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Comparison of the Yield and Quality of Teak Wood from Different Plantations in Phrae Province, Thailand

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ABSTRACT

This study aims to compare the yield and quality of Teak wood from a Forest Industry Organization (FIO) plantation and a private teak plantation (PTP) in Thailand to provide guidelines for the sustainable utilization of teak wood. To quantify yields, we employed a randomized design at two locations (FIO and PTP), and determined volumetric proportions, the yields of milled teak and wood properties. We found that the whole lumber yield differed significantly ($p\leq0.05$) between the two locations, although the yield of lumber sheets did not differ ($p>0.05$). While more teak wood was produced at the FIO plantation than the PTP, the sawing techniques used at the two locations resulted in no significant difference in wood yield. Wood drying had significantly different effects ($p\leq0.05$) between the two locations, but the drying method did not differ ($p>0.05$). Overall, the lumber yields were greater for timber harvested from an FIO plantation than a PTP. Even though there are differences in sawing techniques adopted, the final lumber yield did not differ significantly between these two sources. The mechanical properties of teak wood improved with kiln drying, FIO plantation exhibits better properties than dried wood from the PTP.

1. INTRODUCTION

There is a huge demand for timber resources worldwide (Abdulah et al., 2020). However many countries, including Thailand, are experiencing decrease in forest area due to deforestation and illegal logging and the country imposed a total ban of export of round logs since 1989. Given their large economic impact, forest resources require careful management. Teak (*Tectona grandis*) is an important forest product (Dotaniya et al., 2013; Seviset et al., 2017; Udayana et al., 2019). Teak-wood is renowed for its wood qualities such as its appearance, strength, and durability and is being used in a variety of exterior and interior applications including furniture manufacture (Lima et al., 2021). In Thailand, teak wood production is being solely managed by the Forest Industry Organization (FIO); however, production did not meet the demand under this framework (Kalu and Adeyoju, 2011; Tewari and Mariswamy, 2013). Therefore, Thai government enacted a policy allowing smallholder farmers plant teak tress in their homesteads and promoting and commercial private teak plantations (PTPs).

Several studies have reported that the quantity and quality of teak sourced from the FIO and PTPs differs (Solorzano et al., 2012; Adi et al., 2016). Therefore, efforts are underway to adopt various technologies that improve these wood characteristics to avoid wastage. For instance, saw milling technologies and sawyer expertise impact lumber quantity and efficiency in sawn timber recovery processess. Kaakkurivaara (2022) suggested many

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ways of timber processing technologies to eliminate skidding and harvesting loss of teakwood from FIO plantations before being transported to sawmills. Circular saws are widely used in the lumber industry as they are efficient, stable and precise, thus limiting wastage (Krilek et al., 2014; Li and Zhang, 2017). Moreover, wood drying (seasoning) is the most important stages among wood processing because dried wood at moisture content around 12% offers major advantages over freshly sawn wood, including improved mechanical properties (Batista et al., 2017). For instance, timber intended for furniture and other interior woodwork should be dried to a target moisture content (MC) of 12-15% (Loucanova et al., 2017; Rabidin et al., 2017) under tropical conditions. Various wood seasoning kiln methods are adopted with different characteristics such as steam-heated kilns, dehumidification kilns, electric kilns, solar kilns, and other advanced wood-drying processes.

Phrae province in northern Thailand has a large teakwood industry that employs more than 12,000 people and is valued at >1,800 million baht per year (Yotapakdee et al., 2015). Improving this industry will add value to the local economy and develop infrastructure (Stone et al., 2011). However, there are no authentic data available comparing teak wood is sourced from the FIO and PTPs.

This study investigated the lumber yield and wood properties of teak from FIO plantations and PTPs in Phrae Province, Thailand, with the aim of providing information to help support the sustainable use of this valuable resource.

2. METHODOLOGY

2.1 Study site

The study was undertaken in FIO's teak plantation (47Q, x=656673, y=2040833) and a PTP (47Q, x=618202, y=1996767) located in Phrae Province, Thailand. In each site, timber yields of whole lumber, wood slabs, and sawdust produced by two types of sawmills was determined: a "standard" sawmill (The sawmill has been inspected and complies with the standards for sawing) and a "general" sawmill (The sawmill that uses traditional local wisdom for sawing). The yield of lumber sheets, wood residues and was also assessed and quantified. The properties of wood dried using different technologies of wood-drying kiln with direct heat ("standard" wood-drying kiln and "general" wood-drying kiln).

2.2 Wood sample preparation

Twenty numbers of defect-free (without bends or insect holes or knots) 25 year old teak trees were randomly selected from both the FIO plantation and PTP and harvested, cross cut with a length of about 2.5 m having a girth of 30-40 cm. The lumber was dried for 120 h in a standard kiln at the FIO plantation and in a general kiln at the PTP. To assess the teak wood properties, samples were cut from middle part of tree for each tests: 60 samples measuring 20×20×40 mm was used to determine the MC after drying in an oven for 24 h at 103±2°C; 60 samples measuring 20×20×300 mm were used to assess shrinkage in the cross-sectional or Longitudinal (X), radial (R), and tangential (T) directions after soaking in water for 24 h; and 60 samples measuring 20×20×300 mm were used to assess the modulus of rupture (MOR) and modulus of elasticity (MOE) using a Universal testing machine (BPS INSTRUMENT; BA-100) with BS373 standard (1985) and ASTM D143 (2014).

2.3 Experimental design

For the quantitative wood-sawing experiments, a randomized design was used involving two treatments (FIO and PTP), with 20 replicates per treatment. The first experiment assessed the yields of the whole lumber, wood slabs, and sawdust. Wood slabs and sawdust were measured and calculated based on sawblade thickness, number of cuts, and lumber width and length. Then, the yields after milling were quantified based on the volumes of whole lumber and each sheet produced; the difference between these values corresponded to the wood residue.

Next, wood properties were assessed following a randomized design with six treatments: two locations (FIO and PTP) and three drying methods ("standard" wood drying kiln, "general" wood drying kiln, and no drying- control). The treatment groups were as follows: FIO_1, FIO wood dried in a standard kiln; FIO_2, FIO wood dried in a general kiln; FIO_{ND}, undried FIO wood; PTP_1, PTP wood dried in a standard kiln; PTP_2, PTP wood dried in a general kiln; and PTP_{ND}, undried PTP wood. The average values were calculated for FIO_1 and FIO_2 (FIO_D); and PTP_1 and PTP_2 (PTP_D) for comparison with the undried control samples. For each treatment group, MC, MOR, MOE, and shrinkage were tested. Thus, a total of 120 samples (6 groups×4 tests×5 replicates) were used.

2.4 Data collection

The timber volume was calculated based on the volume of a cylinder:

$$\text{Timber volume (m}^3) = \pi \times r^2 \times h \quad (1)$$

Where; π is 3.14, r is the log radius (m), and h is the log length (m).

Lumber volume was calculated based on the following formula (Lima et al., 2018):

$$\text{Lumber volume (m}^3) = L \times T \times W \quad (2)$$

Where; L is the length (m), T is the thickness (m), and W is the width (m).

Sawdust volume was determined as follows:

$$\text{Sawdust volume (m}^3) = T_{sb} \times N \times W \times L \quad (3)$$

Where; T_{sb} is the thickness of the sawblade (m), N is the sawing time, W is width of the lumber (m), and L is the length of the lumber (m).

The MC was determined as the difference in wood weight before and after drying (Moghanaki et al., 2013):

$$\text{Mc (\%)} = \frac{(W_1-W_2)}{W_2} \times 100 \quad (4)$$

Where W_1 and W_2 are the weights before and after drying (g).

Finally, volumetric shrinkage was calculated as a percentage:

$$\text{Wood shrinkage (\%)} = \frac{\text{(Wood swelling change)}}{\text{(Wood swelling size)}} \times 100 \quad (5)$$

2.5 Data analysis

Statistical differences in yields were analyzed using a t-test. Wood properties were analyzed using one-way analysis of variance (ANOVA). All analyses were performed using SPSS for Windows software (ver. 20.0; IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSION

3.1 Teak timber yield

The whole lumber yield from the FIO plantation (57.21±1.27%) was significantly higher than that of PTP (49.56±1.44%, $p \leq 0.05$). However, the proportion of timber processed into wood slabs was significantly lower from the FIO plantation (36.69±1.28%) than the PTP (44.94±1.60%, $p \leq 0.05$). There was no significant difference in the sawdust proportion between the FIO plantation (6.10±0.24%) and the PTP (5.50±0.16%, $p > 0.05$) (Table 1). These results were similar to those of a previous study that reported that a lumber yield of 28-64% maximizes the economic value of wood (Adu et al., 2014).

The volumetric yield from timber is related to the sawblades, equipment capacity, timber dimensions, and human factors (Baltrušaitis and Pranckevičienė, 2005). For instance, Ovrum et al. (2009) suggested that timber length and diameter strongly influence the lumber yield. One study estimated a total volumetric yield of 47.6% after milling (Munoz et al., 2013). In another study, it was found that when the timber (including bark) was processed into boards, 40% yield was obtained, and of the remaining 60% planer shavings (10%), cutter shavings (26%), sawdust (13%), and bark (11%) (Melo et al., 2016). A previous study found that teak trees in FIO plantations had fewer buttress roots than those in PTPs, resulting in higher yields (Warner et al., 2016). Overall, these findings highlight the importance of intensive silvicultural management for lumber yield (Bermejo et al., 2004).

Table 1. Average percentage yields of whole lumber, wood slabs, and sawdust produced from timber harvested from an FIO plantation and PTP.

Source	Whole lumber yield	Wood slab yield	Sawdust yield
FIO	57.21±1.27	36.69±1.28	6.10±0.24
PTP	49.56±1.44	44.94±1.60	5.50±0.16
p value	≤0.001	≤0.001	0.347

Note: ANOVA was performed followed by t-test; $p \leq 0.05$ indicates statistical significance.

3.2 Teak lumber yield

There were no group differences in the proportion of lumber processed into sheets (FIO: 93.90±1.82%; PTP: 92.54±1.48%, $p > 0.05$) or wood residues (FIO: 6.10±1.82%; PTP: 7.46±1.48%, $p > 0.05$) (Table 2). These results were similar to those of Bomba et al. (2016). The milling equipment capacity, technology, and techniques impact the final lumber volume and wood residues produced (Wang and Rolf, 2003).

Table 2. Average percentage yields of lumber processed into sheets and wood residues from an FIO plantation and PTP.

Source	Lumber sheets	Wood residues
FIO	93.90±1.82%	6.10±1.82%
PTP	92.54±1.48%	7.46±1.48%
p value	0.307	0.307

Note: ANOVA was performed followed by t-test; p≤0.05 indicates statistical significance.

3.3 Impact of drying on teak wood properties

The MCs of teak wood were significantly lower in the FIO_D (10.38%) and PTPD (11.16%) treatments compared to the FIOND (29.95%) and PTPND (44.03%) treatments (all $p \leq 0.05$). This was similar to the results of Wanneng et al. (2014), who measured an initial MC of 47% in 25-year-old teak.

The MOR was significantly higher in FIO_D (100.91 MPa) than in PTP_D (83.35 MPa), FIO_{ND} (83.06 MPa), and PTP_{ND} (77.10 MPa) (all $p \leq 0.05$). The MOE of FIO_D (9,144.90 MPa) was significantly different from that of PTP_{ND} (7,993.20 MPa, $p \leq 0.05$), but not from those of PTP_D (8,541.50 MPa) or FIO_{ND} (8,375.80 MPa) (both $p>0.05$). Djati et al. (2015) measured MOR values in teakwood of 91.57 to 141 MPa, and MOE values of 9,332 to 10,684 MPa. Thulasidas and Bhat (2012) reported that wet, dry, and plantation teakwood at air-dry condition (12% m.c) had MOR values of 109.89, 118.01, and 111.20 MPa, respectively, and MOE values of 9,102.28, 9,709.90, and 10,045.21 MPa, respectively. Teak wood in all sites, dry sites, and wet sites had MOR values of 87, 75, and 88 MPa, respectively, and MOE values of 12,240, 9,920, and 12,420 MPa, respectively (Amoah and Inyoung, 2019; Rizanti et al., 2018) Kiln drying reduces the moisture content within the wood, which affects its strength.

Our FIO_D and PTP_D samples exhibited significantly less shrinkage values than the FIO_{ND} and PTP_{ND} samples in the X direction (0.14% and 0.18% vs. 0.34% and 0.45%, respectively), R direction (0.31% and 0.41% vs. 1.12% and 2.20%, respectively), and T direction (0.39% and 0.46% vs. 1.70% and 3.87%, respectively) (all $p \leq 0.05$; Table 3). These values are comparable to those measured in a previous study of teakwood, i.e., 0.49% (X), 3.50% (R), and 5.17% (T) (Miranda et al., 2010).

Table 3. Average MC, MOR, MOE, and shrinkage of dried and undried teak wood harvested from an FIO plantation and PTP.

Treatment	MC (%)	MOR (MPa)	MOE (MPa)	Shrinkage (%)		
				X	R	T
FIO_D	10.38^a	100.91^a	$9,144.90^a$	0.14^a	0.31^a	0.39^a
FIO_{ND}	29.95^b	83.06^b	$8,375.80^{ab}$	0.34^b	1.12^b	1.70^b
PTP_D	11.16^a	83.35^b	$8,541.50^{ab}$	0.18^a	0.41^a	0.46^a
PTP_{ND}	44.03^c	77.10^b	$7,993.20^b$	0.45^c	2.20^c	3.87^c
p value	≤0.001	≤0.001	≤0.04	≤0.001	≤0.001	≤0.001

Note: Different superscript letters (a-c) indicate significant differences among the treatments for each property in a column; ns, non-significant. ANOVA was performed followed by Duncan's new multiple range test at p≤0.05

3.4 Impact of drying method on teak wood properties

The lowest teakwood MC was obtained in FIO_1 (9.62%), which differed significantly from the MCs of FIO_2 (11.13%), PTP_1 (11.16%), and PTP_2 (11.18%) (all $p \leq 0.05$). In the tropical conditions, the optimum moisture content is around 12-15% with slight variations depending on the season and surrounding atmospheric humidity.

In addition, the mechanical properties of standing bending tests like MOR values of FIO_1 (104.28 MPa) and FIO_2 (97.54 MPa) were significantly higher than those of PTP_1 (84.51 MPa) and PTP_2 (82.20 MPa) (all $p<0.05$). Although FIO_1 (9,331.20 MPa) had the highest MOE, it did not differ significantly from those of FIO_2 (8,958.90 MPa), PTP_1 (8,647.00 MPa), and PTP_2 (8,436.00 MPa) (all $p>0.05$). These results were similar to those of Bhat and Priya (2004), who recorded MOR, MOE of 91.8 MPa and 8,436 Ma, respectively.

In this study, the lowest X shrinkage was observed in FIO_1 (0.14%), but it did not differ significantly from those of FIO_2 (0.15%), PTP_2 (0.17%), and PTP_1 (0.18%) (all $p>0.05$). The lowest R shrinkage was observed in FIO_1 (0.28%), which was not significantly different from that of FIO_2 (0.35%, $p>0.05$) but differed significantly from those of PTP_1 (0.39%) and PTP_2 (0.43%) (all $p<0.05$). The lowest T shrinkage was again observed in FIO_1 (0.33%), which differed significantly from those of FIO_2 (0.45%),

PTP_1 (0.45%), and PTP_2 (0.47%) (all $p<0.05$; Table 4). For teak wood harvested from 15, 20, and 25-year-old teak trees, Izekor and Fuwape (2011) reported mean R shrinkages of 1.51%, 1.30%, and 0.73% and mean T shrinkages of 3.14%, 2.23%, and 1.27%, respectively. Overall, the quality of the drying oven impacts the mechanical properties of wood (Alteyrac et al., 2006).

Table 4. Impact of drying treatment and lumber source on the MC, MOR, MOE, and shrinkage of teak wood harvested from an FIO plantation and PTP.

Treatment	MC (%)	MOR (MPa)	MOE (MPa)	Shrinkage (%)		
				X	R	T
FIO_1	9.62^a	104.28^a	$9,331.20^{ns}$	0.14^{ns}	0.28^a	0.33^a
FIO_2	11.13^b	97.54^a	$8,958.60^{ns}$	0.15^{ns}	0.35^{ab}	0.45^b
PTP_1	11.16^b	84.51^b	$8,647.00^{ns}$	0.18^{ns}	0.39^b	0.45^b
PTP_2	11.18^b	82.20^b	$8,436.00^{ns}$	0.17^{ns}	0.43^b	0.47^b
p value	<0.001	<0.001	0.25	0.58	0.01	0.05

Note: Different superscript letters (a-c) indicate significant differences among the treatments for each property in a column; ns, non- significant. ANOVA was performed followed by Duncan's new multiple range test at $p\leq0.05$

4. CONCLUSION

The lumber yields were greater for timber harvested from an FIO plantation than a PTP in Thailand; however, even though there are differences in sawing techniques adopted, the final lumber yield did not differ significantly between these two sources. The mechanical properties of teak-wood improved with kiln drying, FIO plantation exhibits better properties than dried wood from the PTP.

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