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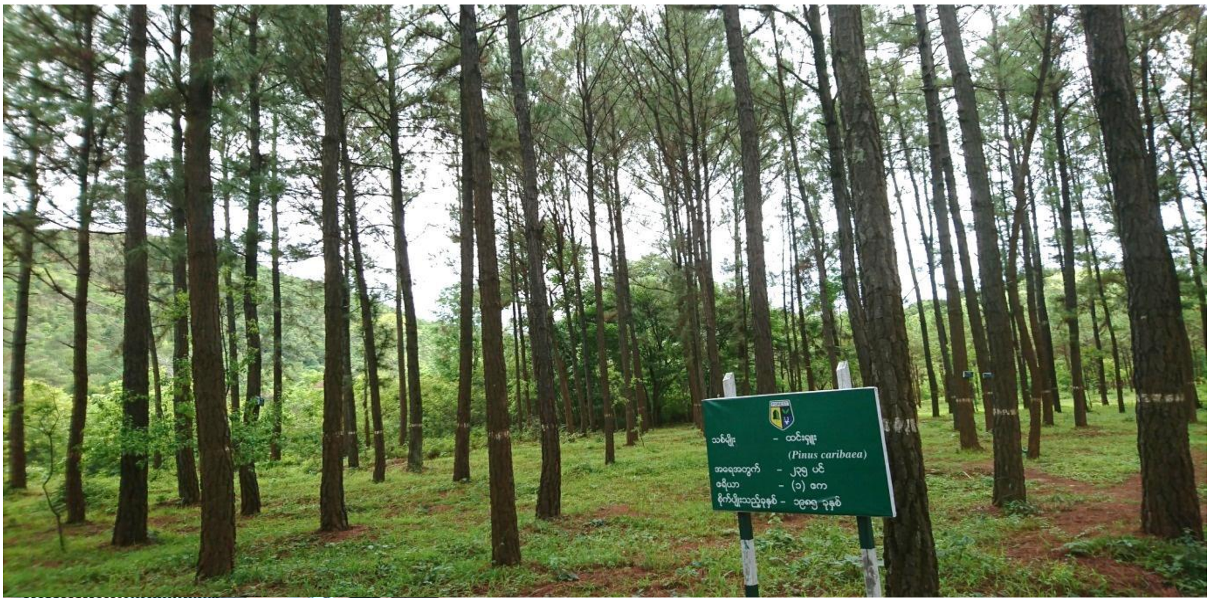
Study on wood properties of four exotic tropical pine species from Taung Lay Lone Reserved Forest, Southern Shan State



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Abstract

In this research, a single tree per species of four exotic tropical pine species as *Pinus caribaea* , *Pinus kesiya*, *Pinus maximinoi* and *Pinus oocarpa* were collected from pine plantation of Taung lay lone reserved forest in Taung-gyi Township, Southern Shan State. The tests were carried out in accordance with American Society for Testing Material- ASTM D143-52(2007) and BS 373(1957). *Pinus caribaea* is a moderately heavy wood species with a basic specific gravity of 0.431 and its shrinkage value is normal condition. But its dimensional stability value is somewhat high. However, it would be suitable timber for making indoor furniture. *Pinus kesiya* is a moderately heavy wood species with a basic specific gravity of 0.415. The mean shrinkage value of *Pinus kesiya* is optimum condition and dimensional stability is less than 2. Thus, it is suitable for light construction or indoor furniture making as cupboard and settee. Similarly, basic specific gravity of *Pinus maximinoi* and *Pinus oocarpa* is 0.463 and 0.418. So those species are moderately heavy wood species. And also shrinkage value is optimum condition and dimensional stability value is less than 2. Therefor its might be suitable for making high quality wood products, light construction and boat building, pole and post in after making the proper preservatives.

Key words: Four exotic tropical pine species (*Pinus caribaea*, *Pinus kesiya*, *Pinus maximinoi*, *Pinus oocarpa*), physical and mechanical properties.

သစ်တောသုတေသနစခန်း တောင်လေးလုံးကြိုးဝိုင်းမှ နိုင်ငံခြားအပူပိုင်း ထင်းရှူးသစ်(၄)မျိုး၏ သစ်ဂုဏ်သတ္တိများအားလေ့လာခြင်း

ဝင်းဦးနိုင်၊ လက်ထောက်သုတေသနအရာရှိ
ဒေါက်တာချိုချိုမြင့်၊ လက်ထောက်သုတေသနအရာရှိ
ဒေါ်ချောရူပါစိုး၊ သုတေသနလက်ထောက်-၂

စာတမ်းအကျဉ်း

ဤသုတေသနစာတမ်းတွင် နိုင်ငံခြားအပူပိုင်း ထင်းရှူးသစ်(၄)မျိုးဖြစ်သည့် *Pinus caribaea*, *Pinus kesiya*, *Pinus maximinoi* နှင့် *Pinus oocarpa* သစ်တစ်ပင်စီကို ရှမ်းပြည်နယ်တောင်ပိုင်း၊ တောင်ကြီးမြို့နယ်၊ တောင်လေးလုံးကြိုးဝိုင်းအတွင်း သစ်တောသုတေသနဌာနမှ စိုက်ပျိုးထားသော ထင်းရှူးစိုက်ခင်းမှ ရယူစုဆောင်းခဲ့ပါသည်။ စမ်း***သပ်မှုများအတွက်*** ASTM D143-52(2007) နှင့် BS-373(1957)တို့ကို စံချိန်စံညွှန်း သတ်မှတ်ချက်များနှင့်အညီ ဆောင်ရွက်ခဲ့ပါသည်။ *Pinus caribaea* သည် အတော်အသင့်လေးသော သစ်မျိုးစာရင်းတွင်ပါဝင်ပါသည်။ ကျုံ့မှုတန်ဖိုးမှာ ပုံမှန်အခြေနေတွင်သာရှိသော်လည်း ပုံသဏ္ဍာန်တည်မြဲမှုတန်ဖိုးတွင် အတော်အသင့်များနေပါသည်။ သို့သော်လည်း အိမ်တွင်းပရိဘောဂများ ပြုလုပ်ရန် သင့်တော်ပါသည်။ *Pinus kesiya* သည်လည်း အတော်အသင့်လေးသော သစ်မျိုးစာရင်းတွင်ပါဝင်ပြီး ကျုံ့မှုတန်ဖိုးမှာလည်း သင့်တော်သည့် အခြေအနေတွင်သာ ရှိသည့်အပြင် ပုံသဏ္ဍာန်တည်မြဲမှုတွင်လည်း ၂ ထက်နည်းသည့် အတွက် အလယ်အလတ် တည်ဆောက်ရေးလုပ်ငန်းများတွင် (သို့မဟုတ်) ဘီဒို၊ ဆက်တီကဲ့သို့သော အိမ်တွင်းပရိဘောဂများပြုလုပ်ရန် သင့်တော်ပါသည်။ အလားတူပင် *Pinus maximinoi* နှင့် *Pinus oocarpa* တို့သည်လည်း အတော်အသင့်လေးသော သစ်မျိုးများစာရင်းတွင်ပါဝင်ပြီး ကျုံ့မှုတန်ဖိုးများမှာလည်း သင့်တော်သည့် အခြေအနေတွင် သာရှိသည့်အပြင် ပုံသဏ္ဍာန်တည်မြဲမှုတွင်လည်း ၂ ထက်နည်းသည့်အတွက် အဆင့်မြင့် ပရိဘောဂများပြုလုပ်နိုင်ပြီး အလယ်အလတ် တည်ဆောက်ရေးလုပ်ငန်းများတွင် အသုံးပြုခြင်းနှင့် ကြာရှည်ခံနိုင်ရန် စနစ်တကျပြုပြင်ပြီး မော်တော် တည်ဆောက်ခြင်းနှင့် မျော၊ တိုင်များအဖြစ်လည်း အသုံးပြုနိုင်ပါသည်။

Study on wood properties of four exotic tropical pine species from Taung Lay Lone Reserved Forest, Southern Shan State

1. Introduction

The genus pines is one of the most widely distributed genera of trees in the Northern Hemisphere. In the North Temperate Zone it is rivaled only by *Quercus*, which has more species and may occupy a greater area. The pines extend from the polar region to the tropics, crossing the Equator at one point. Within this enormous range, they dominate the natural vegetation in many regions. The genus includes some of the most valuable timber trees in the world, and is readily distinguished from other plant (William B. Critchfield and Elbert L. Little, JR. 1966).

In Myanmar, Shan State is the largest state and one of the natural pine regions. But due to over cutting, forest fires and grazing, some forests of these hill regions became deteriorated and some area became denudated, resulting in erosion and degradation of soil. Thus in these region erosion control and soil conservation were urgently needed. To curb those adverse effects, plantation establishment was necessary. Due to experiences gained from plantation establishment, pine plantation establishment is found to be more suitable for this region. Pine plantations have been established on a large scale in Shan State since 1980, using indigenous species *Pinus kesiya*. Due to the slow growth and poor form of the indigenous species, tropical pines from Central America have been introduced and planted extensively in the tropical and sub-tropical countries (Baconand Hawkins, 1980; Hawkinsetal., 1978; Lamb, 1973; Whitmore and Liezel, 1980) with great success due to their good growth and versatility of timber and the Forest Research Institute has initiated trials on exotic in the Shan State in 1981. Among in those species, the following four exotic tropical pine species were also planted in the Taung Lay Lone Research Station in 1986(C.C.Sein 2015).

Species	**Provenance**
Pinus caribaea Morelet., Rev. Hort.	Puerto cabezas, Nicaragua
Pinus kesiya Royle ex Gordon, Gard. Mag. L.	Bodana population, Madagascar
Pinus maximinoi H.EMoore	Dantali, Nicaragua
Pinus oocarpa Schiede ex Schltdl.	Fince la Lagunilla,Guatemala

At present, most of the pine trees were felled for housing and making furniture in those areas. And also some of the peoples fired pine trees to extract oils. Therefore, mature pine forests decreases year by year.

However, the wood properties of those species have never been investigated before. Thus, with the intention of exploring a better and efficient use of those timber species, physical and mechanical properties were investigated as a first step. Later on if situations are favorable its drying behavior, natural durability, anatomy characteristics and other properties would be tested by the respective researchers of the Forest Research Institute.

Therefore, keeping the assumption in mind that the information on the properties will promote the utilization as a value added product of those species, their physical and

mechanical properties were tested.
The objectives of this study are:

(1) To investigate the physical and mechanical properties of four exotic tropical pines species.
(2) To compare the investigated properties of four exotic tropical pine species from Myanmar with those of some other countries.
(3) To suggest the suitable utilization of four exotic tropical pines species based on physical and mechanical properties results.

2. Literature Review

General Description of four exotic tropical pine species

Pinus caribaea

Pinus caribaea has been established in plantation in many parts of the tropics and sub-tropics, very often in site condition which result in a much faster early rate of growth, and sustained fast growth over a longer period, than in the natural range. *Pinus caribaea* grows well where temperatures range from 20 to 27 °C and annual precipitation is between 1000 and 1800 mm. Some trees grow where precipitation is 600 to 3900 mm. In its native region the tree grows from sea level to 850 m; it is occasionally found at 1000 m.

Trees therefore commonly have large central zones of light coloured low density wood, sometimes with an abrupt change after 5 to 6 years to an annual growth pattern with a much greater proportion of latewood and consequently higher density. The average weight of Caribbean pine is about 988 kg/ m^3 at 50 percent moisture content and about 700 to 800 kg/ m^3 at 12 percent moisture content. Average shrinkage from green to oven-dry condition is reported to be about 6.0 percent in the tangential direction and about 3.0 percent radially. Strength properties are high (FPRL 1957). The timber is used for boat building, for making vats for heavy construction and for interior joinery. It should be given appropriate preservative treatment if used for constructional work in exposed situations (FPRL 1959). The heart wood of *P. caribaea* is appropriate for floors and all types of construction. Treated with a preservative, the wood is used in mines, pilings, and railroad ties. Primarily used in construction and carpentry, the wood is also dried and turned (Centro Agronómico Tropical de Investigation Enseñza 1994, SEFORVEN 1993). In Villanueva, Casanare, Colombia, wood obtained by pre-commercial thinning at 8 to 10 years is used in tongue and groove boards and cabinetmaking (portable crates, doors, windows, desks, and bookcases).

Pinus kesiya

Pinus kesiya Royle ex Gordon is a softwood tree species of the family Pinaceae. It is one of the most valuable tree timber species in the tropics. Its world-wide demand is attributed to its high quality timber on account of the durability of the wood it produces. *Pinus kesiya* is native to the Himalaya region (Asian): Burma, India, China, Laos, Philippines, Thailand, Tibet, and Vietnam and it grow well at altitudes from 300 to 2700 m above the sea level. It has been successfully established as exotic in many countries of the world including Malawi, where it is raised as one of the fastest timber species. The tree grows to a height about 45 m with a straight, cylindrical trunk. It has a thick, reticulate and deeply fissured bark and purines branchless with a waxy bloom. It is vital to record the wood parameters prior to large scale expansion of plantations outside its natural range. The information on wood parameters can facilitate tree growth and wood quality in forest management and wood utilization. Wood quality assessment involves the consideration of wood density and mechanical properties. Certain wood properties are reported to be good indicators of timber properties and uses (**Missanjo and Matsumura** 2016).

The sapwood of *Pinus kesiya* is whitish to pale yellow and about 5 cm wide or more in plantation material; heart wood forms after about 15 year or considerably later in the native habitat (Weissmann et al., 1971). The heartwood is orange to red-brown. The wood turns darker on exposure. Growth rings (1-6 per cm in old growth; towards the lower end of this range in plantation) are distinct, with a rather gradual early wood –latewood transition (Savory, 1962; Greguss, 1955). Strength properties of *P. kesiya* are found to be suitable for use as light and heavy structural timber, ship and boat building, flooring, furniture, cabinet work, interior trim, joinery, turnery, pencils, plywood (both veneer and core stock), agricultural implements, poles and pilings, boxes and crates, pulpwood, hardwood and particle board (J.G WORRALL and J. BURLEY 1980).

Pinus maximinoi

Pinus maximinoi is an evergreen tree with an open, pyramidal crow becoming more rounded with age; it usually grows 20 - 35 meters tall, occasionally reaching 50 meters. The straight, cylindrical bole can be un-branched for around half of the tree's height and 70 - 90cm in diameter, occasionally to 100cm.

Pinus maximinoi does not appear to tolerate freezing temperatures (Dvorak and Donahue 1988). The wood of *P. maximinoi* is soft and light; the sapwood is pale yellowish white, and the heartwood is slightly darker (Perry 1991). Specific gravity density in trials in Colombia varied from 0.32 to 0.51 and in South Africa from 0.49 to 0.50 (Wright and Baylis 1993, Wright and Osorio 1993, Wright and Wessels 1992). Its potential uses include paper, firewood, resin extracts, and hewn timbers for roof supports and doorways (Eguiluz-Piedra 1978, Perry 1991, Wright and Wessels 1992).

Pinus oocarpa

Pinus oocarpa (synonyms: *P. oocarpoides*; *P. skinnerii*) as a potentially useful afforestation species for tropical regions poor in native conifers, and the wood is suitable for carpentry, construction, packing cases, posts, railway sleepers and pit props, but it is somewhat brittle for match splints. Its high resin content makes it useful for applications where resistance to weathering is required. The tree can be readily tapped for a good quality resin. Mean fiber length is 5.7 mm, and the dry wood contains 51.2% a-cellulose and 27.2% lignin. *P.oocarpa* is comparable to the southern pines of the USA in terms of the conditions required for mechanical and sulphate pulp production. Wrapping paper produced from the unbleached sulphate pulp has good tearing resistance and moderately good resistance to bursting and rupture. The mechanical pulp, with and admixture of chemical pulp, is suitable for newsprint production. Adequately treated bleached sulphate pulp, can be used for making writing paper (CAB 1982).

In wood utilization, basic information on various aspects of wood is inevitably important for efficient utilization of log (Salang et. al., 1996). Shrinkage and swellings can result in warping, checking, splitting, and loosening tool handles, gaps in strip flooring, or performance problems that can detract from the usefulness of the wood products (USDA, 1999). Therefore, these phenomena must be understood and considered when they can affect a product in which wood is used. Density and specific gravity are the indicative of mechanical properties of the same wood. They can be assessed with simple equipment in a short time.

Strength properties or mechanical properties of wood are qualities that indicate its ability to resist applied external forces. They are very important criteria in determining the relative suitability of different wood species for various uses (Tamolang et. al., 1995). These properties are of great importance in construction timber in classifying strength as beams, strength as post, columns, strength as tool handles, and strength as slippers. Timber species are grouped according to these properties. Thus, it is kept in mind that at least physical and mechanical properties of a timber species should be investigated for clarifying its utility and promoting the uses of those species that have been sporadically used, and for information that may be useful at one time. Wood properties are very considerably variable between and within species.

Even pieces of the same tree show variation. Variability or variation in properties is common to all material (USDA 1999). The variation of density and moisture content should affect the quality of sawn timber, seasoning of timber, seasoning of timber, preservation processes, working properties, mechanical properties and final products quality (Salang et. al., 1996).Thus, the number of trees should be enough to cover the variability of properties between trees and the number specimens should be taken enough from each tree.

3. Materials and Methods

3.1. Materials

For each species, a tree sample was selected from pine plantation of Taung Lay Lone reserved forest in Taung-gyi Township, Southern Shan State. However, all tree sample was already felled due to attacks by bark beetles. The trees were authenticated from herbarium material and anatomy identification. The measurements of the sample logs are shown in Table- 1.

Table 1: Mid Girth and Log length of each species

Sr. No	Scientific Name	Mid Girth (cm)	Log length (m)
1.	*Pinus caribaea* Morelet., Rev. Hort.	109	5
2.	*Pinus kesiya* Royle ex Gordon, Gard. Mag. L.	104	5
3.	*Pinus maximinoi* H.EMoore	147	4
4.	*Pinus oocarpa* Schiede ex Schltdl.	74	5

3.2 Methods

Sample trees were tested for moisture content percent, specific gravity, density, shrinkage, static bending, compression parallel to grain and compression perpendicular to grain. Physical properties were investigated following American Society for Testing and Material-ASTM D143-52(2007) while strength properties were conducted in accordance with British Standard- BS 373-1957.

Figure 1: Photo showing tree sample selected from the logs

Figure 2: Photo showing sample disk of *P.kesiya*

3.2.1 Physical and Mechanical properties

Three disks, each about 80 mm thick were cut from the base of each log. They were used for preparation of specimens for testing physical properties such as radial, tangential, longitudinal and volumetric shrinkage, density and specific gravity. The rest parts of the log were used for mechanical tests.

The sizes of specimens for this research were shown in Table 2.

Table 2: Number and size of specimens for physical tests

Sr. No.	Tests	Size of specimen (mm)	No. of specimens
1	Radial shrinkage	25 x 25 x 50	15
2	Tangential shrinkage	25 x 25 x 50	15
3	Longitudinal shrinkage	20 x 20 x 100	15
4	Volumetric shrinkage, Density, Specific gravity	20 x 20 x 100	15

Table 3: Number and size of specimens for mechanical tests

Sr. No.	Tests	Size of specimen (mm)	No. of specimens
1	Static bending	20 x 20 x 300	15
2	Compression parallel to grain	25 x 25 x 80	15
3	Compression perpendicular to grain	20 x 20 x 60	15

3.2.2 Testing procedures

After preparation of specimens for testing physical properties, they were sanded and cleaned to remove loose material so that they could not affect moisture content. They were weighed and measured for determination of shrinkage and moisture while green and the data were recorded. Then they were air-dried. When the specimens had attained constant weights and measurements under air-drying, the data was recorded. They were then oven-dried at a temperature of 103±2°C. On attaining constant weights, they were measured and data recorded again. For determination of specific gravity, the volume was determined by water displacement method and measurements were read nearest to the thousandth of a millimeter (mm) and weighted to the thousandth of a gram (g). The moisture contents were determined by the oven-dry method.

For mechanical properties, green and air-dry tests were conducted according to the designations in British Standard-BS. The tests and calculated properties are:

(1) Physical properties

a) Density
b) Specific gravity
c) Radial shrinkage
d) Tangential shrinkage
e) Longitudinal shrinkage
f) Volumetric shrinkage
g) Moisture content

(2) Mechanical properties

a) Static bending
a.a) Modulus of elasticity (MOE)
a.b) Modulus of rupture (MOR)
a.c) Fiber stress at proportional limit (FS@PL)
b) Compression parallel to grain
b.a) Maximum crushing strength (MCS)
b.b) Fiber stress at proportional limit (FS@PL)
c) Compression Perpendicular to grain
c.a) Fiber stress at proportional limit (FS@PL)

4. Data analysis

In this research, minimum, maximum, standard deviation and coefficient of variation of physical and mechanical properties were calculated by using Microsoft Excel 2010.

5. Results and Discussion

5.1 Physical properties

The physical properties of ***Pinus caribaea*** are presented in Table 4.

Table 4: Physical properties of *Pinus caribaea*

Property	Minimum	Maximum	Mean	Standard deviation	CV%
Green MC%	73.6	123.8	87.8	13.4	15
Basic specific gravity	0.418	0.442	0.431	0.007	2
Specific gravity 12%	0.447	0.475	0.463	0.008	2
Basic density(Kg/m^3)	418	475	431	7	2
Density 12%(Kg/m^3)	502	533	519	9	2
Oven-dry density(Kg/m^3)	458	490	474	8	2
Shrinkage (green to air dry):					
Radial (%)	1.90	2.05	1.98	0.04	2
Tangential (%)	4.02	4.30	4.17	0.08	2
Longitudinal (%)	0.13	0.29	0.20	0.06	30
Volumetric (%)	4.2	5.8	5.4	0.39	7
Shrinkage (green to oven-dry)					
Radial (%)	3.18	3.42	3.30	0.06	2
Tangential (%)	6.69	7.17	6.95	0.13	2
Longitudinal (%)	0.22	0.49	0.34	0.10	29
Volumetric (%)	7.0	9.7	9.0	0.65	7

The mean moisture content of *Pinus caribaea* is 87.8%. The minimum and maximum moisture content are 73.6 % and 123.8%. The basic specific gravity of *Pinus caribaea* range from 0.418 to 0.442 and the mean basic specific gravity are 0.431.

The mean of wood shrinkage from green to air-dry condition are 2.0% and 4.2% for the radial and tangential shrinkage, respectively. The corresponding values from green to oven dry are 3.3% and 6.9%. The values of coefficient of variation for radial and tangential shrinkage can be high up to 15% (USDA; 1989, 1999). It is found that these values for both properties are much less than 15%.

Like other wood species, the longitudinal shrinkage of *Pinus caribaea* is very small. The mean longitudinal shrinkage from green to oven dry condition is about 0.3%. The difference between longitudinal and horizontal (radial and tangential) shrinkage is due to the alignment of wood cells (Anonymous 1992). As water is removed from the cell walls, the cells move closer together. Movement in the horizontal is greater than in the longitudinal direction.

Dimensional stability is the ratio of tangential shrinkage to radial shrinkage. It is also called the coefficient between tangential and radial shrinkage. The wood having a low ratio is best suited for use (Panshin et.al, 1980). Those timbers, which have dimensional stability lass than or equal to 3.5 and 7% are found to be suitable for making high quality wood products (Kyi, 2000). The dimensional stability of *Pinus caribaea* is 2.1 and it can be said somewhat high. But it tangential shrinkage percent is less than 7%. Thus, it would be suitable timber for high quality wood products.

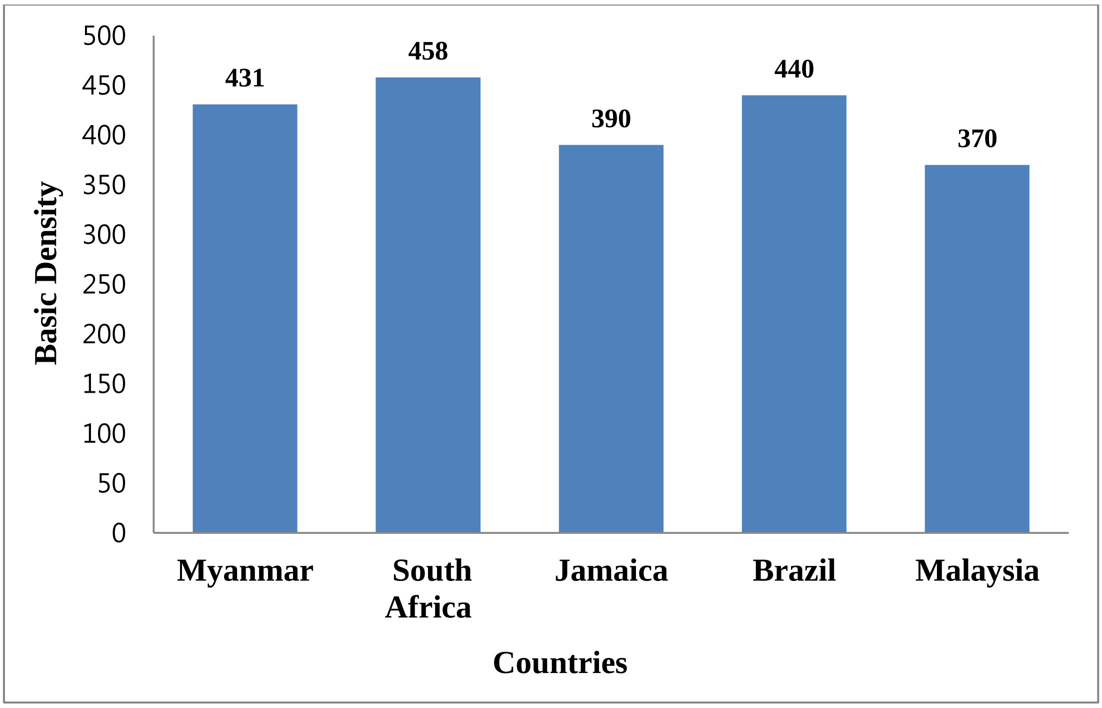

Figure 3: Comparison of Basic density of Plantation grown *Pinus caribaea* (Myanmar) and some other countries

The basic density of *Pinus caribaea* (Myanmar) is 431 kg/m^3. It is higher than that of *Pinus caribaea* (Malaysia) 370 kg/m^3 and (Jamaica) 390 kg/m^3. But it is comparable with basic density of *Pinus caribaea* (South Africa) 458 kg/m^3 and *Pinus caribaea* (Brazil) 440 kg/m^3 shown in figure 3.

5.1.2 Physical properties of *Pinus kesiya*

The physical properties of ***Pinus kesiya*** are presented in Table 5.

Table 5: Physical properties of *Pinus kesiya*

Property	Minimum	Maximum	Mean	Standard deviation	CV%
Green MC%	89.6	139.9	112.9	16.5	14
Basic specific gravity	0.399	0.437	0.415	0.01	2
Specific gravity 12%	0.427	0.471	0.445	0.01	2
Basic density(Kg/m^3)	399	437	415	10	2
Density 12%(Kg/m^3)	478	527	498	13	3
Oven-dry density(Kg/m^3)	438	487	453	14	3
Shrinkage (green to air dry):					
Radial (%)	1.4	2.3	1.8	0.25	14
Tangential (%)	2.7	3.5	3.1	0.26	8
Longitudinal (%)	0.18	0.36	0.24	0.06	25
Volumetric (%)	4.4	6.1	5.0	0.5	10

Shrinkage (green to oven-dry)					
Radial (%)	2.3	3.8	3.1	0.42	13
Tangential (%)	4.5	5.8	5.2	0.44	8
Longitudinal (%)	0.04	0.59	0.40	0.1	25
Volumetric (%)	7.3	10.2	8.3	0.8	10

The mean moisture content of *Pinus kesiya* is 112.9%. The minimum and maximum moisture content are 89.6 % and 139.9%. The basic specific gravity of *Pinus kesiya* range from 0.399 to 0.437 and the mean basic specific gravity are 0.415.

The mean of wood shrinkage from green to air-dry condition are 1.8% and 3.1% for the radial and tangential shrinkage, respectively. The corresponding values from green to oven dry are 3.1% and 5.2%. The values of coefficient of variation for radial and tangential shrinkage can be high up to 15% (USDA; 1989, 1999). It is found that these values for both properties are much less than 15%. Like other wood species, the longitudinal shrinkage of *Pinus kesiya* is very small. The mean longitudinal shrinkage from green to oven dry condition is only 0.4%.

The dimensional stability of *Pinus kesiya* is 1.7 and can be said not more than 2. And also tangential shrinkage percent is not higher than 7%. Thus, it would be suitable timber for high quality wood products.

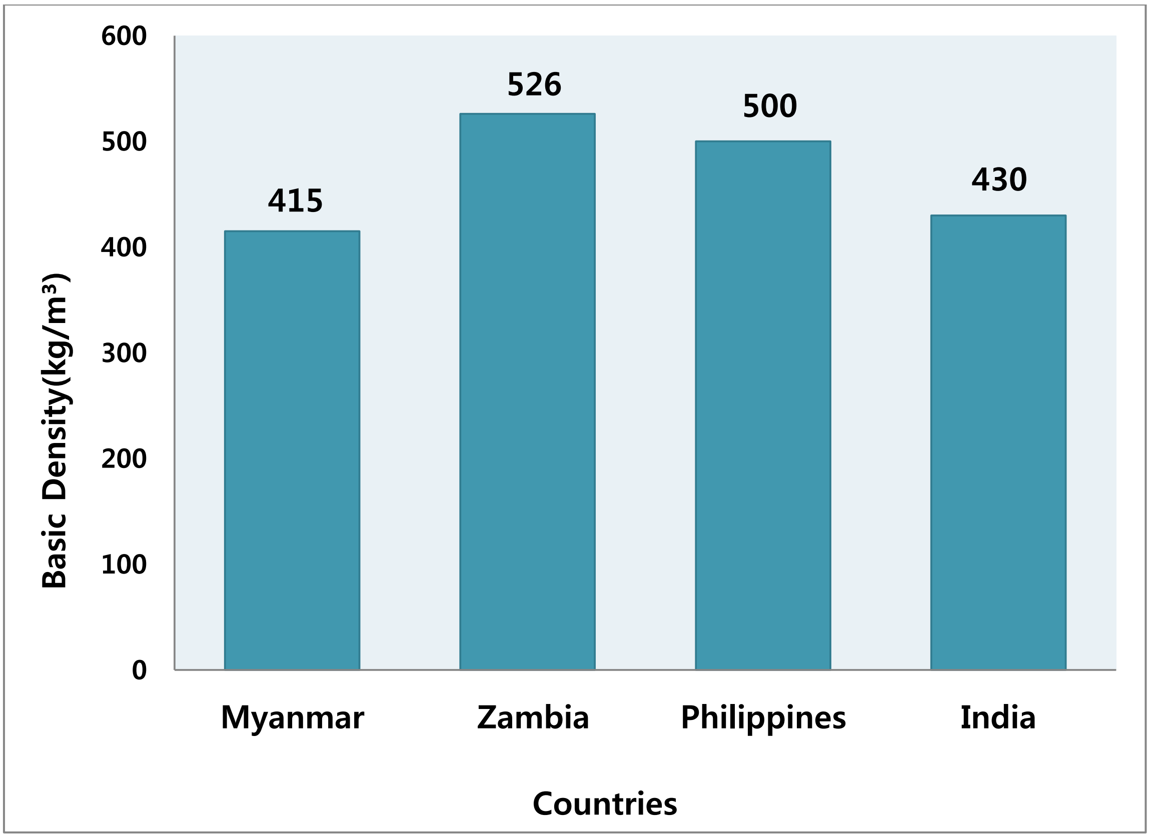

Figure 4: Comparison of Basic density of Plantation grown *Pinus kesiya*(Myanmar) and Some other countries

The basic density of *Pinus kesiya*(Myanmar) is 415 kg/m^3. It is lower than that of

Pinus kesiya (India) 430 kg/m^3, *Pinus kesiya* (Philippines) 500 kg/m^3 and *Pinus kesiya* (Zambia) 526 kg/m^3, shown in figure 4.

5.1.3 Physical properties of *Pinus maximinoi*

The physical properties of ***Pinus maximinoi*** are presented in Table 6.

Table 6: Physical properties of *Pinus maximinoi*

Property	Minimum	Maximum	Mean	Standard deviation	CV%
Green MC%	40.1	65.9	61.7	9.6	15
Basic specific gravity	0.437	0.551	0.463	0.04	9
Specific gravity 12%	0.470	0.606	0.501	0.05	10
Basic density(Kg/m^3)	437	551	463	37.5	8
Density 12%(Kg/m^3)	526	678	561	53.9	10
Oven-dry density(Kg/m^3)	489	616	519	44.2	8
Shrinkage (green to air dry):					
Radial (%)	1.58	2.44	2.06	0.29	14
Tangential (%)	2.91	4.16	3.58	0.41	11
Longitudinal (%)	0.088	0.248	0.182	0.059	32
Volumetric (%)	5.8	7.1	6.4	0.36	7
Shrinkage (green to oven-dry)					
Radial (%)	2.63	4.07	3.43	0.49	14
Tangential (%)	4.81	6.94	5.97	0.68	11
Longitudinal (%)	0.146	0.413	0.303	0.099	33
Volumetric (%)	9.7	11.8	10.7	0.60	7

The mean moisture content of *Pinus maximinoi* is 61.7%. The minimum and maximum moisture content are 40.1% and 65.9%. The basic specific gravity of *Pinus maximinoi* range from 0.437 to 0.551 and the mean basic specific gravity are 0.463.

The mean of wood shrinkage from green to air-dry condition are 2.1% and 3.6% for the radial and tangential shrinkage, respectively. The corresponding values from green to oven dry are 3.4% and 6.0%. The values of coefficient of variation for radial and tangential shrinkage can be high up to 15% (USDA; 1989, 1999). It is found that these values for both properties are much less than 15%. Like other wood species, the longitudinal shrinkage of *Pinus maximinoi* is very small. The mean longitudinal shrinkage from green to oven dry condition is only 0.3%.

The dimensional stability of *Pinus maximinoi* is 1.7 and can be said not more than 2. And tangential shrinkage percent is not also higher than 7%. Thus, it would be suitable timber for high quality wood products.

5.1.4 Physical properties of *Pinus oocarpa*

The physical properties of ***Pinus oocarpa*** are presented in Table 7.

Table 7: Physical properties of *Pinus oocarpa*

Property	Minimum	Maximum	Mean	Standard deviation	CV%
Green MC%	65.7	74.7	70.8	3.10	4
Basic specific gravity	0.397	0.436	0.418	0.11	3
Specific gravity 12%	0.423	0.468	0.448	0.013	3
Basic density(Kg/m^3)	397	436	418	11.6	3
Density 12%(Kg/m^3)	476	523	501	13.9	3
Oven-dry density(Kg/m^3)	432	471	458	13.3	3
Shrinkage (green to air dry) :					
Radial (%)	1.67	2.09	1.87	0.16	8
Tangential (%)	2.9	3.9	3.3	0.27	8
Longitudinal (%)	0.029	0.280	0.109	0.07	64
Volumetric (%)	4.5	6.4	5.2	0.74	14
Shrinkage (green to oven-dry)					
Radial (%)	2.7	3.4	3.1	0.268	9
Tangential (%)	4.8	6.6	5.6	0.45	8
Longitudinal (%)	0.04	0.46	0.18	0.117	64
Volumetric (%)	7.5	10.7	8.7	1.23	14

The mean moisture content of *Pinus oocarpa* is 70.8%. The minimum and maximum moisture content are 65.7% and 74.7%. The basic specific gravity of *Pinus oocarpa* range from 0.423 to 0.468 and the mean basic specific gravity are 0.418.

The mean of wood shrinkage from green to air-dry condition are 1.9% and 3.4% for the radial and tangential shrinkage, respectively. The corresponding values from green to oven dry are 3.1% and 5.6%. The values of coefficient of variation for radial and tangential shrinkage can be high up to 15% (USDA; 1989, 1999). It is found that these values for both properties are much less than 15%. Like other wood species, the longitudinal shrinkage of *Pinus oocarpa* is very small. The mean longitudinal shrinkage from green to oven dry condition is about 0.2%.

The dimensional stability of *Pinus oocarpa* is 1.8 and can be said not more than 2. And also tangential shrinkage percent is not higher than 7%. Thus, it would be suitable timber for high quality wood products.

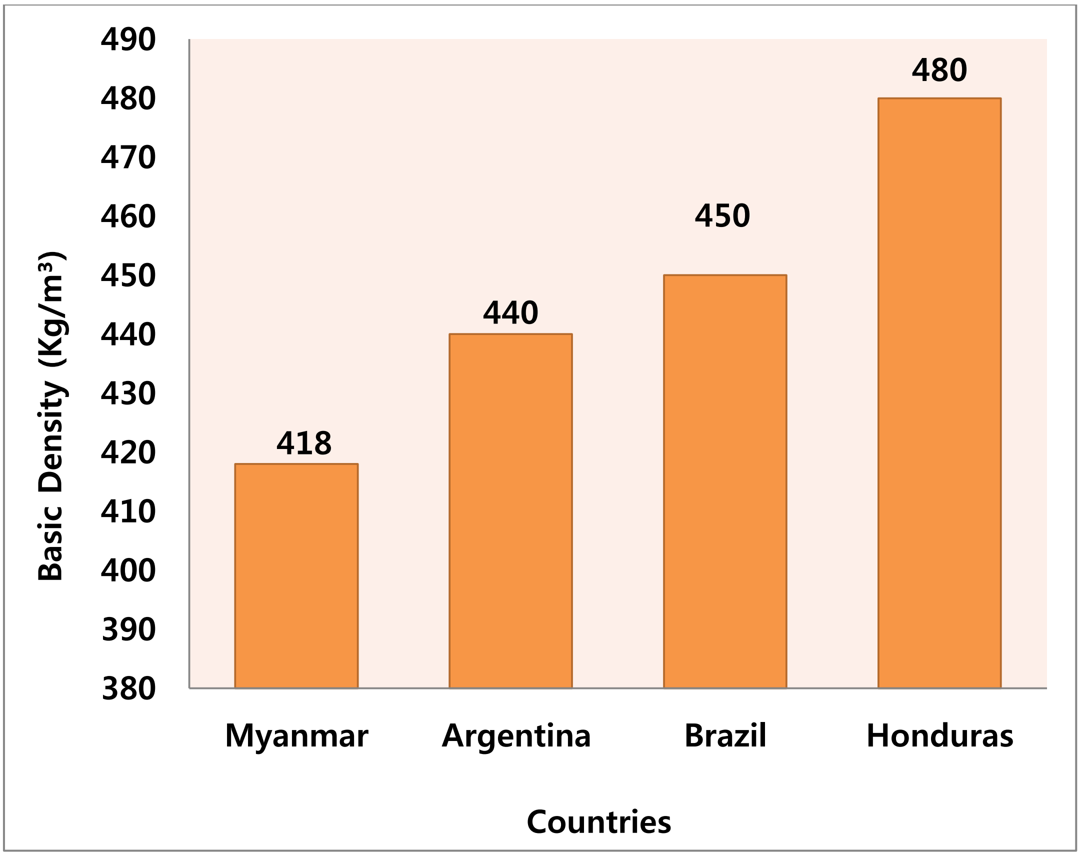

Figure 5: Comparison of Basic density of Plantation grown *Pinus ocarpa*(Myanmar) and some other countries

The basic density of *Pinus oocarpa*(Myanmar) is 418 kg/m^3. It is lower than that of *Pinus oocarpa*(Argentina) 440 kg/m^3, *Pinus oocarpa* of (Brazil) 450 kg/m^3 and Zambia(480 kg/m^3) shown in figure 5.

Table 8: Comparison of Basic specific gravity of four exotic tropical pine species planted in Myanmar

Sr: No.	Scientific name	B.specific gravity	Radial shrinkage (%)	Tangential shrinkage (%)	Dimensional stability
1.	*Pinus caribeae*	**0.431**	**3.30**	**6.95**	**2.1**
2.	*Pinus kesiya*	**0.415**	**3.10**	**5.20**	**1.7**
3.	*Pinus maximinoi*	**0.463**	**3.43**	**5.97**	**1.7**
4.	*Pinus oocarpa*	**0.418**	**3.12**	**5.60**	**1.8**

It is the ratio of tangential shrinkage to radial shrinkage. It is also call the coefficient between tangential and radial shrinkage. The wood having a low ratio is best suited for use (Panshin et.al, 1980). 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% are found to be suitable for making high quality wood products (Kyi, 2000). In this research, the dimensional stability of *Pinus kesiya, P.maximinoi and P.oocarpa* are less than 2. But *Pinus caribeae* is somewhat higher than 2.

5.2 Mechanical properties

5.2.1 Mechanical properties of *Pinus caribaea* are presented in Table 9.

Table (9) Mechanical Properties of *Pinus caribaea*

Property	Seasoning	Minimum	Maximum	Mean	Standard deviation	CV%
Static Bending FS@PL(N/mm^2)	Green	17.5	24.8	19.3	2.3	12
	Air-dry	34.2	46.9	40.5	4.1	10
MOR(N/mm^2)	Green	27.0	35.1	30.9	4.1	13
	Air-dry	57.5	77.1	**67.7**	5.4	8
MOE(N/mm^2)	Green	2900	4248	3511.4	401.4	11
	Air-dry	5420.9	8930.3	**7086.4**	1288.8	18
Compression Parallel to grain FS@PL(N/mm^2)	Green	2.5	8.9	4.4	2.2	50
	Air-dry	20.4	26.9	23.6	2.6	11
MCS(N/mm^2)	Green	3.1	10.9	5.4	2.7	50
	Air-dry	26.5	34.1	**29.6**	2.6	9
Compression Perpendicular to grain FS@PL(N/mm^2)	Green	1.6	3.8	2.5	0.9	36
	Air-dry	6.0	14.4	**8.1**	2.5	31

MOR= Modulus of Rupture; MOE= Modulus of Elasticity:
MCS= Maximum Crushing Strength; FS@PL= Fiber Stress at Proportional Limit

5.2.2 Mechanical properties of *Pinus kesiya* are presented in Table 10.

Table (10) Mechanical Properties of *Pinus kesiya*

Property	Seasoning	Minimum	Maximum	Mean	Standard deviation	CV%
Static Bending FS@PL(N/mm^2)	Green	12.7	22.6	17.8	3.2	18
	Air-dry	23.9	42.1	32.5	5.4	17
MOR(N/mm^2)	Green	21.4	34.4	27.2	5.0	18
	Air-dry	36.6	62.5	**45.1**	7.0	15
MOE(N/mm^2)	Green	2930	5311	4366	755	17
	Air-dry	5184	7195	**6438**	989	15
Compression Parallel to grain FS@PL(N/mm^2)	Green	2.0	6.9	4.7	1.5	32
	Air-dry	11.8	23.4	18.8	3.3	17
MCS(N/mm^2)	Green	2.0	7.2	5.4	1.8	33
	Air-dry	13.7	28.4	**21.1**	4.2	20

Compression Perpendicular to grain FS@PL(N/mm^2)	Green	1.9	3.2	2.6	0.5	19
	Air-dry	4.6	8.9	**6.8**	1.4	20

5.2.3 Mechanical properties of *Pinus maximinoi* are presented in Table 11.

Table (11) Mechanical Properties of *Pinus maximinoi*

Property	Seasoning	Minimum	Maximum	Mean	Standard deviation	CV%
Static Bending FS@PL(N/mm^2)	Green	19.9	26.6	22.7	2.1	9
	Air-dry	43.4	59.2	53.0	4.4	8
MOR(N/mm^2)	Green	30.0	43.1	34.8	4.1	12
	Air-dry	71.1	88.6	**80.6**	4.7	6
MOE(N/mm^2)	Green	5816	8907	7397	1030	14
	Air-dry	8521	12329	**10513**	1169	11
Compression Parallel to grain FS@PL(N/mm^2)	Green	10.3	16.7	12.6	2.1	17
	Air-dry	16.8	32.6	26.0	4.8	18
MCS(N/mm^2)	Green	10.3	17.4	13.7	2.2	16
	Air-dry	20.4	38.6	**29.3**	5.9	20
Compression Perpendicular to grain FS@PL(N/mm^2)	Green	1.7	4.5	2.6	1.1	42
	Air-dry	8.6	11.7	**10.0**	1.1	11

5.2.4 Mechanical properties of *Pinus oocarpa* are presented in Table 12.

Table (12) Mechanical Properties of *Pinus oocarpa*

Property	Seasoning	Minimum	Maximum	Mean	Standard deviation	CV%
Static Bending FS@PL(N/mm^2)	Green	16.9	25.1	21.7	2.4	11
	Air-dry	31.2	43.5	37.7	4.0	11
MOR(N/mm^2)	Green	25.3	40.7	35.0	5.0	14
	Air-dry	48.7	70.8	**59.9**	7.4	12
MOE(N/mm^2)	Green	4474	6920	5289	659	12
	Air-dry	5086	8070	6585	993	15
Compression Parallel to grain	Green	4.1	11.0	8.2	2.2	27

FS@PL(N/mm^2)	Air-dry	14.0	23.9	20.6	3.4	16
MCS(N/mm^2)	Green	5.1	14.3	10.0	2.8	28
	Air-dry	17.1	27.5	24.0	3.4	14
Compression Perpendicular to grain FS@PL(N/mm^2)	Green	1.4	5.2	3.0	1.5	50
	Air-dry	4.8	9.6	6.8	1.3	19

5.2.5 Comparison of Mechanical Properties of Tested species

Table (13)

Species Name	Properties	Seasoning	Mean
Pinus caribaea	**Static Bending**		
	MOR(N/mm^2)	Air-dry	**68**
	MOE(N/mm^2)	Air-dry	**7086**
	Compression Parallel to grain		
	MCS	Air-dry	**30**
	Compression Perpendicular to grain		
	FS@PL(N/mm^2)	Air-dry	**8**
Pinus kesiya	**Static Bending**		
	MOR(N/mm^2)	Air-dry	**45**
	MOE(N/mm^2)	Air-dry	**6438**
	Compression Parallel to grain		
	MCS	Air-dry	**21**
	Compression Perpendicular to grain		
	FS@PL(N/mm^2)	Air-dry	**7**
Pinus maximinoi	**Static Bending**		
	MOR(N/mm^2)	Air-dry	**81**
	MOE(N/mm^2)	Air-dry	**10513**
	Compression Parallel to grain		
	MCS	Air-dry	**29**
	Compression Perpendicular to grain		**10**
	FS@PL(N/mm^2)	Air-dry	
Pinus oocarpa	**Static Bending**		
	MOR(N/mm^2)	Air-dry	**60**
	MOE(N/mm^2)	Air-dry	**6585**

	Compression Parallel to grain		
	MCS	Air-dry	**24**
	Compression Perpendicular to grain		
	FS@PL(N/mm^2)	Air-dry	**7**

According to the table 13, static bending test (MOR, MOE) of P*inus maximinoi* is higher than those of *Pinus caribaea*, *Pinus kesiya* and *Pinus oocarpa*. And also compression parallel to grain test (MCS) is somewhat higher than those of *Pinus kesiya* and *Pinus oocarpa*. But its value is somewhat lower than that of *Pinus caribaea*. Similarly compression perpendicular to grain test (FS@PL) value is somewhat higher than those of *Pinus caribaea*, *Pinus kesiya* and *Pinus oocarpa*.

6. Conclusion

Specific gravity proved to be a good predictor for many other properties. So, it is were concluded in this research based on physical properties.

Pinus caribaea is a moderately heavy wood species with a basic specific gravity of 0.431, which is nearly similar to that of *Pinus caribaea* from Brazil. Its shrinkage value is normal condition. But its dimensional stability value is somewhat high. However, it would be suitable timber for making indoor furniture, because it tangential shrinkage value is less than 7%.

Pinus kesiya is a moderately heavy wood species with a basic specific gravity of 0.415, which is lower than those of plantation grown *Pinus kesiya* from India, Philippines and Zambia. The mean shrinkage value of *Pinus kesiya* is optimum condition and dimensional stability is less than 2. Thus, it is suitable for light construction or indoor furniture making as cupboard and settee.

Basic specific gravity of *Pinus maximinoi* is 0.463. So, it is a moderately heavy wood species. Its tangential shrinkage value is not more than 7% and dimensional stability value is less than 2. Therefore, it might be suitable for making high quality wood products and light construction.

Basic specific gravity of *Pinus oocarpa* is 0.418. So, it is a moderately heavy wood species. Its tangential shrinkage value is not more than 7% and dimensional stability is less than 2.Therefore, it might be suitable for use as light construction, pole and post in after making the proper preservatives.

As are overall conclusion based on the obtained results the wood of four exotic tropical pine species studied could be considered as a medium density and good structural and general purpose wood with somewhat better strength properties compared with those from other countries.

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