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Breeding a hybrid larch in Hokkaido, northern Japan

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Abstract

Japanese larch *(Larix kaempferi*) is an important afforestation species in the boreal temperate zone. However, this species is sensitive to vole (*Myodes rufocanus bedfordiae*) gnawing and shoot blight disease by *Botryosphaeria laricina*. We developed the hybrid larch (*L. gmelinii* var. *japonica* × *L. kaempferi*) to overcome these problems. In addition to improving the resistance to vole gnawing and shoot blight disease, this hybrid showed high wood density and carbon accumulation ability, calculated with DBH, tree height, wood density, and tree number/ha. Wood density is inherited equally from the female and male parents, and growth traits are mainly inherited from the male parent. The hybrid larch exhibited a high Young's modulus and its expected use was for medium and high-rise buildings. Hybridization rates were higher (84.2 – 94.1%) in a single maternal clone seed orchard compared to a multi-clone female and male seed orchard. We propagated nursery stocks of high carbon accumulating females (named "Clean-larch") by rooted cutting with hybridized seedlings produced in a single maternal clone seed orchard. The hybrid larch is susceptible to Armillaria root rot. A research task left for the future is to find the optimum method for selecting the planting area for hybrid larch and Japanese larch.

Key words: Kuril larch, Japanese larch, wood density, carbon accumulation, Young's modulus, Armillaria root rot

Introduction

Japanese larch (*Larix kaempferi*) is one of the most important afforestation species in the boreal temperate zone of Japan because of its rapid growth potential (Ryu et al., 2009; Kita et al., 2018). Japanese larch is native to central Japan, and was introduced to Hokkaido in the late 19th century. In 2019, 4,500 ha of Japanese larch was planted and was the most planted species in Hokkaido, a northern island in Japan. In the 1950s and 1960s, more than 20,000 ha yr^{-1} (Fig. 1) of Japanese larch was planted.

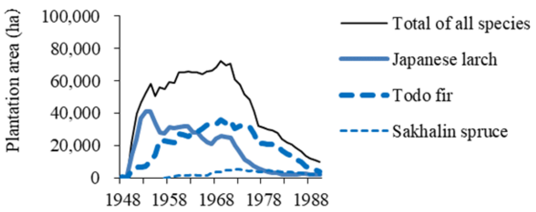

Figure 1. The transition of plantation in Hokkaido from 1948 to 1990

However, this species has some disadvantages for afforestation: sensitivity to vole (*Myodes rufocanus bedfordiae*) gnawing and shoot blight disease by *Botryosphaeria laricina* (Qu et al., 2022). In that period damage by mammals (mainly vole gnawing) (Fig. 2) reached 67,000 ha yr^{-1} and shoot blight disease impacted 70,000 ha yr^{-1} (Hokkaido, 1962; Yokota, 1967, 1968).

The stems of Japanese larch aren't straight, a reason for the decreasing timber yield (Hokkaido Forest Products Research Institute, 2005). As a result, in 1964, Todo fir (*Abie, sachalinensis*) replaced Japanese larch as

Figure 2. Gnawing damage by vole (*Myodes rufocanus bedfordiae*)

the most planted species. However, Japanese larch returned to the top position in 1998 (Fig. 3), because the Japanese larch plantations established in the 1950s became a suitable age for clear cutting.

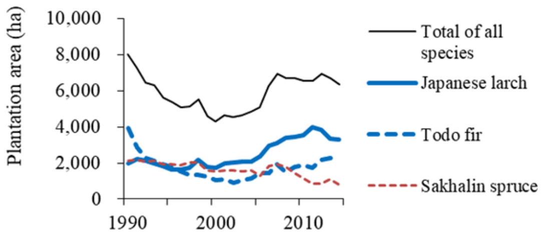

Figure 3. The transition of plantation in Hokkaido from 1990 to 2014

We crossbred *L. gmelinii* var. *japonica* (Kuril larch) and Japanese larch to create a hybrid to overcome the

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disadvantages of Japanese larch. Kuril larch is a regional variation of *L. gmelinii* and found in the Sakhalin and Kuril Islands, Russia. This species was distributed to Hokkaido in the Last Glacial Period and disappeared from Hokkaido 8,000 years ago because of increasing temper-atures.

The genetic materials of Kuril larch and Japanese larch for the tree breeding program were plus-trees selected from plantations in Hokkaido during the 1950s and 1960s.

This report introduces the genetic parameters for growth and wood properties in this hybrid larch (*L. gmelinii* var. *japonica* × *L. kaempferi*), the production methods for seed and nursery stock, and a future research task; reduce the hybrid larch's susceptibility to Armillaria root rot.

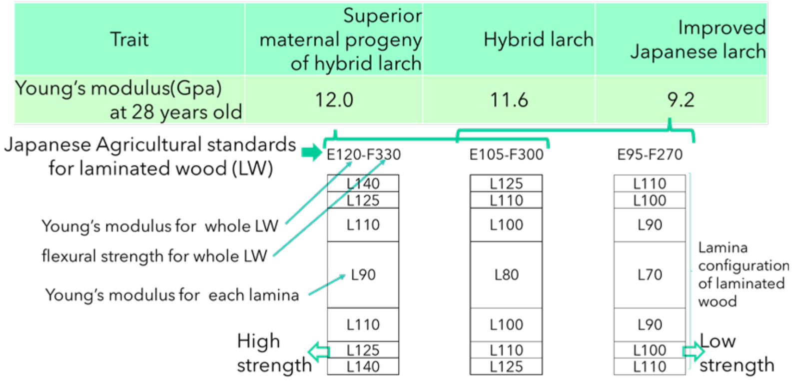

Figure 5. Nine-layer lamina configuration of laminated wood conforming to Japanese Agricultural standards for laminated wood

Figure 4. A progeny test forest consisted of artificial crossing full-sib families at 31 years old at Niikappu in Hokkaido, Japan

Growth and wood property

We established three, plus-tee progeny test plantations in 1974 in eastern (Kun-neppu), western (Bibai) and southern Hokkaido (Niikappu) (Fig 4). These test forests consist of 21 artificial crossings of full-sib families between Kuril larch and Japanese larch (hereinafter referred to as "hybrid larch families" in this section) and open pollinated half-sib families of pure Japanese larch (hereinafter referred to as "plus-tree Japanese larch" in this section). The mean stand volume of hybrid larch families in the three progeny test plantations was 327 m^3/ha at 31 years old. Stand volume in the best female family of the maternal clones was Nakashibetsu 5 (hereinafter referred to as "Nakashibetsu 5 family" in this section) was 354 m^3 ha^{-1}, which was slightly smaller than the plus-tree Japanese larch (Table 1). Narrow sense heritability of DBH and tree height for the hybrid larch families were 0.16 and 0.20, respectively, and DBH and tree height derived from the male parents were larger than those derived from the female parents (Kita et al., 2009).

Wood density sampled in Bibai and Kun-neppu were 0.547 g cm^{-3}, 0.544 g cm^{-3}, and 0.504 g m^{-3} for the Nakashibetsu 5 family, hybrid larch families, and plus-tree Japanese larch, respectively (Table 1). Wood density of the hybrid larch families is inherited equally from both parents, and its narrow sense heritability was 0.28 (Kita et al., 2009). The mean of carbon accumulation amount for the best full-sib family, female parent half-sib family (Nakashibetsu 5 family), and male parent family among the hybrid larch families at the three sites were 106.1, 84.6, and 93.2 C ton ha^{-1}, respectively. These values exceeded those for , which was 82.5 (Table 1). The data shows that hybrid larch progenies display high carbon accumulation ability.

The Young's modulus of timber milled from the logs harvested in the progeny test forest at Bibai was investigated. According to the Japanese agricultural standards (JAS) for laminated timber, the grades L140, L125, and L110 for lamina require Young's modulus to be more than 14.0 GPa, 12.5 GPa, and 11.0 GPa, respectively. The mean value of the plus-tree Japanese larch was 8.8 GPa, and 78% of its lamina met the lamina grades from L70 to L125 (MOE ranges from 7 to 14 GPa), making two grades of laminated timber, E105-F300 and F95-F270 (Fig. 5). However, only 2% had Youngs modulus over 14 GPa, so making E120 -F330 would be difficult with Japanese larch only (Nei et al., 2006). The mean values of Nakashibetsu 5 family and hybrid larch families were 11.1 GPa, and 10.6 GPa, respectively, and they can used for E105-F300, and E120-F330 because 78% and 10% of laminae were over 8 GPa or 14 GPa. The hybrid larch is expected to replace imported wood for high value structural laminated wood.

Table 1. The results of the progeny test forest for the hybrid larch at Kun-neppu, Niikappu, and Bibai in Hokkaido, Japan.

Trait	Nakashibetsu5 family	Hybrid larch families	Plus-tree Japanese larch
Stand volume (m^3/ha) at 31 years old	354	327	364
Wood density (g/cm^3) at 28 years old	0.547	0.544	0.504
Carbon storage in stem (C-ton/ha)	84.6	76.7	82.5

Seed and nursery stock production for a high carbon accumulating female family

We selected the Nakashibetsu 5 family because it

Figure 6.
The selected the superior female family named "Cleanlarch" that maternal plus-tree is "Nakashibetsu5" in Kuril larch and paternal parents are multi clones of Japanese larch plus-tree (31 years old at Niikappu in Hokkaido, Japan).

shows beneficial properties for forestry, such as resistance to vole gnawing and shoot blight disease, fast growth in the juvenile stage, high accumulation of carbon in stem, high strength wood, and straight stem. We named this progeny "Clean-larch" (Fig. 6), and propagated it for plantations.

A common seed orchard for forest trees is composed of many clones to enhance the genetic diversity of the progeny because the long generation time of forest trees increases the chance of them suffering damage. A common seed orchard of hybrid larch is composed of multi-clone Kuril larch and multi-clone Japanese larch (Fig. 7). In the common hybrid larch seed orchard in Kun-neppu, hybridization rates were 23.2 – 53.6%, depending on pollen amount each year; however, larch species easily hybridize (Kita et al., 2014). Crossings within species also occurred in the hybrid larch seed orchard, and we distinguished between hybrid seedlings and pure species seedling by phenotypic traits such as terminal bud-set phenology, number of sylleptic shoots, root collar diameter, and seedling height (Kita et al., 2014).

The female parent of Clean-larch is a single clone. Therefore, the seed orchard for Clean-larch is composed of single-clone Kuril larch "Nakashibetsu 5" × multi-clone Japanese larch (Fig. 7). We call it a "single maternal clone seed orchard." Hybridization rates in the single maternal clone seed orchard were 84.2 – 94.1% without the effects of pollen amount because self-pollination crossing within the female parent and Kuril larch displayed intense inbreeding depression (Moriguchi et al., 2008).

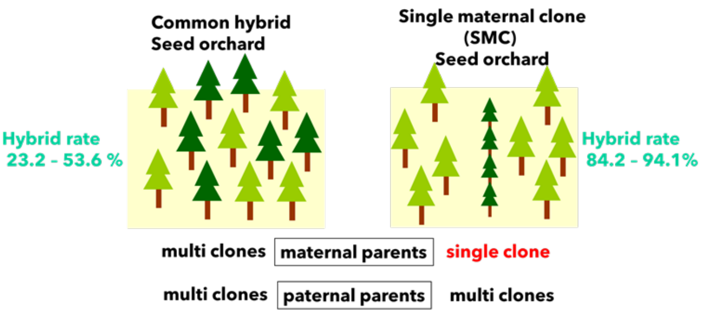

Figure 7. The image diagram of common hybrid seed orchard for hybrid larch and single maternal clone seed orchard for Clean larch

Single maternal clone Clean-larch seed orchards (22.24 ha) were established at Kun-neppu in 1994 and 1996. Seeds have been harvested since 2003, but they cannot produce enough seedlings to meet the demand for nursery stock. Therefore, we propagate nursery stocks of Clean-larch by rooted cutting. Rooted cutting is done with two-year old seedlings to maintain rooting rate and avoid plagiotropism (=the condition of a gene affecting more than one characteristic of the phenotype).

Private nurseries produced 220 thousand rooted cuttings of Clean-larch in 2020. Since 2017 local governments in Hokkaido have planted nursery stocks of Clean-larch to produce 2.8 million trees by 2036 (Hokkaido, 2017), and as of 2020, 22 private nurseries, forest owner cooperatives, and municipalities have established 35 ha of Clean-larch seed orchards.

Research task left for the future - Armillaria root rot

Root rot caused by *Armillaria* sp. is a severe disease of the larch species, preventing regeneration of larch plantations. The Armillaria species is broadly distributed in forest soil (Ota, 2006, 2020). Twelve varieties have been reported in Japan, and *Armillaria ostoyae* shows high pathogenicity in larch trees. A symptom of an infected larch tree (less than ten years old) is resin leakage from the trunk, followed by the tree's death. A critical problem for our larch breeding program is that the Kuril larch is more sensitive to Armillaria root rot than the Japanese larch. From 2002 to 2004, we established five test plantations of the hybrid larch in different regions in Hokkaido: Tsubetsu, Bihoro, and Churui (east), Shibetsu (north), and Yuni (central). Resin leakage from trunks was first observed when the trees reached three years old in all the test plantations.

Figure 8. Rooted cuttings of Clean larch

Death rates of planted larches with resin leakage to planted trees and the death of all trees were 2.3 – 14.7% and 16.8 – 53.1% in the five hybrid larch test plantations for five-year-old trees, respectively (Fig. 8). It was severe, especially in the three plantations located in eastern Hokkaido (Bihoro, Churui, and Tsubetsu). These results suggest that there is a regional difference in the severity of Armillaria root rot. Therefore, selecting a suitable area for a hybrid larch plantation is crucial for its success.

Future perspectives

We started hybrid breeding of larch to improve the resistance to vole gnawing (*Myodes rufocanus bedfordiae*) and have also developed progeny with superior growth potential and strong wood.

Research tasks left for the future of the hybrid breeding program are to reveal the pathogenicity and distribution of Armillaria species and find a method to select the optimum area for planting hybrid larch and Japanese larch to achieve the best outcomes.

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