's extractive chemical content.

The authors are, respectively, Associate Professors, Dept. of Entomology and Plant Pathology (kard@okstate.edu), and Dept. of Forestry (salim.hiziroglu@okstate.edu), and Professor, Statistics Dept. and Assoc. Dean, Graduate College (mark.payton@okstate.edu), Oklahoma State Univ., Stillwater, Oklahoma 74078. We thank Don C. Arnold and Craig R. McKinley for reviewing a draft of this manuscript. The authors respectively acknowledge the financial support provided by the Food and Agri. Products Center (FAPC), Oklahoma State Univ., Stillwater, Oklahoma. This work was approved for publication by the Director of the Oklahoma Agri. Expt. Sta., and supported in part under Project H-2480. This paper was received for publication in January 2007. Article No. 10300.
*Forest Products Society Member.

Forest Prod. J. 57(11):74-79.

Differences have also been observed in survival and feeding responses of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), exposed to wood samples removed from different sections and height locations in the same tree species (Carter et al. 1975, 1983). Thus, different panels made with wood from the same tree or different trees of the same species could differ in their resistance to termite feeding.

Termiticidal components of hardwoods and softwoods have been extracted and identified by several investigators (Saeki et al. 1971, Lenz and Becker 1972, Saeki 1973, French et al. 1979, Jurd and Manners 1980, Jones et al. 1983, McDaniel et al. 1989). Chemicals in termite resistant woods may be contact toxic to termites or act as antifeedants, repellents, or protozoacides (Carter 1979, Carter and Mauldin 1981, Carter et al. 1983). Carter and Beal (1982) showed that susceptible pine wood treated with extracts from naturally resistant woods acquired antitermitic properties, and was protected against feeding by termites. Their results indicated a potential use for antitermitic wood extractives as treatments for wood to impart resistance to subterranean termites. Heartwood of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and one source of western redcedar, *Thuja plicata* Donn ex D. Don, were susceptible to termite feeding damage (Carter and Smythe 1974). In addition, Smith and Cserjesi (1970) demonstrated that Douglas-fir was not resistant to termites, and was consumed without ill effects to feeding termites.

In another study, 11 North American conifers and their natural chemical extracts were tested for susceptibility to *R. flavipes* (Carter and Smythe 1974). Heartwoods of western redcedar, Port-Orford-cedar, *Chamaecyparis lawsoniana* (A. Murr.)Parl., baldcypress, *Taxodium distichum* (L.)Rich., redwood, *Sequoia sempervirens* (D. Don) Endl., ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., and eastern redcedar, were not favorable for termite feeding and survival. Because of its naturally toxic oils, heartwood of one source of western hemlock was resistant to termites in choice tests (Carter and Smythe 1974). Antitermitic properties of *Chaemaecyparis* sp. are also attributable to essential oils (Saeki et al. 1971).

Eastern redcedar is an under-utilized species in Oklahoma and several surrounding states. It is a pest species that overgrows and degrades cattle grazing land (Strizke and Bidwell 1998, Bidwell et al. 2000). Its heartwood contains approximately 3.8 percent oils that are commonly used to scent soaps, impart fragrance to perfumes, and to manufacture disinfectants. Eastern redcedar is considered a naturally chemically-treated wood because of its high oil content.

Preservative treatments to wood composites and wood products using a variety of chemicals have been effective against termite damage (Grace et al. 1992, Thorne and Forschler 1998). Particleboard is one of the wood composites widely used as nonstructural panel product manufactured in the United States, and is primarily used as substrate in furniture production. In previous studies, experimental particleboard panels were made from whole-tree, chipped furnish of eastern redcedar. Results of these studies determined that both physical and mechanical properties of redcedar panels are comparable to those made from other wood species (Hiziroglu 2002, Hiziroglu et al. 2002).

Similar to other composite products, particleboard is prone to destruction by termites. However, the ability of oil components in eastern redcedar panels to impart resistance to subterranean termites needed to be determined to assess this possible value-added feature. Therefore, the objective of this study was to evaluate resistance of experimentally manufactured eastern redcedar panels to feeding damage by *R. flavipes*, a destructive indigenous Oklahoma subterranean termite. This study investigates the susceptibility or resistance of value-added panels developed from underutilized eastern redcedar to damage by termites. The importance of this study lies in its potential to expand the use of panel products made from redcedar in locations where risk of damage by subterranean termites is present.

Materials and methods

Panels

Single-layer and triple-layer panels were manufactured from whole-tree chipped eastern redcedar. Whole-tree furnish was reduced to 5 percent moisture content (MC) in a 1.0 m^3 capacity dryer for 48 hours at 67±2 °C. For triple-layer panel, dried chips were separated and classified into two size categories, fine or coarse, using a 20-mesh screen. Coarse chips were used for the core layer of the triple-layer panel, and fine chips for the face layers. For each panel, 1,520 g of coarse chips and 1,012 g of fine chips were separately blended with urea-formaldehyde (UF) resin in a rotating drum mixer to form separate blends with a solid content of 65.8 percent (w/w). Based on ovendry particle weight, 6 percent or 9 percent UF resin (w/w) was applied using an atomizing spray gun for the core and face layers, respectively. Average resin used for single-layer and triple-layer panel contained approximately 7 percent liquid UF (w/w) based on oven-dried particle weight. No waxes or other additional additives were used during panel manufacturing. Panels measuring 50.8-cm long by 55.8-cm wide by 2.5-cm thick were manufactured for the study.

The ratio of face-layer thickness to the total panel thickness (shelling ratio) was 0.30 for all panels. Hand-formed mats were compressed in a computer-controlled press at a temperature of 180 °C and a pressure of 5.38 MPa for 5.0 minutes. Manufacturing of similar experimental panels has been previously described (Hiziroglu 2002, Hiziroglu et al. 2002).

Termites

R. flavipes were collected from three field colonies in Payne County, 112 km north of Oklahoma City, Oklahoma, USA. Termites were maintained in the laboratory in 15-L galvanized steel containers and provisioned with southern yellow pine sapwood (*Pinus* sp.) boards and water. Separate groups of 1,000 or 100 termites were drawn from each colony for use in 'choice' and 'no-choice' feeding bioassays, respectively. For each of three colonies, bioassays contained six replicates for each test material and ran for 12 weeks. Test units were held in the laboratory at 22±2 °C under low-light conditions.

Foraging substrate

Artificial substrate consisted of clean, sterile sand and vermiculite in a 10:1 ratio (w/w) near-homogeneous mixture. Sterile deionized water was added at a rate of 350 mL per 1,000 g of dry mixture, yielding 26 percent (w/w) MC.

Panels, chips, and radiata pine samples

For both choice and no-choice bioassays for each colony, a total of 72 rectangular blocks (2.5 by 2.5 by 1.3 cm) each of single-layer without foliage, single-layer with foliage, and triple-layer with foliage laboratory-manufactured eastern redcedar panel types were evaluated. Seventy-two Monterey pine (*Pinus radiata* Don.; radiata pine) sapwood blocks of the same dimensions as the redcedar blocks were used as controls. Owing to its palatability and consistent lack of blemishes and knots, radiata pine sapwood is sometimes used as control wood in laboratory and field termite studies (Lenz et al. 2001, Brown et al. 2007). Additionally, for each termite colony, 72 small bundles of raw eastern redcedar chips without foliage and 72 similar-sized bundles with foliage, each weighing approximately the same as the panel blocks, were used for comparison. All blocks and bundles were oven-dried at 103±2 °C for 24 hours, and their dry weights determined. After removal from the oven, these materials were stored at 22±2 °C and 50 to 60 percent relative humidity for 10 days to absorb moisture and stabilize following drying. Subsequently, these materials were placed into cylindrical clear-plastic bioassay units containing foraging substrate and allowed to absorb water and stabilize for 1.0 day. Termites were then added to each bioassay unit. An additional radiata pine block was added to a bioassay unit if the initial radiata pine control block was approximately 80 percent consumed before the end of the bioassay period.

Table 1. — Resistance (mean ± SEM) of eastern redcedar paneling or raw chips to damage by R. flavipes *in Choice feeding tests.*[a]

Paneling or raw material	Final weight	Weight loss[b]	DRI[b,c]
	(g)	g (-%)	
Raw chips without foliage	5.744 ± 0.190	0.124 ± 0.034 A (2.1)	0.7 ± 0.2 A
Raw chips with foliage	5.130 ± 0.121	0.154 ± 0.044 AB (2.9)	0.9 ± 0.2 A
Single-layer panel without foliage	4.860 ± 0.073	0.193 ± 0.010 BC (3.8)	1.1 ± 0.1 AB
Single-layer panel with foliage	4.731 ± 0.063	0.237 ± 0.017 BC (4.8)	1.3 ± 0.1 B
Triple-layer panel with foliage	4.670 ± 0.128	0.303 ± 0.017 C (6.1)	1.9 ± 0.1 C
Radiata pine sapwood (control)	3.841 ± 0.414	3.097 ± 0.177 D (44.6)	3.4 ± 0.1 D

[a]Mean worker survival = 76.0 percent (range 69.6 to 82.9%); Mean soldier survival = 89.6 percent (range 83.9 to 94.4%).

[b]In each column, means with different letters are significantly different, $p \leq 0.05$ ($n = 18$).

[c]DRI = Damage rating index; 0 = no damage, resistant; 1 = superficial damage, surface chewed and etched, ≤5.0 percent weight loss; 2 = moderate penetration into wood, >5.0 to 10.0 percent weight loss; 3 = severe, extensive feeding, >10.0 to 50.0 percent weight loss; 4 = destroyed, not resistant, >50.0 percent weight loss.

Choice bioassays

Using procedures modified from ASTM methodology (ASTM 1999), cylindrical plastic containers (15.2-cm diameter, 6.4-cm height) with a removable cap were partially filled with 307 g of foraging substrate that was tamped down to form a level surface. A single block or bundle of each of the six bioassay materials was placed on top of the substrate and spaced equally around and touching the inside container wall (60° intervals). Each container then received 1,000 worker and 30 soldier termites. Therefore, termites had the choice of feeding on any of the materials they chose and avoiding those that were not preferred or not palatable. A double layer of filter paper (2.0 by 4.0 cm) was then folded over a 2.0-cm length along the container lip to allow air exchange, and the container was capped. Each bioassay was replicated 6 times per colony per material, resulting in 18 replicates per material for each of the three complete bioassays.

No-choice bioassays

Cylindrical clear-plastic containers (5.3-cm diameter, 4.0-cm height) with a removable cap were partially filled with 35 g of foraging substrate that was tamped down to form a level surface. A single block or bundle of one of the test materials was placed on top of the substrate in the center of each container as the only food source for termites. Each container then received 100 worker and 3 soldier termites. A double layer of filter paper (1.0 by 2.0 cm) was folded over a 1.0-cm length along the container lip to allow air exchange, and the container was capped. Each bioassay was replicated six times per colony per material, resulting in 18 replicates per material for each of the three complete bioassays.

Damage assessment

After the introduction of termites, each bioassay unit was observed daily. Termite behavior and mortality were observed during each 12-week test. After final observations, damage to blocks and eastern redcedar chips was assessed by cleaning substrate, fecal material and plastering, and debris off each block and from all chips, and then drying and weighing each material to determine weight loss. Each block or chips bundle was graded by the severity of termite feeding damage using a damage rating index (DRI) of 0.0 to 4.0: 0.0 = no damage or weight loss; 1.0 = superficial damage, surface chewed and etched, ≤5.0 percent weight loss; 2.0 = moderate penetration into wood, >5.0 to 10.0 percent weight loss; 3.0 = severe, extensive feeding and penetration into wood, >10.0 to 50.0 percent weight loss; 4.0 = destroyed, >50.0 percent weight loss.

Statistics

All statistical analyses were performed with PC SAS® Version 9.2 (SAS Institute, Cary, North Carolina). Differences in weight loss among test materials were evaluated by analysis of covariance (ANCOVA) using PROC MIXED with the initial weight of the material as the covariate. The experimental design was a randomized complete block with colony as the block. If the treatments were significant in the ANCOVA, the means of test material weight loss and termite mortality were separated with a DIFF option in an LSMEANS statement using a significance level of ≤0.05.

Results

Choice bioassays

Termites preferred to feed on radiata pine when compared with raw redcedar chips and panel blocks, with pine blocks sustaining severe damage to near destruction (**Table 1**). Redcedar raw chips and panel blocks and radiata pine controls all sustained feeding damage, but raw chips with or without foliage exhibited the least weight loss and least severe DRIs (<3.0 percent weight loss; DRI <1.0). However, the three different panel blocks sustained similar weight loss (−3.8 to −6.1%), although triple-layer panel blocks sustained significantly more feeding damage compared with chips and single-layer panel blocks. Triple-layer panel blocks were second only to radiata pine controls in weight loss and severity of

Table 2. — Resistance (mean ± SEM) of eastern redcedar paneling or raw chips to damage by R. flavipes *in No-choice feeding tests.*[a]

Paneling or raw material	Final weight	Weight loss	DRI[b]	Worker survival	Soldier survival
	(g)	g (-%)		(%)	
Raw chips without foliage	5.618 ± 0.221	0.347 ± 0.051 A (5.9)	1.6 ± 0.2 A	18.1 ± 5.2 B	36.1 ± 10.6 C
Raw chips with foliage	5.197 ± 0.073	0.270 ± 0.020 A (4.9)	1.5 ± 0.1 A	23.3 ± 4.8 B	58.3 ± 10.9 CD
Single-layer panel without foliage	4.782 ± 0.089	0.306 ± 0.064 A (6.0)	1.6 ± 0.2 A	19.9 ± 5.7 B	30.6 ± 9.2 B
Single-layer panel with foliage	4.820 ± 0.075	0.323 ± 0.025 A (6.3)	1.7 ± 0.1 A	16.4 ± 5.3 B	38.9 ± 11.1 C
Triple-layer panel with foliage	4.304 ± 0.076	0.240 ± 0.016 A (5.2)	1.5 ± 0.1 A	2.2 ± 2.2 A	5.6 ± 5.6 A
Radiata pine sapwood (control)	3.813 ± 0.046	0.384 ± 0.068 A (9.2)	2.4 ± 0.2 B	84.8 ± 1.6 C	88.2 ± 5.3 D

[a]In each column, means with different letters are significantly different, $p \leq 0.05$ ($n = 18$)
[b]DRI = Damage rating index; 0 = no damage, resistant; 1 = superficial damage, surface chewed and etched, ≤5.0 percent weight loss; 2 = moderate penetration into wood, >5.0 to 10.0 percent weight loss; 3 = severe, extensive feeding, >10.0 to 50.0 percent weight loss; 4 = destroyed, not resistant, >50.0 percent weight loss.

damage. During the 12-week test, all chips, panels, and radiata pine blocks were progressively plastered over with substrate and termite excrement.

Raw chips consisted of a mixture of cream-colored springwood and orange-to-red colored heartwood. Based on daily observations, termites selectively consumed more sapwood compared with heartwood although these different components of chips were not separated during the study. This feeding discrimination also occurred on the surfaces of the three types of redcedar panel blocks.

No-choice bioassays

Wood chips, panel blocks, and radiata pine sustained similar overall weight loss due to feeding termites, with pine losing the most weight (**Table 2**). All redcedar test materials except raw chips with foliage (4.9 percent weight loss) were moderately damaged (>5.0 to 10.0 percent weight loss). Radiata pine controls sustained significantly more feeding damage (moderate to severe) compared with any of the redcedar chips or panel blocks (superficial to moderate). Redcedar chips or panel blocks sustained similar feeding damage when compared with each other. Redcedar chips and blocks did not support high termite worker survival, but 2.2 to 23.3 percent of worker termites were able to survive for 12 weeks with only one of these materials as their food resource. Triple-layer panel blocks elicited the greatest termite mortality. Radiata pine provided the most palatable resource, supporting 84.8 and 88.2 percent survival for workers and soldiers, respectively **(Table 2).** Chips and blocks became plastered over with substrate and excrement as the study progressed.

Choice / No-choice bioassay comparison

When provided only one food resource, termites fed on all of the redcedar raw chips or panel blocks available, but always caused more damage and weight loss to radiata pine. Additionally, when given a choice of all the test food resources simultaneously, termites always caused significantly more damage to radiata pine compared with the redcedar alternatives. Interestingly, termites consumed 3.10×10^{-3} and 3.84×10^{-3}g of radiata pine per worker termite (based on the initial number of worker termites) in choice and no-choice tests, respectively. Thus, although worker termites were simultaneously offered several different food resources in choice tests, they still consumed a similar amount of control wood per termite compared with no-choice tests (**Tables 1, 2, 3**).

Table 3. — Comparison of damage (mean ± SEM) to eastern redcedar paneling or raw chips by R. flavipes *between Choice and No-choice feeding tests.*[a]

	DRI[b]		
Paneling or raw material	Choice	No-choice	p
Raw chips without foliage	0.7 ± 0.2 X	1.6 ± 0.2 Y	0.0016
Raw chips with foliage	0.9 ± 0.2 X	1.5 ± 0.1 Y	0.0121
Single-layer panel without foliage	1.1 ± 0.1 X	1.6 ± 0.1 Y	0.0012
Single-layer panel with foliage	1.3 ± 0.1 X	1.7 ± 0.1 Y	0.0040
Triple-layer panel with foliage	1.9 ± 0.1 X	1.5 ± 0.1 Y	0.0086
Radiata pine sapwood (control)	3.4 ± 0.1 X	2.4 ± 0.1 Y	0.0001

[a]**Across** each row, means with a different letter are significantly different, $p \leq 0.05$ ($n = 18$)
[b]DRI = Damage rating index; 0 = no damage, resistant; 1 = superficial damage, surface chewed and etched, ≤5.0 percent weight loss; 2 = moderate penetration into wood, >5.0 to 10.0 percent weight loss; 3 = severe, extensive feeding, >10.0 to 50.0 percent weight loss; 4 = destroyed, not resistant, >50.0 percent weight loss.

When comparing feeding damage among the same test materials across choice and no-choice tests, termites caused significantly less damage to redcedar chips and single-layer panel blocks (with or without foliage) in choice tests compared with the same materials in no-choice tests. Notably, damage to triple-layer panels with foliage as well as to radiata pine was more severe in choice tests compared with no-choice tests, demonstrating these two food resources are the most palatable when termites are offered a choice of the six resources. Raw chips with and without foliage, and single-layer panels with and without foliage sustained less severe DRIs in choice tests compared with their counterparts in no-choice tests as they were less preferred than the triple-layer panel and pine alternatives. Overall, pine sustained the greatest damage in choice tests compared with no-choice tests **(Table 3).**

Discussion

Incorporation of insect-resistant wood into paneling reduces the risk of termite damage to the final product. However, if susceptible woods are used in paneling, it should be possible to protect panels by adding phenyl-formaldehyde resin, borates, or other acceptable insect toxicants to panel components. Borates exhibit low mammalian toxicity, are toxic to many wood-destroying insects, and can be applied to wood by dip-diffusion or pressure-treatment methods (Williams 1984, 1990). Borates can be incorporated into glues and resins or directly into wood. Additionally, additives, adhesives, waxes, resins, formaldehyde, solvents, heat treatments, coatings, and drying requirements are part of various wood panel manufacturing processes. These additives and processes may change the resistance of paneling to termite attack.

Based on this study, paneling that incorporates eastern redcedar should be less acceptable to *R. flavipes* than paneling made from more palatable woods or when other, preferred woods are present as alternative food sources. However, because raw eastern redcedar chips were surface etched and chewed in choice tests, and moderately chewed upon and damaged in no-choice tests, redcedar paneling may not always remain non-damaged in structures, but can be considered moderately resistant to termite feeding.

In choice bioassays, triple-layer panels were more severely damaged compared with single-layer panels, although weight loss of these materials was similar (**Table 1**). This result was due to termites preferring to feed on the light/cream-colored chips within the triple-layer panels, while feeding less on the incorporated orange-to-red colored chips. If the orange-to-red chips contain greater concentrations of essential oils, this could deter feeding. The termites fed on the more palatable chips. Thus, if feasible, it may be beneficial to separate light colored from dark red chips when manufacturing redcedar panels.

In no-choice bioassays, significantly fewer (2.2%) worker termites that were provided only triple-layer panels survived compared with all other test materials, although weight loss was similar among test materials **(Table 2)**. Face layers of this panel were treated with 9 percent UF and core layers 6 percent UF, whereas the average treatment for single-layer panels was 7 percent UF. The relatively greater concentration of UF applied to face layers may be responsible for the greater termite mortality. The termites fed on triple-layer panel although this caused greater mortality. This relatively greater mortality did not deter termites from feeding selectively on the cream-colored chips. It is notable that weight loss among all test materials was similar. This indicates that to survive, the same number of termites consumed about the same weight of food resources even though some of these resources are clearly nonpreferred in choice tests. The need to feed and survive overrode the poor palatability of some food resources.

Antitermitic properties of several conifer species are related to their inherent insect-toxic chemicals (Carter et al. 1983, Adams 1987, Adams et al. 1988, Scheffrahn et al. 1988, McDaniel 1989, McDaniel et al. 1989). For example, the antitermitic properties of *Chaemaecyparis* sp. are attributable to essential oils, and Port-Orford-cedar was found to be resistant to termites (Saeki et al. 1971). Sesquiterpenes and their alcohols are components of eastern redcedar that provide some protection against subterranean termites (McDaniel 1989). Redcedar species contain cedarwood oil that comprises several chemicals including the sesquiterpenoids α- and β-cedrene and thujopsene (widdrene), as well as the sesquiterpene alcohols cedrol and widdrol. These chemicals are toxic to termites and are more concentrated in red-colored heartwood compared with cream-colored sapwood, but are most concentrated in the leaves (Guenther 1943, Adams et al. 1983, Adams 1987, Adams et al. 1988, McDaniel et al. 1989). In this study, presence or absence of foliage in the eastern redcedar test materials did not significantly affect weight loss between raw chips due to termite feeding, or between single- and triple-layer panels in choice feeding tests. Similar feeding and DRIs occurred between all eastern redcedar test materials in no-choice feeding tests. This indicated that mixtures of heartwood and sapwood in panel blocks or raw chips contained enough chemicals to impart moderate resistance to termite feeding.

Other wood species such as baldcypress, redwood, and ponderosa pine also contain antifeedant chemicals that reduce termite survival (Carter and Smythe 1974). Therefore, one approach to improve paneling resistance to feeding damage by termites would be to use only termite-resistant woods, or mix non- or moderately termite-resistant woods with very resistant woods during the manufacturing process. Such new composite panels and their resultant susceptibility or resistance to termites would require further investigation.

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