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Standardization of the seasoning schedule for *Melia Dubia* Cav.

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Abstract
Melia Dubia is the most important secondary timber and the most preferred species for the plywood industries. Using the species of *Melia Dubia* with the primary objective of standardizing the seasoning schedule will help to decide the utilization of wood. Planks thicknesses of 1.5 cm, 2 cm, and 2.5 cm, seasoned in an electrically heated seasoning kiln. The initial moisture content before stacking in the kiln was 65% in *Melia Dubia*. The final moisture content to reach about 12% in kiln seasoning took six days. The density of *Melia Dubia* at green conditions was ranged from 490 kg/m^3, and oven-dried at 12% MC was 360 kg/m^3. This species is characterized by lower radial (1.37%) and tangential (2.02%) shrinkage. MOE and MOR were higher when compared to greenwood 5961.60 (N/mm^2) to seasoned woods 6198.70 (N/mm^2). The major seasoning defect observed in the planks of *Melia Dubia* was end splitting, surface cracking, and bowing.

Keywords: Seasoning, *Melia Dubia*, physical properties, mechanical properties, seasoning defects

Introduction
Melia Dubia originates from the Meliaceae family, and it is indigenous to India, South East Asia, and Australia. It is present primarily in moist deciduous, evergreen, and semi-evergreen forests. It is a fast-growing tree species, and the wood from this tree have used in plywood and packing cases industries. In living trees, the scale of moisture content (%) varies depending upon the species. Freshly felled timber contains water in the formation of moisture, generally above its fiber saturation point. Moisture content (%) of the wood needs to be reduced 12% before manufacturing the high-quality wood product. Moisture content reduction in wood depends on environmental conditions, internal and external aspects of wood. The best method of dealing with *Melia Dubia* timber is to convert the log as soon as after felling and should be stacked properly. The wood's proper seasoning is one of the essential factors for efficiently utilizing various end products and uses.

Kiln seasoning has become one of the most important reducing moisture content (%) in wood. This process has minimized the structural distortion and wood defect in the wood. Shahverdi *et al.* (2012) [15] have stated that drying of wood samples takes place by utilizing the hygroscopic nature of wood. Woodworking like machining and finishing is not possible in the high moisture content of wood until reduced to a significant level of moisture content. When the moisture content of wood reduces, its durability, strength, and elasticity can improve. Seasoning improves dimensional stability, coating, and mechanical properties and also increases resistance to biodegradation of wood. Vermaas *et al.* (1995) [18] considered that strength properties would increase when the wood has dried from the green to moisture content below the fiber saturation point (FSP). In the present study, *Melia dubia* in a kiln determined the seasoning rate and prospective physical and mechanical properties for various utilities.

Methods and Materials
The sample tree of *Melia Dubia* was selected based on their DBH greater than 35 cm were harvested, and converted into logs. The logs of *Melia Dubia* sawn into planks dimensions of 6 feet × 30 cm seasoned x 1.5 cm, 6 feet × 30 cm x 2.0 cm, and 6 feet × 30 cm x 2.5 cm and, planks have seasoned in the electrically heated kiln.

Selected kiln seasoning schedules of I and II for *Melia Dubia* based on wood density and seasoning behavior. The initial moisture content (%) of the wood is recorded, and the temperature was fixed initially at 50°C and relatively increased the temperature until the moisture content reduced ESI below 12%. The planks were stack by the horizontal stacking method. Daily moisture loss (%) was computed during the study by weighing the wood samples using the hot air oven-dry method. Before stacking the planks in the kiln, the wood's physical and mechanical properties (initial) was estimated. A universal testing machine has determined green's physical and mechanical properties (initial) and compared seasoned wood (final) and them. The seasoning defects, if any occur, were recorded at all the stages of the seasoning schedule.

Physical Properties

Moisture content

The wood was weighed and dried in the hot air oven at 105°C for 8 hours until the specimen reaches a constant value. The sample size was 2.5 cm × 2 cm × 2 cm. From the loss in weight, the MC% was calculated using the following formula.

$$\text{Moisture content }\% = \frac{\text{Green weight} - \text{oven dry weight}}{\text{Green dry weight}} \times 100$$

Eq.1

Density

Measured the dimension of the rectangular specimens to 0.01 cm accuracy with and finally, volume was estimated. The sample size was 6 cm × 2 cm × 2 cm. The density was expressed as Kg/m^3.

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

Eq. 2

Shrinkage

The rectangular specimen was measured to 0.01 cm in dimension and volume was calculated by multiplying all the specimen dimensions. The sample size was 6 cm × 2 cm × 2 cm

$$S = \frac{Vo - V1}{Vo} \times 100$$

Eq. 3

V_i is initial volume, R_i and T_i are initial radial and tangential dimensions whereas V_f, T_f and R_f are respective values at required moisture content.

Specific gravity

Specific gravity is defined as the ratio of the density of a substance's over density of water. The sample size was 2.5 cm × 2 cm × 2 cm**.** The specific gravity was calculated using the following formula

$$G_m = W_o / (V_m * D_w)$$

Eq. 4

W_o = Oven dry weight of wood; V_m = Volume at same moisture content and
D_w = Density of water

Mechanical properties

The applied force is increased very slowly in the static bending test and gradually until the specimen breaks. The sample size was 30 cm × 2 cm × 2 cm.
The compression stress at the proportional limit and compression stress at maximum load (MOE) and (MOR) were measured for this wood sample. The sample size was 8 cm × 2 cm × 2 cm. The compression stress at the proportional limit and compression stress at a compression of 2.5mm deflection was measured. MOE and MOR were measured for this wood sample. The sample size was 10 cm × 2 cm × 2 cm. MOE and MOR were calculated using the following formula as suggested by ASTM D5456-18 (2018).

Seasoning defects

The seasoning defects such as surface cracking, end splitting, bowing, twisting, and cupping were studied for assessing the seasoning schedule of *Melia Dubia* with a scoring datasheet.

Result and discussion

Seasoning Schedule for *Melia Dubia*

Seasoning of 1.5 cm, 2 cm, and 2.5 cm- thickness of *Melia Dubia* planks from an initial moisture content of about 65% to final moisture content of below 12% took six days to reach from green to seasoned wood. The temperature ranged from 45^{0}c to 70^{0}c, and relative humidity varies from 50.80% to 17.43% for fixing the seasoning schedule of *Melia Dubia* (Table 1). Kumar *et al.* (2017) [9] revealed that they used the drying schedule in 25 mm thick samples of *Tectona grandis* with an initial MC of around 24% to nearly 7.6% final MC in just three days lasting 21 hours.

Table 1: Seasoning schedule for *M. dubia with* different thicknesses

Days	Moisture Content (%)	Time (hrs)	Temperature (°C)	Relative Humidity (%)
1	65	7	45	50.80
2	50	7	50	45.28
3	45	7	55	32.10
4	35	7	60	27.66
5	25	7	65	20.57
6	12	7	70	17.43

Ali *et al*. (2013) revealed that thicknesses of wood influence the drying time of planks, and the rate of moisture loss are reduced rapidly in solar kilns. However, the differences in the seasoning rates were not as significant as in the effect of relative humidity at the early stages. It shows that *Melia dubia* has a high drying capacity in the kiln seasoning schedule under I and II.

Moisture content (%)

The moisture content (%) of *M. dubia* was registered in unseasoned wood and seasoned wood with different plank thicknesses of 1.5, 2.0, and 2.5 cm. The moisture content of *M. dubia* wood across different densities showed significant differences in (unseasoned wood) and it ranged between 56.98% and 54.03% (Table.2). Among all the plank thicknesses, 1.5 cm (54.03%) recorded the lowest moisture content followed by 2.0 cm (56.21%) while the maximum moisture content% was observed at 2.5 cm (56.98%).
Simpson and Tenwolde (1999) [16] reported that bearable moisture level (%) in the wood depends on the final use and the average relative humidity (RH) in the environment where the wood is to be used. Even refractory species like *E. tereticornis* would season below its FSP, and initial moisture content was around 60% to nearly 12% final MC in 16-20 days in solar kiln investigated by Upreti *et al.* (2011) [17].

Density

The density varied significantly due to differences in the moisture content (%) of the unseasoned wood sample. Among all the plank thicknesses, 1.5 cm (490 kg/m^3) recorded the lowest density followed by 2.0 cm (520 kg/m^3) while the maximum density was observed at 2.5 cm (545 kg/m^3) (Table.2).

Compared to all the plank thicknesses 1.5 cm recorded maximum density (400 kg/m^3) followed by 2.0 cm (375 kg/m^3) while the lowest density was observed at 2.5 cm (360 kg/m^3). Hence, there was a significant difference in density between the green and seasoned wood. Kaba *et al.* (2020) [7] reported that the density (specific gravity) values were determined as a significant standard of wood quality since it substantially impacts the physical and mechanical properties, which could happen because of shrinkage of cell wall thicknesses.

Table 2: Effects of variations in before and after seasoning of physical properties for *M. dubia*

Plank Thicknesses		Density kg/m^3	Moisture content%	Specific gravity	Shrinkage%		
					Radial%	Tangential%	Volumetric%
Before Seasoning	1.5 cm	490*	54.03*	0.47	1.37	2.23	3.10
	2.0 cm	520*	56.21*	0.43	2.23	2.21	3.07
	2.5 cm	545*	56.98*	0.44	3.10*	2.19	3.04
After Seasoning	1.5 cm	400	9.01	0.58*	2.02	2.90*	4.29*
	2.0 cm	375	11.56	0.63*	2.04	2.94*	4.31*
	2.5 cm	360	11.58	0.66*	2.09	2.98*	4.36*
Mean		448.33	33.22	0.53	2.14	2.57	3.69
SE(d)		23.595	1.9924	0.0159	0.1036	0.0791	0.1470
CD(0.5)		51.409	4.3410	0.0347	0.2257	0.1723	0.3203

*Significant @ 5% level

Specific gravity

Specific gravity i.e. a 0.66 highest specific gravity was recorded in the (seasoned wood) with a thickness of 2.5 cm sample. The specific gravity values (unseasoned and seasoned wood) obtained in the study ranged from 0.47 to 0.44 and 0.58 to 0.66 respectively (Table.2). Kyi *et al.* (2002) [10] revealed that measured specific gravity from (0.529 to 0.563) when timber seasoned from initial moisture content (green) 70% to final moisture content 12% (dry).

Shrinkage (Dimensional changes)

The tendency of the swelling was similar to that of water absorption in the wood. Found that after 24 hours of immersion of samples in water, the values of green and seasoned wood ranged in radial of 1.5, 2.0 and 2.5 cm (1.37% to 2.02%), (2.23 to 2.04) and (3.10 to 2.09%) tangential (2.23% to 2.90%), (2.21 to 2.94%) and (2.19 to 2.98%) and volumetric shrinkage (3.10% to 4.29%), (3.07 to 4.31%) and (3.04 to 4.36%). Radial shrinkage was least across the surface, followed by tangential and volumetric in green conditions (Table.2). Anish *et al.* (2015) [3] indicated that shrinkage and swelling were higher in fast-grown species like *Melia dubia*, *Eucalyptus*, *Dalbergia sissoo*. Kaba *et al.* (2020) [7] reported that dimensional characteristics cause by differences in radial, tangential and volumetric direction of the wood. Jara *et al.* (2008) concluded that the wood is more compressive in stress at the starting seasoning when the moisture content is above the fiber saturation point. According to the research conducted by (Kord *et al.* 2010 and Pliura *et al.* 2005) [8, 13], higher shrinkage percentages were found commonly in high-density wood species.

Static bending test

Strength properties of wood depend on the species and force direction of the wood load Ezhumalai *et al.* (2021) [4]. *Melia dubia* recorded the Static Bending Test of (31.80 kg/cm^2) in the thickness of 1.5 cm and (35.45 kg/cm^2) in 2.0 cm and (37.87 kg/cm^2) in 2.5 cm respectively (Table.3) were registered in the unseasoned wood samples. Meanwhile, the samples of seasoned wood were observed (37.02 kg/cm^2) in 1.5 cm followed by (39.98 kg/cm^2) in 2.0 cm and (41.56 kg/cm^2) in 2.5 cm thicknesses. Results indicated that seasoned wood (41.56 kg/cm^2) registered a high Static Bending Test compared to the general mean (30.35 kg/cm^2) (Table.3). Johansson *et al.* (2003) [6] reveal that strength properties of any timber in terms of compression, static bending, and tensile factors were significant for wood quality.

Modulus of Elasticity (MOE)

M. dubia recorded the MOE parallel to the grain of 2529.07 N/mm^2 in green condition and the higher values of MOE (3678.54 N/mm^2) were registered in seasoned wood, compared to the green condition of the wood. The MOE perpendicular to the grain was recorded from 5961.60 N/mm^2 in green condition to 6295.32 N/mm^2 seasoned woods. Higher wood strength was observed for seasoned wood compared to that of greenwood. Moreover, the strength of wood generally increases as wood was dried from green condition to moisture content below the fiber saturation point (Table 3).

Table 3: Effects of variations in before and after seasoning of mechanical properties for *M. dubia*

Plank Thicknesses		Static Bending test (kg/cm^2)	Compression strength parallel to grain (kg/cm^2)	Compression strength perpendicular to grain (kg/cm^2)	MOE Parallel to grain (N/mm^2)	MOE Perpendicular to grain (N/mm^2)	MOR Parallel to grain (N/mm^2)	MOR Perpendicular to grain (N/mm^2)
Before Seasoning	1.5 cm	31.80	176.90	68.80	2529.07	5961.60	30.42	29.89
	2.0 cm	35.45*	195.30	104.20	2643.67	5978.84	33.99	33.01
	2.5 cm	37.87*	210.80	120.60*	2754.34	6000.12	35.12	36.76
After	1.5	37.02*	190.90	88.30	3320.90*	6198.70	34.02	34.67

Seasoning	cm							
	2.0 cm	39.98*	225.10*	123.50*	3507.34*	6206.21	37.76	39.76*
	2.5 cm	41.56*	245.20*	140.20*	3678.54*	6295.32	40.21*	41.45*
Mean		30.35	207.36	107.60	3072.31	6106.79	35.25	35.75
SE(d)		1.6735	7.7586	5.0768	130.2050	133.3957	1.6850	1.8961
CD(0.5)		3.6464	16.9047	11.0615	283.6949	290.6470	3.6712	4.1312

*Significant @ 5% level

Modulus of Rupture (MOR)

MOR (Modulus of Rupture) also called shear modulus Zhou *et al.* (2014) [20] indicates that shear stresses cause resistance to deflection of a member. *Melia dubia* recorded the MOR parallel to the grain of 30.42 N/mm^2 in green and recorded the higher value of 35.12 N/mm^2 in seasoned wood. The MOR perpendicular to the grain recorded the value from 29.89 N/mm^2 in green condition to 41.45 N/mm^2 in seasoned timbers.

It also found that the MOR increased from green to seasoned wood, where the strength properties decreased while subjected to high temperature for seasoning of the wood (Table 3). It has also been found that MOE and MOR were enriched during the low moisture content (%) in wood samples (Gerhards 1982 and Matan and Kyokong 2003) [11]. Both MOE and MOR vary within the species with variation in moisture content (%) and specific gravity of wood. Presences of the drying defect in the wood accelerated by a high-temperature drying schedule were reported by Alam *et al.* (2016) [1].

Seasoning defects

The major seasoning defects observed in the planks of *Melia dubia* was end splitting, surface cracking, and bowing. A drying test was conducted to study the degrees of seasoning defects in the plank thicknesses of 1.5 cm, 2.0 cm, and 2.5 cm when seasoned in the electrical solar kiln. Visual observations of seasoning defects were based on the Terasawa scale (Terasawa, 1965) [12]. The seasoning defect recorded in *Melia dubia* planks was End splitting, surface cracking, and bowing. The end splitting was observed during the initial hours of seasoning. The highest degree of end splitting observed in the planks according to the Terasawa scale was rank 5 in the plank thickness of 2.5 cm (Table 4).

Surface cracking were observed in Melia planks, which was visible during the seven hours of seasoning with a temperature of 60°C. According to the Terasawa scale, the highest rank for surface cracking was 5 (Table 4). The degree of seasoning defect regarding bowing was 3 in the plank thickness of 2.5 cm, respectively. Oltean *et al.* (2007) [19] reported surface cracking during seasoning due to various parameters such as high temperature, moisture present within the wood, and wood samples thickness. Passarini *et al.* (2005) indicate that wood rapidly reaches FSP in the outermost layers, hence the stress influencing the external and inside of the wood sample to seasoning defects.

Table 4: Degrees of seasoning defects in *M. dubia* planks with different thicknesses during seasoning

Sample No.	Surface cracking			End splitting			Bowing		
	1.5 cm	2 cm	2.5 cm	1.5 cm	2 cm	2.5 cm	1.5 cm	2 cm	2.5 cm
1	2	3	4	3	3	3	1	0	3
2	3	4	3	3	4	3	0	2	3
3	3	4	4	4	4	5	2	1	2
4	3	3	5	4	3	4	1	2	1
5	3	4	5	3	3	2	2	0	3
6	2	3	3	3	4	3	1	2	2
7	3	4	4	4	4	4	2	2	3
8	3	2	5	3	4	5	2	1	2
9	3	4	5	4	3	4	1	0	3
10	2	3	4	4	3	4	1	2	2
Highest degree	3	4	5	4	4	5	2	2	3

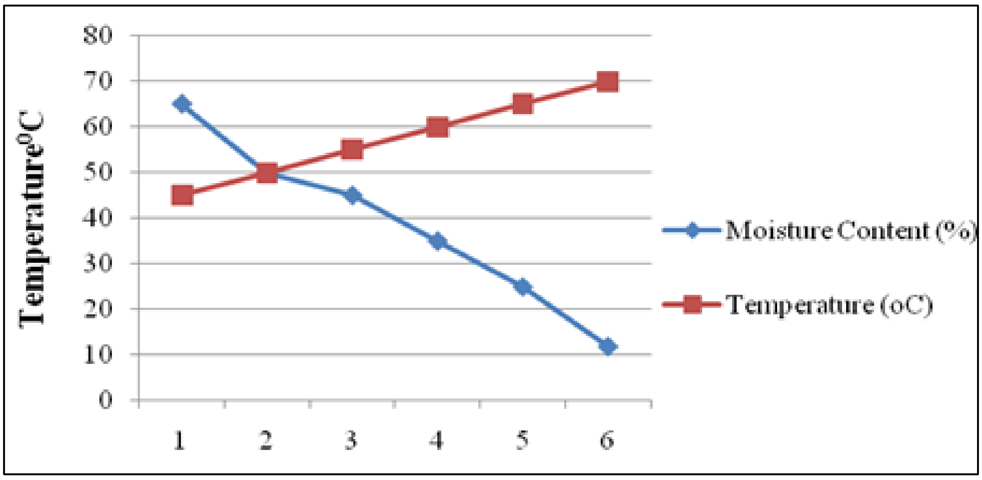

Fig 1: Loss of moisture content% at different stage of wood seasoning

Conclusion

The study reveals that even non-refractory species like *Melia dubia* can be seasoned below its FSP in kiln seasoning. The density of the *Melia dubia* was initially 490 kg/m^3, and they obtained the lowest seasoning time of about (42 hours). MOE and MOR of *Melia dubia* seem to be highest in seasoned wood compared to green condition; this shows an increase in strength properties of wood. The wood of *Melia dubia* is less susceptible to drying defects. The only visible defects during kiln drying tests were surface cracking, surface cracking, and bowing. Other defects like twisting and cupping were not observed. It indicates that the species is suitable for faster kiln drying conditions. Therefore, the kiln seasoning method can help minimize the seasoning time (h), defects, and shrinkage, thereby increasing wood quality. Kiln seasoning allows a more precise rate of drying for various timber species and thickness of boards. So, that timber can be used for packing cases and other structural purposes. Therefore, we conclude that seasoning schedules applied to *Melia dubia* can improve their physical and mechanical properties under kiln seasoning.

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