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WOOD CHEMICAL COMPONENTS AND DECAY RESISTANCE OF FOUR COMMON MONGOLIAN SOFTWOODS

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ABSTRACT

To utilize wood resources in Mongolia, amounts of wood chemical components (hot-water extracts, 1% NaOH extracts, ethanol-toluene extracts, holocellulose, α-, β-, and γ-cellulose, Klason lignin, and ash) were determined in four common Mongolian softwoods, *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, and *Larix sibirica*. In addition, decay resistance of heartwood was evaluated against a white-rot fungus *Trametes versicolor*, and a brown-rot fungus *Formitopsis palustris*. Among the four species, heartwood of *Larix sibirica* was chemically characterized by higher amounts of hot-water and 1% NaOH extracts, and lower amounts of holocellulose and Klason lignin. These characteristics may be related to the presence of arabinogalactan which is easily extracted with cold water. Mean mass loss in each softwood ranged from 6.9% to 28.1% in white-rot fungus, and from 24.8% to 48.3% in brown-rot fungus. Among four species, *Pinus sibirica* showed the highest decay resistance against both fungi. By the linear mixed-effects model analysis, negative relationships were found between mass loss and amounts of extracts in heartwood, suggesting that heartwood having larger amounts of extracts showed higher natural decay durability.

KEYWORDS: *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, *Larix sibirica*, *Trametes versicolor*, *Formitopsis palustris*, extractives.

INTRODUCTION

Forests of Mongolia are mainly found in the northern parts and west parts of the country (FAO 2020). Almost all forests are natural forests and approximately 80% in stock volume of the forests is occupied by *Larix sibirica* (Ministry of Nature, Environment and Tourism 2019). The

nearly 15% of remaining stock volume is composed of *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata* and others (Ministry of Nature, Environment and Tourism 2019). Thus, these four softwood species are considered as common forestry coniferous species in Mongolia.

Recently, we investigated properties of Mongolian wood (Ayush et al. 2019, Tumenjargal et al. 2019, 2020a,b,c, Erdene-Ochir et al. 2020). In our previous reports, we examined dimension lumber quality of the four common Mongolian softwoods (Sarkhad et al. 2020). We found that bending properties of dimension lumber were almost similar with those in similar species in Japan, US and other countries (Sarkhad et al. 2020). Thus, high quality solid wood can be produced from Mongolian softwoods. On the other hand, natural decay resistance of wood is one of the important factors to utilize the wood resources as solid wood production, especially for construction lumber. However, there is currently no information regarding the natural decay resistance of these four common Mongolian softwoods, with the exception of *Larix sibirica* (Ishiguri et al. 2018).

It is known that natural decay resistance of wood is closely related to the extractive contents (Srinivasan et al. 1999, Taylor et al. 2002, Windeisen et al. 2002, Venäläinen et al. 2003, 2006, Archer and Lebow 2010, Jebrane et al. 2014, Takashima et al. 2015, Belt et al. 2017). Venäläinen et al. (2006) reported that significant negative correlations were found between mass loss of wood by three brown-rot fungi (*Coniophora puteana*, *Poria placenta* and *Gloeophyllum trabeum*) and amounts of extractives such as total phenolics, taxifolin, total flavonoids, and water-soluble extractives in *Larix sibirica* wood. Unfortunately, information about the amounts of wood chemical components including extractives is still limited for all four common Mongolian softwoods except for *L. sibirica* (Ishiguri et al. 2018). Thus, wood chemical components, especially for extractives, should be clarified in relation to natural decay resistance of wood in common conifers grown in Mongolia.

This is the first report dealing with amounts of wood chemical components and decay resistance of four common Mongolian softwoods. We determined amounts of wood chemical components (hot-water extracts, 1% NaOH extracts, ethanol-toluene extracts, holocellulose, α- cellulose, β-cellulose, γ-cellulose, Klason lignin and ash). In addition, decay resistance of heartwood was investigated against a white-rot fungus, *Trametes versicolor*, and a brown-rot fungus, *Formitopsis palustris*. Based on the results, relationships between mass loss and amounts of extractives were discussed.

MATERIALS AND METHODS

Materials

P. sylvestris, *P. sibirica*, *P. obovata*, and *L. sibirica* trees were harvested from natural forests located in Mandal, Selenge, Mongolia (Tab. 1). The samples used in the present study were the same as the samples used in the previous study (Sarkhad et al. 2020). Five trees in each species were harvested. The logs with 50 cm lengths were collected from 0.8 to 1.3 m above the ground. The logs were sawn into radial boards (bark to bark with the pith, 30 mm in thickness) and were subsequently air-dried. A board from a tree of *P. obovata* had partial decay in heartwood. Thus, heartwood samples were collected from the boards of 19 trees. By using these

air-dried boards, heartwood and sapwood wood meal (42 to 80 mesh) and small wood blocks of heartwood (10 x 20 x 20 mm, L x R x T) were prepared for determining the wood chemical components and performing the decay test, respectively.

Tab. 1: Information of sampling sites and sample trees (Sarkhad et al. 2020).

Information		*Pinus sylvestris*	*Pinus sibirica*	*Picea obovata*	*Larix sibirica*
Sampling site	Latitude	48°49´N	48°41´N	48°41´N	48°41´N
	Longitude	106°53´E	106°38´E	106°38´E	106°38´E
Sample	*n*	5	5	5	5
	D (cm)	27.1 (2.2)	26.5 (1.3)	27.9 (2.2)	25.6 (1.6)
	TH (m)	16.2 (2.2)	11.9 (1.5)	14.3 (2.3)	15.3 (1.3)
	ARN	72 (3)	62 (4)	60 (6)	50 (9)

Note: *n*- number of sample trees; *D*- stem diameter at 1.3 m above the ground; TH- tree height; ARN- annual ring number at 1.3 m above the ground. Values in parenthesis are standard deviation. Number of heartwood samples in *P. obovata* was four due to partial decay of heartwood.

Wood chemical components

The following wood chemical components were determined: hot-water extracts, 1% NaOH extracts, ethanol-toluene extracts, holocellulose, α-cellulose, β-cellulose, γ-cellulose, Klason lignin, and ash. These chemical components were quantified according to the method described by Kuroda (2000).

Decay resistance

The decay test was conducted according to the Japan Industrial Standard (JIS) K1571: 2010 and Takashima et al. (2015). A white-rot fungus, *Trametes versicolor* (FFPRI 1030), and a brown-rot fungus, *Formitopsis palustris* (FFPRI 0507), were used as the fungal materials. The heartwood samples were weighed after oven-drying at 60°C for 48 hours, and then sterilized with propylene oxide for 2 days. Three sterilized heartwood samples were placed on the surface of the fungal mat which was spread out on the medium (4% glucose, 0.3% peptone, 1.5% malt extracts, and 2.0% agar) in plastic bottles (9.5 cm in diameter and 850 mL in volume). Three bottles were prepared in each tree and fungus. The fungi with heartwood specimens were cultured at 26 ± 2°C and 70% relative humidity for 12 weeks. After 12 weeks of incubation, mycelium was carefully removed from the heartwood specimens using small brash or tweezers. Heartwood specimens were weighed after oven-drying at 60°C for 48 hours. To compare the degree of decay, sapwood samples of *Cryptomeria japonica* were also tested using the same method.

Statistical analysis

Statistical analysis was conducted by R software (R Core Team 2020). For the wood chemical components, mean values and standard deviations in each species were calculated from the data collected from each tree and wood type (heartwood or sapwood). Mean values of mass loss after the decay test in a tree were calculated by averaging the mass loss data of nine heartwood specimens from three plastic bottles for a species. The mean, standard deviation, and minimum and maximum values in each species were calculated by using the mean value for

a tree. The Tukey HSD test (5% level) was applied for detecting the differences of mass loss among species. To evaluate the relationships between mass loss and amounts of extracts in sound wood, the following linear mixed-effects model with species as random intercept was developed by using lmer function in lme4 package (Bates et al. 2015):

$$y_{ij} = \beta_0 x_{ij} + \beta_1 + u_{1j} + e_{ij} \quad (1)$$

where: y_{ij} is the measured value for the ith individual tree of the jth species; x_{ij} is the ith individual tree of the jth species, β_0 and β_1 are the fixed effects parameters, u_{1j} is the random effect of β_1 at the species levels, and e_{ij} is residual. Correlations of determination (R^2) were calculated for each linear mixed-effects model by using the rsq.lmm function in the rsq package (Zhang 2020).

RESULTS AND DISCUSSION

Wood chemical components

Tab. 2 shows amounts of wood chemical components in four common Mongolian softwoods. *L. sibirica* heartwood showed higher amounts of hot-water and 1% NaOH extracts and lower amounts of holocellulose, α-cellulose and Klason lignin as compared to the three other species. With the exception of *L. sibirica*, amounts of wood chemical components in heartwood were similar to those in sapwood. The heartwood of *L. sibirica* contained a large amount of arabinogalactan, which is easily extracted with hot or cold water (Côté et al. 1966, Venäläinen et al. 2006). Higher amounts of arabinogalactan in heartwood may potentially result in lower amounts of polysaccharides and Klason lignin.

Tab. 2: Amounts of wood chemical components in four Mongolian softwoods.

Species	Wood type	Extracts (%)			HC (%)	Cellulose (%)			KL (%)	Ash (%)
		Hot water	1% NaOH	ET		α	β	γ		
Pinus sylvestris	HW	5.6	17.4	5.8	81.5	50.3	1.9	28.7	27.8	0.3
		(1.7)	(2.4)	(3.3)	(2.1)	(2.0)	(0.4)	(1.3)	(1.9)	(0.1)
	SW	3.6	16.1	4.1	79.3	50.6	3.0	25.7	28.1	0.4
		(0.5)	(0.9)	(0.7)	(1.0)	(1.8)	(0.7)	(1.4)	(2.7)	(0.2)
Pinus sibirica	HW	9.3	21.2	7.0	76.7	46.0	1.9	28.8	28.1	0.3
		(1.1)	(2.0)	(1.3)	(2.9)	(2.3)	(0.5)	(0.9)	(1.7)	(0.1)
	SW	5.9	17.8	5.4	76.6	46.9	2.8	26.9	30.0	0.4
		(0.3)	(1.1)	(0.7)	(3.0)	(3.6)	(1.0)	(1.4)	(3.2)	(0.0)
Picea obovata	HW	3.2	13.3	2.8	79.0	49.0	3.3	26.7	28.0	0.4
		(1.0)	(0.8)	(1.0)	(0.9)	(0.9)	(0.9)	(1.3)	(0.8)	(0.1)
	SW	3.5	13.9	2.9	77.9	48.7	2.9	26.3	29.0	0.3
		(0.7)	(0.3)	(0.7)	(3.0)	(2.5)	(0.8)	(0.7)	(0.8)	(0.1)
Larix sibirica	HW	18.9	27.4	5.4	62.6	38.2	2.3	22.2	23.6	0.4
		(4.0)	(5.2)	(1.9)	(5.5)	(5.5)	(0.5)	(2.5)	(2.1)	(0.1)
	SW	4.9	14.3	6.3	78.6	50.8	2.4	25.4	27.1	0.3
		(1.1)	(1.8)	(4.3)	(2.7)	(3.9)	(0.5)	(3.4)	(0.6)	(0.1)

Note: ET- ethanol-toluene; HC- holocellulose; KL- Klason lignin; HW- heartwood; SW- sapwood. Values in parenthesis indicate standard deviations. Number of sample trees n = 5 except for α-, β-, and γ-cellulose in heartwood of *P. sylvestris* (n = 4) and heartwood of *P. obovata* (n = 4).

Amounts of wood chemical components of Japanese softwoods similar to Mongolian softwood species used in the present study are shown in Tab. 3. Compared to Japanese species, Mongolian softwoods showed relatively higher amounts of holocellulose and α-cellulose, although amounts of other wood chemical components were similar.

Tab. 3: Amounts of wood chemical components in Japanese softwoods (Yonezawa et al. 1973).

Species	Extracts (%)		Holocellulose (%)	α -cellulose (%)	Klason lignin (%)	Ash (%)
	Hot water	Ethanol-benzene				
Pinus densiflora	3.3	2.7	71.1	46.5	26.0	0.33
Pinus densiflora	3.9	4.1	65.8	43.6	26.1	0.22
Pinus densiflora	5.7	2.9	65.2	43.6	27.9	0.22
Pinus thunbergia	3.0	3.3	62.9	44.0	25.8	0.21
Pinus pentaphylla	3.2	8.1	68.4	44.5	27.1	0.27
Picea jezoensis	3.6	1.3	71.0	47.3	28.4	0.20
Picea glehnii	3.6	2.0	73.5	49.9	27.8	0.20
Picea hondoensis	3.3	2.2	64.4	41.9	28.8	0.15
Larix kaempferi	9.5	3.2	68.5	47.8	28.0	0.34

Note: Wood chemical components, except for holocellulose and α-cellulose, were determined by method described in JIS. Holocellulose was determined by the Wise method.

Decay resistance

Tab. 4 shows the mass loss of heartwood in four Mongolian common softwoods by *T. versicolor* and *F. palustris*. The mean mass loss ranged from 6.9% to 28.1% in *T. versicolor* and from 24.8% to 48.3% in *F. palustris*. In all four species, mass loss by *F. palustris* was higher than by *T. versicolor*. In general, most brown-rot fungi affect conifers, while white-rot fungi occur more frequently on hardwoods (Schmidt 2006). Our results were similar to those of the previous report (Schmidt 2006).

Among four species, *P. sibirica* heartwood showed the highest decay resistance against both *T. versicolor* and *F. palustris*, whereas mass loss in *P. obovata* showed the highest values (Tab. 4). In Japanese softwoods, a similar tendency was also found: *P. pentaphylla* (five-needle pine, similar to *P. sibirica*) showed relatively higher decay resistance, and mean values of *Picea* species (*P. jezoensis*, *P. glehanii*, and *P. hondoensis*) showed the lowest resistance.

Tab. 4: Mass loss (%) of heartwood specimens by T. versicolor and F. palustris.

Fungus	Statistics	*P. sylvestris*	*P. sibirica*	*P. obovata*	*L. sibirica*	Control
T. versicolor	*n*	5	5	4	5	1
	Mean	14.1^{ab}	6.9^{b}	28.1^{a}	23.4^{a}	34.3
	SD	4.6	1.7	16.3	7.6	5.4
	Min	9.2	5.0	11.2	15.5	-
	Max	19.7	9.6	43.6	32.1	-
F. palustris	*n*	5	5	4	5	1
	Mean	44.5^{a}	24.8^{b}	48.3^{a}	30.5^{b}	51.4
	SD	10.6	7.2	7.3	8.7	6.9
	Min	29.3	16.7	42.5	19.3	-
	Max	55.3	34.6	59.0	41.5	-

Note: *n*- number of sample trees (one tree has nine specimens). Control was sapwood of *C. japonica*. The same alphabet letters after mean values indicate no significances among species at 5% level in the Tukey HSD test.

Fig. 1 shows relative mass loss against the mass loss of sapwood of *Cryptomeria japonica*. Fig. 1 also included the relative mass loss for Japanese softwoods calculated from the data listed in Tab. 5. Compared to the Japanese two-needle *Pinus* spp., *P. sylvestris* showed a similar ratio in *T. versicolor* but a relatively higher ratio in *F. palustris*. In *P. sibirica*, the ratio in *T. versicolor* was lower than that of *P. pentaphylla*, whereas the ratio was higher in *F. palustris*. *P. obovata* showed a lower ratio compared to the Japanese *Picea* spp. in both fungi. *L. sibirica* showed a higher ratio in *T. versicolor* and a lower ratio in *F. palustris* as compared to *L. kaempferi*. It is concluded that higher decay resistance was found in *P. sibirica* against *T. versicolor*, *P. obovata* to both fungi, and *L. sibirica* to *F. palustris* compared to similar Japanese softwoods.

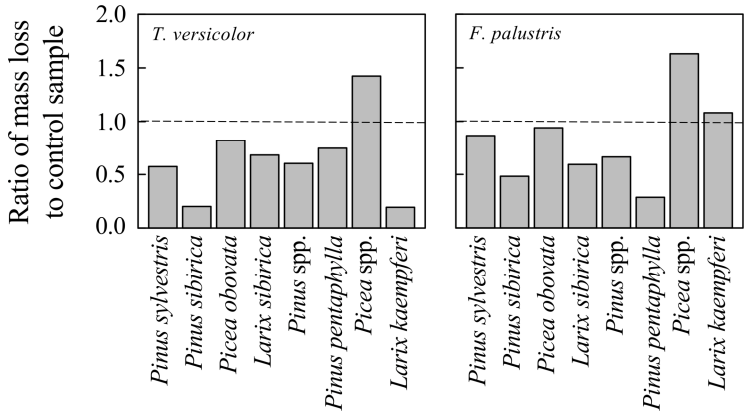

Fig. 1: Mass loss ratio of Mongolian species and Japanese softwoods against mass loss of sapwood in Cryptomeria japonica. Data of four Mongolian species are listed in Tab. 3. Data of Pinus spp. (two-needle pine), P. pentaphylla, Picea spp., L. kaempferi are listed in Tab. 5.

Tab. 5: Mass loss (%) of heartwood in Japanese softwoods by T. versicolor and F. palustris (Wood Technology and Wood Utilization Division 1982).

Species	*T. versicolor*	*F. palustris*
Pinus densiflora	7.0	8.0
Pinus densiflora	2.5	1.2
Pinus densiflora	3.6	13.1
Pinus thunbergia	5.4	3.2
Pinus (two-needle pine, mean)	4.4	7.4
Pinus pentaphylla	2.3	2.0
Picea jezoensis	11.7	20.1
Picea glehnii	13.9	17.5
Picea hondoensis	5.3	17.2
Picea spp. (mean)	10.3	18.3
Larix kaempferi	1.4	12.1
Cryptomeria japonica (SW)	10.8	11.9
Cryptomeria japonica (SW)	6.4	6.2
Cryptomeria japonica (SW)	4.5	15.5
Cryptomeria (SW, mean)	7.2	11.2

Note: Decay test was conducted according to JIS Z2119 (sample size = 20 x 20 x 20; incubation period 60 days). Two-needle pine, *Picea* spp., and *Cryptomeria* was calculated from averaging the two *Pinus* species (*P. densiflora* and *P. thunbergia*), three *Picea* species (*P. jezoensis, P. glehnii*, and *P. hondoensis),* and three *Cryptomeria japonica*, resp. SW- sapwood.

Amounts of extracts are closely related to the natural decay resistance of wood (Taylor et al. 2002, Windeisen et al. 2002, Venäläinen et al. 2003, 2006, Archer and Lebow 2010, Takashima et al. 2015). The heartwood of many tree species exhibits some degree of resistance to attack by decay fungi and insects, and this natural durability can be attributed to a combination of toxic extractives present in the wood as well as low inherent permeability (Archer and Lebow 2010).

Relationships between mass loss and amounts of extracts in normal wood are shown in Fig. 2.

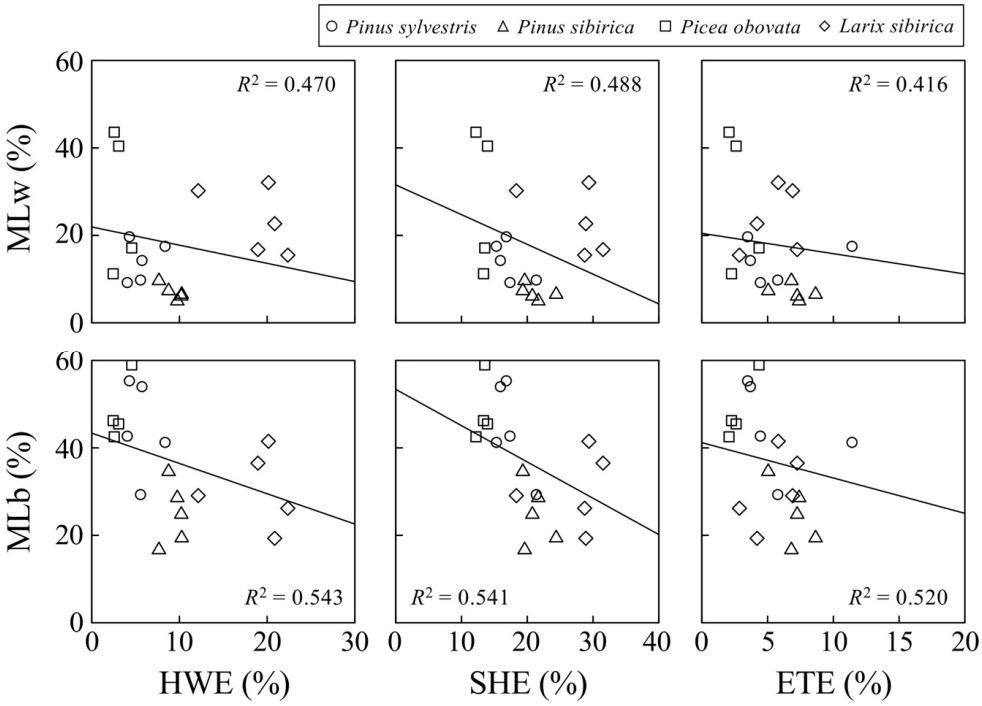

Fig. 2: Relationships between amounts of extracts in heartwood of sound wood and mass loss of heartwood specimens by T. versicolor and F. palustris (n = 19, HWE- hot-water extracts; SHE- 1% sodium hydride (NaOH) extracts; ETE- ethanol-toluene extracts; MLw- mass loss by T. versicolor; MLb- mass loss by F. palustris). Regression lines indicate linear mixed-effects models with species as random intercepts. R^2 is correlation coefficient of the linear mixed-effects model.

By the linear mixed-effects model, mass loss by both fungi was negatively correlated with amounts of extracts, suggesting that wood with larger amounts of extracts has a strong decay resistance. Specifically regarding mass loss by *F. palustris*, correlations of determination showed higher values, indicating that the relationships between mass loss and amounts of extracts in *F. palustris* is stronger than those in *T. versicolor*. In regards to *P. sibirica*, mass loss was significantly lower among four species, and amounts of extracts in heartwood showed relatively higher values. Thus, heartwood of *P. sibirica* may include some extractives with antifungal activities. Further research is needed to clarify the natural decay ability in *P. sibirica* growing in Mongolia.

CONCLUSIONS

In the present study, amounts of wood chemical components and decay resistance of wood against a white-rot fungus, *Trametes versicolor*, and a brown-rot fungus, *Formitopsis palustris*, were determined for four common Mongolian softwoods, *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, and *Larix sibirica*. Compared to Japanese species, Mongolian softwoods showed relatively higher amounts of holocellulose and α-cellulose, although amounts of other wood chemical components were similar. In addition, heartwood of *Larix sibirica* was characterized by higher extracts and lower holocellulose and Klason lignin due to the presence of arabinogalactan. The highest decay resistance of heartwood was found in *Pinus sibirica* for both fungi. Negative correlations were obtained between mass loss and amounts of extracts by linear mixed-effects models, suggesting that heartwood having larger amounts of extracts showed higher natural decay durability.

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