Density and Seasoning Characteristics of *Pinus caribaea* Lumber Grown at Suba Forest, Oromia, Ethiopia

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Abstract

Determination of the seasoning characteristics, physical and mechanical properties of lumber species is helpful in identifying the main factors affecting the quality, suitability and overall performance of wood and wood-based products. The *Pinus caribaea* has been considered as industrial lumber species and there is a little study conducted in identifying the physical characteristics which on turn affects the quality of product derived from the lumber. Therefore, this study aimed at evaluating the density and seasoning characteristics of *P. caribaea* lumber. Sample trees were harvested from Suba Forest Oromia, Ethiopia. The experiments were carried out using air and kiln seasoning methods. To measure the initial moisture content, seasoning rate, shrinkage, wood density, and seasoning defects, six replicates of samples from each tree portions were prepared when green and promptly weighed. Analysis of variance (ANOVA) has been employed in interpreting the experimental results. The obtained results have shown that the mean initial moisture content for air stacks was 78.2% while for the kiln seasoning stacks 82.9%. Seasoning time for sawn boards of 3 cm thick to reach 17% moisture continent (MC) required 61 days, while for kiln seasoning took 4.3 days to reach 14.62% MC. This showed that kiln seasoning was about 14 times faster than air seasoning. In air seasoning the MC (%) of the lumber from 78.2% to 16.9%; and, the obtained mean values of shrinkages were tangential (3.6%), radial (1.9%) and volumetric (5.4%). The initial moisture content (IMC) and green density (GD) of the lumber were significant difference along the tree height at a 95% probability level. The seasoning rate % and final MC (%) along the tree height were significant difference at 95% probability level, while the seasoning rate % and final MC were significant difference between seasoning methods at 99% probability level. Seasoning defects such as cup, bow, twist, and crook were observed on kiln seasoned. In addition, end checks and splits were observed on air seasoned boards. Therefore, the experimental factors should be monitored and optimized properly to obtain the lumber with good quality and utilize it for different purposes, including construction and industrial applications.

Keywords: Density, lumber, moisture content, seasoning, shrinkage characteristics, *Pinus caribaea*

1. Introduction

In Ethiopia, the demand for wood-based products in 2017 was measured in terms of equivalent volume of consumed round wood and it was estimated to be 114 million cubic meters (UN-FAO, 2019). The demand and supply of industrial round wood in Ethiopia were 7.4 and 3 million m^3, respectively (Ministry of Environment, Forest and Climate Change [MEFCC], 2018; United Nations - Food and Agricultural Organization [UN-FAO], 2019). This shows there is a

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wide gap between the demand and supply. The gap is being filled by imported lumber and unsustainable harvesting and utilization of natural and plantation forests (Environment, Forest and Climate Change Commission [EFCC], 2020); and this could jeopardize the natural ecosystem and biodiversity thereby inducing overexploitation of the dwindling forest resources.

Moreover, the potential lumber species have been introduced and planted continuously all over the country to fill the gap and bring about sustainable utilization of the country's plantation forests and woodlot resources (Gemechu et al., 2018). Among these tree species, *Pinus caribaea* is a well-known and substantial industrial lumber species that has been planted and adopted in Ethiopia to achieve the goal of plantation development and sustainable utilization of forest resources (Mebrate, 2006).

The *P. caribaea* (Family Pinaceae) is an evergreen, monoecious, and medium-sized tree that is 20 - 45 m in height, 60-135 cm in diameter and bole branchless of 21 m. *P. caribaea* is fast growing species with a mean annual volume increment of 10 - 40 m^3/ha and 15-25 years rotation for sawn wood, veneer, large posts and pulpwood. The wood properties of *P. caribaea* shows variations as heavy, hard, narrow ringed and resin saturated at one end of the spectrum to soft, light, wide ringed and almost lacking in latewood and resin at the other end. The tree is usually straight, cylindrical, bark surface reddish brown to pale brownish grey, inner bark very resinous, crown thin, rounded to pyramidal, slightly spreading, twigs orange brown, later turning grey-brown (Oteng-Amoako and Brink, 2008; Orwa et al., 2009).

Furthermore, *P. caribaea* is grown in 1000 -1500 m altitude above sea level (asl), in areas with a mean annual temperature of 20 - 27°C, an average annual rainfall of 650-4000 mm, and a dry season of up to 6 months. The tree is moderately tolerant to wind and can be planted near the coast. It grows on a wide variety of soils like loams or sandy loams, sometimes with high amounts of gravel and generally well drained (Oteng-Amoako and Brink, 2008; Orwa et al., 2009). According to some authors the species is native to the Caribbean area, Cuba, Honduras, Bahamas and Colombia, Guatemala, Mexico, Nicaragua and Panama. As an exotic plantation species *P. carebea* is planted fairly widely in Australia, Brazil, Canada, India, Indonesia, United States of America, Venezuela, south, east, east west and central parts of African countries including Ethiopia (Orwa et al., 2009).

The effective, efficient and sustainable utilization of the lumber species (i.e., *P. caribaea*) necessitated adequate knowledge and deep understanding of its natural variations, density and seasoning characteristics, physical and mechanical characteristics and its industrial applications (Nascimento et al., 2018). Hence, generation of appropriate technological information regarding the tree seasoning and the selection of suitable utilization method is of prime importance while enhancing the service life of the product(s). In light of this explanation, the intended study was carried out to generate technical information (i.e., density and seasoning characteristics) and selecting appropriate methods for utilization of the lumber species, *P. caribaea*, grown at Suba Forest of Oromia Forestry and Wildlife Enterprise (OFWE), Ethiopia.

2. Materials and methods

2.1 Description of the study site

Sample trees of *P. caribaea* were harvested at the age of 44 from Suba Forest of OFWE. Suba Forest is located 40 km west of Addis Ababa and lies within longitude and latitude coordinates of 38°31'– 39'E and 08°54'N–09°04'N, respectively, and the altitude ranges between 2330 and 3300 m asl. The mean annual rainfall of 1100 mm and the mean temperatures (min and max) are 15 c° and 22c°, respectively. The tree species is originated from the Bossum provenance of

Holland and currently available in Ethiopia at Belete, Hamulo and Menagesha-Suba (Mebrate Mihreiu, 2004; Mebrate Mihertu, 2006)

2.2 Trees harvesting and test samples preparation

Twelve sample trees with good morphological characteristics and free from visible defects were selected, harvested and cross-cut into a series of 5 m long logs up to top merchantable diameter of 20 cm. The selected trees have a mean height of 22 m and 30 cm diameter. Harvested logs while green (> 30% MC) were transported to Laboratory of Forest Products Innovation Center (FPIC), Addis Ababa, for the preparation and testing samples. Logs were flat sawn to 3 cm thick boards and converted to samples with appropriate dimensions for each wood characteristic (Moisture content, seasoning rate, seasoning defects, shrinkage and density) tests following the ISO standards (ISO 3129, 1975; ISO 3130, 1975; ISO 3131, 1975; Denig et al., 2000; FPL, 2010; Moya et al., 2013).

2.3 Lumber stacking for air and kiln seasoning

Sawn boards from sawmill area were transported to the air seasoning yard and kiln seasoning chamber areas (Figure 1). Boards were sorted according to their thickness, width, and types (heart, sap, tangential and radial boards). Then, lumber stacked horizontally in vertical alignments separated by well- seasoned standard stickers. Stickers were put at equal distance (75 cm across each layer of lumber) and aligned vertical board on board from bottom of the stack to the top. While stacking boards, care was taken to ensure free circulation of fresh air all around each stack and board. In addition, the control sample boards were distributed properly and positioned in the pockets of the different layers (i.e., bottom, middle and top) of each stack to represent the different zones/layers in the stack (Figure 1).

(1a)

(1b)

Figure 1: Air seasoning stack (1a) and Kiln seasoning stack (1b) at the entrance of the kiln chamber

Boards for air seasoning were stacked on firm level foundation 45 cm above the ground, under open-sided shed without direct exposure to moisture, rainfall and sunshine (Figure 1a). The boards were aligned in a north-south direction where the ends were not exposed to the direction of the wind. Boards for kiln seasoning were stacked out of the kiln on the transfer carriage having dimensions of 1.6 m width, 0.30 m height and 2.7 m length and then placed in the kiln-seasoning chamber by sliding the stack on the rail (Figure 1b). Top loading (heavy stones) weighing about 50 kg/m^2 was applied on top of the air and kiln seasoning stacks to minimize warping of the boards as seasoning progresses. The Kiln Schedule adapted from

Boone et al. (1988) having a serious of temperature and relative humidity at different corresponding MC levels was applied (Table 1)

Table 1: The employed kiln schedule

Step	Moisture Content (%)	Dry-bulb Temperature (°F)	Wet-bulb Temperature (°F)	Relative Humidity (%)	Equilibrium Moisture Content (%)
1	Above 50	60	56	82	14.2
2	50 to 40	60	54.5	75	12
3	40 to 35	60	51.5	64	9.6
4	35 to 30	60	49	55	8
5	30 to 25	65.5	51.5	49	6.8
6	25to 20	71	54.5	43	5.8
7	20 to 15	76.5	57	39	5.1
8	15 to Final	82	54.5	26	3.5

Source: Boone et al., 1988.

2.4 Lumber characteristics determination

Initial moisture content determination

Six replicates of Samples from each tree portion were prepared while green and immediately weighted to determine initial moisture content of the stack. A well-ventilated oven machine/ chamber with trays having open grids was used to allow free air circulation around the test pieces while keeping the seasoning temperature constant at 105°C. Drying and re-weighing of samples was carried out continuously at four hours interval until the difference between two successive weights of each specimen became constant (0.000 - 0.200 g) and the final weights were taken as the oven- dry weights (ISO 3130, 1975; FPL, 2010). Afterwards, the moisture content of air and kiln seasoning stacks were determined using the following formula.

$$MC\ (\%) = \left(\frac{\text{Green weight} - \text{Oven dry weight}}{\text{Oven dry weight}}\right) \times 100 \quad (1)$$

After initial MC determination, the control sample boards were weighed, analytically determined oven dry weights were calculated and the control samples placed into the stack. During air seasoning the control samples were re-weighed at a week interval until the average final moisture content of the stack reached final moisture content (about 12%), which is the equilibrium moisture content for in-and out-door purposes and standard for comparison within and between lumber species. During kiln seasoning test, samples were weighed, moisture content was calculated, psychrometers were regulated, steaming was done, and the direction of the fan changed at 8 hours interval (i.e., three times in 24 hours) to allow uniform air circulation. The process was continuous until the final MC reached. This is used to control the seasoning process and maintain the quality of seasoned lumber (FPL, 2010; Moya et al., 2013).

Rate of seasoning determination

Air and kiln seasoning rates of the species was estimated from the MC samples of the species. Seasoning rate (%/hour) = IMC-FMC (%)/Drying time (Hour) (Loulidi I. et al., 2012) where, IMC-initial moisture content and FMC- final moisture content. The Air and Kiln seasoning rates classification lumber for the lumber was done based on the adapted literatures (Longwood, 1961; Farmer, 1987).

Shrinkage characteristics determination

Twenty samples of the lumber species with the dimension of 2x2x3 cm (ISO/DIS 4469, 1975) were seasoned in the oven machine at the temperature of 105°C until a constant weight was obtained for each sample. Initial dimensions and weights of all the shrinkage samples were measured and put in the oven. Measurements of weights were continuous until the difference between the two successive weights of each specimen was constant (0.000 - 0.200 g). Then, the final weights were taken as oven dry weights and final dimensions were measured Shrinkage of each specimen at tangential, radial, longitudinal directions and volumetric were determined from green condition to 12% MC and from green to 0% MC using the formula in (Equation 2):

$$\text{Shrinkage\%} = \left(\frac{\text{Change in dimension}}{\text{Green dimension}} \text{ x } 100\right) \tag{2}$$

Finally, the rate of tangential shrinkage to radial shrinkage (coefficient of anisotropy) was calculated to know the tendency of the species to present warping, cracking and splitting during seasoning. According to Acosta et al (2008) the higher this ratio from the value of one will be the higher to present these defects during seasoning of the wood.

Density determination

The sampling procedures and measurements applied during shrinkage experiments as stated earlier were used to determine the density values of the species using mathematical formulas at different MC and sample conditions (i.e., Green, oven dry and seasoned to 12% MC). Basic density was determined based on green volume and oven dry weight (ISO/DIS 3131, 1975). The dry density values were converted to standard 12% equilibrium MC (Table 2) by applying the formulas adapted from (ISO/DIS 3131, 1975; Denig et al., 2000; Reeb and Brown, 2007; FPL, 2010; Moya et al., 2013). Density value of the species at 12% MC was classified based on the adapted standard classification from Farmer (1987).

Seasoning defects determination

Natural, initial and after seasoning defects of lumber species including knots, cup, bow, twist, end split, end and surface checks were measured and determined using digital caliper, ruler and tape meter. Seasoned boards were properly piled in the air seasoning yard, board on board, without stickers between them. Boards were handled and conditioned well without direct exposure to moisture and sunshine to avoid/minimize dimensional movement (shrinkage and swelling), seasoning defects and biodegradation attack.

2.4 Data analysis

The measurements of dimension (Length, width and thickness) and weight were helped to determine the following parameters: (i) moisture content (%) at green, current and final, (ii) density (gm/cm^3) at green and air-dry conditions, (iii) rate of seasoning (%/day), (iv) shrinkage (%) from green to 12% MC and green to 0% MC in tangential, radial and longitudinal directions and volumetric, and (v) initial and seasoning defects (observation and measurements). Analysis of variance (ANOVA) for shrinkage, density and seasoning characteristics was performed at 95% confidence interval. Significant differences among tree height were determined by Duncan's homogeneity groups. Statistical analysis was performed using the statistical Package for the Social Sciences (SPSS) 20 version.

3. Results and Discussion

3.1 Lumber appearance

The wood of *P. caribaea* showed different lumber characteristics. The lumber appearance revealed the creamy white sapwood and the dark brown heartwood (Figure 2a).

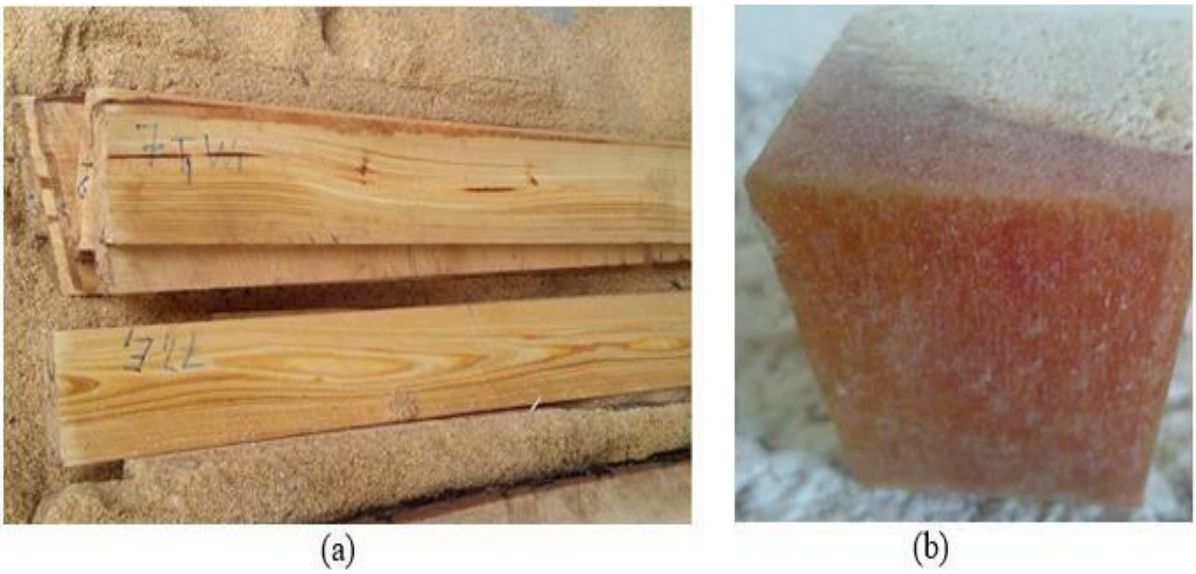

Figure 2: Appearance (a) and high resin content (b) *from P. caribaea* lumber

3.2 Moisture content

The mean initial moisture content of *P. caribaea* lumber was 78.2% for air seasoning and 82.9% for kiln seasoning; whereas, the final mean moisture content for air and kiln seasoning stacks were 16.9% and 12.4 %, respectively. During air seasoning, the mean initial MC slightly varies along the height of lumber. The bottom part of *P. caribaea* tree had 79.4% MC, middle part had 77.7% MC, while top part had 77.6% which is almost similar with the middle part (Figure 3). The trend of MC along the height of the tree varies irregularly.

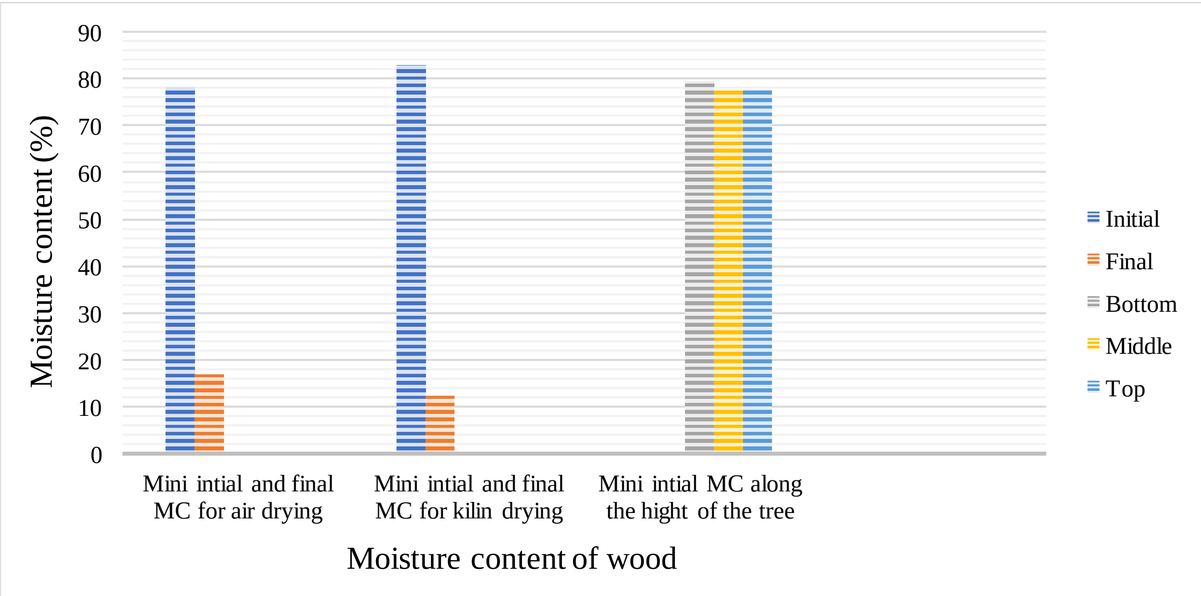

Figure 3: *Pinus caribaea* lumber initial (green) (IMC) and final seasoned MC (FMC) (%)

3.3 Shrinkage characteristic

When seasoning the *P. Caribaea* lumber from green to 12% MC, the obtained mean percentage values of shrinkage were tangential 4% (small), radial 1.9% (very small) and volumetric 5.4% (small); whereas, seasoning the lumber from green to 0% MC, the tangential, radial and volumetric shrinkage values of 6%, 3.2% and 9%, were obtained, respectively (Table 3). The shrinkage values of seasoned wood at 12% MC vary from 4.7-12.7% for tangential shrinkage and 2.1-7.9% for radial shrinkage. Tangential shrinkage is generally 1.5 to 2 times greater than radial shrinkage. The ratio of total tangential shrinkage to total radial shrinkage (T/R) was used as an index of dimensional stability. The ratio of tangential to radial shrinkage was 1.9% which was higher than 1.5 (Table 3). Ratios higher than 1.5 considered pronounced (Acosta *et al.*, 2008). This pronounced differential shrinkage is likely to cause wide splits, checks and distortions if the necessary precautions are not taken to seasoning of *P. caribaea* lumber species.

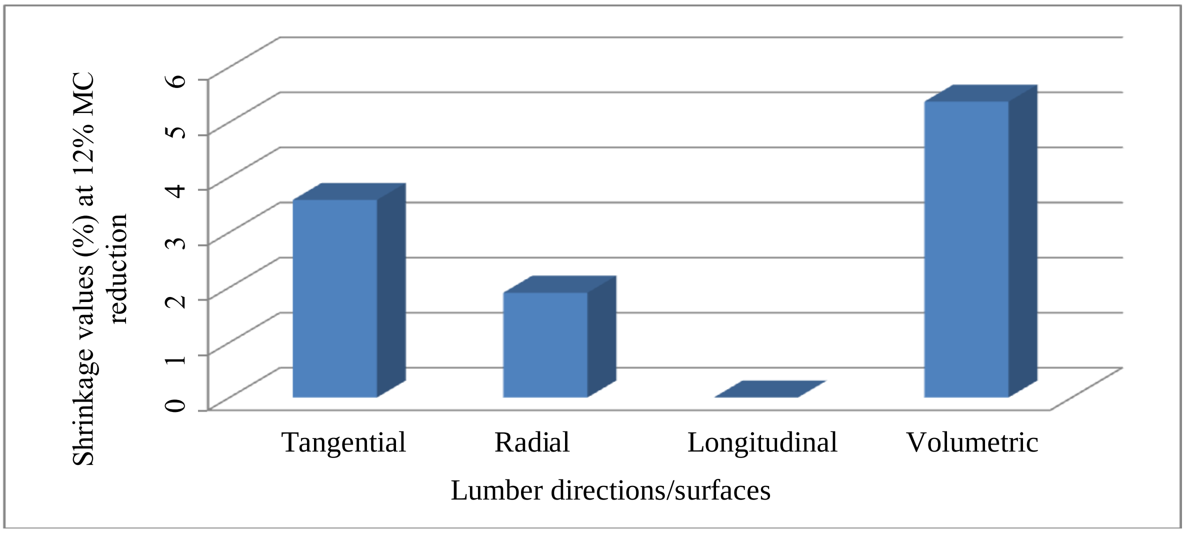

Figure 4: Shrinkage characteristics values (%) at 12% MC reduction

3.4 Density characteristics

The mean density of *P. caribaea* lumber species at green (initial), basic, oven dry conditions and when seasoned to 12% MC were 690, 383, 350 and 660 kg/m^3, respectively (Table 4). Based on the density value (660 kg/m^3) at 12% MC, the lumber species can be classified under heavy density (650-800 kg/m^3) category. According to Oteng-Amoako and Brink (2008), wood properties show large differences between sites and between trees. The wood is moderately light weight to fairly heavy, with a density of 350-820 kg/m^3 at 12% moisture content. The wood from slower-growing trees from natural stands has a higher density and lower resin content than the wood from faster-growing trees from plantations (Oteng- Amoako and Brink, 2008; Orwa et al., 2009). For the same species, similar value of density was observed in the rage of 450 – 650 kg/m^3 (Udoakpan, 2013).

3.5 Air and kiln seasoning rate of P. caribaea lumbers

The time required for air seasoning of *P. caribaea* sawn boards that have 3 cm thickness to reach to about 17% MC was 61 days, while kiln seasoning using the kiln that operates at a temperature range of 40-70ºC took 4.3 days to reach 12.4% moisture content. Kiln seasoning rate was 0.62%/day. Thus, the kiln seasoning was 14 times faster than the air seasoning. The species was classified as very rapid in air and kiln seasoning. The kiln seasoning significantly shortens the seasoning time required to season the lumber to ~ 12% MC (Getachew D et al., 2015)

Table 2: Summary of ANOVA on moisture content, densities and shrinkages of *P. caribaea* lumber

Source of Variation	DF	Mean square and statistical significances							
							Shrinkage from green to 12% MC (%)		
		IMC	GD	BD	OD	Density 12% MC	Tangential	Radial	Volumetric
Position	2	3850.18*	0.043*	0.004 ns	0.004 ns	0.006 ns	1.16 ns	0.132ns	1.925 ns

*Note: ns-not significant at $p<0.05$, *-significant at $p<0.05$. Where: - DF- degree of freedom, IMC-Initial moisture content, GD-Green density, BD-Basic density, OD- Oven dry density*

The initial moisture content (green) (IMC) and green density (GD) along height of the tree were significant ($p<0.05$) at 95% probability level, while density (basic and at 12% MC), tangential, radial and volumetric at 12% MC were non- significant (Table 2).

Table 3: Summary of ANOVA on seasoning characteristics of *P. caribaea* lumber

Source of variation	DF	Mean square and statistical significances			
		Seasoning rate %/(hour)	Final MC (%)	Initial MC (%)	Seasoning rate %/hour
Position	2	229051.56*	60.436*	37.228ns	0.006ns
Seasoning method	1	4412437.770**	122.899**	132.963ns	3.713**

*Note: ns-not significant at $p < 0.05$, *-significant at $p < 0.05$, highly significant at $p < 0.01$. Where: DF- degree of freedom, MC- moisture content*

Seasoning rate (%/hour) and final MC (%) along height of the tree and seasoning methods were significant ($p < 0.05$) at 95% probability level, while seasoning methods were significant ($p < 0.01$) at 99% probability level (Table 3). According to Oteng-Amoako and Brink (2008), the wood of *P. caribaea* exhibits good quality under air seasoning, though the end splits may occur during seasoning. Boards of 3 cm thick required about 6 weeks (1.5 month) to air dry lumber from green to 16.88% moisture content. This is similar with the study carried out in Fiji that around six weeks was required to dry 3 cm thick lumber from green (170% MC) to 20% MC) in open air (Plumptre, 1984). To dry *P. caribaea* in conventional kiln up to 12% moisture content took 3-4 days; in average the kiln seasoning rate for the species was 0.62%/hour.

3.6 Seasoning defects

During both air and kiln seasoning methods, different defects were recorded on *P. caribaea* lumber. Even if the degree varies, defects like warp (cup, bow, twist, and crook/spring) were seen on kiln-seasoned boards. In addition to the above defects, end splits were observed on air seasoned boards. During air seasoning crook/spring was the serious defect while on kiln seasoned boards twist was the more pronounced defect (Table 4). Kiln seasoning is preferred over air seasoning to produce better-quality boards at a lower cost of operation, even though some seasoning defects on seasoned boards have been observed. The dead knot which is the natural defect was the dominant type on *P. caribaea* lumber species.

Table 4: The extent of mean seasoning defects in air and kiln seasoning stacks.

Seasoning method	**Warp (mm)**				**Checks (mm)**		**Splits Dia. (mm), L. (cm)**		**Knots**		**Other defects occur**
	Cup	Bow	Twist	Crook	Surface check	End check	End split	End split	Knots Dia. (mm)	No. of knots	
Air	2	4	7	8	---	---	2	17	34	5	Wane
Klin	3	2	12	3	---	---	---	---	30	5	Wane

Proper stacking using standard and well-seasoned stickers, end sealants or plastic end cleats, top loading/ adjustable strapping are paramount for preventions or remedies of seasoning to minimize these defects.

3.7 Comparison of P. caribaea lumber with commercial lumbers grown in Ethiopia

Comparable lumber species with *P. caribaea* in terms of the rate of seasoning by kiln method (4.3 days) were *Eucalyptus viminalis, Eucalyptus saligna* and *Morus mesozygia* (4 days), *Ocotea kenyensis* (4.4 days) (Getachew Desalegn et al., 2012; Getachew Desalegn et al., 2015; Getachew Desalegn and Gemechu Kaba, 2017; Gemechu Kaba and Getachew Desalegn, 2020). Besides, for the density at 12% MC (660 kg/m^3), comparable species with *P. caribaea* were *Eucalyptus fastigata* (650 kg/m^3), *Eucalyptus obliqua* (670 kg/m^3), *Eucalyptus viminalis* (670 kg/m^3), *Morus mesozygia* (670 kg/m^3) (Getachew Desalegn et al., 2012; Getachew Desalegn et al., 2015; Getachew Desalegn and Gemechu Kaba, 2017; Gemechu Kaba and Getachew Desalegn, 2020).

4. Conclusion and Recommendations

Pinus caribaea has lumber and several non-lumber forest products and services. The species has comparable wood with many indigenous and home-grown exotic lumbers of Ethiopia in terms of density, seasoning rate and shrinkage characteristics. Different seasoning defects were observed that need care during lumber seasoning. Lumber shall be seasoned using kiln seasoning method to shorten seasoning time, better maintain wood quality and suitability for different applications. In this study, the density and seasoning characteristics of *Pinus caribaea* lumber was evaluated; and it has been observed that the moisture content (MC), seasoning time, seasoning characteristics and density of wood are amongst the main factors that can highly influence the quality, suitability and overall performance of the lumber.

The main experimental factors considered in the experimentation were percentage of moisture content at green, current and final moisture content, the seasoning rate, seasoning shrinkages (i.e., in tangential, radial and volumetric directions), density of the lumber at green and air-dry conditions, and associated seasoning defects have been observed. This implies that kiln seasoning method is more effective and hence, preferable to the air seasoning of the *P. caribaea* lumber so as to obtain lumber products with less defects, better quality and minimum operational cost. Therefore, kiln seasoning method is recommended for seasoning the lumber species in wood and forest products processing industries, and construction sectors thereby ensuring the effective, efficient and sustainable utilization of the considered *P. caribaea* tree.

For future work, the research should be conducted regarding the presence of high resin in *P. caribaea* lumber and its effect on the lumber quality. The improvement of silvicultural practice is necessitated besides expanding plantation in the country (Ethiopia).

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