Drying Schedule and Effect of Seasoning on Physical and Mechanical Properties of Three Available Timber Species in Bangladesh

Rabiul Alam, Azharul Islam, S. M. Feroz, Shamima Nasrin*, Tanay Biswas, Khandkar-Siddikur Rahman and Lulu Rayhan Khushi

Forestry and Wood Technology Discipline, Khulna University, Khulna – 9208, Bangladesh

Abstract: Drying schedules for seasoning of *Gmelina arborea* (Gamar), *Swietenia macrophylla* (Mahagony) and *Mangifera indica* (Mango) timber with minimum drying defects were developed. The effects of the drying on physical and mechanical properties of timber of these species were studied. New drying schedules for these three species were compared with an accelerated drying schedule. Physical properties i.e., density, water absorption and thickness swelling, as well as mechanical properties i.e., modulus of elasticity (MOE), modulus of rupture (MOR) of the wood of these species seasoned by new drying schedules and accelerated drying schedule were tested. Lower water absorption and thickness swelling were found for *G. arborea, S. macrophylla* and *M. indica* wood dried with new drying schedules of A, B and C respectively. MOE and MOR of wood of *G. arborea, S. macrophylla* and *M. indica* were significantly higher when seasoned with new drying schedules compared to those of green wood, and seasoned with accelerated drying schedule. Though seasoning was slower by using new drying schedules compared to accelerated drying schedule, the former resulted in no drying defects.

Keywords: Drying schedule, drying defect, *Gmelina arborea*, *Swietenia macrophylla*, *Mangifera indica,* physical properties, mechanical properties.

1. INTRODUCTION

Wood is lingo-cellulosic biological product [1] and one of the most important sectors of the national economy of Bangladesh. In living trees, the moisture content (MC%) of wood ranges from 50% to 200% depending on the species and on the position of wood in the log. MC (%) of wood needs to be reduced between 8% and 15% before using it to manufacture high quality products in the furniture industry. It also depends on climatic conditions, external and internal uses of wood [2]. When wood is converted to lumber, it requires to remove some of its moisture to enhance the attributes and properties of the lumber, thereby increasing its value and service life [3].

Wood, while in service, virtually always undergoes dimensional changes with fluctuation in atmospheric relative humidity and temperature. Kiln drying has become one of the most important processes of wood seasoning and the efficient uses of wood products. Proper machining, gluing, and finishing of wood are not possible until the moisture content of it is reduced to an appropriate level [4, 5]. Proper drying of wood before use is one of the most important factors in its efficient and rational utilization [5]. Drying of green wood minimizes warping, shrinkage, checking and susceptibility to biological degradation in service condition by removing much of its moisture content. Drying also reduces transportation costs by reducing the weight of wood. In addition, strength properties increase when wood is dried from the green condition to moisture contents below the fiber saturation point [4-8]. Drying improves dimensional stability, coating, adhesive compatibility, mechanical properties, and also increases resistance to biodegradation of wood [9].

Gmelina arborea (Gamar), *Swietenia macrophyll* (Mahagony), and *Mangifera indica* (Mango) are available and commercially valuable timber species in Bangladesh. The timbers of these species are used for door, furniture, cabinet manufacturing etc. for their higher wood value and good appearance in use [10]. *G. arborea* has been one of the most important plantation species in tropical regions [11]. Timber of this species possesses good working properties [12]. Timber of *S. macrophylla* is durable and used for furniture, light construction, boat building etc. [13]. Timber of *M. indica* is medium textured and possesses excellent nailing properties [14]. If these timbers are not properly seasoned, dimensional change, and microbial degradation might occur during use. Consequently, their end-use properties will be adversely affected. Proper seasoning will ensure the proper machining; fastening with nails and screws and elimination of checking, splitting and other harmful microbial degradation of wood. Thus, effective utilization of these timber species can be achieved after proper seasoning of them.

*Address correspondence to this author at the Forestry and Wood Technology Discipline, Khulna University, Khulna – 9208, Bangladesh;
Tel: +88 01731601357; E-mail: nasrin.shamima@outlook.com

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Several studies were conducted on kiln drying of planks of timber species in Bangladesh. But the recommended drying schedules for these three species were not compared with accelerated drying schedule. Even, physical and mechanical properties of wood of these species after drying were not tested in all previous studies. Therefore, this work is the first attempt to develop of drying schedule for seasoning of *G. arborea, S. macrophylla* and *M. indica* timber with minimum drying defects and to investigate the effect of drying on the physical and mechanical properties of these timber species. Recommended drying schedules are also compared with accelerated drying schedule for the same species.

2. MATERIALS AND METHODS

2.1. Raw Material Collection

Logs of the selected three species were collected from the local area of Khulna district of Bangladesh. 10-13 years old, defect free trees of *G. arborea, S. macrophylla* and *M. indica* were selected randomly. Straight and clean bole, DBH (Diameter at Breast Height) more than 30 cm were selected. 2.5 m long logs were collected from the bottom portion of the boles of each species.

2.2. Sample Preparation and Seasoning

Logs were sawn into 20 cm × 2.5 cm × 2.5 cm planks for experimental drying of it. Ten representative planks were taken as test samples for each species. Green moisture content and density of the sample planks were measured by using following formula.

MC (%) = (Green weight – Oven Dry weight)/Green weight × 100

Density (kg/m^3) = Weight /Volume

The sample planks were end-coated with bituminous salt paint. Their initial weight was taken.

Table 1: Accelerated Drying Schedule

Phase	Temperature (^{0}C)		Relative Humidity (%)	Operation Duration (hrs)	Moisture Content %	Operation Steps
	Dry Bulb	Wet Bulb				
1st	80	75	82	12	85	Preconditioning
2nd	80	75	82	12	60	Drying
3rd	90	62	56	12	40	
4th	100	55	52	12	28	
5th	110	50	48	12	20	
6th	120	53	45	12	13	
7th	130	52	45	12	8	Post conditioning start
8th	82	75	83	12	12	Post conditioning

Table 2: Drying Schedule A for *Gmelina Arborea* (Gamar)

Days	Temperature (^{0}C)		Relative Humidity (%)	Operation Duration (hrs)	Moisture Content %	Operation Steps
	Dry Bulb	Wet Bulb				
1st	45	40	72	24	91	Pre-conditioning
2nd	47	40	64	24	86	Drying
3rd	49	40	56	24	78	
4th	65	40	45	24	70	
5th	65	40	45	24	63	
6th	65	40	45	24	56	
7th	60	40	45	24	47	
8th	60	40	45	24	40	
9th	65	40	38	24	33	
10th	70	40	35	24	27	
11th	70	40	35	24	21	
12th	78	40	35	24	15	
13th	82	40	70	24	8	Post conditioning start
14th	45	40	90	24	12	Post conditioning

The sample planks were then seasoned in a compartment kiln situated in Otobi Furniture Industry, Savar, Dhaka, Bangladesh by following a accelerated kiln drying schedule (Table **1**). New drying schedules of A, B, and C were selected for the wood of *G. arborea, S. macrophylla* and *M. indica* respectively (Table **2**, Table **3**, and Table **4**) on the basis of density of the wood. Then the wood was seasoned according to the specified drying schedule for each species. During the experimental period, daily moisture loss data were computed simply by weighing the samples. By comparing respective drying schedule for each species with accelerated schedule, the schedule which offered proper drying of wood with minimum or no drying defects were considered as appropriate one. Finally, physical and mechanical properties of green and seasoned wood (by new and accelerated drying schedules) were evaluated and compared.

2.3. Laboratory Test

The seasoned wood samples were conditioned in a chamber with temperature of 25±3°C and relative humidity of 65±2% before any laboratory test. After conditioning, twelve wood samples (240 mm × 50 mm × 18 mm each) were cut from the planks of each species of the three species for testing physical and mechanical properties. Among physical properties, density (EN 323 1993), water absorption (EN 317 1993) and thickness swelling (EN 317 1993) of seasoned samples were measured following the European Standards (EN). Among the mechanical properties, Modulus of Elasticity (MOE) (EN 310 1993),

Table 3: Drying Schedule B for *Swietenia Macrophylla* (Mahagony)

Days	Temperature (^{0}C)		Relative Humidity (%)	Operation Duration (hrs)	Moisture Content (%)	Operation Steps
	Dry Bulb	Wet Bulb				
1st	35	32	80	24	84	Pre-conditioning
2nd	45	40	80	24	76	Drying
3rd	46	39	76	24	68	
4th	48	41	71	24	57	
5th	50	42	65	24	45	
6th	55	42	56	24	33	
7th	60	42	65	24	28	
8th	66	39	76	24	22	
9th	72	36	80	24	17	
10th	80	34	80	24	8	Post conditioning start
11th	45	40	80	24	12	Post conditioning

Table 4: Drying Schedule C for *Mangifera Indica* (Mango)

Days	Temperature (^{0}C)		Relative Humidity (%)	Operation Duration (hrs)	Moisture Content (%)	Operation Steps
	Dry Bulb	Wet Bulb				
1st	40	36	80	24	82	Pre-conditioning
2nd	45	40	76	24	73	Drying
3rd	50	42	65	24	65	
4th	55	42	56	24	54	
5th	60	42	65	24	47	
6th	68	40	76	24	34	
7th	72	36	80	24	25	
8th	78	36	80	24	16	
9th	83	40	85	24	8	Post conditioning start
10th	40	42	85	24	12	Post conditioning

and Modulus of Rupture (MOR) (EN 310 1993) were tested. All the samples were tested following the European Standards with Universal Testing Machine.

2.4. Statistical Analysis

Effects of different drying treatments were compared by analysis of variance (ANOVA) and least significant difference (LSD) (α = 0.05) by using MS Excel and SAS 6.1 statistical software.

3. RESULTS AND DISCUSSION

3.1. Drying Graphics

The drying graphic for *G. arborea* (Gamar), *S. macrophylla* (Mahagony) and *M. indica* (Mango) wood represented loss of moisture content (%) of these three species seasoned with their respective drying

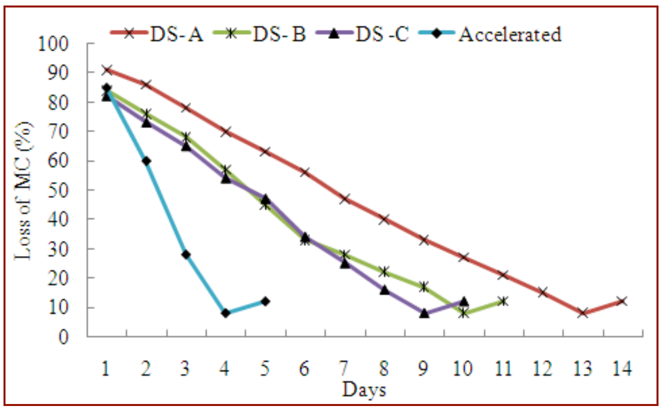

Figure 1: Loss of MC (%) at different stage of wood seasoning.

schedules (A, B, and C respectively) also with accelerated drying schedule in common (Figure **1**). It showed that the drying processes of A, B and C schedules were slower compared to the accelerated one. Each drying schedule consisted of three stages namely pre-conditioning, drying and post conditioning. At the initial stage of each schedule, one day was allowed for heating up the stock and was denoted as pre-conditioning. Post-conditioning was applied to ensure uniform distribution of moisture throughout the cross section of each lumber in order to recover possible drying defect except for accelerated drying schedule because of high temperature (130°C) both at dry and wet bulbs at that stage. Even in industrial practice, it is difficult to attain and maintain these dry and wet bulb temperatures. However the most important in conditioning phase is to keep the relative humidity of air as close as possible to 100% at high temperature.

Drying time for accelerated drying schedule was 4 days (96 hours) to reach from green condition to 12% moisture content whereas the drying time for A, B, and C schedules were 14, 11 and 10 days for *G. arborea, S. macrophylla* and *M. indica* wood respectively. Moisture of wood was lost in a regular manner during the entire duration of drying schedule of A, B, and C compared to that of accelerated drying schedule. Variation in early moisture content of wood would regulate the variation of the drying rate [15]. Therefore, these drying times were considered normal for the *G. arborea, S. macrophylla* and *M. indica* wood. Similar results were reported by Lahiry [16] for the wood of same range of density.

3.2. Drying Defects

Natural defects of wood dead, live knots, and presence of pith in sawn lumber might result in high level of drying defects during kiln drying of wood. But in this study all the lumbers were selected based on their soundness. Checking, splitting and cupping were found in the dried samples of *G. arborea, S. macrophylla* and *M. indica* when seasoned with accelerated drying schedule (Table **5**). Due to the presence of such kinds of drying defects in seasoned lumber, volume loss in during industrial processing of wood would be higher. The major cause of this high level of defect was that initial drying stress was created due to the loss of

Table 5: Drying Defects

Drying Schedule	Species	Drying Defects
Accelerated	Gamar	Checking, splitting and cupping
	Mahagony	End split and surface check
	Mango	Checking and end splitting
A	Gamar	Nil
B	Mahagony	Nil
C	Mango	Nil

higher level of moisture from the surface compared to the inner part of the wood during accelerated drying of wood. Similar result was reported by Chen *et al*. [17] Bergman [18]. They stated that the drying temperature was the most important processing factor which resulted in those defects. However, new experimental drying schedules of A, B, and C when applied to *G. arborea, S. macrophylla* and *M. indica* wood respectively, no such drying defects were observed. This happened due to moderate temperature applied for drying of wood of these species. Thus, based on the quality of timber, new drying schedules of A, B, and C can be acceptable for drying wood of *G. arborea, S. macrophylla* and *M. indica*.

3.3. Physical Properties

3.3.1. Density

The mean density of wood of *G. arborea, S. macrophylla* and *M. indica* were 694kg/m^3, 766kg/m^{3}and 536kg/m^3, respectively for green and seasoned wood (Figure **2**). There was significant difference (F =39.52, df = 8, 45 and p<0.05) in density among the green and seasoned wood. However, there was no significant difference (p>0.05) in density of wood when seasoned by new and accelerated drying schedules. Hence, minor differences in wood density of these species were found when compared between accelerated drying schedule and new drying schedule for each species. This could happen because of

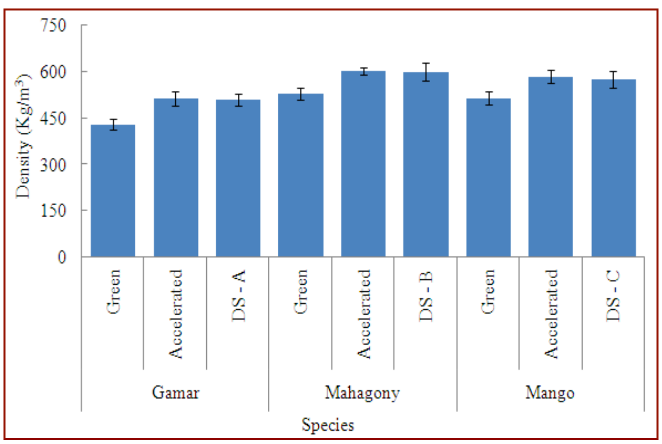

Figure 2: Changes in density.

shrinkage of cell wall thickness. According to Bowyer *et al*. [19], density decreases as moisture content decreases, but below the FSP the specific gravity increases as the moisture content decreases. So, findings of this study complied with the results of Simpson [20].

3.3.2. Water Absorption

Water Absorption (WA) and Thickness Swelling (TS) properties of lingo-cellulosic materials are directly related to moisture content of wood. Wood seasoned by accelerated drying schedule showed higher WA compared to wood of *G. arborea, S. macrophylla* and *M. indica* seasoned by new drying schedule A, B, and C respectively (Figure **3**). It was found that there was significant difference (F =18.37, df = 8, 45 and p<0.05) in WA after 24 hours between the green and seasoned wood of each species. However, there was no significant difference (p>0.05) in WA of wood of each species when seasoned by accelerated drying schedule and new drying schedule. As a whole, the WA of seasoned wood specimen decreased as the seasoning temperature increased during the kiln drying of wood. In the hygroscopic ranges, the moisture content of specimens is dominated by the number of hydrophilic sites in wood, especially hydroxyl groups of carbohydrate. But in this study deviation from general hygroscopic behavior was found. However, WA after immersion is mainly determined by the permeability of wood. The main factor influencing permeability of wood is the radius and number of effective openings on pit membranes. When wood is subjected to heat, lignin softens and blocks the cell pores, thereby decreasing the radius and number of effective openings on pit membrane [21]. But here minor defects on the surface and at the end or cross section might open the end grain which enhanced the permeability of wood. Thus, wood dried by accelerated drying schedule absorbed more water than wood dried by new drying schedules. This findings complied with the results of Bekhta and Niemz [22].

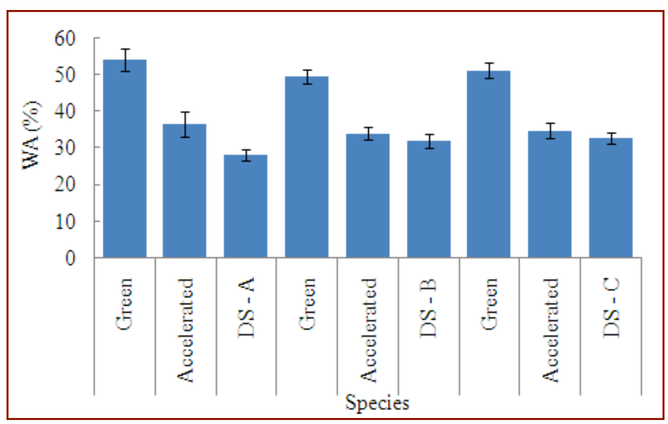

Figure 3: Changes in water absorption.

3.3.3. Thickness Swelling

The tendency of the Thickness Swelling (TS) was similar to that of WA. It was found that after 24 hours of immersion in water at room temperature, the mean value of TS of green and dried wood of *G. arborea, S. macrophylla* and *M. indica* wood ranged from 3.55 to 8.02%, 4.04 to 6.46% and 4.28 to 8.67% respectively (Figure **4**). It was found that there was significant difference (F = 21.67, df = 8, 45 and p<0.05) in TS after 24 hours between green and seasoned wood of each species. However, there was no significant difference (p>0.05) in TS between the seasoned wood of each species by accelerated and new drying schedules. The lowest thickness swelling was found for seasoned wood by new schedules compared to those of green wood and seasoned by accelerated drying schedule. It was also observed that TS varied between and within the same species based on the drying conditions. The TS was slightly higher for wood dried by accelerated drying schedule compared to that of new drying schedules when exposed to the same condition. Again this variation in thickness swelling might be due to the formation of drying defects at the surface and cross section of the wood sample during the accelerated drying of the wood of these three species. Moreover, it was observed that the higher water absorption resulted in higher thickness swelling in case of all wood samples. In addition, Skaar [23] found that hygroscopicity of hemicellulose is higher than the cellulose and lignin. For this reason, WA and TS of green and seasoned wood significantly differs within and between species.

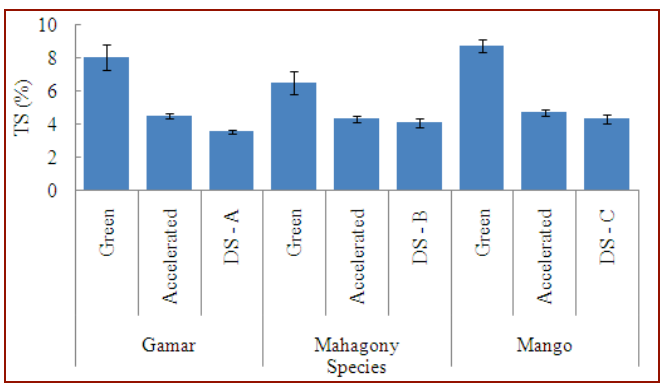

Figure 4: Changes in thickness swelling.

3.4. Mechanical Properties

3.4.1. Modulus of Elasticity (MOE)

The mean modulus of elasticity (MOE) of *G. arborea, S. macrophylla* and *M. indica* wood ranged from 7441.38 to 9785.45 N/mm^2, 8111.53 to 11660.34 N/mm^2 and 7665 to 11440 N/mm^2 respectively (Figure **5**). The MOE of *G. arborea, S. macrophylla* and *M. indica* wood seemed to increase under the experimental conditions used from green to seasoned wood. It was found that there was significant difference (F = 27.30, df = 8, 45 and p<0.05), of modulus of elasticity among the three types of wood. Moreover, higher wood strength resulted from the higher wood density (Figure **2** and Figure **5**) because of the correlation between density and mechanical properties. Moreover, higher wood strength was observed for seasoned wood compared to that of green wood. Strength of wood generally increased as wood is dried from the green condition to moisture contents below the fiber saturation point [6-8]. However, wood dried by new drying schedule possessed significantly higher MOE than those of the wood dried by accelerated drying schedule. Thus, the results indicated that the wood of all these species lost some strength properties during the accelerated drying of it. Similar observation was also reported by Tari *et al*. [24] for Paulownia wood (*Paulownia fortune.* Seem.). This might be due to the break-up of the hemicelluloses and cellulose polymers and formation of drying defects as a result of high temperature drying of wood.

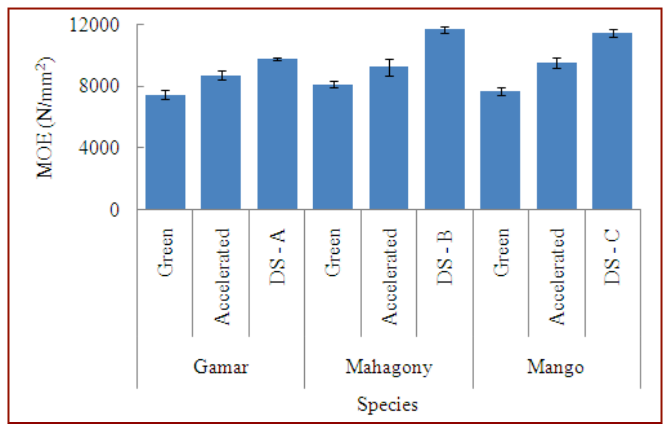

Figure 5: Changes in MOE.

3.4.2. Modulus of Rupture (MOR)

The mean modulus of rupture (MOR) of *G. arborea, S. macrophylla* and *M. indica* wood ranged from 19.84 to 47.87 N/mm^2, 33.12 to 66.88 N/mm^{2}and 30.18 to 53.54 N/mm^2 respectively (Figure **6**). It was found that there was significant difference (F = 81.60, df = 8, 45 and p<0.05), of MOR among the three types of wood. It was also found that the MOR of all species increased from green to seasoned wood and strength properties decreased while subjected to high temperature for seasoning of wood. This might be due to the presence of drying defects in wood dried by accelerated drying schedule at high temperature. Similar results were reported by Poncsák *et al*. [25] for high temperature drying of wood.

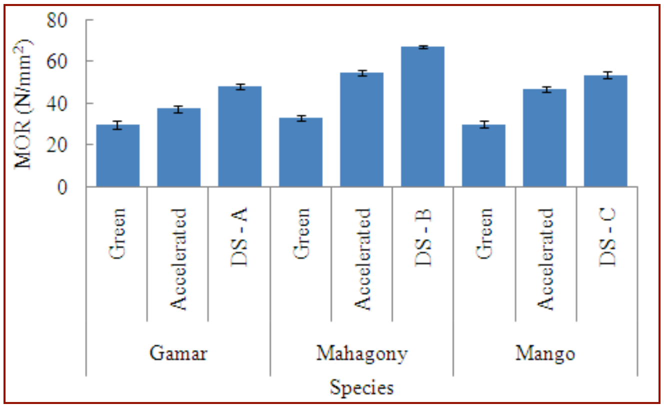

Figure 6: Changes in MOR.

Ali *et al.* [26] studied on kiln drying of 11" planks of Bangladesh timber species. Sattar and Talukdar [27] also studied on kiln drying of 5cm thick planks of thirty timber species. But the recommended drying schedules for the studied species were not compared with accelerated drying schedule for the same species. Munoz and Moya [9] studied on kiln drying of *Gmelina arborea*. This study mainly focused on moisture content variability and its relationship with initial moisture content, distance from pith, specific gravity, and anatomical features. Ogunsanwo and Amao-onidundu [28] investigated selected drying characteristics of plantation grown *Gmelina arborea* but physical properties such as water absorption, thickness swelling, and mechanical properties such as modulus of elasticity, and modulus of rupture of wood of the selected species after drying were not tested in all the previous studies.

Therefore, this study was a holistic approach to develop of drying schedules and to evaluate the effects of seasoning on physical and mechanical properties of *G. arborea, S. macrophylla* and *M. indica*.

CONCLUSION

Wood of *G. arborea, S. macrophylla* and *M. indica* exhibited no drying defects when seasoned with A, B, and C new drying schedule respectively. However, drying defects of wood of these species were observed when seasoned with accelerated drying schedule. Wood density of these three species didn't vary significantly when compared separately between new drying schedules and accelerated drying schedule. Water absorption and thickness swelling of wood of three species were the lowest in case of new drying schedules. MOE and MOR of *G. arborea, S. macrophylla* and *M. indica* wood seasoned with new drying schedules were the highest compared to those of green wood and seasoned with accelerated drying schedule. Therefore, we conclude that new drying schedules applied to these three species would improve their physical and mechanical properties, thereby improving their performance under service conditions.

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