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# Study on Physical and Mechanical Properties of Plantation Teak from Provenance Trial

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# Study on Physical and Mechanical Properties of Plantation Teak from Provenance Trial

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## Abstract

In this research, physical and mechanical properties of 15 years old plantation teak from provenance trial were investigated. Two thinning poles were collected for each provenance from teak trial consisting of eight provenances, located in compartment No.9 of Ngalaik Reserved Forest, Ottara Thiri Township, Naypyidaw, which was established in 2007. Physical and mechanical properties were tested, following ASTM D-143-52 (2007) standard, BS-373 (1957) standard and German standard DIN (52184). Regarding physical properties, it was found that moisture content, density, specific gravity, shrinkage, swelling and water absorption were significantly different among provenances, between trees and within a tree. Among the provenances, Bago provenance had the highest basic specific gravity and Kanbalu provenance had the lowest. The basic specific gravity of the provenances was lower than that of natural teak. It was found that Thabeikkyin provenance had the highest tangential shrinkage/swelling value. Dimensional stability values of different provenances were greater than that of natural teak. It means that provenances are not as dimensionally stable as natural teak. Kanbalu provenance absorbed water most but Bago provenance absorbed the least. According to the classification of wood based on basic specific gravity, all provenances would be in "Moderately Heavy". According to classification of strength properties, all tested provenances would be in Group (III). Therefore, all tested provenances have lower strength properties and higher shrinkage than natural teak. It will require proper drying before putting it to uses. Moreover, they are not suitable for heavy constructions, requiring higher strengths.

**Keywords**: provenance trial, teak, physical properties, mechanical properties

# အနယ်နယ်ကျွန်းစမ်းသပ်ကွက်မှ စိုက်ခင်းကျွန်း၏ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိကိုလေ့လာခြင်း

ဒေါက်တာချိုချိုမြင့်၊ လက်ထောက်သုတေသနအရာရှိ
သစ်တောသုတေသနဌာန

## စာတမ်းအကျဉ်း

ဤသုတေသနတွင် အနယ်နယ်ကျွန်းစမ်းသပ်ကွက်မှ ၁၅နှစ်သား စိုက်ခင်းကျွန်းတို့၏ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကို စမ်းသပ်လေ့လာခဲ့ပါသည်။ ၂၀၀၇ ခုနှစ်တွင် နေပြည်တော် ကောင်စီနယ်မြေ၊ ဥတ္တရသီရိမြို့နယ်၊ ငလိုက်ကြိုးဝိုင်းအကွက် အမှတ် ၉ ၌ တည်ထောင်ထားသည့် အနယ်နယ်ကျွန်း စမ်းသပ်စိုက်ကွက်မှ အနယ်နယ်ကျွန်း ၈ မျိုး အတွက် တစ်မျိုးလျှင် ပင်ကျပ်တိုင် ၂ ပင်စီကို စုဆောင်းခဲ့ပါသည်။ ASTM D–143–52 (2007)၊ BS Standard–373 (1957)နှင့် German Standard DIN (52184) တို့နှင့် အညီ ကျွန်းတိုင်များ၏ ရူပနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိများကို စမ်းသပ်ခဲ့ပါသည်။ ရူပဂုဏ်သတ္တိများနှင့် ပတ်သက်၍ အစိုဓာတ်ပါဝင်မှု၊ သိပ်သည်းမှု၊ သိပ်သည်းဆ၊ ကျုံ့မှု၊ ကြွမှုနှင့် ရေစုပ်ယူမှုတို့သည် ဒေသ တစ်ခုမှ အခြားဒေသတစ်ခုသို့ လည်းကောင်း၊ သစ်တစ်ပင်နှင့် တစ်ပင်ကြားတွင် လည်းကောင်း၊ သစ်တစ်ပင် အတွင်းတွင်လည်းကောင်း သိသာစွာခြားနားမှု ရှိကြောင်းတွေ့ရပါသည်။ အနယ်နယ်ကျွန်းများအနက် ပဲခူးကျွန်းသည် သိပ်သည်းဆအမြင့်ဆုံး x ဖြစ် ပြီးကန့်ဘလူ ကျွန်းသည် အနည်းဆုံးဖြစ်ပါသည်။ အနယ်နယ်ကျွန်းအားလုံး၏ ရေချိန်သိပ်သည်းဆသည် သဘာဝကျွန်းထက် နိမ့်ပါသည်။ သပိတ်ကျင်းကျွန်းသည် နှစ်ကွင်းအပြိုင် ကျုံ့ခြင်း၊ ကြွခြင်း တွင် အမြင့်မားဆုံးဖြစ်ပြီး ဖြူးကျွန်းသည် အနိမ့်ဆုံးဖြစ်သည်ကို တွေ့ရပါသည်။ ယေဘုယျ အားဖြင့် အနယ်နယ်ကျွန်းတို့၏ ပုံသဏ္ဌာန်တည်မြဲမှု တန်ဖိုးများသည် သဘာဝကျွန်းထက် များနေပါသည်။ သဘာဝကျွန်းလောက် ပုံသဏ္ဌာန်တည်မြဲမှု မကောင်းဟု ဆိုလိုပါသည်။ ကန့်ဘလူကျွန်းသည် ရေ အများဆုံးစုပ်ယူသည်ကိုတွေ့ရပြီး ပဲခူးကျွန်းသည် အနည်းဆုံး စုပ်ယူပါသည်။ ရေချိန်သိပ်သည်းဆကို အခြေခံသော သစ်အမျိုးအစားအုပ်စုခွဲခြားမှု စနစ်အရ အနယ်နယ်ကျွန်းအားလုံးသည် “အသင့်အတင့် လေးသောအုပ်စု”တွင်ပါဝင်ပါသည်။ သစ်အင်အားကို အခြေခံသော အုပ်စုခွဲခြားမှုအရ စမ်းသပ်ခဲ့သော အနယ်နယ်ကျွန်း အားလုံး သည် အုပ်စု(၃)တွင် ပါဝင်ပါသည်။ သို့ဖြစ်၍ စမ်းသပ်ခဲ့သော အနယ်နယ် ကျွန်းအားလုံးသည် သဘာဝကျွန်းထက် သစ်အင်အားတွင် ပိုနည်းပြီး ကျုံ့မှု၊ ကြွမှုတွင် ပိုများနေပါ သည်။ သို့ဖြစ်၍ အသုံးချခြင်း မပြုသေးမီ စနစ်တကျအခြောက်ခံသင့်ပါသည်။ အင်အားအများအပြား လိုသော ဆောက်လုပ်ရေးလုပ်ငန်းကြီးများတွင်လည်း အသုံးမပြုသင့်ပေ။

**Study on Physical and Mechanical Properties of Plantation Teak from Provenance Trial**

## 1. Introduction

Teak is a very popular hardwood species in tropical countries. Natural teak is well-known for having many desirable properties such as good color and grain, high natural durability, high dimensional stability and good strength. Teak is commonly used for building construction, door and window frames, furniture making, flooring, ship building, plywood and more. However, natural teak is becoming rare. So, teak plantations are now being increasingly established. Therefore, plantation teak will be used more in the future.

During 2008 and 2009, plantation teak pre-project was conducted in collaboration with Forest Department and CFC/ ITTO 73 FT PPD 68/03 Rev.2 (1). Physical and mechanical properties of plantation teak at different ages were studied during the project. Different ages 14, 20, 25 and 30 years-old teak were collected from Yetashe, Oktwin, Lewe and Thandwe Townships, respectively. And then, during 2019 and 2021, physical and mechanical properties of plantation teak from Sagaing and Bago Region were also studied. In that studies, different ages 20, 32, 37 and 40 years old teak were collected from Wuntho Township, Katha District, Sagaing Region and the other ages 20,25, 30 and 34 years old teak were collected from Bago township, Bago District, Bago Region.

According to the research findings, the properties of plantation teak at different ages varied from one age to another and also from one locality to another. And then, it was found that age has a significant influence on the properties of plantation teak in the same locality.

For better comparison, it is necessary to test these properties of plantation teak of the same age, grown in different localities or of different ages grown in the same locality. Therefore, in this research, physical and mechanical properties of plantation teak of the same age from provenance trial established in Ngalaik Reserved Forest, Ottara Thiri Township, Naypyidaw. were studied.

## 2. Objectives

The objectives of this research are:

(1) to study physical and mechanical properties of plantation teak from provenance trial.

(2) to compare the properties of plantation teak from provenance trial with those of plantation teak previously tested and

(3) to suggest the utilization potential of plantation teak from provenance trial based on result findings.

## 3. Materials and Methods

In this research, sixteen thinning poles were collected from teak provenance trial established in 2007 and being 15 years old. The provenance trial is situated in Compartment No.9 of Ngalaik Reserved Forest, Ottara Thiri Township, Naypyidaw. The provenance trial comprises eight provenances (townships) of such teak as Nattalin, Paukkaung, Kanbalu, Oktwin, Taungoo, Phyu, Bago and Thabeikkyin, where teak grows naturally. Two thinning poles of each provenance (townships) were randomly selected to study physical and mechanical properties. Each sample tree was divided into three equal bolts of about 6 ft (1.83 m) long. From the base of each bolt, three disks of 3-inches (0.076 m) thick were cut and used for physical tests. The rest portions were used for mechanical tests. Wood specimens were prepared according to ASTM D-143-52 (2007) standard, British standard BS-373 (1957) and German standard (DIN-52184). Moisture content, density, specific gravity and shrinkage were determined in accordance with standard ASTM D-143-52 (2007). Shrinkage in radial, tangential and longitudinal directions were determined from green to oven dry and from green to 12% MC. Swelling in radial, tangential and longitudinal directions and water absorption were determined from oven dry to green condition by using German standard (DIN-52184). Mechanical properties were tested for green condition and air-dried condition by using BS-373 (1957) standard. Tested wood properties and size of specimens were shown in Table 1.

Table1. Tested wood properties and size of specimen of plantation teak from provenance trial

| Sr. No | Wood Properties | Size of Specimen (mm) |
|---|---|---|
| 1 | Moisture content, Specific gravity, Density | 20 x 20x 60 |
| 2 | Shrinkage (Radial, Tangential, longitudinal) | 25x 25 x 100 |
| 3 | Swelling (Radial, Tangential, Longitudinal) | 20 x 20 x 10 |
| 4 | Water absorption | 20x 20 x 10 |
| 5 | Static bending | 20 x 20 x 300 |
| 6 | Compression parallel to grain | 20 x 20 x 60 |
| 7 | Compression perpendicular to grain | 20 x 20x 60 |

## 4. Results and Discussion

### 4.1 Physical Properties

#### 4.1.1 Moisture content

Table 2.Moisture content of eight provenances

| Provenances | No. of specimens | Mean moisture content (%) | Standard deviation | Coefficient of variation (%) |
|---|---|---|---|---|
| Nattalin | 57 | 102.58 | 17.87 | 17.42 |
| Paukkaung | 56 | 104.63 | 11.86 | 11.34 |
| Kanbalu | 59 | 111.77 | 12.92 | 11.56 |
| Oktwin | 61 | 106.19 | 12.83 | 12.08 |
| Taungoo | 60 | 92.58 | 14.70 | 15.88 |
| Phyu | 59 | 96.99 | 14.52 | 14.97 |
| Bago | 58 | 82.13 | 14.25 | 17.35 |
| Thabeikkyin | 60 | 93.08 | 14.33 | 15.40 |

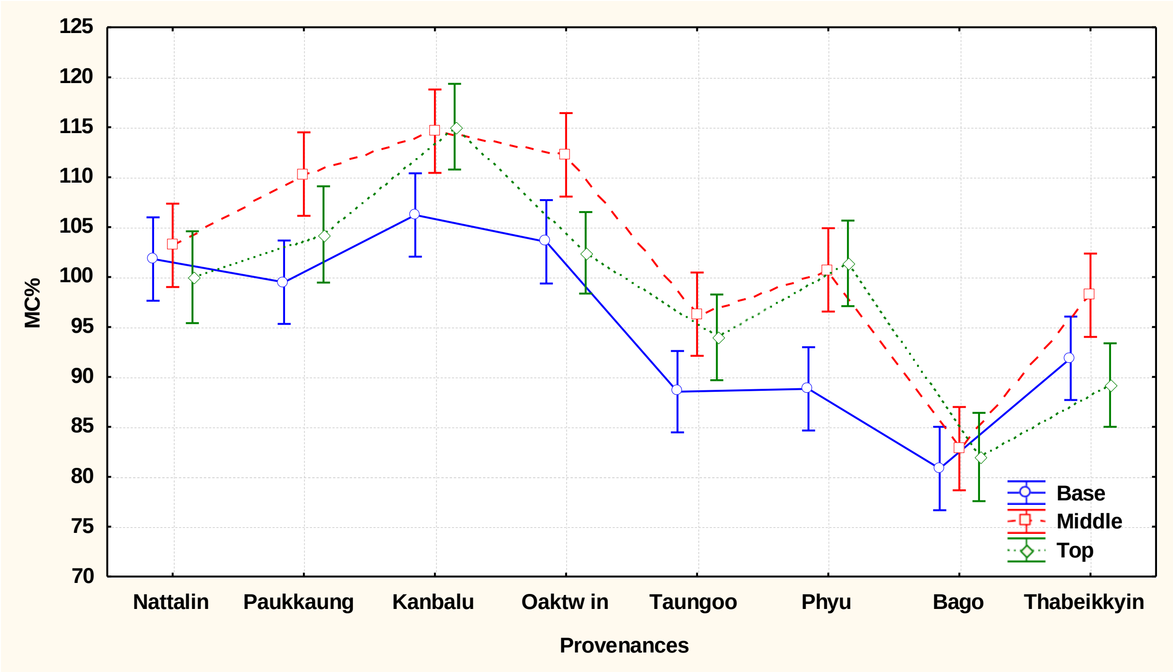


Figure 1. Moisture content of eight provenances at different height

Moisture content of eight provenances is given in Table 2. Mean moisture contents are 102.58 % for Nattalin provenance, 104.63 % for Paukkaung provenance, 111.77% for Kanbalu provenance, 106.19 % for Oktwin provenance, 92.58 % for Taungoo provenance, 96.99 % for Phyu provenance, 82.13 % for Bago provenance and 93.08 % for Thabeikkyin provenance. Analysis of variance shows that moisture content is significantly different among eight provenances, between trees and within a tree. Tukey's test was conducted for significant differences among eight provenances. Kanbalu provenance has the highest moisture content of 111.77% and significantly differs from Nattalin,Taungoo,Phyu, Bago and Thabeikkyin provenances but does not differ from Paukkaung and Oktwin provenances. Bago provenance has the lowest moisture content of 82.13% and significantly differs from other seven provenances. Figure 1 shows the moisture content of eight provenances at different heights. The analysis of variance shows that the middle section has the highest moisture content and is significantly higher than base and top section. Moisture content can vary within any species depending on location, age, season of harvest, and tree size. In hardwoods, moisture content plays a very important role in kiln drying because kiln schedule is based on it (Shmulsky and Jones., 2019).

### 4.1.2 Density

Table 3. Wood densities of eight provenances

| Provenances | No. of specimens | Green density ($kgm^{-3}$) | | | 12% MC density ($kgm^{-3}$) | | | Basic density ($kgm^{-3}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | CV% | Mean | SD | CV% | Mean | SD | CV% |
| Nattalin | 57 | 1060 | 47 | 4.43 | 648 | 89 | 13.73 | 529 | 66 | 12.48 |
| Paukkaung | 56 | 1055 | 58 | 5.50 | 633 | 74 | 11.69 | 518 | 55 | 10.62 |
| Kanbalu | 59 | 1016 | 14 | 1.38 | 584 | 39 | 6.68 | 481 | 30 | 6.24 |
| Oktwin | 61 | 1015 | 13 | 1.28 | 601 | 42 | 6.99 | 494 | 32 | 6.48 |
| Taungoo | 60 | 1029 | 38 | 3.69 | 658 | 54 | 8.21 | 537 | 40 | 7.45 |
| Phyu | 59 | 1018 | 15 | 1.47 | 635 | 61 | 9.61 | 520 | 46 | 8.85 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bago | 58 | 1016 | 13 | 1.28 | 691 | 64 | 9.26 | 561 | 47 | 8.38 |
| Thabeikkyin | 60 | 1019 | 19 | 1.86 | 650 | 54 | 8.31 | 530 | 41 | 7.74 |

MC = moisture content; SD = standard deviation, CV % = coefficient of variation (%)

Table 3 shows wood densities of eight provenances. According to the results, basic density of Bago provenance is the highest and that of Kanbalu provenance is the lowest among provenances. The basic density is 529 kgm$^{-3}$ for Nattalin provenance, 518 kgm$^{-3}$ for Pakkaung provenance, 481 kgm$^{-3}$ for Kanbalu provenance, 494 481 kgm$^{-3}$ for Oktwin provenance, 537 kgm$^{-3}$ for Taungoo provenance, 520 kgm$^{-3}$ for Phyu provenance, 561 kgm$^{-3}$ for Bago provenance and 530 kgm$^{-3}$ for Thabeikkyin provenance. A coefficient of variation of about 10% is considered suitable for describing the variability of oven dry density (Forest products Laboratory, 2010). According to results, coefficient values for Kanbalu, Oktwin, Taungoo, Phyu, Bago and Thabeikkyin are lower than 10%. This means that the results are assumed to be reliable.

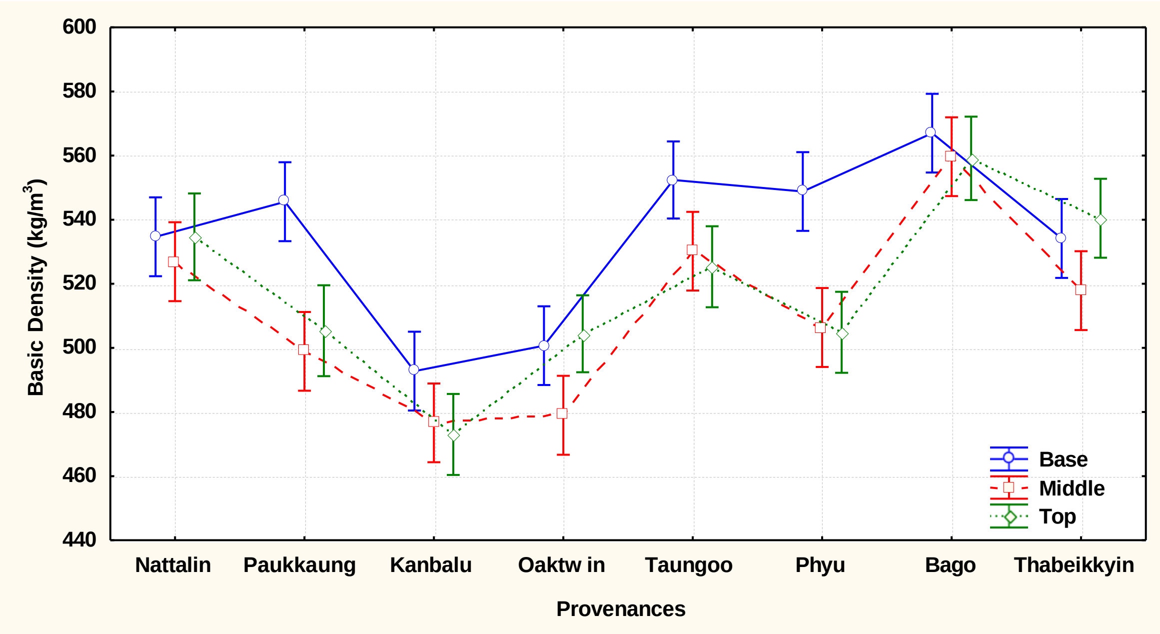


Figure 2.Basic density of eight provenances at different height

Analysis of variance shows that wood density is significantly different among eight provenances, between trees and within a tree. Tukey's test was conducted for significant differences among provenances. Bago provenance has the highest basic density of 561 kgm$^{-3}$ among eight provenances and significantly differs from other provenances except Taungoo provenance. Similarly, Kanbalu provenance has the lowest basic density of 481 kgm$^{-3}$ among eight provenances and significantly differs from other provenances except Oktwin provenance. Figure 2 shows the basic density of eight provenances at different heights. According to Tukey's test, the highest basic density value is found in the base section and is significantly higher than middle and top section. Base portion has generally higher density than top portions with some exceptions (Kollman and Cote, 1968).

### 4.1.3 Specific gravity

Table 4. Specific gravity of eight provenances

| Provenances | No. of specimens | Basic specific gravity | | | A t 12% MC specific gravity | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Standard deviation | CV% | Mean | Standard deviation | CV% |
| Nattalin | 57 | 0.529 | 0.066 | 12.48 | 0.578 | 0.079 | 13.67 |
| Paukkaung | 56 | 0.518 | 0.055 | 10.62 | 0.565 | 0.066 | 11.68 |
| Kanbalu | 59 | 0.481 | 0.030 | 6.24 | 0.521 | 0.035 | 6.72 |
| Oktwin | 61 | 0.494 | 0.032 | 6.48 | 0.537 | 0.038 | 7.08 |
| Taungoo | 60 | 0.537 | 0.040 | 7.45 | 0.588 | 0.048 | 8.16 |
| Phyu | 59 | 0.520 | 0.046 | 8.85 | 0.567 | 0.055 | 9.70 |
| Bago | 58 | 0.561 | 0.047 | 8.38 | 0.617 | 0.057 | 9.24 |
| Thabeikkyin | 60 | 0.531 | 0.041 | 7.72 | 0.580 | 0.049 | 8.45 |

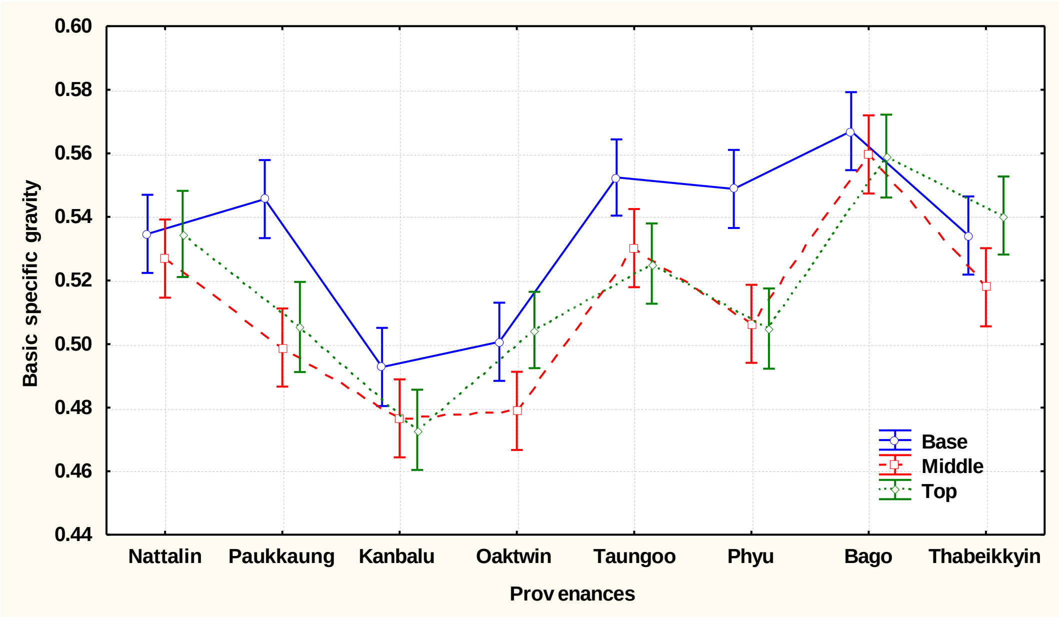


Figure3. Basic specific gravity of eight provenances at different height

Specific gravity of eight provenances is shown in Table 4. According to the results, basic specific gravity is the highest in Bago provenance and the lowest in Kanbalu provenance. Analysis of variance shows that basic specific gravity is significantly different among provenance, between trees and within section. According to Tukey's test, Bago provenance is significantly different from other provenances except Taungoo provenance. Kanbalu provenance has the lowest specific gravity and is significantly different from other provenances except Oktwin provenance. Regarding the height, the base section has higher specific gravity values than middle and top section as shown in Figure 3. The coefficient of variation for specific gravity can be high up to 10% (Forest products laboratory, 2010). In this study, coefficient of variation for specific gravity is found to be less than 10% in Kanbalu, Oktwin,Taungoo, Phyu, Bago and Thabeikkyin provenances except Nattalin and Paukkaung provenances. Thus, specific gravity values for these provenances are to be reliable.

The comparison of basic specific gravity of eight provenances obtained in this study and other studies is shown in Figure 4. In general, Kanbalu and Oktwin provenances have the lowest basic specific gravities among the provenances tested and are similar to 25- and 30-years old Bago plantation teak. Almost all provenances have similar basic specific gravity to 14 years old Yetashe plantation teak. Within the same township, Bago provenance has a higher basic specific gravity than 25- and 30-years old plantation teak, but lower than 20 years old plantation teak.

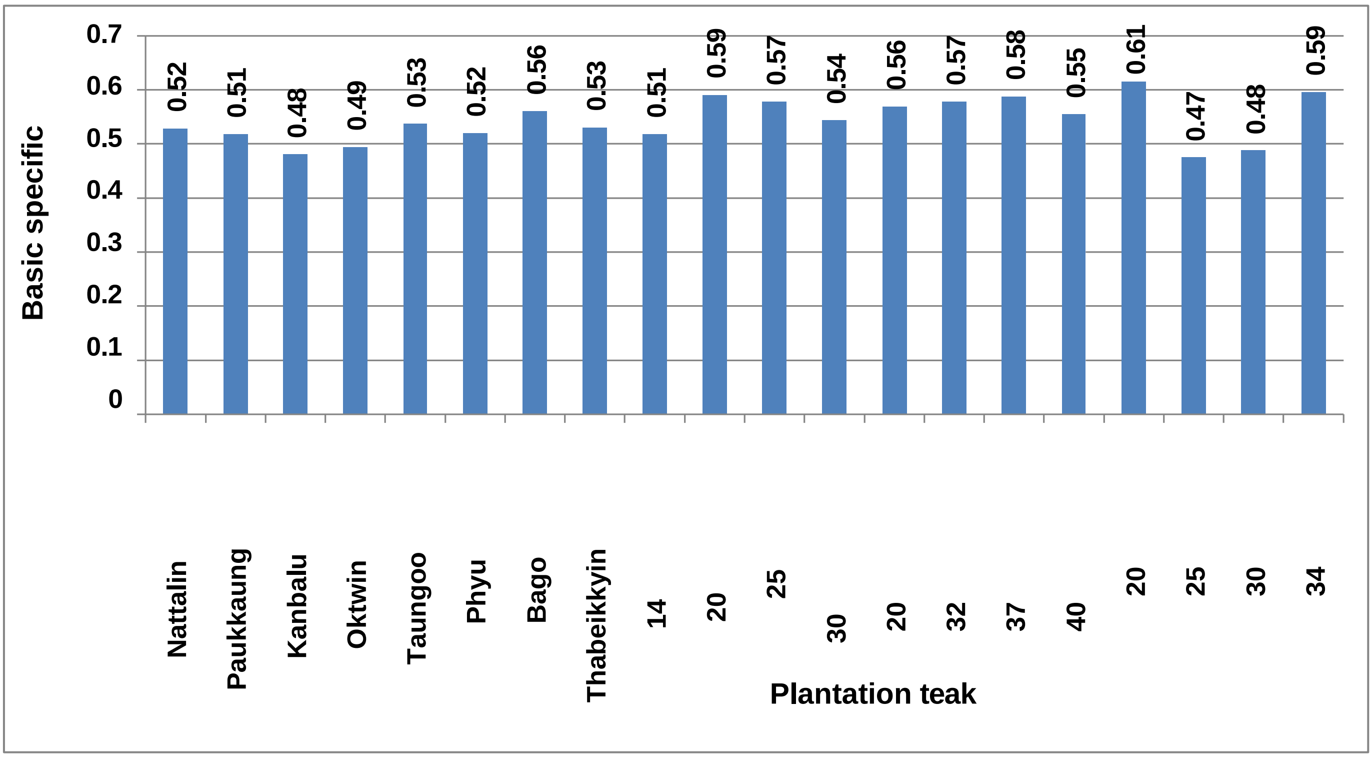


Figure 4 Comparison of basic specific gravity of eight provenances in this study and that of other studies (Naing, 2009), (Myint, et. al, 2021) and (Myint &Naing, 2023)

Wood specific gravity varies greatly within and between species (Negi 1997; Forest Products Laboratory 2010; Dinwoodie 2000). This variation is attributed to many factors such as site, climate, geographic location, growth stresses, anatomical structure, etc. (Forest Products Laboratory, 2010). According to Negi (1997), wood can be classified into six groups based on their basic specific gravity. Woods with basic specific gravity of 0.28 and less are considered very light, 0.28 to 0.42 light, 0.42 to 0.56 moderately heavy, 0.56 to 0.70 heavy, 0.70 to 0.85 very heavy and above 0.85, extremely heavy. In accordance with this classification system, all provenances will be in “Moderately Heavy” Group. These provenances are not as heavy as natural teak of 0.598 (Kyi, 1993), which is in “Heavy” Group.

### 4.1.4 Shrinkage

Table 5 (a-c) shows radial, tangential and longitudinal shrinkage of eight provenances. It can be seen that tangential shrinkage is the largest, radial shrinkage is second largest and longitudinal shrinkage is the lowest in eight provenances. Wood is an anisotropic material. It shrinks (swells) most in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally) (Forest Products Laboratory, 2010). Thus, shrinkage in tangential direction is higher than those in radial and longitudinal direction in eight provenances.

Table 5 (a) Radial shrinkage of eight provenances

| Provenances | Number of Specimen | Radial shrinkage (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | from Green to oven dry | | | from Green to 12% MC | | |
| | | Mean | SD | CV% | Mean | SD | CV% |
| Nattalin | 62 | 1.95 | 0.42 | 21.54 | 1.17 | 0.25 | 21.37 |
| Paukkaung | 44 | 2.29 | 0.25 | 10.92 | 1.38 | 0.15 | 10.87 |
| Kanbalu | 43 | 2.01 | 0.31 | 15.42 | 1.20 | 0.19 | 15.83 |
| Oktwin | 47 | 2.15 | 0.39 | 18.14 | 1.29 | 0.23 | 17.83 |
| Taungoo | 43 | 1.87 | 0.35 | 18.72 | 1.12 | 0.21 | 18.75 |
| Phyu | 56 | 1.86 | 0.25 | 13.44 | 1.12 | 0.15 | 13.39 |
| Bago | 49 | 1.85 | 0.48 | 25.95 | 1.11 | 0.29 | 26.13 |
| Thabeikkyin | 47 | 2.48 | 0.59 | 23.79 | 1.49 | 0.35 | 23.49 |

Table 5 (b) Tangential shrinkage of eight provenances

| Provenances | Number of Specimen | Tangential shrinkage (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | from Green to oven dry | | | from Green to 12% MC | | |
| | | Mean | SD | CV% | Mean | SD | CV% |
| Nattalin | 49 | 4.21 | 0.81 | 19.24 | 2.53 | 0.49 | 19.37 |
| Paukkaung | 47 | 4.46 | 0.79 | 17.71 | 2.68 | 0.48 | 17.91 |
| Kanbalu | 46 | 4.13 | 0.75 | 18.16 | 2.48 | 0.45 | 18.15 |
| Oktwin | 44 | 4.28 | 0.75 | 17.52 | 2.57 | 0.45 | 17.51 |
| Taungoo | 46 | 3.70 | 0.42 | 11.35 | 2.22 | 0.25 | 11.26 |
| Phyu | 58 | 3.46 | 0.57 | 16.47 | 2.08 | 0.34 | 16.35 |
| Bago | 59 | 4.13 | 0.60 | 14.53 | 2.48 | 0.36 | 14.52 |
| Thabeikkyin | 48 | 4.84 | 0.78 | 16.12 | 2.90 | 0.47 | 16.21 |

Table 5 (c) Longitudinal shrinkage of eight provenances

| Provenances | Number of Specimen | Longitudinal shrinkage (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | from Green to oven dry | | | from Green to 12% MC | | |
| | | Mean | SD | CV% | Mean | SD | CV% |
| Nattalin | 57 | 0.29 | 0.16 | 55.17 | 0.17 | 0.10 | 58.82 |
| Paukkaung | 56 | 0.30 | 0.21 | 70.00 | 0.18 | 0.13 | 72.22 |
| Kanbalu | 59 | 0.31 | 0.20 | 64.52 | 0.18 | 0.12 | 66.67 |
| Oktwin | 61 | 0.31 | 0.17 | 54.84 | 0.19 | 0.10 | 52.63 |
| Taungoo | 60 | 0.36 | 0.17 | 47.22 | 0.22 | 0.10 | 45.45 |
| Phyu | 59 | 0.24 | 0.15 | 62.50 | 0.15 | 0.09 | 60.00 |
| Bago | 58 | 0.34 | 0.20 | 58.82 | 0.20 | 0.12 | 60.00 |
| Thabeikkyin | 60 | 0.23 | 0.16 | 69.57 | 0.14 | 0.09 | 64.29 |

The shrinkage from green to oven-dry is from 1.85 % to 2.48 % in radial direction, from 3.46 % to 4.84 % in tangential direction and from 0.23% to 0.36% in longitudinal direction. Shrinkage variability is characterized by a coefficient of variation of approximately 15% (Forest products Laboratory, 2010). Most provenances in this research have higher coefficients of variation than 15%, which is attributable to higher juvenile contents.

Analysis of variance shows that radial, tangential and longitudinal shrinkage are significantly different among eight provenances, between trees of the same provenance and within a tree. According to Tukey's Test, Thabeikkyin provenance has the highest shrinkage values and significantly differs from Nattalin, Kanbalu, Oktwin, Taungoo, Phyu and Bago provenances, but does not significantly differ from Paukkaung provenance. Phyu provenance has the lowest shrinkage value, and significantly differs from other provenances except Taungoo provenance. Figure 5 indicates tangential shrinkage of eight provenances at different heights. The top section has the highest tangential shrinkage value and significantly differs from base and middle sections.

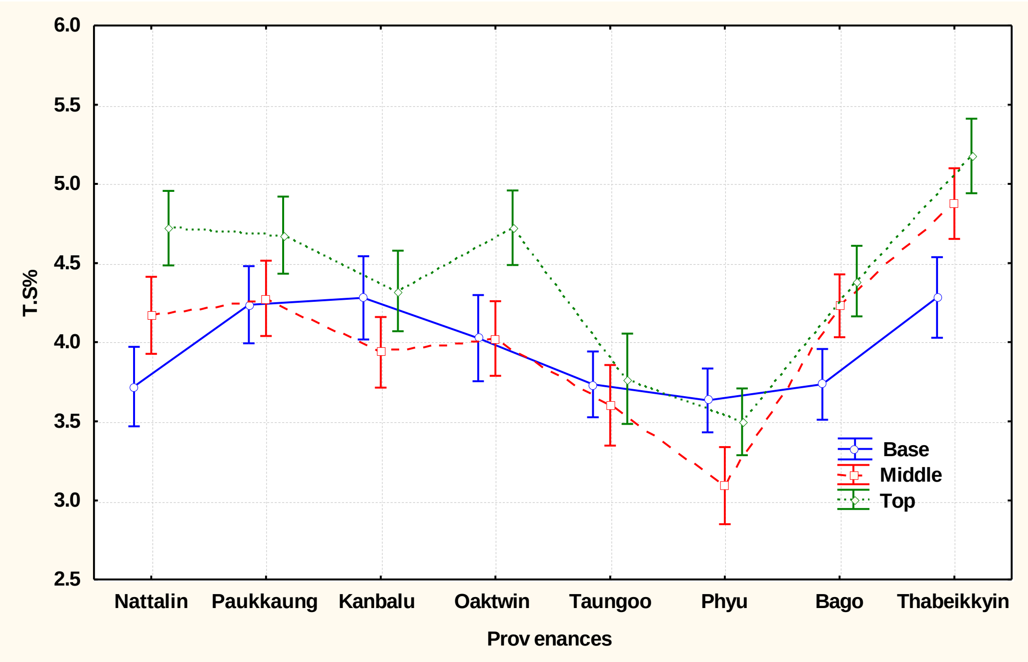


Figure 5. Tangential shrinkage of eight provenances at different height

Table 6 shows comparison of radial and tangential shrinkage of eight provenances in this study and other studies. The tangential shrinkage of eight provenances is less than those of 20 years old Bago, 34 years old Bago, 14 years old Yetashe, 20 years old Oktwin, 25 years old Lewe and 30 years old Thandwe plantation teak. The tangential shrinkage of Paukkaung provenance (4.46 %) is nearly the same as those of 25 years and 30 years old plantation teak from Bago and is not much different from those of 32 years old and 40 years old Wuntho plantation teak. The radical shrinkage of the provenances is less than those of 25 years old Bago, 20 years old Oktwin, 25 years old Lewe and 30 years old Thandwe plantation teak. Shrinkage depends on the size, shape, and the density of the specimens in the same species (Shmulsky and Jones., 2019). Generally, naturally grown teak shrinks about 2.3% radially and 4.2% tangentially (Kyi, 1993). Thus, most provenances have similar radial and tangential shrinkage values or lower values, which reflect lower densities of the provenances.

Table 6. Comparison of radial and tangential shrinkage of eight provenances in this study and other studies

| Age (years) | Locality/ provenances | Tangential shrinkage from green to oven dry (%) | Radial shrinkage from green to oven dry (%) | Remarks |
|---|---|---|---|---|
| 15 | Nattalin | 4.21 | 1.95 | This study |
| 15 | Paukkaung | 4.46 | 2.29 | |
| 15 | Kanbalu | 4.13 | 2.01 | |
| 15 | Oktwin | 4.28 | 2.15 | |
| 15 | Taungoo | 3.70 | 1.87 | |
| 15 | Phyu | 3.46 | 1.86 | |
| 15 | Bago | 4.13 | 1.85 | |
| 15 | Thabeikkyin | 4.84 | 2.48 | |
| 20 | Bago | 5.22 | 2.26 | (Myint & Naing, 2023) |
| 25 | Bago | 4.41 | 2.60 | |
| 30 | Bago | 4.47 | 2.08 | |
| 34 | Bago | 5.61 | 2.15 | |
| 20 | Wuntho | 4.05 | 2.05 | (Myint, et. al, 2021). |
| 32 | Wuntho | 4.61 | 2.00 | |
| 37 | Wuntho | 4.15 | 2.15 | |
| 40 | Wuntho | 4.50 | 3.22 | |
| 14 | Yetashe | 5.20 | 2.30 | (Naing, 2009) |
| 20 | Oktwin | 5.20 | 2.70 | |
| 25 | Lewe | 5.00 | 2.70 | |
| 30 | Thandwe | 5.60 | 2.70 | |

### 4.1.5 Swelling

Table 7. Swelling in the radial, tangential and longitudinal directions

| Provenances | No. of specimens | Swelling from oven dry to green (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Radial | | | Tangential | | | Longitudinal | | |
| | | Mean | SD | CV% | Mean | SD | CV% | Mean | SD | CV% |
| Nattalin | 55 | 1.86 | 0.62 | 33.33 | 4.59 | 1.20 | 26.14 | 0.59 | 0.22 | 37.29 |
| Paukkaung | 52 | 1.90 | 0.48 | 25.26 | 3.84 | 0.57 | 14.84 | 0.76 | 0.20 | 26.32 |
| Kanbalu | 60 | 1.86 | 0.45 | 24.19 | 4.18 | 1.10 | 26.32 | 0.72 | 0.24 | 33.33 |
| Oktwin | 59 | 1.99 | 0.42 | 21.11 | 4.45 | 0.65 | 14.61 | 0.78 | 0.18 | 23.08 |
| Taungoo | 60 | 1.93 | 0.50 | 25.91 | 4.04 | 0.49 | 12.13 | 0.84 | 0.39 | 46.43 |
| Phyu | 57 | 1.86 | 0.45 | 24.19 | 3.79 | 0.75 | 19.79 | 0.75 | 0.22 | 29.33 |
| Bago | 60 | 2.06 | 0.43 | 20.87 | 4.75 | 0.71 | 14.98 | 0.71 | 0.23 | 32.39 |
| Thabeikkyin | 59 | 2.42 | 0.62 | 25.62 | 5.05 | 0.99 | 19.60 | 0.82 | 0.22 | 26.83 |

Swelling in radial, tangential, and longitudinal directions is shown in Table 7. According to the results, tangential swelling is the largest, radial swelling the second largest and longitudinal swelling the lowest. Swelling values in tangential direction are higher than twice of the swelling values in radial direction. Among the provenances, Thabeikkyin provenance is found to swell the highest and Phyu provenance the lowest. This is due to the fact that swelling is affected by specific gravity, and thus the species with higher specific gravity swell higher (Grekin and Verkasalo, 2010). However, Bago provenance with the highest specific gravity does not swell the highest and is found to swell lower than Thabeikkyin provenance. Kanbalu provenance with the lowest specific gravity does not swell the lowest and is found to swell higher than Paukkaung, Taungoo and Phyu provenances. It may probably be due to the presence of a high amount of extractives, higher percentage of juvenile wood or reaction wood (Forest Products Laboratory, 2010; Shmulsky and Jones., 2019). There are also other factors affecting shrinkage and swelling like size and shape of specimen and the rate of drying (Forest Products Laboratory 2010).

Analysis of variance shows that radial, tangential and longitudinal swelling are significantly different among eight provenances, between tree and within a tree. Tangential swelling from oven dry to green is compared for significant difference using Tukey's test. Thabeikkyin provenance has the highest tangential swelling value of 5.05%, and significantly differs from Paukkaung, Kanbalu, Oktwin, Taungoo and Phyu but does not significantly differ from Nattalin and Bago provenance. Phyu provenance has the lowest tangential swelling value and significantly differs from Nattalin, Oktwin, Bago and Thabeikkyin provenances. The top section has the highest tangential swelling value and significantly differs from base and middle sections.

Table 8. Comparison of radial and tangential swelling of eight provenances in this study and other studies

| Age (years) | Locality/provenance | Radial Swelling from oven dry to green (%) | Tangential Swelling from oven dry to green (%) | Remarks |
|---|---|---|---|---|
| 15 | Nattalin | 1.86 | 4.59 | This study |
| 15 | Paukkaung | 1.90 | 3.84 | |
| 15 | Kanbalu | 1.86 | 4.18 | |
| 15 | Oktwin | 1.99 | 4.45 | |
| 15 | Taungoo | 1.93 | 4.04 | |
| 15 | Phyu | 1.86 | 3.79 | |
| 15 | Bago | 2.06 | 4.75 | |
| 15 | Thabeikkyin | 2.42 | 5.05 | |
| 20 | Bago | 2.96 | 7.33 | (Myint & Naing, 2023) |
| 25 | Bago | 2.49 | 5.64 | |
| 30 | Bago | 1.69 | 4.63 | |
| 34 | Bago | 2.42 | 4.86 | |
| 20 | Wuntho | 1.94 | 4.51 | (Myint et al, 2021). |
| 32 | Wuntho | 2.16 | 6.07 | |
| 37 | Wuntho | 1.99 | 4.88 | |
| 40 | Wuntho | 2.27 | 5.24 | |
| 14 | Yetashe | 1.96 | 4.84 | (Myint et al, 2014). |
| 20 | Oktwin | 2.15 | 4.99 | |

| | | | | |
|---|---|---|---|---|
| 25 | Lewe | 2.69 | 5.08 | |
| 30 | Thandwe | 1.97 | 4.77 | |

A comparison of radial and tangential swelling of eight provenances in this study and other studies is shown in Table 8. According to results, swelling values of eight provenances are lower than those of plantation teak from other studies.

#### 4.1.6 Water absorption

Table 9. Water absorption of eight provenances

| Provenances | No. of specimens | Water absorption (kgm$^{-3}$) | | | | |
|---|---|---|---|---|---|---|
| | | Mean | Minimum | Maximum | SD | CV% |
| Nattalin | 55 | 592.07 | 515.36 | 663.16 | 45.82 | 7.74 |
| Paukkaung | 52 | 615.34 | 554.54 | 652.45 | 29.68 | 4.82 |
| Kanbalu | 60 | 647.17 | 612.60 | 679.62 | 18.54 | 2.86 |
| Oktwin | 59 | 629.57 | 593.36 | 694.86 | 22.78 | 3.62 |
| Taungoo | 60 | 616.04 | 558.06 | 658.20 | 18.32 | 2.97 |
| Phyu | 57 | 607.03 | 565.63 | 643.96 | 15.84 | 2.61 |
| Bago | 60 | 580.21 | 531.42 | 625.67 | 23.99 | 4.13 |
| Thabeikkyin | 59 | 624.73 | 593.33 | 660.52 | 15.78 | 2.53 |

Water absorption of eight provenances is given in Table 9. According to the results, water absorption of Kanbalu provenance is the highest among eight provenances and Bago provenance the lowest. This could be attributed to their densities. Kanbalu provenance has the lowest basic density and thus absorbs water most. Sint and Hapla (2009) found that timbers with higher densities absorb less water or solution than those with lower densities. Again, among timbers of the same density, those with deposits in cell lumina show lower absorption than those without deposits (Sint 2010; Sint et. al. 2011). Moreover, the absorption is also influenced by anatomical structure of timber species (Sint et. al. 2013; Sint et. al. 2012).

Analysis of variance shows that water absorption is significantly different among eight provenances, between trees and within a tree. According to Tukey's test, Kanbalu provenance has the highest water absorption value of 647.17 kgm$^{-3}$, and significantly differs from water absorption value of other seven provenances. Bago provenance has the lowest water absorption value of 580.21 kgm$^{-3}$, and significantly differs from water absorption value of other provenances except Nattalin provenance. Figure 6 indicates water absorption of eight provenances at different heights. The top section has the highest water absorption value and significantly differs from base and middle sections.

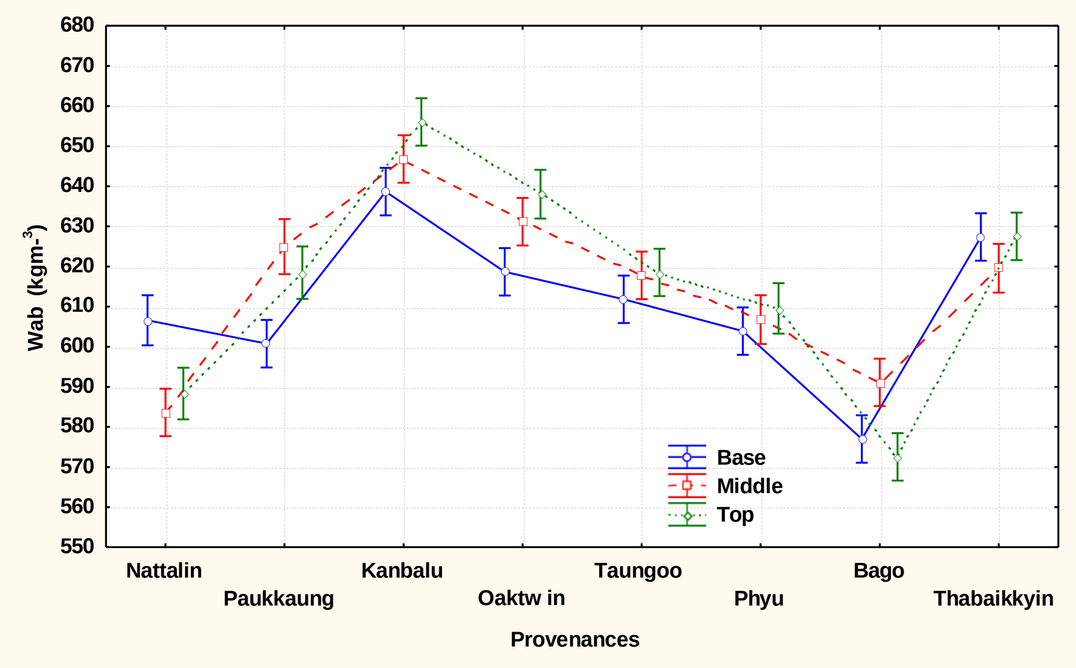


Figure 6. Water absorption of eight provenances at different height

Table 10. Comparison of water absorption of eight provenances in this study and other studies

| Age (years) | Locality/ provenance | Water absorption ($kgm^{-3}$) | Remarks |
|---|---|---|---|
| 15 | Nattalin | 592 | This study |
| 15 | Paukkaung | 618 | |
| 15 | Kanbalu | 647 | |
| 15 | Oktwin | 629 | |
| 15 | Taungoo | 616 | |
| 15 | Phyu | 606 | |
| 15 | Bago | 580 | |
| 15 | Thabeikkyin | 625 | |
| 20 | Bago | 588 | (Myint & Naing, 2023) |
| 25 | Bago | 582 | |
| 30 | Bago | 641 | |
| 34 | Bago | 567 | |
| 20 | Wuntho | 612 | (Myint et al, 2021). |
| 32 | Wuntho | 571 | |
| 37 | Wuntho | 582 | |
| 40 | Wuntho | 613 | |
| 14 | Yetashe | 618 | (Myint et al, 2014). |
| 20 | Oktwin | 572 | |

| | | | |
|---|---|---|---|
| 25 | Lewe | 579 | |
| 30 | Thandwe | 617 | |

A comparison of water absorption of eight provenances in this study and other studies is shown in Table 10. The water absorption values of the provenances except Bago and Nattalin are higher than those of 20-, 25- and 34-years old Bago, 32- and 37-years old Wuntho and 20 years old Oktwin plantation teak and are nearly the same as those of the rest. Thus, the provenances generally absorb more water than or at least the same as the other plantation teak, which reflects their lower densities.

## 4.2 Mechanical Properties

### 4.2.1 Static Bending

**4.2.1.1** Modulus of elasticity (MOE) in static bending

Table 11. Modulus of elasticity of eight provenances ($Nmm^{-2}$)

| Provenances | Seasoning | Moisture content (%) | Number of specimens | Modulus of Elasticity($Nmm^{-2}$) | | |
|---|---|---|---|---|---|---|
| | | | | Mean | SD | CV% |
| Nattalin | Green | 108.46 | 25 | 4814 | 1522 | 31.62 |
| | Air-dry | 12% | 27 | 5963 | 2827 | 47.41 |
| Paukkaung | Green | 112.87 | 32 | 5876 | 1286 | 21.89 |
| | Air-dry | 12% | 35 | 6078 | 2143 | 35.26 |
| Kanbalu | Green | 96.13 | 40 | 5417 | 2370 | 43.75 |
| | Air-dry | 12% | 41 | 6007 | 1661 | 27.65 |
| Oktwin | Green | 94.62 | 41 | 5674 | 1809 | 31.88 |
| | Air-dry | 12% | 46 | 6032 | 1430 | 23.71 |
| Taungoo | Green | 85.35 | 30 | 5930 | 1512 | 25.50 |
| | Air-dry | 12% | 43 | 7475 | 1559 | 20.86 |
| Phyu | Green | 84.94 | 35 | 6178 | 1557 | 25.20 |
| | Air-dry | 12% | 45 | 6743 | 1537 | 22.79 |
| Bago | Green | 88.67 | 33 | 5360 | 2263 | 42.22 |
| | Air-dry | 12% | 34 | 7668 | 2649 | 34.55 |
| Thabeikkyin | Green | 89.84 | 42 | 5307 | 2149 | 40.49 |
| | Air-dry | 12% | 41 | 7088 | 2015 | 28.43 |

The mean modulus of elasticity values of eight provenances at green and air-dry condition are given in Table 11. The number of specimens, standard deviation and coefficient of variation are also given. According to results, Bago provenance possesses the highest MOE among eight provenances whereas Nattalin provenance possesses the lowest MOE. Analysis of variance shows that MOE significantly differs between trees and within a tree but does not significantly differ among provenances at green condition. At air-dry condition, MOE significantly differs among provenances and within a tree but not significantly different between trees. Bago provenance is significantly different from Nattalin, Paukkaung, Kanbalu and Oktwin provenances in MOE. Figure 7 shows the modulus of elasticity of eight provenances at different heights. Within a tree, the top section has significantly higher MOE than middle and base sections. So, MOE increases with height along the stem at both green and air dry condition.

The value of coefficient of variation for modulus of elasticity can be high up to 22% (Forest products laboratory, 2010). According to results, at green condition, coefficient of variation of modulus of elasticity for Paukkaung provenance is less than 22% which means that the result is to be reliable. At 12% moisture content, coefficient of variation of modulus of elasticity for Taungoo provenance is less than 22% which might mean that the result is to be reliable.

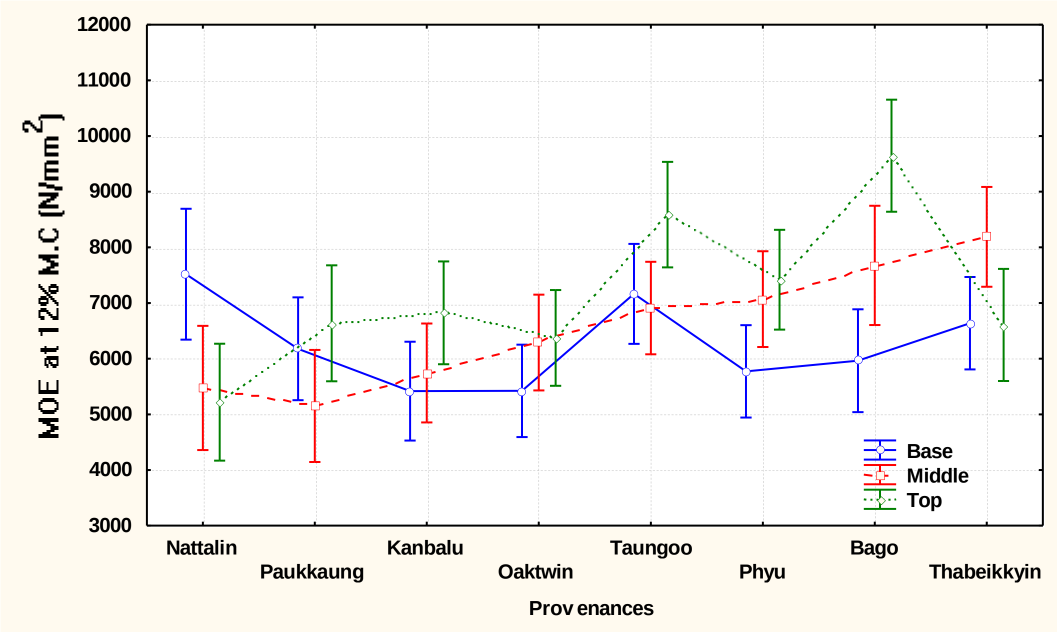


Figure 7. Modulus of elasticity of eight provenances at different height (at 12% MC)

#### 4.2.1.2 Modulus of Rupture (MOR) in static bending

Table 12. Modulus of Rupture of eight provenances (Nmm$^{-2}$)

| Provenances | Seasoning | Moisture content (%) | Number of specimens | Modulus of Rupture(Nmm$^{-2}$) | | |
|---|---|---|---|---|---|---|
| | | | | Mean | SD | CV% |
| Nattalin | Green | 108.46 | 25 | 38 | 18 | 47.37 |
| | Air-dry | 12 | 28 | 79 | 14 | 17.72 |
| Paukkaung | Green | 112.87 | 32 | 45 | 11 | 24.44 |
| | Air-dry | 12 | 35 | 65 | 13 | 20.00 |
| Kanbalu | Green | 96.13 | 40 | 34 | 17 | 50.00 |
| | Air-dry | 12 | 41 | 57 | 16 | 28.07 |
| Oktwin | Green | 94.62 | 41 | 39 | 19 | 48.72 |
| | Air-dry | 12 | 46 | 52 | 18 | 34.62 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Taungoo | Green | 85.35 | 30 | 40 | 18 | 45.00 |
| | Air-dry | 12 | 43 | 49 | 18 | 36.73 |
| Phyu | Green | 84.94 | 35 | 33 | 17 | 51.52 |
| | Air-dry | 12 | 45 | 41 | 21 | 51.22 |
| Bago | Green | 88.67 | 33 | 48 | 25 | 52.08 |
| | Air-dry | 12 | 34 | 51 | 23 | 45.10 |
| Thabeikkyin | Green | 89.84 | 42 | 41 | 13 | 31.71 |
| | Air-dry | 12 | 41 | 52 | 25 | 48.08 |

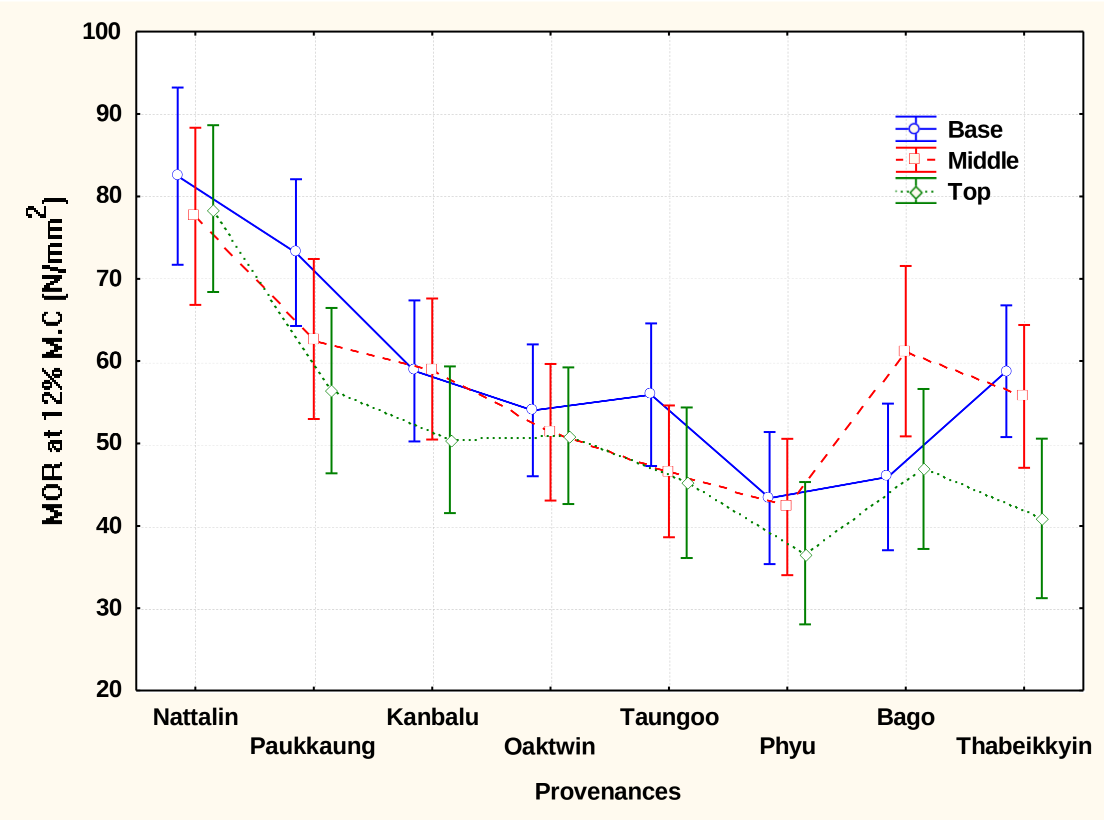


Figure 8. Modulus of Rupture of eight provenances at different height (at 12% MC)

The mean modulus of rupture values of eight provenances at green and 12% moisture content are shown in Table 12. According to the results, Nattalin provenance possesses the highest MOR but Phyu provenance possesses the lowest. Analysis of variance shows that MOR is significantly different among the provenances and within a tree but not significantly differs between trees. In accordance with Tukey's test, Nattalin provenance is significantly different from other provenances except Paukkaung provenance. Phyu provenance significantly differs from Nattalin, Paukkaung and Kanbalu provenances but not from others. Figure 8 shows modulus of rupture of eight provenances at different heights. Within a tree, the base section is significantly higher MOR than middle and Top section, which is due to higher density at the base.

#### 4.2.1.3 Mean fiber stress at proportional limit (FS@PL) in static bending

Table 13. Fiber stress at proportional limit of eight provenances in static bending ($Nmm^{-2}$)

| Provenances | Moisture content (%) | Number of specimens | Fiber stress at proportional limit ($Nmm^{-2}$) | | |
|---|---|---|---|---|---|
| | | | Mean | SD | CV% |
| Nattalin | 108.46 | 25 | 22 | 12 | 54.55 |
| | 12.00 | 28 | 45 | 8 | 17.78 |
| Paukkaung | 112.87 | 32 | 24 | 6 | 25.00 |
| | 12.00 | 35 | 34 | 8 | 23.53 |
| Kanbalu | 96.13 | 40 | 19 | 12 | 63.16 |
| | 12.00 | 41 | 31 | 9 | 29.03 |
| Oktwin | 94.62 | 41 | 21 | 10 | 47.62 |
| | 12.00 | 46 | 29 | 11 | 37.93 |
| Taungoo | 85.35 | 30 | 22 | 11 | 50.00 |
| | 12.00 | 43 | 28 | 10 | 35.71 |
| Phyu | 84.94 | 35 | 18 | 9 | 50.00 |
| | 12.00 | 45 | 23 | 12 | 52.17 |
| Bago | 88.67 | 33 | 27 | 14 | 51.85 |
| | 12.00 | 34 | 28 | 12 | 42.86 |
| Thabeikkyin | 89.84 | 42 | 22 | 8 | 36.36 |
| | 12.00 | 41 | 28 | 13 | 46.43 |

Table 13 shows fiber stresses at proportional limit of eight provenances. At green condition, analysis of variances shows that FS@PL significantly differs among provenances but does not significantly differ within a tree. Bago provenance possesses the highest FS@PL whereas Phyu provenance possesses the lowest FS@PL. At green condition, significant difference occurs just between Bago and Phyu provenances.

Figure 9 shows fiber stresses at proportional limit of eight provenances (at 12% moisture content). Analysis of variances shows that FS@PL significantly differs among provenances and within a tree. According to Tukey’s test. Nattalin provenance possesses the highest FS@PL and significantly differs from other seven provenances. Phyu provenance possesses the lowest FS@PL and significantly differs from Nattalin, Paukkaung and Kanbalu provenances. The value of coefficient of variation for fiber stress at proportional limit can be high up to 22% (Forest products laboratory, 2010). Most of the provenances have higher coefficients of variation which can be due to different contents of juvenile woods in the test specimens.

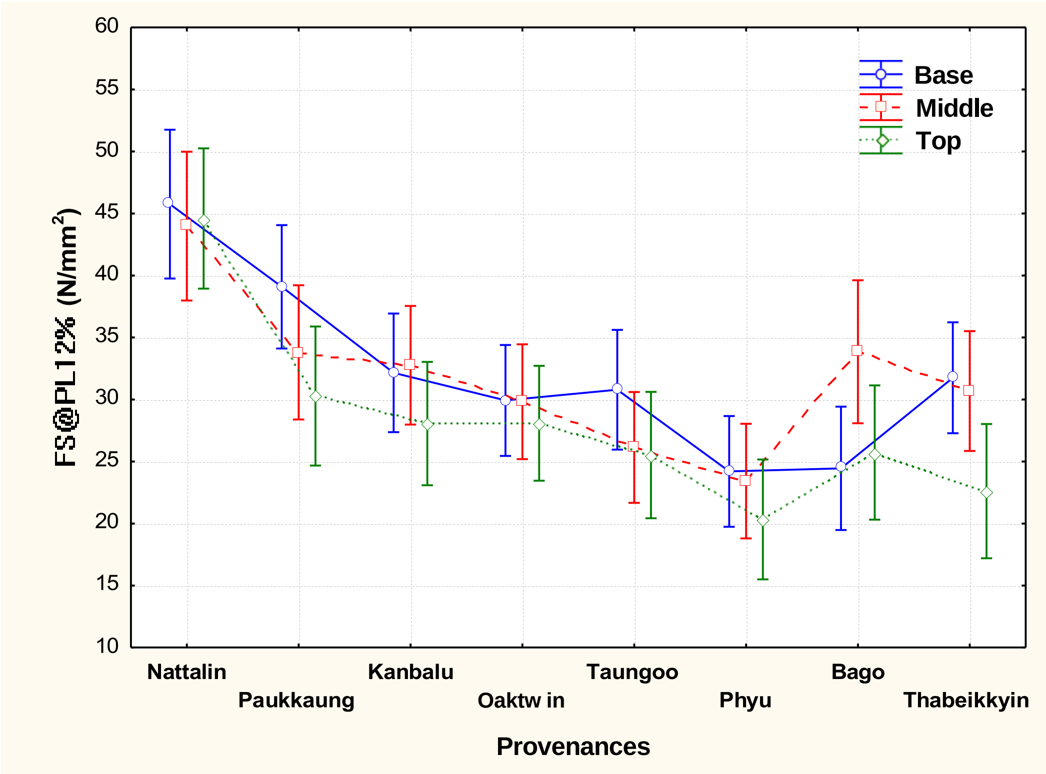


Figure 9.Fiber stress at proportional limit of eight provenances in static bending (at 12% moisture content)

### 4.2.2 Compression Parallel to Grain

#### 4.2.2.1 Maximum crushing strength in compression parallel to grain

Table 14. Maximum crushing strength of eight provenances (Nmm$^{-2}$)

| Provenance | Moisture content (%) | No. of specimens | Maximum Crushing Strength (Nmm$^{-2}$) | | |
|---|---|---|---|---|---|
| | | | Mean | SD | CV% |
| Nattalin | 113.16 | 37 | 28 | 8 | 28.57 |
| | 12 | 46 | 32 | 16 | 50.00 |
| Paukkaung | 119.08 | 33 | 27 | 6 | 22.22 |
| | 12 | 36 | 35 | 9 | 25.71 |
| Kanbalu | 127.92 | 32 | 25 | 5 | 20.00 |
| | 12 | 37 | 35 | 8 | 22.86 |
| Oktwin | 113.49 | 31 | 25 | 5 | 20.00 |
| | 12 | 37 | 33 | 9 | 27.27 |
| Taungoo | 105.19 | 30 | 27 | 5 | 18.52 |
| | 12 | 36 | 42 | 4 | 9.52 |
| Phyu | 99.07 | 30 | 27 | 6 | 22.22 |
| | 12 | 36 | 43 | 2 | 4.65 |

| | | | | | |
|---|---|---|---|---|---|
| Bago | 98.46 | 30 | 29 | 7 | 24.14 |
| | 12 | 36 | 48 | 4 | 8.33 |
| Thabeikkyin | 109.09 | 36 | 28 | 4 | 14.29 |
| | 12 | 59 | 44 | 6 | 13.64 |

The mean values of maximum crushing strength of eight provenances at green and 12% moisture content are shown in Table 14. The number of specimens per provenance, standard deviation and coefficient of variations are also given.

Figure 10 shows maximum crushing strength of eight provenances at 12 % moisture content condition. Analysis of variances shows that maximum crushing strength (MCS) significantly differs among provenances, between trees and within a tree. Bogo provenance possesses the highest MCS and significantly differs from Nattalin, Paukkaung, Kanbalu, Oktwin and Taungoo provenances but does not differ from the rest provenances. Nattalin provenance possesses the lowest MCS among provenances, and significantly differs from Taungoo, Phyu, Bago and Thabeikkyin provenances. Within a tree, MCS increases with height along the stem. So, the top section has a significantly higher MCS than base and middle section.

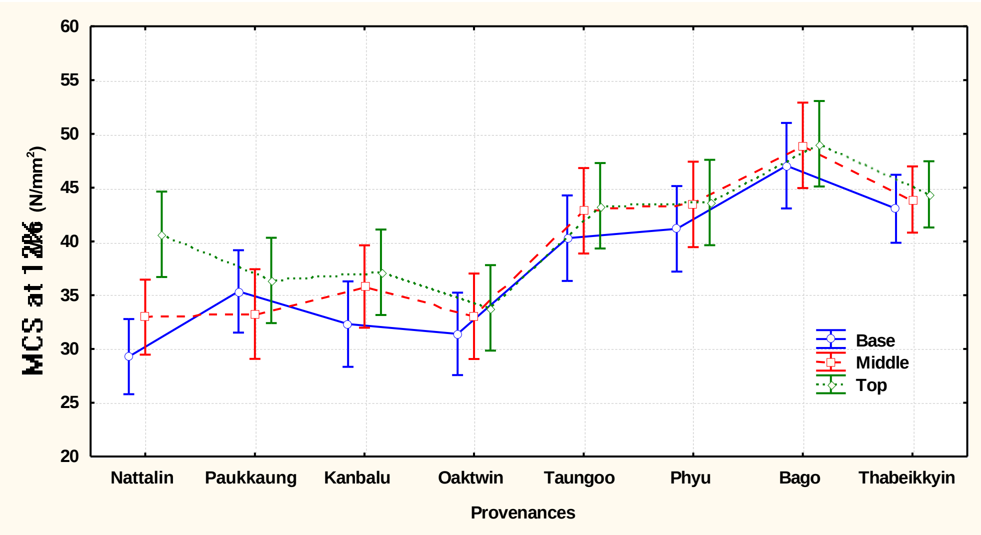


Figure 10. Maximum crushing strength of eight provenances (at 12% MC)

### 4.2.2.2 Fiber stress at proportional limit in compression parallel to grain

Table 15. Fiber stress at proportional limit of eight provenances in compression parallel to grain ($Nmm^{-2}$)

| Provenance | Moisture content (%) | No. of specimens | Fiber Stress at Proportional Limit ($Nmm^{-2}$) | | |
|---|---|---|---|---|---|
| | | | Mean | SD | CV% |
| Nattalin | 113.16 | 37 | 23 | 7 | 30.43 |
| | 12 | 46 | 26 | 14 | 53.85 |
| Paukkaung | 119.08 | 33 | 22 | 6 | 27.27 |
| | 12 | 36 | 28 | 8 | 28.57 |
| Kanbalu | 127.92 | 32 | 20 | 6 | 30.00 |

| | | | | | |
|---|---|---|---|---|---|
| | 12 | 37 | 28 | 8 | 28.57 |
| Oktwin | 113.49 | 31 | 20 | 5 | 25.00 |
| | 12 | 37 | 27 | 9 | 33.33 |
| Taungoo | 105.19 | 30 | 23 | 5 | 21.74 |
| | 12 | 36 | 35 | 4 | 11.43 |
| Phyu | 99.07 | 30 | 22 | 5 | 22.73 |
| | 12 | 36 | 35 | 4 | 11.43 |
| Bago | 98.46 | 30 | 24 | 7 | 29.17 |
| | 12 | 36 | 42 | 4 | 9.52 |
| Thabeikkyin | 109.09 | 36 | 23 | 5 | 21.74 |
| | 12 | 59 | 36 | 7 | 19.44 |

Fiber stresses at proportional limit of eight provenances at green and 12% moisture content are shown in Table 15. The number of specimens per provenance, standard deviation and coefficient of variations are also given. At green condition, Kanbalu and Oktwin provenances have the lowest fiber stress at proportional limit whereas Bago provenance possesses the highest FS@PL. At 12% moisture content, Nattalin provenance has the lowest whilst Bago provenance has the highest. The value of coefficient of variation for fiber stress at proportional limit can be high up to 24% (Forest products laboratory, 2010).

At air-dry condition, analysis of variance shows that fiber stress at proportional limit significantly differs among provenances and between tree but not significantly differs within a tree. Figure 11 shows fiber stress at proportional limit of eight provenances at different height (at 12% MC). Bago provenance significantly differs from Nattalin, Paukkaung, Kanbalu, Oktwin, Taungoo and Phyu provenances but does not significantly differ from Thabeikkyin provenance. Nattalin provenance significantly differs from Taungoo, Phyu, Bago and Thabeikkyin provenances but does not significantly differ from Paukkaung, Kanbalu and Oktwin provenances.

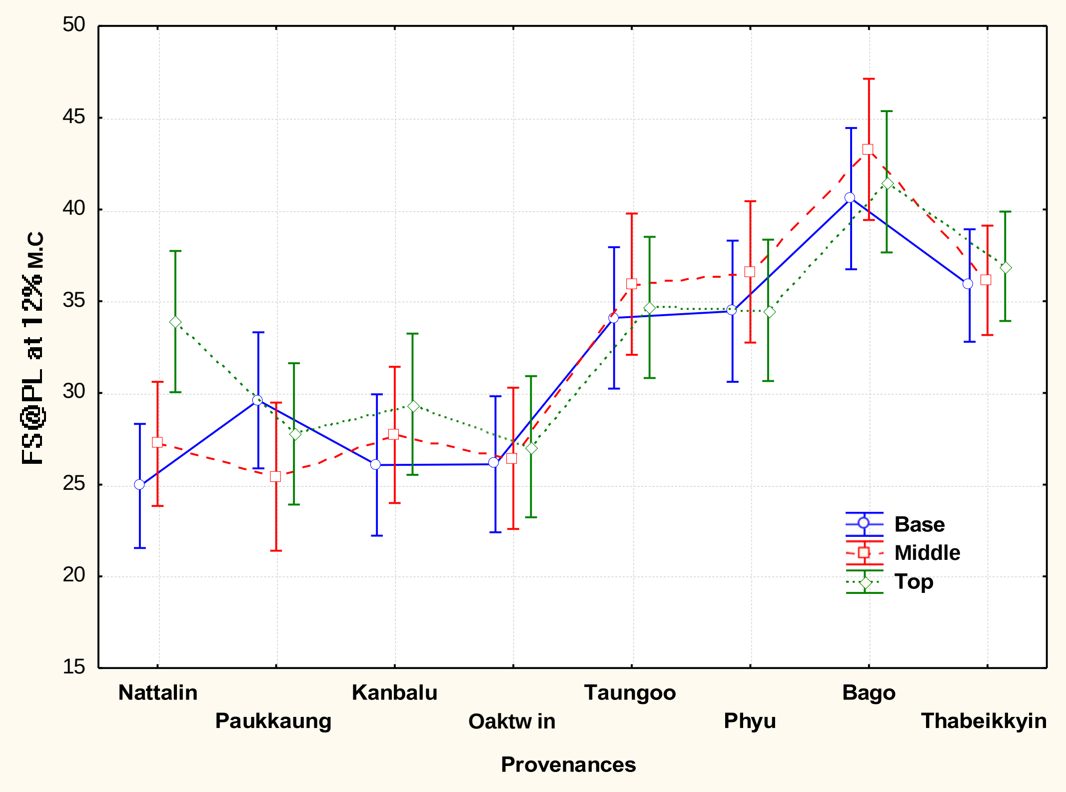


Figure 11. Fiber stress at proportional limit of eight provenances at different heights in compression parallel to grain test (at 12% MC)

### 4.2.3 Compression Perpendicular to Grain

#### 4.2.3.1 Fiber stress at proportional limit in compression perpendicular to grain test

Table 16. Fiber stress at proportional limit of eight provenances in compression perpendicular to grain test (Nmm$^{-2}$)

| Provenance | Moisture content (%) | Number of specimens | Fiber Stress at Proportional Limit(FS @PL) (Nmm$^{-2}$) | | |
|---|---|---|---|---|---|
| | | | Mean | Standard deviation | CV% |
| Nattalin | 107.70 | 39 | 6.74 | 2.22 | 32.94 |
| | 12.00 | 41 | 6.85 | 2.24 | 32.70 |
| Paukkaung | 106.87 | 35 | 5.59 | 2.44 | 43.65 |
| | 12.00 | 34 | 5.66 | 2.57 | 45.41 |
| Kanbalu | 118.70 | 29 | 3.14 | 1.95 | 62.10 |
| | 12.00 | 61 | 4.82 | 2.92 | 60.58 |
| Oktwin | 112.71 | 30 | 4.47 | 2.60 | 58.17 |
| | 12.00 | 44 | 5.18 | 2.68 | 51.74 |
| Taungoo | 97.14 | 30 | 4.11 | 2.38 | 57.91 |
| | 12.00 | 69 | 6.10 | 3.90 | 63.93 |

| | | | | | |
|---|---|---|---|---|---|
| Phyu | 95.95 | 30 | 3.74 | 2.37 | 63.37 |
| | 12.00 | 68 | 6.24 | 3.84 | 61.54 |
| Bago | 89.70 | 30 | 4.10 | 2.99 | 72.93 |
| | 12.00 | 60 | 6.54 | 3.80 | 58.10 |
| Thabeikkyin | 112.10 | 54 | 7.13 | 1.44 | 20.20 |
| | 12.00 | 44 | 7.31 | 2.65 | 36.25 |

The mean fiber stresses at proportional limit of eight provenances at green and 12% moisture content are given in Table 16. The number of specimens, standard deviation and coefficient of variation are also given. At both green condition and 12% moisture content, Thabeikkyin provenance possesses the highest FS@PL whereas Kanbalu provenance possesses the lowest. The coefficient of variation for fiber stress at proportional limit can be high up to 28% (Forest products laboratory, 2010).

Analysis of variances shows that fiber stress at proportional limit significantly differs among provenances, between trees and within a tree at green condition but at air-dry condition, only among provenances. At air dry condition, fiber stress at proportional limit of eight provenances at different height is shown in Figure 12. The highest Thabeikkyin provenance significantly differs from Kanbalu and Oktwin provenances but does not differ from other provenances.

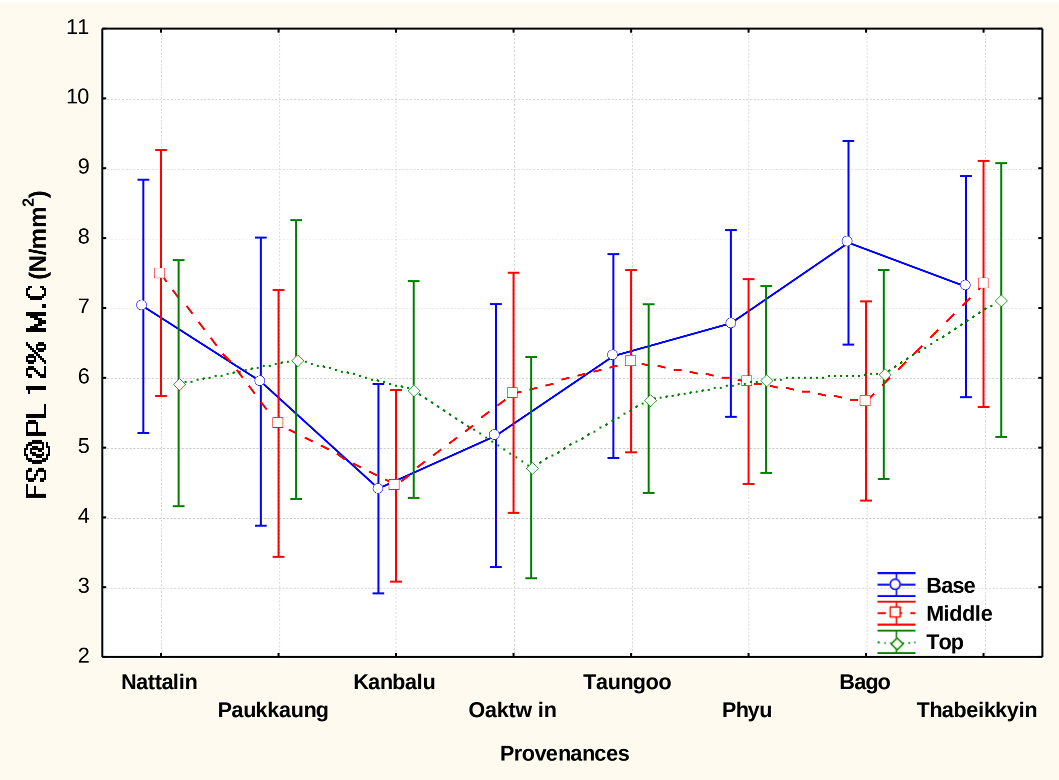


Figure 12. Fiber stress at proportional limit for eight provenances at different height in compression perpendicular to grain (at 12% moisture content)

Table 17. Comparison of mechanical properties of eight provenances in this study and other studies

| Locality/provenances | Age (years) | Properties | | | | | |
|---|---|---|---|---|---|---|---|
| | | Static bending ($Nmm^{-2}$) | | | Compression Parallel to grain ($Nmm^{-2}$) | | Compression Perpendicular to grain ($Nmm^{-2}$) |
| | | MOE | MOR | FS@PL | MCS | FS@PL | FS@PL |
| Nattalin | 15 | 5963 | 79 | 45 | 32 | 26 | 6.9 |
| Paukkaung | 15 | 6078 | 65 | 34 | 35 | 28 | 5.7 |
| Kanbalu | 15 | 6007 | 57 | 31 | 35 | 28 | 4.8 |
| Oktwin | 15 | 6032 | 52 | 29 | 33 | 27 | 5.2 |
| Taungoo | 15 | 7475 | 49 | 28 | 42 | 35 | 6.1 |
| Phyu | 15 | 6743 | 41 | 23 | 43 | 35 | 6.2 |
| Bago | 15 | 7668 | 51 | 28 | 48 | 42 | 6.5 |
| Thabeikkyin | 15 | 7088 | 52 | 28 | 44 | 36 | 7.3 |
| Bago | 20 | 11314 | 98 | 61 | 51 | 45 | 9.0 |
| Bago | 25 | 10946 | 81 | 49 | 36 | 33 | 6.2 |
| Bago | 30 | 10081 | 84 | 53 | 40 | 38 | 4.9 |
| Bago | 34 | 11804 | 91 | 56 | 40 | 39 | 9.6 |
| Wuntho | 20 | 12178 | 99 | 64 | 32 | 28 | 8.9 |
| Wuntho | 32 | 13534 | 104 | 69 | 28 | 26 | 8.0 |
| Wuntho | 37 | 12784 | 102 | 65 | 31 | 28 | 5.2 |
| Wuntho | 40 | 13896 | 90 | 59 | 33 | 31 | 7.8 |
| Yetashe | 14 | 9491 | 98 | 60 | 46 | 38 | 11.8 |
| Oktwin | 20 | 10570 | 105 | 63 | 50 | 42 | 13.1 |
| Lewe | 25 | 11480 | 114 | 21 | 53 | 45 | 13.7 |
| Thandwe | 30 | 10550 | 95 | 59 | 44 | 38 | 10.8 |

The comparison of mechanical properties of eight provenances in this study and other studies is shown in Table 17. It shows that MOE and MOR values of eight provenances are lower than those of plantation teak from other studies. Moreover, MCS values of eight provenances are lower than those of plantation teak from Yetashe. Oktwin, Lewe, Thandwe and Bago township, but nearly the same as those of plantation teak from Wuntho township.

### 4.2.4 Comparison of properties of eight provenances and natural Teak

Table 18. Comparison of physical properties of eight provenances in this study and those of natural teak

| Species | Moisture content (%) | Specific gravity | Density (kg/m3) | Radial shrinkage from green to oven dry | Tangential shrinkage from green to oven dry | Dimensional stability |
|---|---|---|---|---|---|---|
| Nattalin provenance | 102.58 | 0.529 | 1060 | 1.95 | 4.21 | 2.16 |
| | 12.00 | 0.578 | 648 | 1.17 | 2.53 | |
| Paukkaung provenance | 104.63 | 0.518 | 1055 | 2.29 | 4.46 | 1.95 |
| | 12.00 | 0.565 | 633 | 1.38 | 2.68 | |
| Kanbalu provenance | 111.77 | 0.481 | 1016 | 2.01 | 4.13 | 2.06 |
| | 12.00 | 0.521 | 584 | 1.20 | 2.48 | |
| Oktwin provenance | 106.19 | 0.494 | 1015 | 2.15 | 4.28 | 1.99 |
| | 12.00 | 0.537 | 601 | 1.29 | 2.57 | |
| Taungoo provenance | 92.58 | 0.537 | 1029 | 1.87 | 3.70 | 1.98 |
| | 12.00 | 0.588 | 658 | 1.12 | 2.22 | |
| Phyu provenance | 96.99 | 0.520 | 1018 | 1.86 | 3.46 | 1.86 |
| | 12.00 | 0.567 | 635 | 1.12 | 2.08 | |
| Bago provenance | 82.13 | 0.561 | 1016 | 1.85 | 4.13 | 2.23 |
| | 12.00 | 0.617 | 691 | 1.11 | 2.48 | |
| Thabeikkyin provenance | 93.08 | 0.531 | 1019 | 2.43 | 4.84 | 1.99 |
| | 12.00 | 0.580 | 650 | 1.49 | 2.90 | |
| Natural teak * | 51.80 | 0.598 | 913 | 2.30 | 4.20 | 1.83 |
| - | 12.00 | 0.664 | 740 | 1.38 | 2.52 | |

*Data source: Physical and mechanical properties of some Myanma Timbers (Kyi, 1993).

Physical properties of eight provenances in this study and natural teak are shown in Table 18. It can be found that specific gravity values of all provenances are lower than that of natural teak. Density values of all provenances at green condition are greater than that of natural teak, which reflect the higher water contents of the provenances at green condition. At 12% moisture content, the density of natural teak is also higher than those of the provenances.
Except Thabeikkyin provenance, other provenances have lower radial shrinkage than natural teak. Except Paukkaung, Oktwin and Thabeikkyin provenances, others have similar or lower tangential shrinkage than natural teak. Lower shrinkage than natural teak do not mean that they are better for structural applications, but reflect their lower densities than natural teak. However, it can be found that all eight provenances have tangential shrinkage less than 7% and radial shrinkage less than 3.5%. Moreover, the dimensional stability of the provenances is also about 2, which is similar to natural teak. Win Kyi (2000) stated that those timbers which have dimensional stability less than or equal to 2.0 and dimensional changes i.e. radial shrinkage and tangential shrinkage less than or equal to 3.5% and 7.0% are found to be suitable for making high quality wood products. Thus, they all could be used for making

such quality products. However, Paukkaung, Oktwin, Taungoo, Phyu and Thabeikkyin provenances could be better for making high quality wood products.

Table 19. Comparison of mechanical properties of eight provenances in this study and natural teak

| Species | Condition | Static bending ($Nmm^{-2}$) | | Compression Parallel to grain ($Nmm^{-2}$) |
|---|---|---|---|---|
| | | MOE | MOR | MCS |
| Nattalin provenance | Green | 4814 | 38 | 28 |
| | Air dry | 5963 | 79 | 32 |
| Paukkaung provenance | Green | 5876 | 45 | 27 |
| | Air dry | 6078 | 65 | 35 |
| Kanbalu provenance | Green | 5417 | 34 | 25 |
| | Air dry | 6007 | 57 | 35 |
| Oktwin provenance | Green | 5674 | 39 | 25 |
| | Air dry | 6032 | 52 | 33 |
| Taungoo provenance | Green | 5930 | 40 | 27 |
| | Air dry | 7475 | 49 | 42 |
| Phyu provenance | Green | 6178 | 33 | 27 |
| | Air dry | 6743 | 41 | 43 |
| Bago provenance | Green | 5360 | 48 | 29 |
| | Air dry | 7668 | 51 | 48 |
| Thabeikkyin provenance | Green | 5307 | 41 | 28 |
| | Air dry | 7088 | 52 | 44 |
| Natural teak* | Green | 11535 | 79 | 40 |
| | Air dry | 13011 | 103 | 60 |

*Data source: Physical and mechanical properties of some Myanma Timbers (Kyi, 1993)

The comparison of mechanical properties of eight provenances in this study and natural teak is shown in Table 19. It is found that static bending strengths and longitudinal strengths of the provenances are lower than those of natural teak at both green and 12 % moisture content.

According to the classification of strength properties of Negi (1997), two factors such as modulus of elasticity and modulus of rupture at 12% moisture content are taken into account for end-use of timbers as a construction material. According to this grouping, all provenances would be in Group III. Thus, the tested eight provenances are not suitable for heavy constructions, requiring higher strengths.

## 5. Conclusion

Physical and mechanical properties are significantly different among the provenances except modulus of elasticity from static bending test. Bago provenance has the highest basic specific gravity and Kanbalu provenance has the lowest. The basic specific gravity of all provenances is lower than that of natural teak. Thabeikkyin provenance has the highest tangential shrinkage/swelling value and Phyu provenance has the lowest. Tangential shrinkage of Nattalin provenance is the same as that of natural teak. The dimensional stability of all provenances is greater than that of natural teak. Kanbalu provenance has the highest water absorption and Bago provenance the lowest. Bago provenance possesses the highest modulus of elasticity and maximum crushing strength but Nattalin provenance possesses the lowest. Nattalin provenance possesses the highest modulus of rupture and Phyu provenance possesses the lowest. The strength properties of all provenances are lower than those of natural teak. According to the results of physical and mechanical properties, all tested provenances studied in this research are not suitable for uses in heavy constructions, requiring higher strengths. Almost all provenances, especially Paukkaung, Oktwin, Taungoo, Phyu and Thabeikkyin provenances can be used for making quality products.

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