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# Comparative Study on Water Absorption and Swelling Behavior of Four Exotic Tropical Pine Species from Taung Lay Lone Reserved Forest, Southern Shan State

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# Comparative Study on Water Absorption and Swelling Behavior of Four Exotic Tropical Pine Species from Taung Lay Lone Reserved Forest, Southern Shan State

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**Abstract**

In this research, four exotic tropical pine species (*Pinus kesiya*, *Pinus caribaea* , *Pinus maximinoi* and *Pinus oocarpa*) were collected from pine plantation in Taung Lay Lone Reserved Forest, located in Taung-gyi Township, Southern Shan State. One tree for each species was collected. Density, specific gravity, water absorption, and swelling properties were tested according to German standard DIN (52184). The results from the study showed significant differences in density, specific gravity, radial swelling, tangential swelling, and water absorption among the four species. However, longitudinal swelling did not show significant differences among the species. *Pinus maximinoi* had the highest basic density, while *Pinus kesiya* had the lowest. It was found that *Pinus maximinoi* exhibited the highest swelling value whereas *Pinus caribaea* had the lowest swelling value. Swelling anisotropy of *Pinus kesiya* and *Pinus maximinoi* is less than 2 while that of *Pinus caribaea* and *Pinus oocarpa* is greater than 2. Except for *Pinus caribaea*, tangential swelling of *Pinus kesiya, Pinus maximinoi,* and *Pinus oocarpa* is greater than 7. *Pinus kesiya* absorbed the highest amount of water but *Pinus maximinoi* absorbed the least. According to classification of wood based on basic specific gravity, four exotic tropical pine species would be in "Moderately Heavy" group. According to the results of swelling and water absorption, the four exotic tropical pine species could be suitable for internal applications. To reduce swelling, varnish and paint should be applied to the wood to prevent moisture from entering.

**Key words:** Swelling, water absorption, density, specific gravity, pine species (*Pinus kesiya Pinus caribaea*, *Pinus maximinoi* and *Pinus oocarpa*)

# ရှမ်းပြည်နယ်တောင်ပိုင်း၊ တောင်လေးလုံးကြိုးဝိုင်းမှ နိုင်ငံခြား အပူပိုင်းထင်းရှူးသစ်(၄)မျိုး၏ ရေစုပ်ယူမှုနှင့်ကြွမှုအခြေအနေများကို နှိုင်းယှဉ်လေ့လာခြင်း

ဒေါက်တာချိုချိုမြင့်၊ လက်ထောက်သုတေသနအရာရှိ

## စာတမ်းအကျဉ်းချုပ်

ဤသုတေသနတွင်နိုင်ငံခြားအပူပိုင်းထင်းရှူးသစ်(၄)မျိုး (*Pinus caribaea*, *Pinus kesiya*, *Pinus maximinoi* နှင့် *Pinus oocarpa*) ကို ရှမ်းပြည်နယ် တောင်ပိုင်း၊ တောင်ကြီးမြို့နယ်ရှိ တောင်လေးလုံးကြိုးဝိုင်းအတွင်းထင်းရှူးစိုက်ခင်းမှ ရယူ စုဆောင်း ခဲ့ပါသည်။ သစ်မျိုးတစ်မျိုးလျှင် နမူနာသစ်တစ်ပင်စီရယူစုဆောင်းခဲ့ပါသည်။ သိပ်သည်းခြင်း၊ သိပ်သည်းဆ၊ ရေစုပ်ယူမှုနှင့် ကြွမှုဂုဏ်သတ္တိများကို German standard DIN (52184) အတိုင်း စမ်းသပ်ခဲ့ပါသည်။ လေ့လာတွေ့ရှိချက်များအရ သိပ်သည်းမှု၊ သိပ်သည်းဆ၊ ဒုအလိုက်ကြွမှု၊ ဖြက်အလိုက်ကြွမှုနှင့် ရေစုပ်ယူမှုတို့သည် သစ်တစ်မျိုးနှင့် တစ်မျိုးအကြား သိသိသာသာ ခြားနားမှုရှိကြောင်း တွေ့ရှိရပါသည်။ သို့သော်လည်း ဒေါင်လိုက်ကြွမှုမှာ သိသိသာသာ ခြားနားမှုမရှိကြောင်း တွေ့ရှိရပါသည်။ *Pinus maximinoi* သည် သိပ်သိပ်ခြင်း အမြင့်ဆုံး ဖြစ်ပြီး *Pinus kesiya* သည် အနိမ့်ဆုံးဖြစ်ကြောင်းတွေ့ရှိရပါသည်။ *Pinus maximinoi* သည် ကြွမှုအမြင့်ဆုံးဖြစ်ပြီး *Pinus caribaea* သည် အနိမ့်ဆုံး ဖြစ်ကြောင်း တွေ့ရပါသည်။ *Pinus kesiya* နှင့် *Pinus maximinoi* တို့၏ အသားငြိမ်မှုမှာ ၂ အောက် ငယ်ပြီး *Pinus caribaea* နှင့် *Pinus oocarpa* တို့မှာ ၂ ထက်ကြီးကြောင်း တွေ့ရပါ သည်။ *Pinus caribara* မှတစ်ပါး ကျန်ထင်းရှူးတို့၏ ဖြက်အလိုက်ကြွမှုမှာ ၇ ထက် ကြီးကြောင်း တွေ့ရှိရပါသည်။ *Pinus kesiya* သည် ရေအများဆုံးစုပ်ယူပြီး *Pinus maximinoi* သည် အနည်းဆုံး စုပ်ယူသည်ကို တွေ့ရပါသည်။ရေချိန်သိပ်သည်းဆကို အခြေခံသော သစ်အမျိုး အစားအုပ်စုခွဲခြားမှုစနစ်အရ နိုင်ငံခြားအပူပိုင်း ထင်းရှူးသစ်(၄)မျိုးလုံး သည် "အသင့်အတင့် လေးသော အုပ်စု" တွင် ပါဝင်ပါသည်။ ကြွမှုနှင့် ရေစုပ်ယူမှု ရလဒ်များအရ ဤအပူပိုင်း ထင်းရှူးသစ် (၄)မျိုးသည် အိမ်တွင်း အသုံးပြုရန်သင့်လျော်ပါသည်။ ကြွမှုများလျော့နည်းစေရန်အတွက် သစ်များ အတွင်း အစိုဓာတ်ဝင်ခြင်းမှကာကွယ်ရန် သစ်များကို အရောင်တင်ဆေးနှင့် သဘော်ဆေးများ သုတ်သင့်ပါသည်။

# Comparative Study on Water Absorption and Swelling Behavior of Four Exotic Tropical Pine Species from Taung lay Lone Reserved Forest, Southern Shan State

## 1. Introduction

Wood is a hygroscopic material. Thus, it can absorb water both as a liquid when in contact with water and as vapor from the surrounding atmosphere. Wood is a part of the living tree or as a material and always contains moisture. Shrinking and swelling occur as wood changes moisture content in response to daily and seasonal fluctuations in atmospheric relative humidity. When the air is humid, wood adsorbs moisture and swells; when the air is dry, wood loses moisture and shrinks.

Wood is an anisotropic material. Thus, its dimensional changes are unequal along the three structural directions: radial, tangential and longitudinal. Radial shrinkage in solid wood can vary from less than 2% for some stable wood species to around 8% for least stable species; most woods fall in the range of about 3% to 5% of radial shrinkage. Tangential shrinkage can vary from about 3% up to around 12%; most woods fall in the range of about 6% to 10% of tangential shrinkage. The amount of a piece of wood will shrink lengthwise, called longitudinal shrinkage**,** is so small-typically about 0.1% to 0.2%.

Shrinking and swelling can result in warping, checking, splitting and loosening of tool handles, gaps in wooden applications or performance problems that detract from the usefulness of wood products (Jain and Kurhekar, 2015). Therefore, understanding shrinkage and swelling of wood is crucial. Although shrinkage, swelling and water absorption of some Myanma timber species have been tested, swelling and water absorption of pine species have not been tested yet.

Pinus is a genus of evergreen conifers belonging to the family Pinaceae. In Myanmar, Shan State is the largest state and one of natural pine regions. Pine plantations have been established on a large scale in Shan State since 1980, using indigenous species *Pinus kesiya*. Due to slow growth and poor form of indigenous species, tropical pines from Central America have been introduced and planted extensively in tropical and sub-tropical countries (Baconand Hawkins, 1980; Hawkinsetal., 1978; Lamb, 1973) with great success due to their good growth and versatility of timber. In Myanmar, Forest Research Institute has initiated trials on exotic pines in Shan State since 1981. Six tropical exotic pine species (*Pinus caribaea, Pinus kesiya, Pinus maximinoi, Pinus oocarpa, Pinus patula and Pinus pseudostrobus* ) were planted in Taung Lay Lone Research Station in 1986.

During 2019 and 2021, wood properties of four exotic tropical pine species (*Pinus caribaea*, *Pinus kesiya*, *Pinus maximinoi* and *Pinus oocarpa*,) from Taung Lay Lone Reserved Forest, Southern Shan State were studied. In that study, their physical and mechanical properties were tested but swelling and water absorption were not tested. Therefore, it is essential to test these properties to thoroughly understand their water absorption and swelling behavior.

## 2. Objectives

The objectives of this research are:

(1) to study swelling and water absorption of four exotic tropical pine species,

(2) to compare swelling and water absorption of four exotic tropical pine species with those of some Myanmar timber species and

(3) to recommend their utilization potential based on finding results.

## 3. Materials and Methods

### 3.1 Materials

In this research, four exotic tropical pine species (*Pinus kesiya* Royle ex Gordon, *Pinus caribaea* Morelet, *Pinus maximinoi* H.E Moore and *Pinus oocarpa* Schiede ex Schltdl) were selected to study water absorption and swelling behavior. For each species, one tree sample was collected from the pine plantation of Taung Lay Lone reserved forest in Taung-gyi Township, Southern Shan State which was established in 1986.

### 3.2 Methods

Wood specimens were prepared according to German standard (DIN-52184). Swelling in radial, tangential and longitudinal directions and water absorption were determined from oven dry to green condition in accordance with the guidance in the standard. Tested wood properties and size of specimens were shown in Table 1.

Table 1. Tested wood properties and size of specimens of four exotic tropical pine species

| Sr. No | Properties | Size of Specimen (mm) |
|---|---|---|
| 1 | Basic Density, Specific gravity | 30 x 30x 10 |
| 2 | Swelling (Radial, Tangential, Longitudinal) | 30 x 30 x 10 |
| 3 | Water absorption | 30 x 30x 10 |

#### 3.2.1 Basic Density

Basic density was calculated by dividing oven dry weight of a sample by its saturated volume. The saturated volume of the sample was determined by multiplying dimensions of the wood specimen at its maximum swollen state.

$$\rho_b = \frac{W_o}{V_{sat}}$$

where:

$\rho_b$ = Basic density ($kgm^{-3}$)

$W_o$ = Oven dry weight (kg)

$V_{sat}$ = Saturated volume of wood sample ($m^3$)

#### 3.2.2 Specific gravity

Specific gravity is a ratio of density of wood to the density of water. It is also known as relative density. Specific gravity is used as a basis to standardize comparisons among species and products (Forest Product Laboratory, 1999).

### 3.2.3 Swelling

As a hygroscopic material, wood swells when it absorbs moisture from the environment. To study swelling, the samples were oven-dried so that their moisture contents become zero. First, dimensional length measurements of the samples were taken using a vernier caliper and recorded before the immersion into water. Then, the specimens were immersed in water. Thereafter, readings were taken every hour for 4 hours. Then, the specimens were continuously immersed in water, and measurements were made until steady weights were obtained when all specimens were completely immersed in water. Maximum weights and dimensions were also recorded. Swelling was calculated as follows:

$S_w$ (%) = [(Ds-Dg)/$D_g$] x 100

Where:

$S_w$ = Percentages of swelling (%)

$D_g$ = Original dimensions of samples

$D_s$ = Swelling dimensions of the samples

### 3.2.4 Water absorption

Water absorption was calculated by using the following formula:

WA = ($W_{end}$ – $W_{start}$) / V (kgm$^{-3}$)

Where:

WA = Water absorption by a specimen

$W_{end}$ = Weight of the specimen after a specific time (after 1,2,3,4 hour, etc.)

$W_{start}$ = Weight of the specimen at the start

V = Volume of the specimen through which water diffuses

## 4. Results and Discussions

### 4.1 Basic Density

Table 2. Basic density of four exotic tropical pine species

| Species | No. of specimens | Basic density (kgm$^{-3}$) | | |
|---|---|---|---|---|
| | | Mean | Standard deviation | Coefficient of variation (%) |
| *Pinus kesiya* | 11 | 384 | 7.39 | 1.92 |
| *Pinus caribaea* | 13 | 426 | 22.39 | 5.26 |
| *Pinus maximinoi* | 15 | 441 | 5.48 | 1.24 |
| *Pinus oocarpa* | 15 | 406 | 5.02 | 1.23 |

The basic density of four exotic tropical pine species is shown in Table 2. The average basic density is 384 kgm$^{-3}$ for *Pinus kesiya*, 426 kgm$^{-3}$ for *Pinus caribaea*, 441 kgm$^{-3}$ for *Pinus maximinoi*, and 406 kgm$^{-3}$ for *Pinus oocarpa*. According to the results, the basic density of *Pinus maximinoi* is the highest and that of *Pinus kesiya* is the lowest among the species. A coefficient of variation of about 10% is considered acceptable for describing the variability of oven dry density of a species (Forest products Laboratory, 2010). According to the results, the coefficient values for four exotic tropical pine species are lower than 10%. This means that the results are assumed to be reliable. Analysis of variance shows that basic density is significantly different among four species. Tukey's test was conducted for significant differences among four species. According to Tukey's test, all species are significantly different from each other.

The basic density of the four exotic tropical pine species is compared with those of other countries as shown in Table 3. *Pinus kesiya* has a lower basic density compared to research findings from Zambia, Philippines and India. Similarly, *Pinus caribaea* in this research has a lower density than that of South Africa and Brazil but greater than that of Jamaica and Malaysia. *Pinus oocarpa* has a lower basic density than those reported from Brazil, Argentina and Honduras.

Table 3. Comparison of basic density of four exotic tropical pine species with those of other countries

| Species | This Paper | South Africa | Jamaica | Brazil | Malaysia | Zambia | Philippines | India | Argentina | Honduras |
|---|---|---|---|---|---|---|---|---|---|---|
| *Pinus kesiya* | 384 | - | - | - | - | 526 | 500 | 430 | - | - |
| *Pinus caribaea* | 426 | 458 | 390 | 440 | 370 | - | - | - | - | - |
| *Pinus maximinoi* | 441 | - | - | - | - | - | - | - | - | - |
| *Pinus oocarpa* | 406 | - | - | 450 | - | - | - | - | 440 | 480 |

### 4.2 Specific gravity

Table 4. Specific gravity of four exotic tropical pine species

| Species | No. of specimens | Basic specific gravity | | |
|---|---|---|---|---|
| | | Mean | Standard deviation | CV% |
| *Pinus kesiya* | 11 | 0.384 | 0.01 | 1.92 |
| *Pinus caribaea* | 13 | 0.426 | 0.02 | 5.26 |
| *Pinus maximinoi* | 15 | 0.441 | 0.01 | 1.24 |
| *Pinus oocarpa* | 15 | 0.406 | 0.01 | 1.23 |

Specific gravity of four exotic tropical pine species is shown in Table 4. According to the results, basic specific gravity is the highest in *Pinus maximinoi* and the lowest in *Pinus kesiya*. Analysis of variance shows that basic specific gravity is significantly different among four species. According to Tukey's test, all species are significantly different from each other. The coefficient of variation for specific gravity can be high up to 10% (Forest products laboratory, 2010). In this research, the coefficient of variation for specific gravity is found to be less than 10% for all four exotic tropical pine species. Thus, specific gravity values for four exotic tropical pine species are reliable. Wood can be classified into four groups based on their basic specific gravity. Woods with basic specific gravity of 0.360 and less are considered light, 0.361 to 0.500 moderately heavy, 0.501 to 0.800 heavy and above 0.800 very heavy. In accordance with this classification system, four exotic tropical pine species will be in "Moderately Heavy" Group. Four exotic tropical pine species are not as heavy as *Pinus* *merkusii* Jungh. & de Vriese and *Pinus insularis* Endl. of 0.470 and 0.460, respectively (Kyi, 1993), which are also in "Moderately Heavy" Group.

### 4.3 Swelling

Table 5. Swelling in radial, tangential and longitudinal directions

| Species | No. of speci-mens | Swelling from oven dry to green (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Radial | | | Tangential | | | Longitudinal | | |
| | | Mean | SD | CV% | Mean | SD | CV% | Mean | SD | CV% |
| *Pinus kesiya* | 11 | 4.20 | 0.34 | 8.14 | 7.65 | 0.50 | 6.57 | 0.56 | 0.31 | 54.90 |
| *Pinus caribaea* | 13 | 2.46 | 0.35 | 14.13 | 6.38 | 0.47 | 7.41 | 0.61 | 0.26 | 42.69 |
| *Pinus maximinoi* | 15 | 4.25 | 0.49 | 11.60 | 8.22 | 0.42 | 5.08 | 0.63 | 0.23 | 36.53 |
| *Pinus oocarpa* | 15 | 3.55 | 0.40 | 11.33 | 8.08 | 0.64 | 7.91 | 0.62 | 0.20 | 31.75 |

Swelling in radial, tangential and longitudinal directions is shown in Table 5. Among four species, *Pinus maximinoi* is found to swell the highest and *Pinus caribaea* the lowest. Swelling is affected by specific gravity, and thus the species with higher specific gravity swell higher (Grekin and Verkasalo, 2010). *Pinus maximinoi* with the highest specific gravity swells the highest. *Pinus kesiya* with the lowest specific gravity does not swell the lowest and is found to swell higher than *Pinus caribaea*.

According to the results, tangential swelling is the largest, radial swelling the second largest and longitudinal swelling the lowest. Swelling value of *Pinus kesiya* in tangential direction is lower than twice of the swelling value in radial direction. But, swelling values of *Pinus caribaea* and *Pinus oocarpa* in tangential direction are greater than twice of the swelling values in radial direction. Swelling value of *Pinus maximinoi* in tangential direction is twice the swelling value in radial direction.

Analysis of variance indicates that there are significant differences in radial and tangential swelling among the four species. However, there is no significant difference in longitudinal swelling among the four species. Tangential swelling from oven dry to green is compared for significant difference using Tukey's test. *Pinus maximinoi* has the highest tangential swelling value of 8.22 % and significantly differs from *Pinus caribaea* but does not significantly differ from *Pinus kesiya* and *Pinus oocarpa*. *Pinus caribaea* has the lowest tangential swelling value and significantly differs from other species.

A comparison between tangential swelling values for tested pine species and plantation teak of different ages in Myanmar is shown in Table 6. According to the results, tangential swelling values of *Pinus kesiya*, *Pinus maximinoi* and *Pinus oocarpa* are greater than those of different ages of plantation teak in Myanmar. Moreover, tangential swelling of *Pinus caribaea* is also greater than those of different ages of plantation teak in Myanmar except 20 years old Bago plantation teak.

Table 6. Comparison between tangential swelling for tested pine species and plantation teak of different ages in Myanmar

| Species | Tangential Swelling from oven dry to green (%) | Remarks |
|---|---|---|
| *Pinus kesiya* | 7.65 | This study |
| *Pinus caribaea* | 6.38 | |
| *Pinus maximinoi* | 8.22 | |

| Species | Tangential Swelling from oven dry to green (%) | Remarks |
|---|---|---|
| *Pinus oocarpa* | 8.08 | |
| 15 years old Nattalin provenance | 4.59 | (Myint, C.C, 2024) |
| 15 years old Paukkaung provenance | 3.84 | |
| 15 years old Kanbalu provenance | 4.18 | |
| 15 years old Oktwin provenance | 4.45 | |
| 15 years old Taungoo provenance | 4.04 | |
| 15 years old Phyu provenance | 3.79 | |
| 15 years old Bago provenance | 4.75 | |
| 15 years old Thabeikkyin provenance | 5.05 | |
| 20 years old Bago plantation teak | 7.33 | Myint,C.C & Naing,W.O, 2023) |
| 25 years old Bago plantation teak | 5.64 | |
| 30 years old Bago plantation teak | 4.63 | |
| 34 years old Bago plantation teak | 4.86 | |
| 20 years old Wuntho plantation teak | 4.51 | (Myint, C.C et al, 2021) |
| 32 years old Wuntho plantation teak | 6.07 | |
| 37 years old Wuntho plantation teak | 4.88 | |
| 40 years old Wuntho plantation teak | 5.24 | |
| 14 years old Yetashe plantation teak | 4.84 | (Myint, C.C et al, 2014) |
| 20 years old Oktwin plantation teak | 4.99 | |
| 25 years old Lewe plantation teak | 5.08 | |
| 30 years old Thandwe plantation teak | 4.77 | |

A comparison between tangential swelling for tested pine species and other Myanmar timber species is shown in Table 7. According to results, tangential swelling values of four exotic tropical pine species are lower than those of Thitya, Pyaukseik, Taukkyan and Gyo, but are greater than those of Pyinkado, Padauk,Thingan, Ingyin, Tamalan, Letpan, Bonmeza, Kokko and Tawthayet. Tangential swelling of *Pinus caribaea* is nearly the same as that of Thingan, Sagasein, Gwe, Baing, Didu, Taungthayet, Nabe,and Thitmagyi.

Table 7. Comparison between tangential swelling for tested pine species and other Myanmar timber species

| **Species** | **Tangential swelling from oven dry to green (%)** | **Remarks** |
|---|---|---|
| *Pinus kesiya* | 7.65 | Pinus species |
| *Pinus caribaea* | 6.38 | |
| *Pinus maximinoi* | 8.22 | |
| *Pinus oocarpa* | 8.08 | |
| Pyinkado | 3.17 | Group 1 species |
| Padauk | 3.69 | |
| Thingan | 6.07 | |
| Thitya | 8.92 | |
| Ingyin | 5.18 | |
| Tamalan | 3.58 | |

| Species | Tangential swelling from oven dry to green (%) | Remarks |
|---|---|---|
| Letpan | 4.83 | Light wood species |
| Bonmeza | 5.31 | |
| Sagasein | 6.63 | |
| Gwe | 6.79 | |
| Thitkado | 5.29 | Moderately heavy wood species |
| Baing | 6.38 | |
| Kuthan | 7.15 | |
| Dwabok | 8.61 | |
| Didu | 6.13 | |
| Kokko | 4.85 | Heavy wood species |
| Pyinma | 7.08 | |
| Tawthayet | 5.24 | |
| Taungthayet | 6.08 | |
| Leza | 7.18 | |
| Pyaukseik | 9.80 | |
| Nabe | 6.36 | |
| Thit-magyi | 6.79 | Very heavy wood species |
| Taukkyan | 9.63 | |
| Gyo | 14.04 | |

Figure 1 – 4 and Table 8 shows swelling in radial, tangential and longitudinal directions of four exotic tropical pine species during the first four hours. In three different directions, swelling reached its peak nearly within one hour and became nearly constant thereafter. According to the results, swelling anisotropy of *Pinus kesiya* and *Pinus maximinoi* is less than 2 but that of *Pinus caribaea* and *Pinus oocarpa* is greater than 2. Except *Pinus caribara*, tangential swelling of *Pinus kesiya*, *Pinus maximinoi* and *Pinus oocarpa* is greater than 7. So, swelling problems can occur when putting them into uses. Thus, it is necessary to make proper drying before they are put into services.

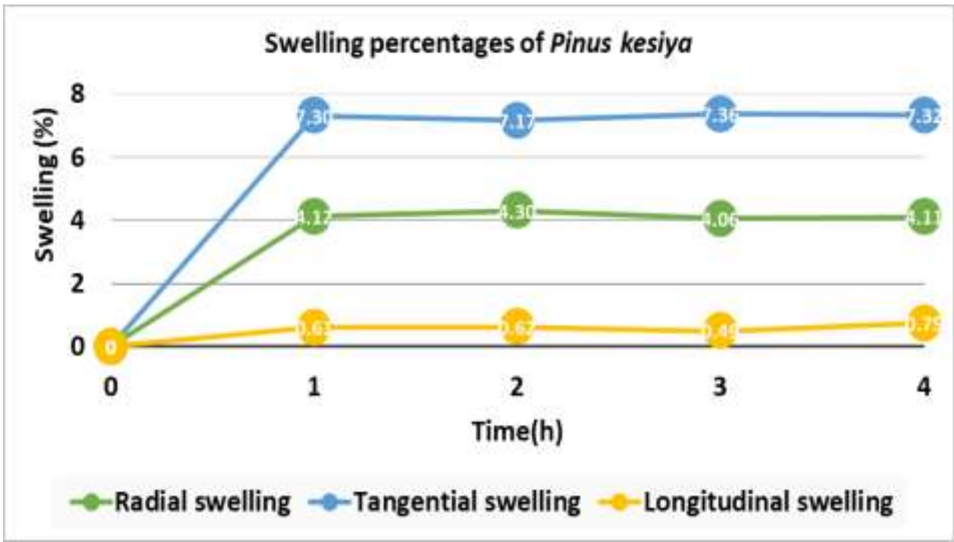


Figure 1. Swelling of *Pinus kesiya*

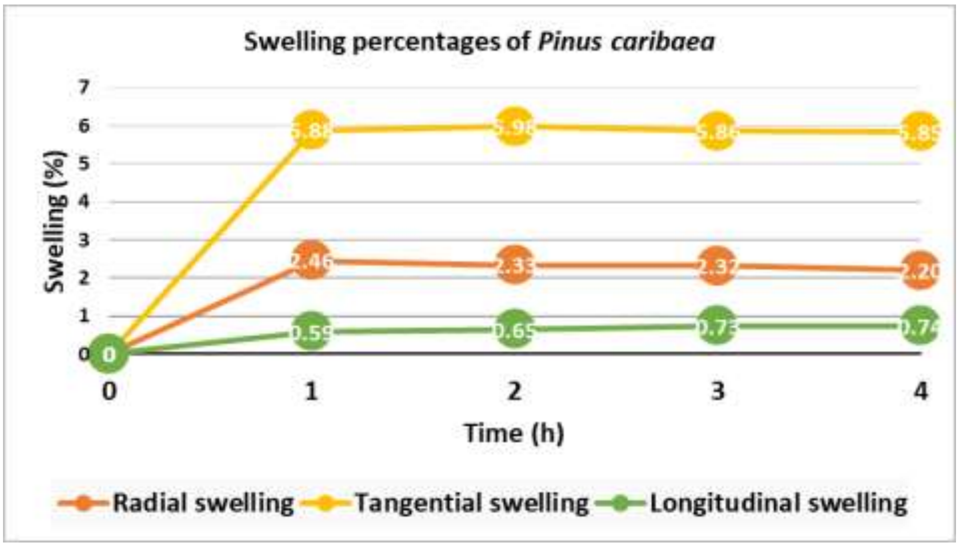


Figure 2. Swelling of *Pinus caribaea*

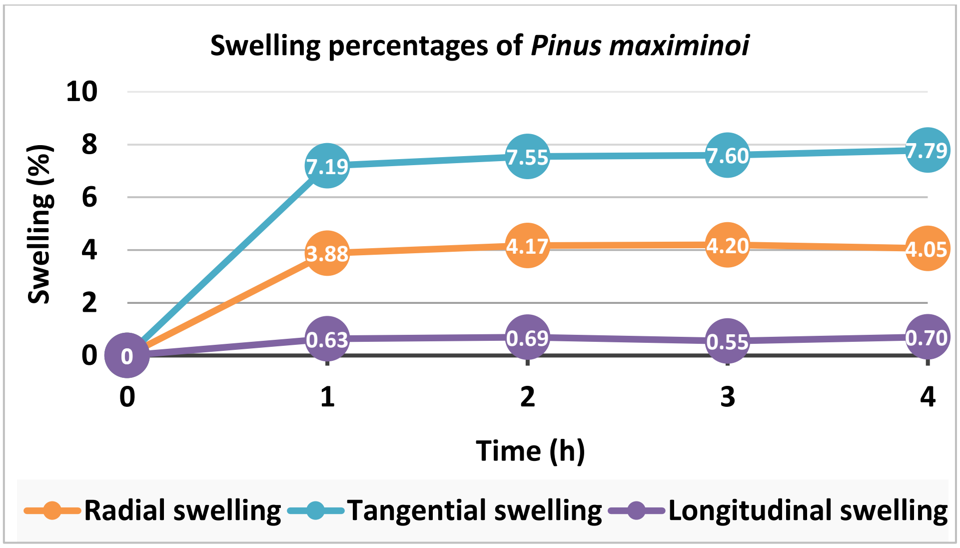


Figure 3. Swelling of *Pinus maximinoi*

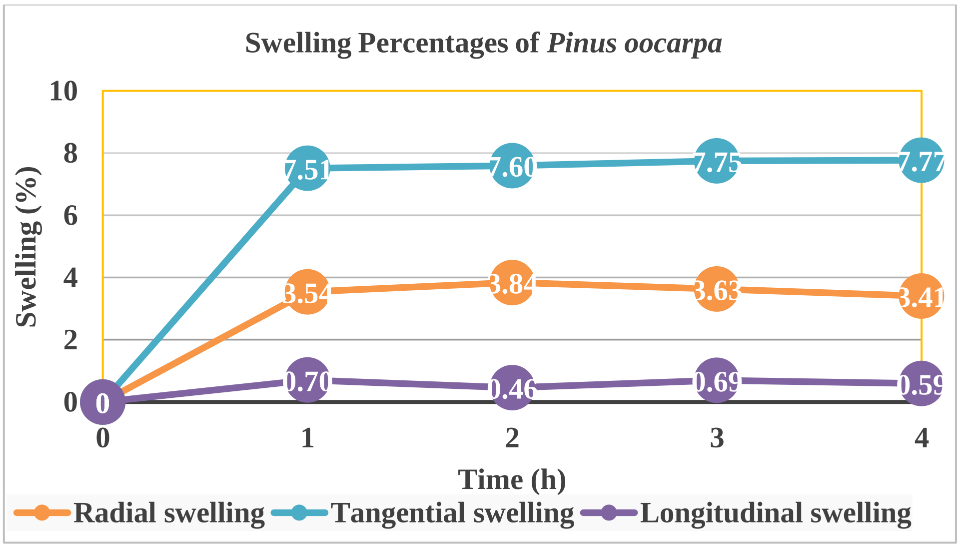


Figure 4. Swelling of *Pinus oocarpa*

Table 8. Swelling in radial, tangential and longitudinal directions of four exotic tropical pine species during the first four hours

| Species | Time (hour) | Swelling (%) | | | Swelling anisotropy T/R |
|---|---|---|---|---|---|
| | | Radial | Tangential | Longitudinal | |
| *Pinus kesiya* | 1 | 4.12 | 7.30 | 0.61 | 1.77 |
| | 2 | 4.30 | 7.17 | 0.62 | 1.67 |
| | 3 | 4.06 | 7.36 | 0.49 | 1.81 |
| | 4 | 4.11 | 7.32 | 0.75 | 1.78 |
| *Pinus caribaea* | 1 | 2.46 | 5.88 | 0.59 | 2.39 |
| | 2 | 2.33 | 5.98 | 0.65 | 2.57 |
| | 3 | 2.32 | 5.86 | 0.73 | 2.53 |
| | 4 | 2.20 | 5.85 | 0.74 | 2.66 |
| *Pinus maximinoi* | 1 | 3.88 | 7.19 | 0.63 | 1.85 |
| | 2 | 4.17 | 7.55 | 0.69 | 1.81 |
| | 3 | 4.20 | 7.60 | 0.55 | 1.81 |
| | 4 | 4.05 | 7.79 | 0.70 | 1.92 |
| *Pinus oocarpa* | 1 | 3.54 | 7.51 | 0.70 | 2.12 |
| | 2 | 3.84 | 7.60 | 0.46 | 1.98 |
| | 3 | 3.63 | 7.75 | 0.69 | 2.13 |
| | 4 | 3.41 | 7.77 | 0.59 | 2.28 |

### 4.4 Water absorption

Table 9. Water absorption of four exotic tropical pine species

| Species | No. of specimens | Water absorption (kgm$^{-3}$) | | |
|---|---|---|---|---|
| | | Mean | SD | CV% |
| *Pinus kesiya* | 11 | 724.55 | 10.78 | 1.49 |
| *Pinus caribaea* | 13 | 710.48 | 12.79 | 1.80 |
| *Pinus maximinoi* | 15 | 703.68 | 5.56 | 0.79 |
| *Pinus oocarpa* | 15 | 718.53 | 7.14 | 0.99 |

Water absorption of four exotic tropical pine species is given in Table 9. According to the results, the water absorption of *Pinus kesiya* is the highest among the species, while *Pinus maximinoi* has the lowest. This difference can be attributed to their densities. *Pinus kesiya* has the lowest basic density, which results in the highest water absorption, while *Pinus maximinoi* with the highest basic density, absorbs the least water. Sint and Hapla (2009) found that timbers with higher densities absorb less water or solution than those with lower densities.

Analysis of variance shows that water absorption is significantly different among four exotic tropical pine species. According to Tukey's test, *Pinus kesiya* has the highest water absorption value of 724.55 kgm$^{-3}$ and significantly differs from water absorption values of *Pinus caribaea* and *Pinus maximinoi* but not significantly differs from that of *Pinus oocarpa*. *Pinus maximinoi* has the lowest water absorption value of 703.68 kgm$^{-3}$ and significantly differs from water absorption values of *Pinus kesiya* and *Pinus oocarpa* but not significantly differs from *Pinus caribaea*. Figure 2 indicates water absorption of four exotic tropical pine species.

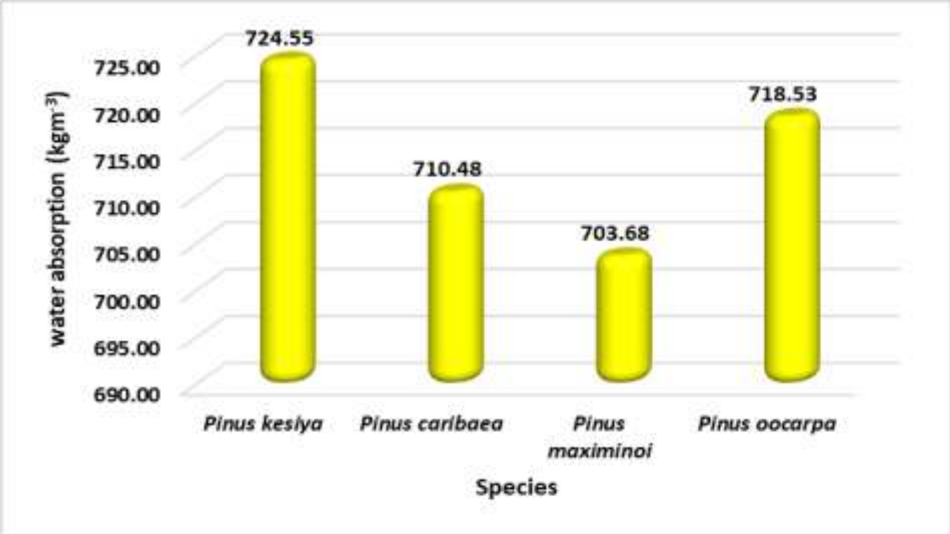


Figure 5. Water absorption of four exotic tropical pine species

Table 10.Comparison between water absorption values for four exotic tropical pine species and other tested plantation teak in Myanmar

| Species | Water absorption ($kgm^{-3}$) | Remarks |
|---|---|---|
| *Pinus kesiya* | 725 | This study |
| *Pinus caribaea* | 710 | |
| *Pinus maximinoi* | 704 | |
| *Pinus oocarpa* | 719 | |
| 15 years old Nattalin provenance | 592 | (Myint, C.C, 2024) |
| 15 years old Paukkaung provenance | 618 | |
| 15 years old Kanbalu provenance | 647 | |
| 15 years old Oktwin provenance | 629 | |
| 15 years old Taungoo provenance | 616 | |
| 15 years old Phyu provenance | 606 | |
| 15 years old Bago provenance | 580 | |
| 15 years old Thabeikkyin provenance | 625 | |
| 20 years old Bago plantation teak | 588 | Myint, C.C & Naing, W.O, 2023) |
| 25 years old Bago plantation teak | 582 | |
| 30 years old Bago plantation teak | 641 | |
| 34 years old Bago plantation teak | 567 | |
| 20 years old Wuntho plantation teak | 612 | (Myint, C.C et al, 2021) |
| 32 years old Wuntho plantation teak | 571 | |
| 37 years old Wuntho plantation teak | 582 | |
| 40 years old Wuntho plantation teak | 613 | |
| 14 years old Yetashe plantation teak | 618 | (Myint, C.C et al, 2014) |
| 20 years old Oktwin plantation teak | 572 | |
| 25 years old Lewe plantation teak | 579 | |
| 30 years old Thandwe plantation teak | 617 | |

A comparison between water absorption values for four exotic tropical pine species in this study and those of plantation teak in Myanmar is shown in Table 10. According to the results, water absorption values of four exotic tropical pine species are higher than those of plantation teak in Myanmar.

Table 11. Comparison between water absorption values for four exotic tropical pine species and other tested hardwood species in Myanmar

| Species | Water absorption ($kgm^{-3}$) | Remarks |
|---|---|---|
| *Pinus kesiya* | 724.55 | Pinus species |
| *Pinus caribaea* | 710.48 | |
| *Pinus maximinoi* | 703.68 | |
| *Pinus oocarpa* | 718.53 | |
| Pyinkado | 156.23 | Group 1 species |
| Padauk | 226.70 | |
| Thingan | 377.14 | |
| Thitya | 240.15 | |
| Ingyin | 132.41 | |
| Tamalan | 165.23 | |
| Letpan | 827.41 | Light wood species |
| Bonmeza | 838.76 | |
| Sagasein | 843.84 | |
| Gwe | 839.07 | |
| Thitkado | 785.24 | Moderately heavy wood species |
| Baing | 835.25 | |
| Kuthan | 700.88 | |
| Dwabok | 737.17 | |
| Didu | 666.00 | |
| Kokko | 600.66 | Heavy wood species |
| Pyinma | 619.84 | |
| Tawthayet | 665.11 | |
| Taungthayet | 617.08 | |
| Leza | 629.00 | |
| Pyaukseik | 602.00 | |
| Nabe | 552.00 | |
| Thit-magyi | 539.22 | Very heavy wood species |
| Taukkyan | 461.59 | |
| Gyo | 393.98 | |

Table 11 showed a comparison between water absorption values for four exotic tropical pine species and other tested hardwood species in Myanmar. According to results, water absorption values of four exotic tropical pine species are greater than those of Group 1 species, heavy wood species and very heavy wood species. And then, water absorption values of four exotic tropical pine species are lower than that of light wood species. In moderately heavy wood species, water absorption value of Kuthan, Dwabok and Didu is nearly the same as that of four exotic tropical pine species. And then, water absorption value of four exotic tropical pine species is lower than that of Thitkado and Baing.

## 5. Conclusion

Basic density of *Pinus maximinoi* is the highest, while that of *Pinus kesiya* is the lowest among the four species. Based on the basic specific gravity results, the four exotic tropical pine species fall into the “moderately heavy” group. In swelling, *Pinus maximinoi* exhibits the highest, while *Pinus caribaea* shows the lowest among the four species. Except *Pinus caribara*, tangential swelling of *Pinus kesiya*, *Pinus maximinoi*, and *Pinus oocarpa* is greater than 7 %. Swelling anisotropy of *Pinus kesiya* and *Pinus maximinoi* is less than 2 while that of *Pinus caribaea* and *Pinus oocarpa* is greater than 2. In water absorption study, *Pinus kesiya* shows the highest while *Pinus maximinoi* shows the lowest. To reduce swelling, varnishes and paint should be applied to prevent moisture from entering. Additionally, the location where the wood will be placed is an important factor to consider. To minimize the problems associated with their utilization, it should be dried to a moisture level appropriate for its intended service environment. Typically, water-resistant treated wood is used for exterior applications, while untreated wood is suitable for interior use. Based on the results of swelling and water absorption, the four exotic tropical pine species studied in this research could be suitable for internal applications.

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