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Forest Tree Breeding for Japanese larch

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Abstract

Literatures related to the forest tree breeding for Japanese larch were reviewed in the six research fields: seed orchard, progeny testing, and wood quality improvement, breeding for resistance, hybrid larch and breeding in abroad. Procedure of seed orchard establishment was studied intensively during 1960's, and then the focus was moved on to the orchard management for efficient seed production in 1970's. Papers reporting the results of progeny tests appeared in 1980's and then the topic shifted toward genetic parameters estimated in control pollinated progeny test in 1990's. Research on wood quality improvement was conducted in two ways: improvement in spiral grain and assessment on wood qualities as sawn timber. Systematic study on resistance breeding to needle cast disease was started in 1960's and the result was reported in the late of 1970's. Advantages with hybrid larch were recognized since 1960's, and several registered varieties were developed recently with its efficient seedling production system.

Key words: forest tree breeding, hybrid breeding, Japanese larch, progeny test, seed orchard

Introduction

Japanese larch, *Larix kaempferi*, is one of the major plantation species in Japan and thus the tree breeding had been started in the north-central regions of Japan in the early 1950's (Toda 1979; Ohba and Katsuta 1991). Until 2000, 530 plus trees of Japanese larch had been selected and they are used in 35 clonal seed orchards of 172 hectors to produce improved seeds in Kanto, Tohoku and Hokkaido breeding regions. In addition, Kuril larch, *L. gmelinii* that has been long recognized as a promising species for hybrid breeding with Japanese larch (Kurahashi 1988; Chiba 1997), has been selected from plantations in Hokkaido and they are used in establishing hybrid orchards with Japanese larch.

Tree breeding for Japanese larch has been conducted almost the same procedure as other Japanese major plantation species; starting with plus tree selection followed by the establishment of clonal seed orchards, then the seeds from the orchards were used for operational reforestation as well as progeny testing (Toda 1979; Ohba and Katsuta 1991). Some notable features with the breeding of Japanese larch might be the emphasis on hybrid breeding and wood quality improvement. Therefore the literature is reviewed by establishing the following six chapters; seed orchard, progeny testing, wood quality improvement and breeding for resistance, hybrid and abroad.

Seed orchard establishment and management

In the early stages of seed orchard, fertilizer application including site selection, density control and tree forming for seed trees in the orchard were investigated to develop a standard procedure on seed orchard management for Japanese larch (Momose 1967b; Mori 1972). After seed trees reached the size for flowering, budding which is a modified grafting technique using small bud as scion to graft on to the seed trees, was recommended to save time until flowering (Hamaya *et al.* 1968, 1989), although the budding is effective when it is done with the stocks of abundant flowering (Hamaya *et al.* 1989, Kawamura 1992).

Fairly long interval of heavy seed crop year, once per five to seven years under natural condition, was recognized as a major obstacle in producing improved seed from the seed orchards of Japanese larch (Momose 1967a). It was reported that the seed crop in the orchards is closely related to the previous year's climate: total sunny days with less precipitation during May until July will enhance flowering differentiation and hence resulting a heavy seed crop in the next year (Goushu 1980). For this reason, various flowering-stimulation techniques had been tested and stem girdling for seed trees was found to be most effective (Hamaya and Kurahashi 1970; Mikami *et al.* 1979; Momose 1967a). Root pruning was effective also (Itahana *et al.* 1983; Itahana 1984), while hormone applications did not give any significant increase in flowering (Mikami *et al.* 1979).

Flowering and mating occurring in the orchards were studied to increase quality of the seed as well as to develop control pollination technique. Male flowering starts few days earlier than the females for most of the clones, while all of them seemed to have a chance for self-pollination because of the overlapped flowering period of the both (Itoh *et al.* 1979). This inference would be supported by the fact that 98-100% of ovules were found to be pollinated by one-day natural pollination (Yokoyama 1975), although filled seed rate by artificial self-pollination was variable among clones (Yokoyama and Kaneko 1979). According to the results of controlled pollination clonal variation in the number

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of seed per corn and filled seed rate were significantly different (Katsuta *et al.* 1979), while the repetition of pollination does not increase the filled seed rate as long as it is done at an optimum stage (Yokoyama *et al.* 1973).

Seed-orchard seeds were generally larger in size, heavier than the ordinary seed by 30% and they tend to show better germination rate at the nursery in spite of the significant variation among parent clones (Kaji and Hatakeyama 1979a, 1979b). These desirable characteristics are beneficial in seedling production at the nursery, whereas these physiological advantages coupled with a rapid initial growth persisted until one years of age then they were replaced with the inherent superiority of the seed parents (Kaneko 1974).

Progeny test and genetic gain

Superiority of plus tree progeny growth over the commercial check were confirmed with open pollinated progeny tests in Central Honshu and Hokkaido, although there was a significant variation among plus tree families. Average superiority of the plus tree progeny in height across 12 tests in Central Honshu was 7% at 5 years old (Kaneko 1980; Kurinobu *et al.*1982a) and 5% across 15 tests at 10 years old (Kaneko and Kurinobu 1986). This superiority tends to be evident in the tests established at fertile site (Kurinobu *et al.*1982a). In Hokkaido, the percentage superiority was 3% at the first year (Kaji and Hatakeyama 1979b), whereas it increased up to 6% at 10 and 15 years old (Oshima 1991, 1998b).

Genotype-environment interaction detected by the progeny testing is sometimes not neglectable to realize maximum genetic gain to be brought by seed orchard rouging based on progeny test. Significant family-site interaction was reported in the progeny tests at one year old in Hokkaido (Kaji *et al.* 1979). Highly significant interaction was also observed at five years' measurements across the 12 progeny tests in Central Honshu, whereas the interaction could be reduced by classifying the tests into three zones; the area closer to the species natural habitat, the marginal area and outside the natural distribution (Kurinobu *et al.*1982b). In addition, the three zones were well described with the differences in seasonal rainfall patterns (Kurinobu 1984).

Since most of the plantations of Japanese larch were established to produce sawn timber, stem straightness is also an important trait that can be assessed after 10 years old. According to the result of assessments with subjective scoring system, plus tree progenies were better than the commercial check by 4% and there is no significant correlation with the growth traits (Oshima 1988, 1991, Oshima and Takahashi 1991). The result of direct measurement on stem crookedness revealed that the percentages of above second graded logs were 30% for commercial check and 45% for plus tree progeny (Oshima 1998b).

Controlled pollinated progeny tests were established in several locations in Central Honshu and Hokkaido to estimate heritability and related genetic parameters. Reciprocal effect observed in the two years' seedling height of 8 x 8 complete diallel cross was considered partly due to the maternal effects caused by the differences in their seed size (Kaneko 1979). According to the results of analysis for the two sets of factorial mating (6 x 6), narrow sense heritability for height was 0.37 at the nursery stage (Kawasaki *et al.* 1992), then it reduced to around 0.2 at 5 years old (Kawasaki *et al.* 1997; Kubota *et al.* 2000). In the case of stem straightness, GCA was reported as predominant (Oshima *et al.* 1997) and the narrow sense heritability was estimated around 0.33 at 20 years old (Oshima and Kuromaru 1996).

Wood quality improvement

Wood quality improvement for Japanese larch might be divided into two categories; improvement on density and module of elasticity (Hatakeyama 1983; Katayose 1984); and improvement on spiral grain (Mikami 1988). The first category is common to most of the Japanese plantation species, the most concern laid in a simultaneous improvement in growth and wood quality, while the second one is peculiar to the plantation grown Japanese larch that tends to show end splitting and twisting caused by spiral grain.

Average spiral grain of plantation grown Japanese larch is ranging from 2° to 10° with an average of around 6° and it is under strong genetic control as reported by several studies with stem disks sampled from the clone bank (Mikami *et al.* 1972; Hanabusa *et al.* 1980; Kaneko 1981; Fujisawa *et al.* 1999). The broad sense heritability was 0.4 at 8 years old (Mikami *et al.* 1972), 0.5 at age 15 years old (Hanabusa *et al.* 1980) and the correlation with diameter was weak and not significant (Hanabusa *et al.* 1980; Kaneko 1981; Mikami 1988; Fujisawa *et al.* 1999). For this reason, national forest tree breeding center conducted a five-years' project to select additional plus trees with less spiral grain from the plantations in Hokkaido, Tohoku and Central Honshu since 1980 (Mikami 1986). Total number of plus trees selected for less spiral grain was 239 among those, 61 from Hokkaido (Orita and Katayose 1986), 81 from Tohoku (Kawamura *et al.* 1986) and 97 from Central Honshu (Kaneko *et al.* 1986), and their grafts were kept at the clone banks in the respective regions. Controlled pollinated progenies from the above plus trees showed positive response in the spiral grain and the amount of genetic progress, reduction in spiral grain, was roughly equal to the predicted gain (Kawamura 1993). Tissue culture technique was also applied for mass production of clones with less spiral grain and then it successfully developed to regenerate plantlets and acclimatization (Itahana 1986, 1993). However, the technique has not been applied operationally.

Despite the drawbacks of spiral grain, Japanese larch is an unique plantation species in the cool temperate region of Japan that could not be replaced with other native conifer; hence the study on wood quality improvement has been conducted to examine their genetic variation and interrelationships. Highly significant clonal variations were reported in module of elasticity (Takata *et al.* 1989; Koizumi *et al.* 1990a;

Katayose *et al.* 1991; Fujisawa *et al.* 1998) as well as in specific gravity (Orita 1985; Oshima *et al.* 1985; Koizumi *et al.* 1988; Koizumi *et al.* 1990a; Katayose *et al.* 1991; Fujisawa *et al.* 2000). These two traits are well correlated each other (Koizumi *et al.* 1988; Katayose *et al.* 1991), however, they are regarded as independent from the growth: annual ring width or diameter (Oshima *et al.* 1985; Koizumi *et al.* 1988, 1990b; Takata *et al.* 1989; Katayose *et al.* 1991; Fujisawa *et al.* 1998). In addition, clonal ranking in module of elasticity was fairly stable between different locations (Takata *et al.* 1989) and relatively strong parent-offspring correlation in specific gravity was confirmed in a controlled pollinated progeny test (Oshima 1998a). These results suggest that the wood quality improvement might be possible for Japanese larch without reducing the superiority of growth that has been achieved so far.

Resistance breeding for pests and diseases

Needle cast disease, not fatal but causing a great loss in growth, is one of the major diseases spreading out almost whole of the plantation areas of Japanese larch. To cope with this disease, research project on resistance breeding had been conducted by Forestry & Forest Products Research Institute, Japanese Forestry Agency since 1958. Disease free individuals in heavily infested stand were grafted and then they were tested in the field to grade their tolerance to the disease (Kobayashi *et al.* 1979). Controlled pollinations were made among the susceptible parents and the tolerant ones (Watanabe *et al.* 1979), and then the progenies were tested with artificial inoculation at the nursery to examine the inheritance of the tolerance (Yokozawa *et al.* 1979; Hayashi *et al.* 1979; Hayashi 1992). According to the results of analysis on the inoculation tests, tolerance to the disease was regarded as under poly-gene control, while it was easily affected by genotype environment interaction (Akasi *et al.* 1979). Under similar concept of the research, a result of the field test on shoot blight disease, *Guignardia laricina* Yamamoto *et.* Ito, was reported (Yokozawa 1981; Noguchi and Yokozawa 1985).

Another serious pest to the Japanese larch is vole damage in Hokkaido. It has long been recognized that Japanese larch is prone to vole attack compared to Kuril larch (Takahashi and Hamaya 1973), whereas they're found a variation in the vole's preference among clones (Chiba *et al.* 1982) as well as progenies (Iizuka *et al.* 1993) according to the feeding tests.

Hybrid breeding and vegetative propagation

Unlike the hybrid larch in Europe, the hybrid between Kuril larch, *L. gmelinii* and Japanese larch, *L. kaempferi* was proved as promising in Hokkaido. The current share of the hybrid has reached almost one third of the operational reforestation area of larch with the expansion of hybrid orchards in Hokkaido (Kudoh 1998). The primary reason for this high popularity of the hybrid larch is due to its good growth and tolerance to the vole damage (Takahashi *et al.* 1967; Chiba *et al.* 1982; Kurahashi 1988a).

Practical advantages for the production of hybrid larch are high frequency of natural hybridization and distinct morphological differences of the hybrid from the ordinary Kuril larch. Flowering seasons for the two species, Kuril larch and Japanese larch, are overlapped by one week under normal climate, thus abundant pollen from Japanese larch tends to fertilize with female flowers of Kuril larch when they are planted together (Kurahashi 1988a, 1988b). Percentage of hybrid seed from Kuril larch is ranging from 30 to 60% depending on the position and flowering habit of parent trees (Shimizu *et al.* 1991). Hybrid seedlings are easily sorted from the seedling of Kuril larch by examining the three distinct characters; seedling height (higher for hybrid), winter bud formation (later for hybrid) and branching habit (denser for hybrid) (Kurahashi 1988a; Takahashi and Hamaya 1973).

The hybrid shows slightly better growth than that of Japanese larch until 10 years old (Takahashi *et al.* 1967; Chiba and Nagata 1980), however, Japanese larch outperformed the hybrid in diameter growth after 10 years old (Kurahashi 1993). Despite the relative performance mentioned in the above, fairly large variation among the F1 hybrid was reported (Kurahashi *et al.* 1985; Fukuchi 1987), thus the choice of parent trees for hybridization would be also essential. According to the current research results, stem straightness was found as an evident advantage with the hybrid (Kuromaru *et al.* 1995). Percentage of the above second-class log was 70% for the F1 hybrid, much higher than those for improved Japanese larch: 45% and ordinary one: 30% (Kuromaru 2000).

With a careful choice of mating parents based on performances in the previous trial, two F1 hybrids were approved as registered cultivars (Kurahashi 1993; Kuromaru 2000), however, the constant supply of hybrid seed is still a problem except for a few heavy crop years (Kurahashi *et al.*. 1986; Nagata 1986). One of the possible option to cope this problem would be a mono-clonal orchard where selected clones of Kuril larch with high-GCA (general combining ability) was planted at the spot after removing several lines of seed trees in an ordinary seed orchard of Japanese larch. With this replacement of seed trees, hybrid percentage from the orchard increased up to 90% (Kuromaru *et al.* 2003). Other practical option might be a production of rooted cuttings from the hybrid seedlings at the nursery (Kuromaru and Kita 2003). This procedure seems economically feasible as compared to the mass production system with tissue culture that had been studied for many years (Kuromaru 1988, 1991; Kuromaru and Nishikohri 1994).

Overseas breeding and tree improvement for Japanese larch

Japanese larch was introduced and tested for breeding mainly in Europe, northern China and northeastern part of America where the climates are similar to the natural habitat in Japan and it sometimes outgrows indigenous larches (Park and Fowler 1983).

In Europe, Japanese larch has received much attention on the use of hybrid with European larch

(Paques 1989; Weiser 1992), hence the mating systems occurred in the hybrid orchards were investigated with using isozyme genetic markers (Hacker and Bergmann 1991; Ennos and Tang 1994). DNA marker (RAPD) was also applied to estimate genetic distance and they found that crosses between genetically distant parents produce hybrids with excellent growth performances (Arcade *et al.* 1996). Field test with stem cuttings of hybrid among the three larch species: European larch, Japanese larch and tamarack (*Larix lariciana*) was measured at age 8 years and the hybrid between European larch and Japanese larch was found to be the best in terms of growth (Paques 1992).

In China, Japanese larch had been introduced for operational reforestation to the northeastern provinces since 1930's then they were spread to the high-mountainous areas in Central provinces also (Kohno 1999). Japanese larch has become one of the major species in the northeastern provinces because of its rapid growth as compared to their native larches; *Larix olgensis* A. Henry and *Larix principis rupprechtii* Mayer (Kah 1996; Kah *et al.* 1996). For this reason, breeding programs for Japanese larch had been conducted for several decades in China and Korea and studies on seed production in the orchard (Wang *et al.* 2000), introduction strategy (Zhou *et al.* 1999), hybrid performances (Shin and Karnosky 1995; Zhang *et al.* 1998) were reported.

In the northeast America, Japanese larch grows better under mild climate, while the hybrid with European larch tended show higher survivals at other sites (Zaczek *et al.* 1994). According to the results of provenance trials, several studies suggested a good possibility for tree improvement by choosing promising provenances (Farnsworth *et al.* 1972; Park and Fowler 1983). Based on these finding combined with the previous study results, a breeding strategy using hybrid between European larch and Japanese larch was proposed (Li 1994).

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