UTILISATION OF *STYRAX TONKINENSIS* WOOD IN LAOS AND ITS PHYSICAL PROPERTIES

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MATSUO MU, SUJAN KC, HIROTA I, KOJIMA M, YOSHIDA M & YAMAMOTO H. 2016. Utilisation of *Styrax tonkinensis* wood in Laos and its physical properties. The study investigated the physical characteristics of *Styrax tonkinensis* trees in Laos, used for benzoin tapping and subsequently abandoned, as timber for building materials. The study consisted of a multidisciplinary approach. First, a survey was conducted on tree species currently used as building materials at a site where villagers cultivated *S. tonkinensis* for shifting-cultivation-cycle agriculture. Second, the physical properties of *S. tonkinensis* were analysed, namely, dry density, tensile elasticity, dimensional changes due to boiling and drying and microfibril angle (MFA). The survey demonstrated the possibility of using *S. tonkinensis* as timber. The wood of *S. tonkinensis* was intermediate to other timber species in terms of material properties. Growth stress and physical properties indicated that *S. tonkinensis* formed tension wood in its inclined stem, thus the timber should be processed carefully. The results suggested that there was potential to expand the focus of *S. tonkinensis* cultivation to include building material use, contributing towards sustainable agroforestry.

Keywords: Benzoin, housing materials, interview, mechanical properties, tension wood, growth stress

INTRODUCTION

Styrax is a genus of fast-growing trees, widely distributed in South-east Asia. These trees are found transplanted in parts of China and French Guiana. Large-scale use of the wood is rare, with the exception of pulp production in Vietnam. The wood is used in a small scale for match splints, chopsticks, wooden shoes, pencils, firewood, poles, laminates and as building material in the highlands of Laos (Pinyopusarerk 1994, Hoesen 2000, Phuong et al. 2006).

Styrax trees have long been used to tap benzoin resin which is an economically important product used in the manufacture of perfumes, cigarettes and medicine. Indonesia and Laos have been the primary producers of benzoin resin. Benzoin resin from *S. tonkinensis* in Laos, commercially named Siam benzoin or Lao benzoin, is highly prized for its quality. Traditionally, tapping of *S. tonkinensis* in Laos begins when the trees are 6–8 years old. Thereafter, the production declines over time and the trees eventually die at 14–16 years of age (Pinyopusarerk 1994, Hoesen 2000). In Laos, the tapping of *S. tonkinensis* is part of a shifting-cultivation-cycle. Trees are grown till 8–12 years old and then cut and burned to clear the land for upland rice planting. Upon rice harvesting, *S. tonkinensis* trees grow as a result of either natural regeneration or artificial seedlings. The trees grow during fallow period and produce abundant biomass. This cycle, combined with upland rice cultivation, maintained forest ecosystems and enhanced recovery from the damage caused by shifting cultivation (Kashio 2001, Hirota et al. 2014).

The wood from *S. tonkinensis* is white or dull red to pale brown in colour with coarse grains. Its low durability limited its use as an exterior building material. Its density range from 0.413 to 0.450 g cm^{-3} and 0.470 to 0.710 g cm^{-3}, at 15% moisture content. Bending strength and Young's modulus are 81.2 MPa and 8.42 GPa respectively, at density 0.45 g cm^{-3}. Its fungal resistance is improved by heat treatment (Pinyopusarerk 1994, Hoesen 2000, Phuong et al. 2007).

The pattern of growth stress distribution within the stem is also important. Defects caused by growth stress include brittle heart, heart checks, ring shakes in living trees and splitting and warping during timber processing (Kübler 1987). Growth stress is often generated in fast-growing, tropical hardwood species due to the formation of reaction wood in the tilted stem which limit its use as timber (Wahyudi et al. 1999, Valencia et al. 2011, Kojima et al. 2012). However, regardless of the growth stress, the use of the wood for value-added timber products is an important aspect. *Styrax tonkinensis* trees which grow on mountainous slopes in Laos should be studied for better understanding of its growth stress and formation of reaction wood.

This study investigated the characteristics of *S. tonkinensis* trees that grew in Laos, used for benzoin tapping and subsequently abandoned, as wood for timber. The study consisted of a multidisciplinary approach that included interviewing villagers to determining the types of wood most frequently used in the village, and whether it was possible to use *S. tonkinensis* as timber. The study focused on the physical properties of tilted *S. tonkinensis* trees which had tension wood formation with tensile growth stress. The following parameters were measured, i.e. surface growth stress, morphological characteristics, microfibril angel (MFA), xylem density, tensile Young's modulus and dimensional changes due to drying and boiling. The relationship between each property was discussed. The results contributed to the development of new, effective uses for *S. tonkinensis* wood for sustainable agroforestry which is of ecological and social importance.

MATERIALS AND METHODS

Study site

The study site is Kachet village (20° 34' N, 102° 18' E), situated in the north-west of Nam Bak District, Luang Prabang Province, Laos with an area of 1890 ha (Figure 1). As of 2011, the village had 98 households and 486 individuals of the Khmu ethnic, the traditional shifting cultivators. Most of the villagers practiced shifting cultivation for crop production, including the harvest of benzoin resin (Hirota et al. 2014).

Survey of trees used for housing

To determine the types of wood used and whether *S. tonkinensis* was among them, a survey was carried out on five houses in the village (Figure 2). A traditional Khmu house is a pile dwelling made of wood or bamboo with a thatched or bamboo roof and bamboo mat wall (Chazée 1999, Oikawa et al. 2009). However, various styles and building materials have been recently introduced. In the present study, the houses were selected to encompass a broad range of styles including pile and floor dwelling. Bamboo mat and wood board walls as well as block or cement walls with corrugated roofs were included in the study. Each homeowner was interviewed about the wood material used

Figure 1 The study site, Kachet village (●)

	Building materials		
	Frame	Wall	Roof
(a)	Wood	Bamboo	galvanised plate
(b)	Wood	Wood	galvanised plate
(c)	Wood	Wood, cement	galvanised plate
(d)	Wood	Block	galvanised plate
(e)	Wood	Cement	galvanised plate

Figure 2 Houses (a) and (b) use more natural materials, while (c), (d) and (e) use them only for frames, doors and windows; the table shows the types of materials used

for different construction purposes, i.e. columns, beams, roof and roof trusses, walls, windows, doors, ceilings, stairs and foundation.

Sampled trees

Eight *S. tonkinensis* trees, 4–10 years old, grown in mountainous fallow land were sampled to measure growth stress and material properties (Figure 3, Table 1). In six of the trees (B1–B6), growth stress and material properties were measured, in two other trees (B7 and B8), only growth stress was measured.

Released strain of surface growth stress

The peripheral distribution of released strain was measured as index of growth stress. Six or eight measuring points were set peripherally at the breast height of each standing tree (Figure 4a). The outermost surface of secondary xylem was exposed using a hand chisel and a strain gauge was glued to the tree (Okuyama et al. 1981, Yamamoto et al. 1989, Yoshida & Okuyama 2002). The foil strain gauge used was prepared from polyimide, 10 mm in length and enabled a single-gauge, three-wired connection. The gauges were

Figure 3 Felling of a *Styrax tonkinensis* tree in mountainous fallow land, debarked part at breast height was used for the determination of material properties

Table 1 *Styrax tonkinensis* sample trees

Tree	Angle of tilt (deg)	Tree height (m)	DBH (cm)	Tree age (year)	Growth rate (cm year^{-1})
B1	3	14.5	16.2	10	0.81
B2	3	13.4	10.6	10	0.53
B3	7	12.5	12.7	8	0.80
B4	10	8.1	9.0	9	0.50
B5	13	12.8	12.4	8	0.78
B6	17	8.2	9.4	9	0.52
B7	8	12.2	12.1	5	1.21
B8	14	11.0	10.8	4	1.35

Angle of tilt = angle between the uppermost side of the stem and the direction of gravitational force, DBH = diameter of breast height, growth rate = (DBH/2)/tree age

glued with cyanoacrylate along the longitudinal (L) and tangential (T) sides and connected to a handy strain meter. After measuring the initial strain, a groove was carved in the secondary xylem surface around the gauge, 10 mm in depth, using a hand saw, to release surface growth stress. The strain was then measured again. Released strain was calculated as the difference between the initial and after grooved strain.

Specimen preparation

Soon after harvesting, the wood was wrapped with a water-impermeable sheet to prevent drying during storage. Tree B1 was used to measure the radial distribution of tensile Young's modulus from surface to pith. Green specimens with dimensions of 50 mm (L) × 15 mm (T) × 5 mm (radial [R]) were cut from B1 along the R direction (Figure 4b). For trees B2–B8, green specimens of similar dimensions were cut from the xylem adjacent to the glued strain gauges to observe the peripheral distribution of material properties and their relationship with growth stress (Figure 4c).

Measurement of material properties

The measured material properties included xylem density when dried (ρ), tensile Young's

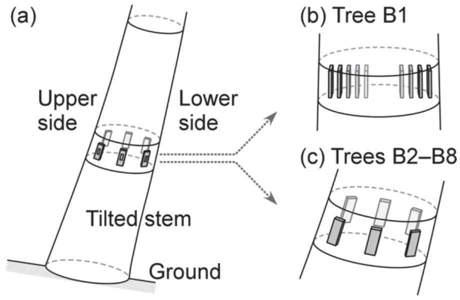

Figure 4 Measurement of released strain of surface growth stress and specimen preparation, (a) measuring points of released strain, (b) specimen preparation for radial distribution of tensile Young's modulus, (c) specimen preparation for peripheral distribution of material properties

modulus in L direction (E_L) and dimensional change in L direction due to drying (α_d) and boiling (α_b). ρ and E_L were fundamental material properties that indicated mechanical performance, where higher ρ and E_L values correlated with stronger and rigid materials. α_d and α_b indicated dimensional change, as defined in formulae 1 and 2, due to water removal and heating in the presence of water respectively. Wood deformation due to drying resulted in serious defects such as cracks, splits and collapse. Wood deformation due to boiling was akin to the initial stage of kiln drying. Therefore, α_d and α_b were important indicators to evaluate the dimensional stability during material processing. Lower values of α_d and α_b indicated higher dimensional stability of materials.

Upon measurement of the longitudinal dimensions, the green wood specimens were dried consecutively in air-condition, silica gel desiccator and phosphorus pentoxide desiccator for 2 weeks each, to measure ρ, E_L, and α_d. The specimens were then rehydrated to achieve a water saturated condition and boiled in an autoclave at 120 °C and 0.2 MPa for 10 min, to measure α_b. Boiled specimens were equilibrated at 20 °C for 2–3 hours and dimensions measured. The values of α_d and α_b were calculated as follows,

Formula 1: $$\alpha_d\,(\%) = 100\,\frac{l_g - l_d}{l_g}$$

Formula 2: $$\alpha_b\,(\%) = 100\,\frac{l_g - l_b}{l_g}$$

where l_g = longitudinal dimension of green wood specimen, l_b = longitudinal dimension of boiled specimen and l_d = longitudinal dimension of dried specimen. Dimensional changes were measured using a dial gauge comparator with an accuracy of 0.001 mm. E_L was measured using a universal testing machine.

MFA measurement and microscopic observation

Upon measurements, each specimen was cut into (1) flat-sawn sections, 10 mm (L) × 10 mm (T) × 2 mm (R), for MFA measurement, and (2) cross-sections, 0.01 mm (L) × 10 mm (T) × 5 mm (R), for microscopic observation. X-ray diffraction spectrums were obtained using an X-ray diffractometer for MFA determination (Cave 1966, Yamamoto 1993). For microscopic observation, the sections were stained overnight with safranin-astra blue solution followed by dehydration with a series of increasing ethanol concentrations, i.e. 25, 50, 75 and 100%. The sections were then fixed on slide glass using Entellan™. Anatomical features of *S. tonkinensis* wood were observed using an optical microscope.

RESULTS AND DISCUSSION

Wood used for housing

A list of wood species used for structural purposes is shown in Table 2. In total, 19 wood species were used to build these houses. The villagers provided the tree names in Khmu language and attempted to translate them into Laotian or scientific names. *Castanopsis diversifolia*, known as 'kha lang' in Khmu language, was the most frequently used species due to its large size. In contrast, *S. tonkinensis* did not appear on the list. Since some tree names could not be translated into Laotian or scientific names, the survey had less information than anticipated. The study revealed that *S. tonkinensis* was not currently used as a construction material, however, it had the potential to be used for home building and furniture making.

Anatomical characteristics

Figure 5 shows the cross-sections of lower and upper sides of a tilted stem. *Styrax tonkinensis* is a diffused-porous wood (Figure 5a). Anatomical characteristics of *Styrax* normal wood have been reviewed and analysed in previous studies (Metcalfe & Chalk 1950, Lobdell 2013). Therefore, this study will focus on the characteristics of reaction wood. Compared with normal wood (Figure 5b), the fibres of tension wood had typical characteristics such as thick wall and astra blue-stained areas (Figure 5c), suggesting the presence of a gelatinous layer of cellulose-rich cell wall. Although the border between the astra blue-stained area and the safranin-stained area was unclear, the results suggested that tension wood was formed in *S. tonkinensis* on the upper side of tilted stems.

General description of material properties

Table 3 summarises the average values of material properties of normal wood and tension wood with standard deviations and number of specimens tested. The values of ρ and E_L were similar to previously reported values (Pinyopusarerk 1994, Phuong et al. 2007). The wood of *S. tonkinensis* was intermediate to other fast-growing species in terms of ρ, which dominated the physical and mechanical properties, e.g., average values

Table 2 Species used by five houses in the village

Species name in Khmu language	Laotian name	Scientific name	Usage
Kha lang (ko kheey)		*Castanopsis diversifolia*	Foundation, joist, roof truss, floor, door, door frame, window frame
Kok (kok paa)			Stair
Tood dang		*Trevesia palmata*	Floor
Tala		*Cephalostachyum virgatum*	Wall
Tanet	Hok	*Dendrocalamus hamiltonii*	Wall
Taven	Nyang	*Hopea or Dipterocarpus*	Foundation
Ble	Moon paa	*Morus* sp.	Joist, wall, stair
Bouang			Joist, wall, floor
Kouang deng	Kouang deng		Door, roof truss
Khob	Tam sai		Beam, roof truss
Kient			Roof truss, window frame
Sanam	Seuad		Roof truss
Sangching	Sangching		Roof truss
Lang kang	Kang	*Phoebe lanceolata*	Roof truss
Satou	Nyom hom		Door
Line			Door
Dour			Ceiling
Chileum clook		*Cratoxylum formosum* ssp. *prunifolium*	Firewood
Moon	Moon	*Morus* sp.	Beam, roof truss, ceiling

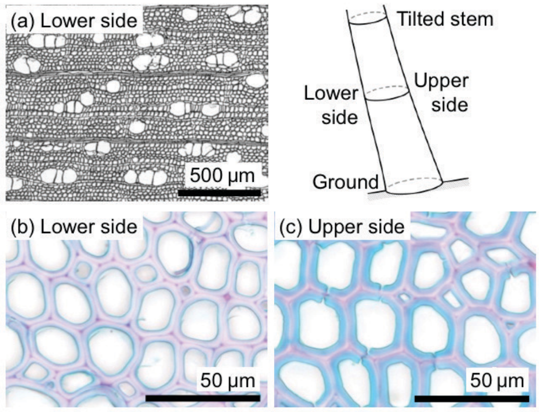

Figure 5 Observation of *Styrax tonkinensis* wood by optical microscopy, (a) and (b) fibres in the lower side of a tilted stem, (c) fibres in the upper side

Table 3 Average values for material properties

	MFA (°)	ρ (g cm^{-3})	E_L (GPa)	α_d (%)	α_b (%)
Average	12.3	0.500	9.54	0.282	0.0769
Standard deviation	3.27	0.0430	1.75	0.224	0.291
Maximum	18.0	0.595	14.2	0.920	1.14
Minimum	5.79	0.427	6.58	0.0486	-0.186
No. of specimens	38	38	31	33	33

MFA = microfibril angle, ρ = xylem density when dried, E_L = tensile Young's modulus in the L direction, α_d = dimensional change in L direction due to drying, α_b = dimensional change in L direction due to boiling

of ρ were 0.683 g cm^{-3} for *Acacia mangium*, 0.391 g cm^{-3} for *Paraserianthes falcataria*, 0.664 g cm^{-3} for *Eucalyptus grandis*, 0.35 g cm^{-3} for *Populus tremuloides*, 0.40 g cm^{-3} for *Picea sitchensis*, 0.42 g cm^{-3} for *Pinus radiata*, 0.55 g cm^{-3} for *Tectona grandis* and 0.68 g cm^{-3} for *Quercus alba* (Forest Products Laboratory 1989, Kojima et al. 2009).

Peripheral distribution of growth stress and material properties

Figure 6 shows the peripheral distribution of released strain of growth stress in L and T directions, MFA, ρ, E_L, α_d and α_b. Trees B1 and B2 from vertical stems demonstrated constant released strain in L direction around the periphery (Figure 6a). In contrast, trees B3–B8 with tilted stems showed higher negative released strain in L direction on the upper side of the stems (relative position = 0), which implied the presence of higher tensile growth stress. For samples B5 and B6, relatively higher ρ, lower MFA and larger α_d and α_b were observed in the upper side of stems (Figure 6c, d, f, g), which coincided with higher tensile growth stress. In these samples, the released strain in L direction correlated with the rest of the material properties. The following section will detail the relationship between released strain in L direction and other properties. Released strain in T direction and E_L were constant, regardless of the position.

Relationship between growth stress and material properties

Figure 7 shows the relationship between released strain of growth stress in L versus T directions for MFA, ρ, E_L, α_d, and α_b. Little to no correlations were observed between released strain in L direction and MFA, ρ and E_L. In contrast, α_d and α_b demonstrated relatively strong correlation with released strain in L direction which implied that the tension wood of *S. tonkinensis* may cause defects during drying such

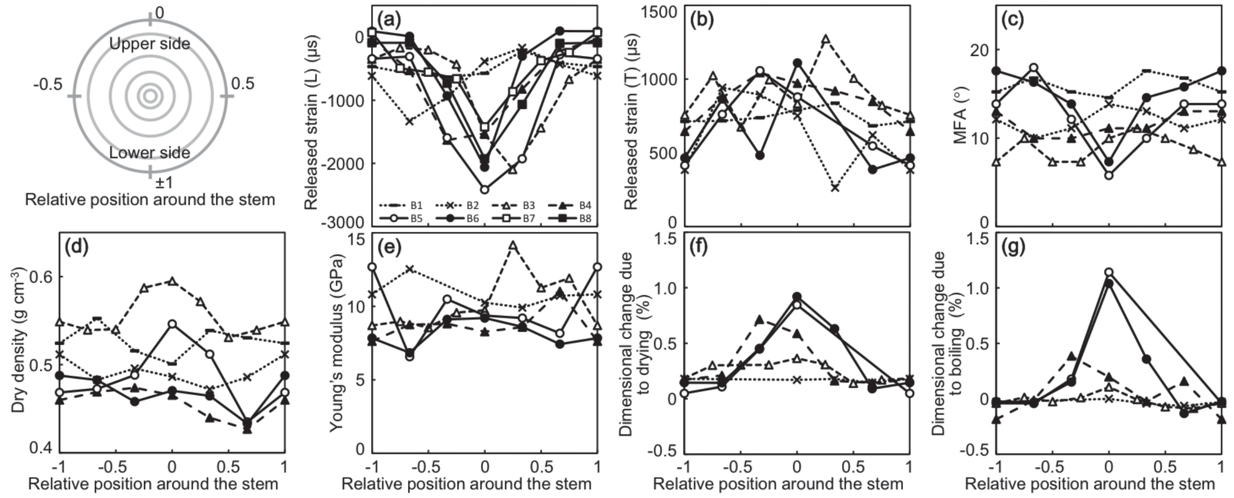

Figure 6 Peripheral distribution of (a) released strain of growth stress in L direction, (b) released strain of growth stress in T direction, (c) MFA, (d) dry density, (e) tensile Young's modulus, (f) dimensional changes due to drying, (g) dimensional changes due to boiling; X axis shows the relative positions around the stem, 0 = lowermost side, 1/-1 = uppermost side

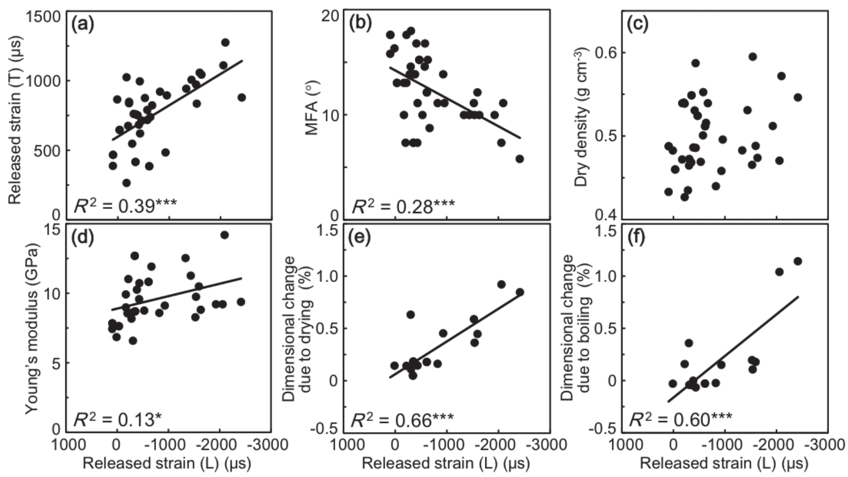

Figure 7 Relationship between released strain of growth stress in L direction and (a) released strain of growth stress in T direction, (b) MFA, (c) dry density, (d) tensile Young's modulus, (e) dimensional change due to drying, (f) dimensional change due to boiling; r = correlation coefficient, * and *** = significant levels of 5 and 0.1% respectively

as cracks, splits, deformation and collapse. Therefore, if logs or timber contain tension wood, the drying process should be performed carefully.

Radial distribution of Young's modulus

Figure 8 shows the radial distribution of E_L in sample B1. The value was 10 GPa near the bark and gradually decreased by 50% near the pith. Radial distribution of E_L could be due to the difference in morphological and physical properties between mature and juvenile wood (Zobel & Sprague 1998). Since sample B1 was 10 years of age, it was likely that *S. tonkinensis* needed at least 10 years to start producing mature wood. However, in the village, trees were cut at 8–12 years old due to tree tapping of the shifting cultivation cycle (Hirota et al. 2014). It is advisable to keep trees growing as long as possible, without compromising

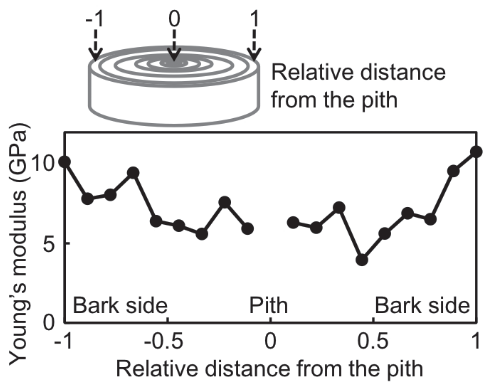

Figure 8 Radial distribution of tensile Young's modulus. X axis shows the relative positions from pith to bark, 0 = position of the pith, 1/-1 = outermost side

to benzoin demands, to obtain wood of higher quality.

There are many challenges to face with the expanding usage of *S. tonkinensis* as timber. For instance, trees frequently undergo cladoptosis which leaves scars on their stems. However, the physical characteristics of *S. tonkinensis* detailed in this study demonstrated the possibility of its use as timber. The results could support proposals on practical uses of the wood after benzoin harvesting.

CONCLUSIONS

The use of *S. tonkinensis* wood as timber, after harvesting benzoin, was investigated through surveys of its utilisation and measurement of its physical properties as well as observation of its morphological characteristics. The interviews revealed that *S. tonkinensis* had not been used for housing. However, the measured values of dry density and tensile Young's modulus were found to be adequate for building material use. The difference in anatomical characteristics and material properties between the upper and the lower sides of tilted stems indicated that *S. tonkinensis* formed tension wood within its tilted stems. The multidisciplinary approach demonstrated a potential for sustainable use of *S. tonkinensis* wood. Since the physical characteristics of tension wood may cause defects, it should be carefully processed using methods such as sawing and kiln drying.

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