Wood and Lumber Properties of *Larix gmelinii* var. *olgensis* Planted in Japan

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In order to promote plantation establishment of *Larix gmelinii* var. *olgensis* (syn. *L. olgensis* A. Henry), a 'near threatened' species, the wood and lumber properties were preliminary investigated for five trees from two clones of 57-year-old trees planted in Japan. The mean value of dynamic Young's modulus of logs was 10.16 GPa. The mean values of annual ring width, latewood percentage, basic density, MOE, and MOR of five sample trees were 2.1 mm, 29.3%, 0.47 g•cm^{-3}, 8.06 GPa, and 60.4 MPa, respectively. In addition, the MOE and MOR of 2 by 4 lumber were 10.43 GPa and 42.4 MPa, respectively. These values were similar to those obtained from other *Larix* species. Thus, construction lumber could be produced from the wood from plantation grown *L. gmelinii* var. *olgensis*.

Keywords: Larix gmelinii var. olgensis; Annual ring width; Latewood percentage; Basic density; Bending property

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INTRODUCTION

Larix gmelinii var. *olgensis* (syn. *L. olgensis* A. Henry) is a species of larch distributed widely in Olga bay, Primorskaya Oblast, Russia, the north part of the Korean peninsula, and the northeast part of China (Vasyutkina *et al*. 2007). This species is a 'Near Threatened' species in IUCN Red List, although it is considered an important forestry resource in China (Wang *et al*. 2006; Li *et al*. 2011; Peng *et al*. 2018). In Japan, *L. gmelinii* var. *olgensis* and other *Larix* species have been introduced to produce hybrid larch with *L. kaempferi* (Takahashi *et al.* 1968). However, data on the properties of *L. gmelinii* var. *olgensis* is very limited (Nakagawa 1963), compared with *L. kaempferi* planted in Japan (Takada *et al*. 1992; Takata and Hirakawa 2000; Nagao *et al*. 2003; Koizumi *et al*. 2005; Nakada *et al*. 2005; Ishiguri *et al*. 2008).

Kubojima *et al*. (2010) pointed out that, for *Picea koyamae*, a 'critically endangered' species in the IUCN Red List, if the wood of this species from appropriate plantations can be utilized, the extinction of this species might not occur. This is also true for *L. gmelinii* var. *olgensis* that it could be a possible valuable wood resource, as the wood of the other *Larix* species are mainly utilized as construction lumber (Iijima 1983; Miyajima 1985; Tokumoto *et al*. 1997; Takeda 2000; Nagao *et al*. 2003; Ishiguri *et al*. 2008). Therefore, wood properties of the species should be clarified to enhance the establishment of plantation of this species.

In the present study, five trees from two clones of *L. gmelinii* var. *olgensis* were obtained by thinning treatment in a progeny test site located in Iwate, Japan. Available information was very limited for wood and lumber properties of this species. Thus, wood and lumber properties were preliminary investigated to consider the establishment of plantation of this species in Japan, although number of sample trees were limited.

EXPERIMENTAL

A total of five trees from two clones (three trees from one clone, and two trees from the other clone) of 57-year-old *Larix olgensis* A. Henry were used in the present study. The trees were planted in the progeny test site, Tohoku Regional Breeding Office, Forest Tree Breeding Center, Forestry and Forest Products Research Institute, Iwate, Japan (39°49'N, 141°08'E, 652 m above sea level) in 1960. The trees were cut down after measuring the stem diameter at 1.3 m above the ground (Table 1).

Table 1. Stem Diameter, Tree Height, and Dynamic Young's Modulus of Logs in Sample Trees

Sample	Stem Diameter (cm)	Tree Height (m)	DMOE of Logs (GPa)
A1	19.0	10.3	9.92
A2	20.6	10.2	11.08
A3	21.5	9.7	10.42
B4	23.0	11.3	10.11
B5	26.2	11.3	9.25
Mean / Total	22.1 (2.7)	10.6 (0.7)	10.16 (0.67)

Note: Dynamic Young's modulus (DMOE) of logs. A and B indicate individual clones. Values in parentheses followed by mean values indicate standard deviations.

After cutting down the trees, two logs in each tree were obtained from 1.0 m to 1.5 m, and from 1.5 m to 3.5 m above the ground (Fig. 1). The shorter length logs and the longer length logs were used for measuring wood and lumber properties, respectively. Before producing lumber, dynamic Young's modulus (DMOE) of the longer length logs was determined by the tapping method (Sobue 1986).

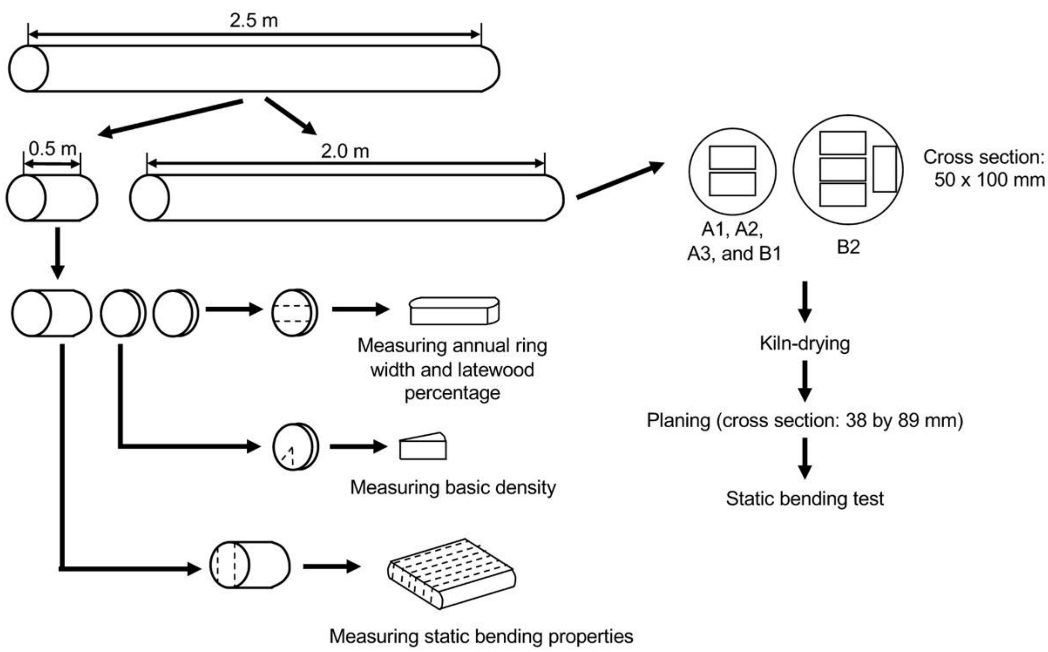

Fig. 1. Illustration of the experimental procedure

Radial variations of the wood properties such as annual ring width, latewood percentage, basic density, and static bending properties were evaluated. Sample specimen disks of 3 cm in thickness were obtained from the shorter length logs in order to evaluate the wood properties except static bending properties (Fig. 1). Pith to bark strip was prepared from the disk sample, and the surface of the strip was sanded. Digital images (1200 dpi) of transverse sections were obtained by a scanner (GT-9300UF, Epson). Due to narrower annual rings in some samples, small blocks were prepared, and then the transverse surface was trimmed by a sliding microtome. The transverse images were obtained by a stereomicroscope (SZX12, Olympus, Tokyo, Japan) with a digital camera. Width and latewood width at every annual ring were determined by using a software (ImageJ, National Institute of Health, USA). To determine the basic density, a wedge-shaped specimens were prepared from the disk (Fig. 1). The wedge-shaped specimens were again cut at 5-year interval until the 30th annual ring from pith. Due to narrower annual rings, the specimens could not be cut after the 35th annual ring from pith. Basic density was calculated using oven-dry weight samples divided by green volume determined by water displacement method. Small-clear specimens for static bending test (*ca*. 320 (L) × 20 (R) × 20 (T) mm) were prepared from bark to bark radial boards (20 mm in thickness) obtained from the shorter length logs (Fig. 1). The radial boards were air-dried in laboratory (with air-conditioner, but without humidity control), and then cut at 20-mm interval from pith. Static bending test was conducted by using a universal testing machine (MSC-5/200-2, Tokyo Testing Machine) with a span of 280 mm. The load was applied to the center of radial surface of the specimens at the load speed of 5 mm/min. Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from the obtained data. Due to lower moisture content of the specimens (mean ± standard deviation = 6.4 ± 0.3%), the MOE and MOR values were adjusted to those at 12% moisture content (Murata 2017).

The longer logs were sawn into 12 pieces of lumber (50 mm × 100 mm in cross section) (Fig. 1). The lumber was kiln dried at 70 °C to 75 °C of dry-bulb temperature and 43 °C to 86 °C for wet-bulb temperature for 114 h. After kiln drying, the surface of lumber was planed into 38 mm × 89 mm in cross section. Before static bending test, bow, crook, and twist were determined. In addition, DMOE of lumber were also measured by the methods described above. Four-points static bending test was conducted by using a material testing machine (IPA-100R, Maekawa, Tokyo, Japan) under the following conditions: load speed of 14 to 16 mm/min, support span of 1602 mm, distance between load points of 534 mm. After bending test, small-clear specimens were collected and moisture content, density at testing, and annual ring width were measured for the lumber.

RESULTS AND DISCUSSION

The dynamic Young's modulus of sample logs is listed in Table 1. The DMOE values of logs ranged from 9.25 to 11.08 GPa, resulting in the mean value of 10.16 GPa. Nakada *et al*. (2005) reported that the DMOE of logs from 472 plus trees of *L. kaempefri* planted in Japan ranged from 5.7 to 15.2 GPa, and the mean value was 11.4 GPa. Similar results for *L. kaempefri* planted in Japan were obtained by several researchers (Takata and Hirakawa 2000; Nagao *et al*. 2003; Ishiguri *et al*. 2008). On the other hand, the DMOE of logs from *L. sibirica* was 7.6 to 11.2 GPa in Russia (Koizumi *et al*. 2003), 5.17 GPa to 9.72 GPa in five different provenances of Mongolia (Tumenjargal *et al*. 2018), and 6.31 GPa to 9.65 GPa in Tosontsengel, Mongolia (Ishiguri *et al*. 2018). It is considered that the DMOE of *L. gmelinii* var. *olgensis* used in the present study is similar to those of *L. kaempferi* planted in Japan, but relatively higher compared to those of *L. sibirica* grown in Russia and Mongolia.

Figure 2 shows the radial variation of annual ring width. Annual ring width rapidly increased from pith and then showed peak values. After that, it gradually decreased up to around 30th annual ring from pith and then became a constant value. The mean value of five trees was 2.1 mm (Table 2).

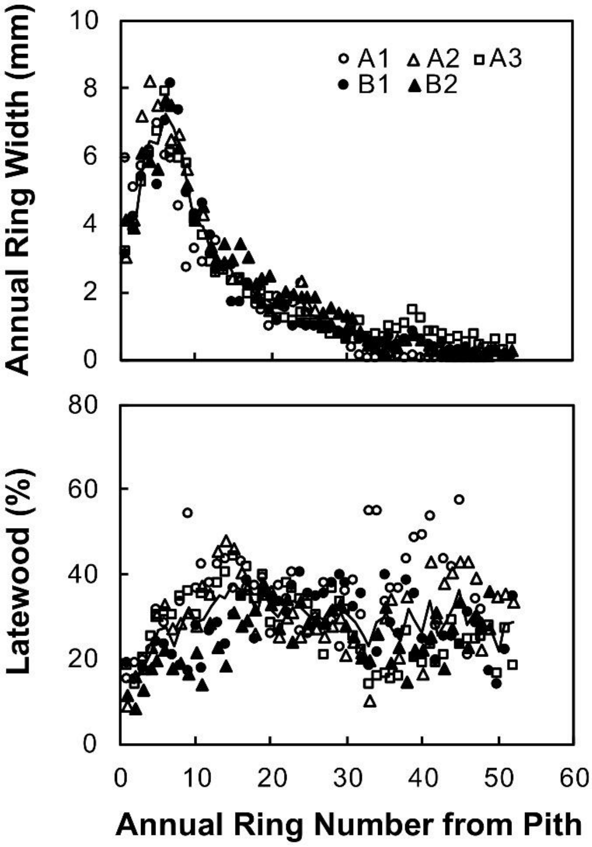

Fig. 2. Radial variations of annual ring width and latewood percentage. Solid lines indicate average values from five trees.

Latewood percentage increased from 30% to 40% at around the 15th annual ring from pith and then fluctuated from 30% to 40% (Fig. 2) with the mean value of five logs was at 29.3% (Table 2). Similar results were obtained in *L. kaempferi* by Takada *et al*. (1992): latewood percentage was 22% to 25% in core wood (pith side), and 37% to 47% in outer wood (bark side). Karlman *et al*. (2005) examined latewood percentage in five different *Larix* species (*L. sibirica, L. sukaczewii, L. decidua, L. x eurolepis*, and *L. kaempferi*) with different ages. They found that first 20 annual rings of the *Larix* species constituted the juvenile wood and had usually a latewood percentage less than 30%. After the period, *L. decidua* and *L. sibirica* had about 40% to 50%, and 40% of latewood, respectively. Radial variation of latewood percentage in the present study was similar to those obtained in other *Larix* species (Takada *et al*. 1992; Karlman *et al*. 2005; Luostarinen 2011). On the other hand, Luostarinen (2011) found no significant correlation between annual ring width and latewood percentage in *L. sibirica* planted in Finland. In *L. kaempferi* wood planted in Japan, a significant negative correlation was found between them in outer wood, but no significance in core wood (Takada *et al*. 1992) was observed. The obtained results in the present study (r = -0.499, p < 0.01, Fig. 3) were similar to those obtained in outer wood of *L. kaempferi* planted in Japan (Takada *et al*. 1992).

Table 2. Wood Properties of *L. gmelinii* var. *olgensis*

Sample	Annual ring width (mm)			Latewood (%)			Basic density (g•cm^{-3})			Bending property							
										n	OD (g•cm^{-3})		MOE (GPa)		MOR (MPa)	
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD		Mean	SD	Mean	SD	Mean	SD
A1	49	1.9	2.1	49	35.8	10.2	6	0.46	0.03	7	0.49	0.04	8.12	1.79	54.6	22.8
A2	52	2.1	2.3	52	30.2	8.8	6	0.46	0.03	9	0.51	0.04	8.25	1.76	66.4	14.5
A3	52	2.1	1.9	52	27.7	8.0	6	0.48	0.01	9	0.53	0.02	8.22	1.56	60.9	14.4
B4	52	1.9	2.1	52	28.0	7.6	6	0.49	0.05	9	0.46	0.05	8.17	2.25	64.9	16.3
B5	49	2.3	2.1	49	24.9	6.9	6	0.46	0.03	12	0.47	0.06	7.51	2.30	55.0	21.6
Mean / total	5	2.1	0.2	5	29.3	4.1	5	0.47	0.01	5	0.49	0.03	8.06	0.31	60.4	5.5

Note: *n*, number of radial positions in 'A1 to B5' and number of trees in 'mean / total'; SD, standard deviation; OD, oven-dry density; MOE, modulus of elasticity; and MOR, modulus of rupture. A1 to B5 indicate individual tree. MOE and MOR values were adjusted to those at 12% MC by the methods described by Murata (2017).

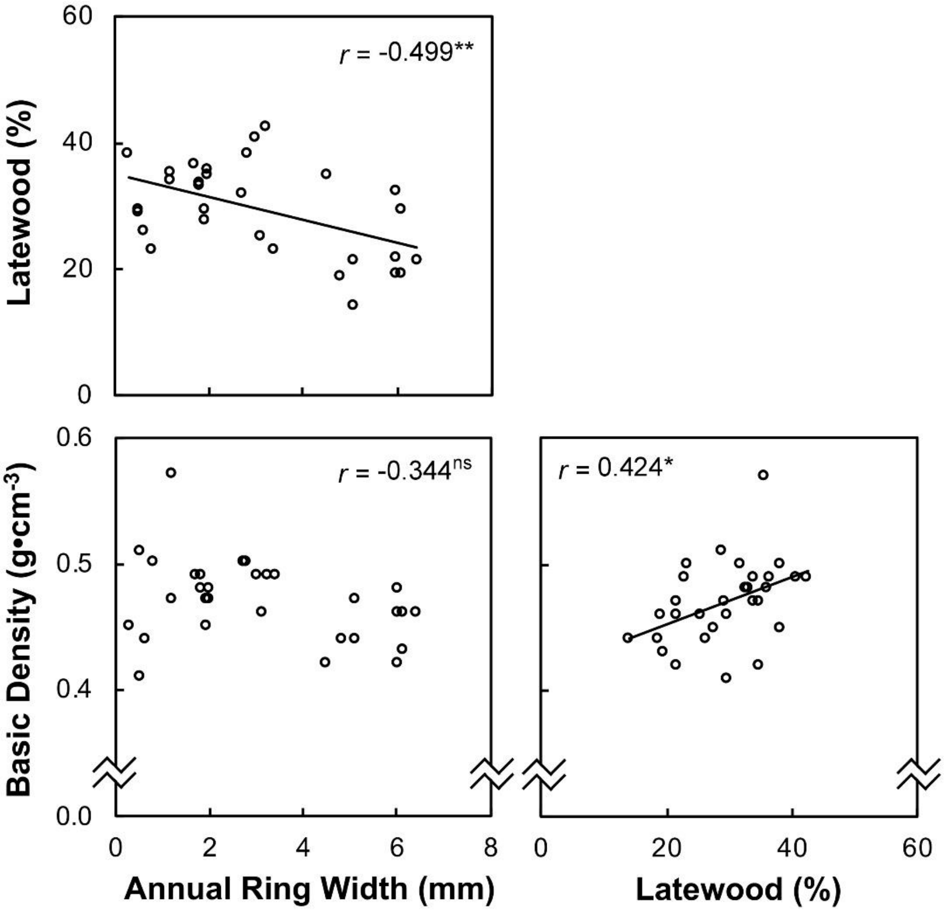

Fig. 3. Relationships between annual ring width, latewood percentage, and basic density. *r*, coefficient of correlation; *, significance at 5% level; **, significance at 1% level; ns, no significance. Circles in those figures indicate mean values at 5 annual rings and mean values after 30 annual ring from pith in each individual tree. Number of radial positions from five trees = 30.

In *L. decidua*, wood density determined by X-ray densitometry was generally lower near the center of stem than in mature outer wood (Keith and Chauret 1998). Koizumi *et al*. (2003) reported that ring density determined by X-ray densitometry gradually increased with ring number within the heartwood region and then decreased within the sapwood region in *L. sibirica* grown in Russia. In 67-year-old *L. kaempferi* grown in Japan, Kawaguchi *et al*. (1987) reported that basic density increased from pith area (0.3 g•cm^{-3}) to about the 15th annual ring from the pith (0.4 g•cm^{-3}), and then gradually increased until reaching the maximum value (0.5 g•cm^{-3}). After that, it gradually decreased and showed the values from 0.43 g•cm^{-3} to 0.45 g•cm^{-3}. The results obtained in the present study were similar to those obtained in other *Larix* species: basic density was lower near pith area and then increased to 0.4 g•cm^{-3} to 0.5 g•cm^{-3} (Fig. 4). As shown in Table 2, the mean value of five sample logs was 0.47 g•cm^{-3}. The mean value was similar to those in *L. gmelinii* var. *olgensis* planted in Japan (Nakagawa 1963), but was relatively higher compared to *L. decidua* (Nakagawa 1963), and *L. kaempferi* (Nakagawa 1963; Kawaguchi *et al*. 1987; Takada *et al*. 1992). It has been reported that, in *Larix* species, the basic density is significantly correlated with latewood percentage, but not with annual ring width (Nakagawa 1963; Takada *et al*. 1992; Luostarinen 2011). Similar tendency was also found in *L. gmelinii* var. *olgensis* in the present study (Fig. 3). On the other hand, Cáceres *et al*. (2017) pointed out that basic density and oven-dry density of *L. kaempferi* were affected by amounts of hot-water extractives. Thus, further research is needed for evaluating the effects of extractives on basic density of this species.

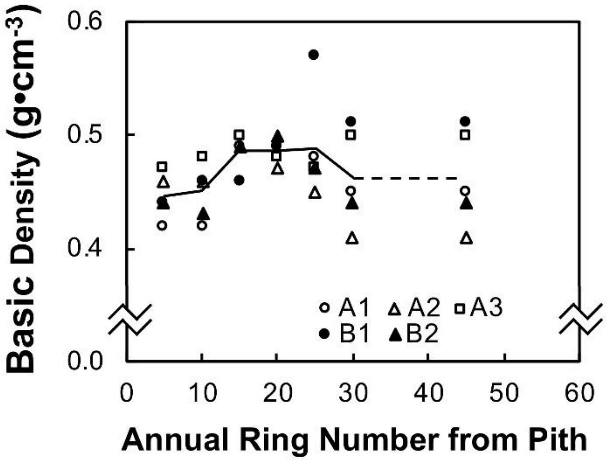

Fig. 4. Radial variation of basic density. Solid and dotted lines indicate mean values. Due to narrower annual ring width after 30th annual ring from pith, the basic density values were determined for one specimen (after 30th annual ring from pith to bark side) in each individual trees.

Figure 5 shows radial variations of MOE and MOR. Both MOE and MOR increased from pith to bark side. In other *Larix* species, the MOE and MOR values were the lowest near the pith and then increased until certain radial position. After that these values gradually decreased or became constant (Kawaguchi *et al*. 1987; Ishiguri *et al*. 2018). Tendency of radial variations in MOE and MOR were similar to that of other *Larix* species, although constant values were not found at bark side in the present study. As shown in Table 2, the mean values of MOE and MOR in five sample trees were 8.06 GPa and 60.4 MPa, respectively. The mean values obtained in the present study were relatively lower compared to those of *L. kaempferi* planted in Japan (Kawaguchi *et al*. 1987; Koizumi *et al*. 2005), *L. sibirica* naturally grown in Mongolia (Ishiguri *et al*. 2018), *L. gmelinii* var. *olgensis* planted in China (Bao *et al*. 2001), and hybrid larch (*L. gmelinii* var. *japonica* x *L. kaempferi*) planted in Japan (Fujimoto *et al*. 2006). Compared to 22 to 30 years old trees of *L. laricina* planted in Canada, the obtained mean values in the present study were relatively higher in MOE, but lower in MOR (Beaudoin *et al*. 1989).

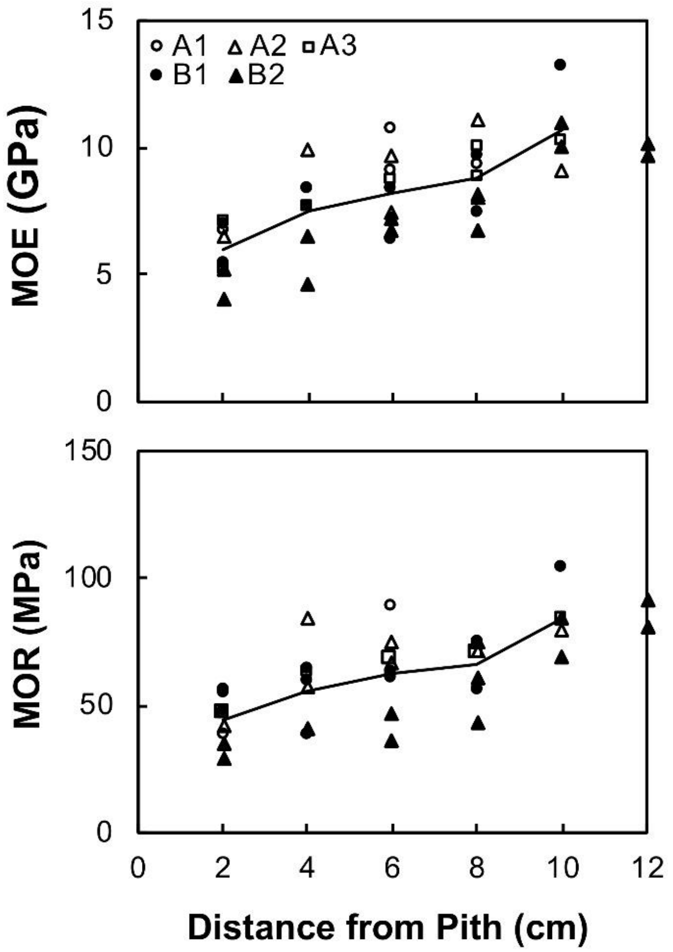

Fig. 5. Radial variations in static bending properties of small-clear specimen. Solid lines indicate mean values.

Table 3 displays the lumber properties. Mean values of crook, bow, and twist of lumber were 0.01%, 0.08%, and 1.60°, respectively. The mean values of DMOE, MOE, and MOR of lumber were 10.99 GPa, 10.43 GPa, and 42.4 MPa, respectively. Miyajima (1985) reported that MOE and MOR of 2 by 4 lumber from 53-year-old *L. kaempferi* planted in Japan were 8.04 GPa and 42.5 MPa, respectively.

Table 3. Lumber Properties of *L. gmelinii* var. *olgensis*

Property	Total (*n* = 12)	
	Mean	**SD**
ARW (mm)	4.6	1.4
MC (%)	10.2	0.4
WD (g•cm^{-3})	0.52	0.03
Crook (%)	0.01	0.03
Bow (%)	0.08	0.08
Twist (°)	1.60	0.91
DMOE (GPa)	10.99	1.24
MOE (GPa)	10.43	1.36
MOR (MPa)	42.4	7.8

Note: *n*, number of lumber; SD, standard deviation; ARW, annual ring width; MC, moisture content determined by oven drying method; WD, wood density at testing; DMOE, dynamic Young's modulus determined by the tapping method; MOE, modulus of elasticity; and MOR, modulus of rupture.

In 2 by 4 lumber from *Larix* species grown in Russia, mean MOE and MOR values in each grading class ranged from 8.62 GPa to 13.23 GPa, and 24.2 MPa to 61.3 MPa, respectively (Iijima 1983). In addition, the mean value of MOR for 2 by 4 lumber from *L. gmelinii* grown in China ranged from 46.7 MPa to 65.1 MPa (Zhong and Ren 2014). The obtained results of MOE and MOR in *L. gmelinii* var. *olgensis* were similar to those in *L. kaempferi* planted in Japan. It is concluded, therefore, that plantation-grown *L. gmelinii* var. *olgensis* is suitable for construction of lumber production.

CONCLUSIONS

1. In *L. gmelinii* var. *olgensis* (syn. *L. olgensis* A. Henry), a 'Near Threatened' species, the dynamic Young's modulus of logs ranged from 9.25 GPa to 11.08 GPa.
2. Mean values of annual ring width, latewood percentage, basic density, MOE, and MOR of five sample logs were 2.1 mm, 29.3%, 0.47 g•cm^{-3}, 8.06 GPa, and 60.4 MPa, respectively.
3. MOE and MOR of 2 by 4 lumber were 10.43 GPa and 42.4 MPa, respectively. These obtained values were similar to those in other *Larix* species.
4. Based on the results, it is considered that the wood resource from plantation-grown *L. gmelinii* var. *olgensis* is suitable for lumber production.

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