



Development of a Sustainable Wood Treatment Process for Palmyra Palm Fronds toward Furniture Production

Palachai Khaonuan¹, Noppadon Podkumnerd^{1*}, Kosin Teeparuksapun¹, Jirapat Phookwantong¹,
Supranee Wunsri¹, Nuntachai Chusilp², and Mahamasuhaimi Masae²

¹ Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand

² Faculty of Engineering, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand

* Correspondence: Noppadon.p@rmutsv.ac.th

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Abstract: This study investigated the potential of Palmyra palm frond wood preservation treatments as an alternative material for furniture production. The palm fronds were composed of $74.94 \pm 2.05\%$ moisture, $30.61 \pm 17.67\%$ cellulose, $23.54 \pm 1.00\%$ hemicellulose, and $45.36 \pm 0.55\%$ lignin. Specimens (2.5x2.5 cm) were treated with boron compounds (boric acid: borax, 1:1.5) or wood vinegar at concentrations of 1%, 3%, and 5%, and then tested for fungal resistance, termite resistance, and mechanical properties. The 3% boron compound treatment demonstrated optimal performance, with $55.62 \pm 1.96\%$ absorption after 6 days, significantly higher than 3% wood vinegar ($46.91 \pm 1.58\%$). Termite resistance testing revealed weight loss of $5.83 \pm 0.17\%$ for the 3% boron-treated samples compared to $11.21 \pm 0.35\%$ for wood vinegar and $23.90 \pm 1.40\%$ for untreated controls after 45 days. Mechanical testing showed numerically higher flexural strength values for boron-treated specimens (34.87 ± 4.48 N/mm²) than for controls (27.85 ± 1.10 N/mm²), although the difference was not statistically significant ($p > 0.05$). Color stability remained acceptable with L-values decreasing from 68.60 ± 0.53 to 59.30 ± 0.44 after three months. Microscopic examination confirmed preservative penetration into the cellular structure. The optimized 3% boron compound treatment provided an economically viable and environmentally sustainable solution for utilizing abundant Palmyra palm resources in Southern Thailand, creating durable furniture components while reducing the pressure on endangered hardwood species.

Keywords: Palmyra palm wood; wood preservation; boron compounds; termite resistance; sustainable furniture

1. Introduction

Based on the 2021 global greenhouse gas emissions scenario, carbon dioxide (CO₂) emissions are expected to rise by 4.8% due to the accelerating economic recovery [1]. Biomass, produced through photosynthesis in green plants under sunlight, is among the Earth's most significant organic materials [2]. Thailand is an agrarian-based nation, with approximately 28% of its population employed in the agricultural sector [3]. The increasing demand for naturally durable wood species like Blackwood, Ironwood, and Teak, which command high market prices, is leading to significant depletion of resources. Thailand primarily uses rubberwood as a raw material for furniture production, but its low natural durability, due to its high carbohydrate content, makes it susceptible to wood-destroying pests, including fungi, powder-post beetles,

and termites [4-6]. Thai processed rubber wood typically requires treatment with boron compounds (a mixture of borax and boric acid) to enhance resistance against these destructive agents, thereby increasing its cost [7, 8]. The need for alternative wood sources has prompted research into other plant species, including the Palmyra palm (*Borassus flabellifer*), which is an important economic plant in Southern Thailand, particularly in the Sathing Phra Peninsula of Songkhla Province. Palmyra palms are typically planted in rice fields at a density of 20 trees per rai (1,600 m²), with the number growing from 1 million trees in 2007 to 3 million in Songkhla Province. The Palmyra palm has become integrated into local community lifestyles and culture [9, 10]. The wood is economically significant in Southern Thailand and primarily utilized for furniture or interior structural work due to its lightweight properties, moderate strength, and ease of processing [11]. However, Palmyra palm wood has low natural durability, making it vulnerable to termites, fungi, and other pests.

Treatments using boron compounds and wood vinegar offer effective protection against wood-destroying organisms through simple soaking and coating methods that are easy to apply, time- and labor-efficient, and that extend the service life of the wood. Wood vinegar, produced through wood pyrolysis, contains various organic acids and alcohols derived from hemicellulose and cellulose decomposition, as well as phenolic compounds from lignin breakdown [12]. Wood vinegar is primarily water, with organic acids and other organic compounds in smaller proportions. These substances are highly acidic and have specific gravities only slightly higher than that of water. These properties vary depending on the type of wood used as raw material [13, 14]. Boron compounds offer advantages as wood preservatives by preventing termite, powder-post beetle, and fungal infestation [15]. These substances are particularly suitable for treating wood due to their low toxicity to humans and mammals, transparent appearance when dissolved in water, preservation of wood color after treatment, affordability, and availability [16]. Previous research has shown that the processed plywood treated with boron compounds containing borax and boric acid demonstrated increased resistance to decay fungi (*Trametes versicolor* and *Fomitopsis palustris*) and termites (*Coptotermes formosamus*) compared to untreated wood [17]. In 2007, Kartal and co-workers reported that wood soaked in 6% borax and boric acid solutions exhibited enhanced resistance against subterranean termites (*Coptotermes formosanus* Shiraki), with weight loss of 3% to 5% after three weeks of termite exposure, compared to 23.9% in untreated samples [18].

This study aimed to develop an effective preservation process for wood from Palmyra palm fronds by first examining its fundamental composition, then evaluating the performance of boron compounds and wood vinegar as treatment agents, followed by formulating a suitable treatment process, and finally testing the treated wood for termite resistance, durability, and mechanical strength.

2. Materials and Methods

2.1 Materials

2.1.1 Palm frond samples

Palmyra palm frond samples were obtained from the Palmyra palm community in Bang Khiad Subdistrict, Singhanakhon District, Songkhla Province. The samples were cut into small pieces and dried at 95 ± 5°C for 5 hours in a hot-air oven until constant weight, for subsequent physical and chemical analysis.

2.1.2 Chemicals

Boric acid (analytical grade, ≥99.5% purity; Ajax Finechem, Thailand) and borax (sodium tetraborate decahydrate, analytical grade, ≥99.0% purity; Ajax Finechem, Thailand) were used to prepare boron compound solutions at a boric acid:borax molar ratio of 1:1.5. Wood vinegar (pH 2.8-3.2, specific gravity 1.015-1.020; obtained from a local charcoal kiln in Songkhla Province, Thailand) was used as the second preservative agent. Solutions were prepared at concentrations of 1%, 3%, and 5% (w/v) in distilled water immediately before use. All glassware was rinsed with distilled water before use.

2.2 Methods

2.2.1 Physical and chemical composition analysis

The physical and chemical properties analyzed included moisture content, ash content, pH (Electrometric Method), fat (Direct Extraction Methods), cellulose, hemicellulose, and lignin (Klason Lignin

method). Carbohydrate content was determined using the Anthrone Method [19], and reducing sugars were measured using the Dinitrosalicylic Acid Method [20].

2.2.2 Treatment methods

Palmyra palm frond samples measuring 2.5 x 2.5 cm were prepared and dried at 95 ± 5 °C for 5 hours in a hot-air oven until constant weight. Three treatment methods were employed. Method 1: The samples were soaked in boron compound solutions (boric acid: borax at 1:1.5 ratio) at concentrations of 1%, 3%, and 5% for 12 hours. After soaking, the samples were dried at 95 ± 5 °C for 5 hours and weighed. Method 2: The samples were soaked in wood vinegar solutions at 1%, 3%, and 5% for 12 hours, then subjected to the same procedures as in Method 1. Method 3: The control sample was soaked in tap water for 12 hours, and then subjected to the same procedures as Method 1.

2.2.3 Fungal resistance testing

The treated palm frond samples (4-5 pieces per treatment) were placed on trays with air circulation to allow fungal growth for 45 days. After the testing period, the samples were examined by swabbing to calculate fungal contamination. The dominant fungal species observed were *Aspergillus niger* and *Trichoderma* spp., identified by colony morphology and microscopic examination of conidia structure on potato dextrose agar (PDA) after 7 days at 28°C.

2.2.4 Termite resistance testing

Termite resistance was investigated using the method described in ASTM D 3345-74 [21]. Briefly, treated palm frond samples (4-5 pieces per treatment) of known constant weight were exposed to 1 g of termites (0.9 g worker termites and 0.1 g soldier termites) per sample piece for 45 days. The termites used were *Microcerotermes crassus* Snyder, collected from naturally infested Palmyra palm trunks in the Singhanakhon District, Songkhla Province. Species identity was confirmed by an entomologist at Rajamangala University of Technology Srivijaya through morphological examination of soldier caste head-capsule characteristics. After the testing period, the samples were dried to constant weight. The termite damage was calculated as equation (1).

$$\text{Termite damage (weight loss) (\%)} = \frac{(\text{Initial weight} - \text{Final weight}) \times 100}{\text{Initial weight}} \quad (1)$$

2.2.5 Water absorption testing

Water absorption was investigated using the ASTM D7264 method [22]. Test specimens (5 x 5 cm) were immersed in distilled water at 25 ± 2 °C for 6 days. The water absorption was calculated using equation (2).

$$\text{Water absorption (\%)} = \frac{(t_2 - t_1)}{t_1} \times 100 \quad (2)$$

Where t_1 and t_2 are the weights before and after water immersion (g), respectively.

2.2.6 Flexural strength and elastic modulus testing

Flexural strength (FS) and elastic modulus (E) were determined using a Universal Testing Machine (QC-506M1F Extend) in three-point bending mode. The span between the lower supports was 70 mm, and the testing speed was 10 mm/min. The FS and E were calculated using equations (3) and (4), respectively.

Flexural strength

$$(\text{FS}) = \frac{L^3 m}{4bh^3} \quad (3)$$

$$\text{Elastic modulus } (\sigma) = \frac{3PL}{2bh^2} \quad (4)$$

where P is the maximum load the specimen can bear (N), L is the span of the supports (mm), m is the load increase in the linear region of the graph (N), b is the width at the center of the specimen (mm), and h is the thickness at the center of the specimen (mm).

2.2.7 Morphological examination

The morphology of the palm frond wood was examined using a Trinocular Fluorescence Stereo Microscope (Leica M205FCA).

2.2.8 Statistical analysis

All data were expressed as mean $\pm$ standard deviation (SD). Statistical comparisons among treatment groups were performed using one-way analysis of variance (ANOVA) followed by Duncan's multiple-range test for post hoc comparisons, with statistical significance set at $p < 0.05$ and $p < 0.01$ as indicated. A paired t-test was used to compare absorption rates between two treatment groups at each time point. All statistical analyses were performed using R statistical software.

3. Results and Discussion

3.1 Basic physical and chemical composition of palm fronds

Analysis of Palmyra palm frond wood revealed a moisture content of $74.94 \pm 2.05\%$, ash content of $27.91 \pm 0.47\%$, cellulose content of $30.61 \pm 17.67\%$, hemicellulose content of $23.54 \pm 1.00\%$, and lignin content of $45.36 \pm 0.55\%$. Carbohydrate and reducing sugar contents were 9.00 ± 0.47 and 4.33 ± 0.56 g/L, respectively, with a pH value of 7.43 ± 0.10 (Table 1). The high carbohydrate content rendered this material susceptible to biological degradation, as the oil palm leaflets and fronds contain a high amount of cellulose [23]. Palmyra palm fronds contain a gradient of vascular bundle density from the dense peripheral zone to the looser central parenchyma, resulting in large sample-to-sample variation in cellulose content.

Table 1. Physical and chemical composition of Palmyra palm frond wood

Component	Value
Moisture content (%)	74.94 ± 2.05
Ash content (%)	27.91 ± 0.47
pH	7.43 ± 0.10
Carbohydrate (g/L)	9.00 ± 0.47
Reducing sugar (g/L)	4.33 ± 0.56
Cellulose (%)	30.61 ± 17.67
Hemicellulose (%)	23.54 ± 1.00
Lignin (%)	45.36 ± 0.55

3.2 Effectiveness of treatment solutions against fungi and termites

After 45 days of testing, the control sample showed the highest fungal contamination at 1.13 ± 0.16 log CFU/g. Samples treated with different solutions demonstrated significantly lower contaminations ranging from 0.69 ± 0.21 log CFU/g to 0.94 ± 0.06 log CFU/g (Table 2), indicating improved resistance to fungal growth. These results aligned with Puttinun [11] findings regarding the antifungal properties of wood vinegar. Termite resistance testing revealed that boron compound treatments provided superior protection, with weight-loss percentages ranging from $5.48 \pm 0.58\%$ to $8.79 \pm 1.53\%$. The wood vinegar-treated samples showed moderate protection ($9.54 \pm 0.95\%$ to $12.46 \pm 1.80\%$ weight loss), while the control sample suffered the highest damage ($23.90 \pm 1.40\%$ weight loss). The termites were identified as *Microcerotermes crassus* Snyder. These results concurred with a previous study reporting significantly reduced weight loss in boron-treated wood compared to untreated samples [18].

Table 2. Fungal contamination (log CFU/g) and termite damage (weight loss, %) after 45 days

Treatment method	Soaking time (hours)	Fungal contamination (log CFU/g)	Termite damage (weight loss, %)
Water (control)	12	1.13±0.16 ^b	23.90±1.40 ^d
1% Boron compounds	12	0.88±0.16 ^{ab}	8.79±1.53 ^{ab}
3% Boron compounds	12	0.77±0.21 ^a	5.83±0.17 ^a
5% Boron compounds	12	0.69±0.21 ^a	5.48±0.58 ^a
1% Wood vinegar	12	0.94±0.06 ^{ab}	12.46±1.80 ^c
3% Wood vinegar	12	0.89±0.11 ^{ab}	11.21±0.35 ^{bc}
5% Wood vinegar	12	0.82±0.11 ^a	9.54±0.95 ^{bc}

Different superscript letters indicate statistically significant differences at $p < 0.05$

3.3 Absorption rates of treatment solutions

The absorption rate of the 3% boron compound solution reached 55.62±1.96% after 6 days, while the 3% wood vinegar solution achieved 46.91±1.58% (Table 3). The highest absorption rate occurred on days 1 and 2, with a gradual decrease from days 3 to 6. Statistically significant differences ($p < 0.01$) between the solutions suggested better penetration of boron compounds into the wood structure [17]. Ionic borate species ($B(OH)_4^-$) form reversible covalent bonds with polyol hydroxyl groups in hemicelluloses, facilitating diffusion into the cell wall matrix; wood vinegar's complex mixture of organic acids and phenolics may interact non-specifically with surface sites, limiting deeper penetration [24].

Table 3. Absorption rates (%) of 3% boron compounds and 3% wood vinegar solutions over time

Soaking time (days)	Absorption rate (%)		t-value	p-value
	3% Boron compounds	3% Wood vinegar		
0	0.00±0.00	0.00±0.00	-	-
1	38.42±2.07	23.93±2.05	8.624**	<0.001
2	47.21±1.03	36.80±0.51	15.636**	<0.001
3	51.18±1.61	40.89±0.90	9.658**	<0.001
4	52.94±2.10	43.15±1.24	6.940**	0.002
5	54.20±1.98	44.88±1.48	6.530**	0.003
6	55.62±1.96	46.91±1.58	5.977**	0.004

** Significant difference at $p < 0.01$

3.4 Color analysis before and after treatment

The color analysis (L, a*, b* values) showed that palm frond wood treated with 3% boron compounds maintained high brightness (L values 68.60±0.53 to 59.30±0.44) compared to wood vinegar-treated samples (47.57±1.90 to 44.70±4.20). All samples showed decreased brightness after 3 months, with wood vinegar causing greater darkening (Table 4). This applies to the control and boron compound groups, while wood vinegar-treated samples maintained consistently low brightness values throughout from time zero. For color change: phenolic compounds from lignin pyrolysis in wood vinegar bind to cell wall surfaces and undergo oxidative polymerization under ambient conditions, producing irreversible brown-black chromophores [13]. These findings aligned with a previous report showing that both treatments could maintain wood appearance with minimal color changes over time.

3.5 Mechanical strength after treatment

Ultimate strength testing of the samples treated with 3% boron compounds, 3% wood vinegar, and the control sample yielded values of 29.19±5.24 N, 26.71±1.61 N, and 29.65±1.27 N, respectively. The elastic modulus values were 29.40±7.18 N/mm², 29.04±7.47 N/mm², and 27.27±4.04 N/mm², with flexural strength 34.87±4.48 N/mm², 32.07±3.83 N/mm², and 27.85±1.10 N/mm², respectively (Table 5). The improved mechanical properties in the boron-treated samples were attributed to the adhesive properties of borax, which enhanced bonding to cellulose hydroxyl groups, as noted in previous studies [25].

Table 4. Color analysis (L, a*, b*) of Palmyra palm frond wood before and after treatment

Treatment	Time (months)	Color parameters		
		L	a*	b*
Control	0	71.17±0.58 ^d	9.87±0.74 ^b	22.13±0.25 ^c
	1	68.57±0.12 ^c	10.37±0.60 ^b	21.13±0.50 ^b
	2	63.63±1.69 ^b	10.93±1.03 ^b	37.30±0.26 ^a
	3	60.70±1.10 ^a	13.90±0.35 ^a	37.20±0.46 ^a
3% Boron compounds	0	68.60±0.53 ^c	12.10±0.70 ^a	21.03±0.38 ^a
	1	66.63±0.93 ^b	12.80±0.75 ^a	22.57±0.59 ^b
	2	60.13±0.67 ^a	13.30±0.20 ^a	37.43±0.25 ^c
	3	59.30±0.44 ^a	15.43±0.91 ^b	37.73±0.61 ^c
3% Wood vinegar	0	47.57±1.90 ^a	11.03±0.15 ^a	34.03±0.93 ^a
	1	47.43±0.81 ^a	12.10±0.70 ^a	34.33±0.55 ^a
	2	46.20±0.26 ^a	13.97±0.59 ^b	33.73±0.31 ^a
	3	44.70±4.20 ^a	14.20±0.66 ^b	32.77±2.61 ^a

Different superscript letters indicate statistically significant differences at $p < 0.05$ within each treatment group

Table 5. Mechanical properties of Palmyra palm frond wood after different treatments

Treatment	Ultimate Strength (N)	Elastic Strength at P.L. (N/mm ²)	Elastic modulus (N/mm ²)	Flexural strength (N/mm ²)
Control	29.65±1.27 ^a	26.32±1.56 ^a	27.27±4.04 ^a	27.85±1.10 ^a
3% Boron compounds	29.19±5.24 ^a	28.26±4.89 ^a	29.40±7.18 ^a	34.87±4.48 ^a
3% Wood vinegar	26.71±1.61 ^a	23.27±2.20 ^a	29.04±7.47 ^a	32.07±3.83 ^a

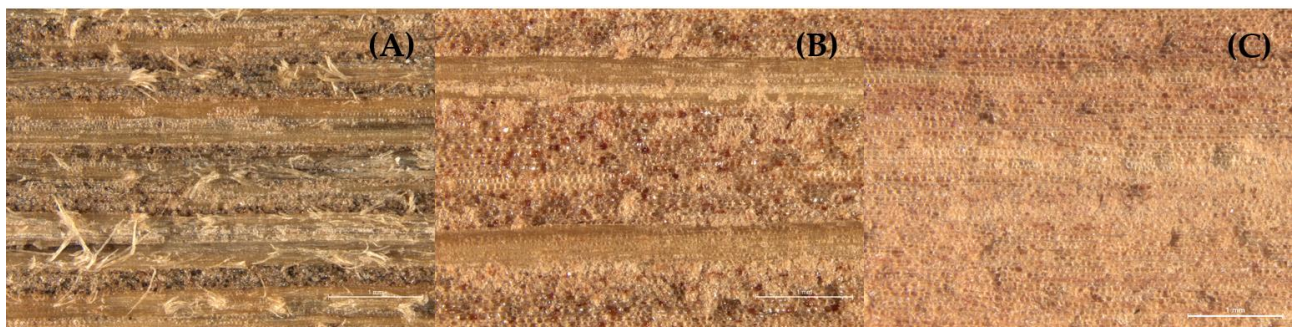
The same superscripts indicate no statistically significant differences at $p < 0.05$

3.6 Morphological characteristics

Microscopic examination revealed that the treated samples showed evidence of preservative penetration into the cellular structure (Table 6, Figure 1), confirming the effectiveness of the treatment methods in reaching the internal structure of the Palmyra palm frond wood. This penetration is essential for long-term protection against biodegradation [26-27].

Table 6. Morphological analysis of Palmyra palm frond wood before and after treatment

Treatment	Surface texture	Fiber arrangement	Visible treatment penetration
Untreated	Rough, porous	Longitudinal, parallel	N/A
3% Boron compounds	Smooth, less porous	Maintained structure	Visible in cross-section
3% Wood vinegar	Smooth, slightly darkened	Maintained structure	Visible in surface layers

**Figure 1.** The morphology of the Palmyra palm frond wood was examined using a Trinocular Fluorescence Stereo Microscope; (A) Untreated, (B) 3% Boron compounds, and (C) 3% Wood vinegar

4. Conclusions

Treatment with 3% boron compounds (boric acid:borax at a 1:1.5 ratio) provided superior protection for Palmyra palm frond wood against fungal growth and termite attack, while also enhancing mechanical properties. The 12-hour soaking period was effective for treatment penetration, with 3% boron compound absorption reaching $55.62 \pm 1.96\%$ after 6 days. Palmyra palm frond wood treated with 3% boron compounds showed multiple advantages for furniture production applications, including enhanced durability against biodegradation, improved mechanical strength (flexural strength of $3,487.60 \pm 448.75$ N/mm²), and minimal color alteration (higher brightness than wood vinegar treatment). These characteristics are suitable for indoor furniture components, decorative elements, and non-structural applications requiring moderate strength. The economic benefits include utilizing an abundant local resource from Southern Thailand, with 3 million Palmyra palm trees in Songkhla Province. This treatment process is cost-effective, using readily available preservatives applied through simple soaking methods, and requires minimal equipment or specialized facilities. Small-scale local furniture producers and community enterprises can utilize this technology. The environmental benefits include reduced pressure on endangered hardwood species by providing an alternative material source. Boron compounds have lower environmental toxicity than other conventional wood preservatives, aligning with sustainable production practices. This preservation process extends the service life of Palmyra palm wood products, reducing replacement frequency and resource consumption. It should be noted that boron compounds are water-soluble and susceptible to leaching under repeated wetting conditions, which is a recognized limitation for long-term use in humid tropical environments. The treated products are therefore recommended for indoor applications where direct water contact is minimized. Future research should investigate the long-term performance of treated products under various environmental conditions and explore additional treatment combinations to further the effectiveness and production efficiency of Palmyra palm frond wood preservation.

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