Pinaceae—Pine family

Larix P. Mill.

larch

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Occurrence. The larches—*Larix* P. Mill.—of the world are usually grouped into 10 species that are widely distributed over much of the mountainous, cooler regions of the Northern Hemisphere (Hora 1981; Krüssmann 1985; Ostenfeld and Larsen 1930; Rehder 1940; Schmidt 1995). Some species dominate at the northern limits of boreal forests and others occur above subalpine forests (Gower and Richards 1990). Seven species are included (table 1)—the others, Master larch (*L. mastersiana* Rehd. & Wils.), Chinese larch (*L. potaninii* Batal.), and Himalayan larch (*L. griffithiana* (Carr.))—are rarely planted in the United States. All species (except possibly Himalayan larch) are hardy in the United States (Bailey 1939). However, the seeds should come from a site with comparable conditions, as demonstrated at the Wind River Arboretum in southwestern Washington, where 7 larch species, some with several varieties, and 1 hybrid were planted from 1913 to 1939 (Silen and Olson 1992). European larches there are doing better than Asian species in this warm, moist Washington state climate. The native western larch from more continental climates with lower humidity are doing poorly. In 1992, a larix arboretum containing all species, several varieties, and 3 hybrids of larch was established at Hungry Horse, Montana, within the natural range of western larch (Shearer and others 1995).

Growth habit. Larches are unique among conifers because their needles are deciduous. The trees are valued for their light green hues in the spring and shades of yellow to gold in the fall. Branching is usually pyramidal with spreading branches (Hora 1981). Maximum height for the 10 species ranges widely, influenced by elevation and site conditions. Subalpine and Chinese larches often grow at or near timberline and mature trees may reach only 7 to 13 m in height (Krüssmann 1985). The tallest known subalpine larch, as reported by Arno and Habeck (1972), grows on a protected, favorable site and reached 46 m. Western larch, tallest of the world's larches species, can reach about 61 m (Schmidt and others 1976; Schmidt and Shearer 1990).

Use. Of the 3 American species, tamarack and western larch are used for reforestation. Because of its rot resistance, larch wood is especially valuable for posts, transmission poles, railroad ties, and mine props. Most larches are now recognized as important for timber production, habitat or food for wildlife, watershed protection, environmental forestry, and also for ornamental purposes (Rudolf 1974). Venetian turpentine can be obtained by tapping larches; a water-soluble trisaccharide sugar melecitose is extracted from wood chips (Dallimore and Jackson 1967; Hora 1981). Probably because of this high sugar content, black bears—*Ursus americanus cinnamomum*—often seek out vigorous young pole-size western larch in late spring and feed on the inner bark and cambium, usually on the lower 1 to 2 m of the trees (Schmidt and

Gourley 1992). Often the trees are girdled and die; partially girdled trees frequently produce large cone crops following damage (Shearer and Schmidt 1987).

Genetics. Larch species vary widely in growth rates, cold hardiness, form, pest resistance, and other characteristics. This variability is often under strong genetic control and genetic gain is expected through tree improvement efforts (Eysteinsson and Greenwood 1995). Winter hardiness, change in foliage color, and cessation of height growth of Japanese larch were correlated with latitude of provenance origin, but date of bud flush was not (Toda and Mikami 1976). Further, branching habit, stem crookedness, spiral grain, and disease susceptibility varied between provenances. Genetic variation of tamarack throughout its range is comparable to other species of woody plants with extensive ranges (Cheliak and others 1988). Based on genetic differences in total height and survival of 210 clones of 5-year-old vegetatively propagated tamarack in central New Brunswick, Park and Fowler (1987) believed that clonal forestry was a good option for this species. Farmer and others (1993) also showed genetic variation in height of tamarack was related to rate and duration of shoot elongation and from differences in late-season elongation.

Conversely, low genetic variation occurs among populations of western larch for growth, phenology, and cold hardiness (Rehfeldt 1982) compared with other Rocky Mountain conifers. Rehfeldt (1983) identified an 11% variation associated with the elevation of the seed source and recommended that seedlots not be transferred more than " 29 m or "2 contour bands. Based on genetic variation in allozymes of western larch seeds, Fins and Seeb (1986) cautioned transferring seeds from eastern Washington to north Idaho and recommended that seedlots for planting should include seeds from a diversity of locations within an area. Hall (1985) concluded that yields of cones and seeds from interspecific and intraspecific crosses and open-pollinated seeds of European larch were reduced in hybrid crosses compared to non-hybrid crosses. Wide variation in yield suggests that both genetic and environmental factors are important in controlling yield of seeds.

Hybrids. Larches hybridize readily (Rudolf 1974; Lewandowski and others 1994; Young and Young 1992), and geographic isolation is a major factor for lack of hybridization. Natural hybrids of western and subalpine larches occur where their ranges overlap (Carlson and Blake 1969; Carlson and others 1990). Seeds from natural hybrid trees closely resemble those of western larch (Carlson and Theroux 1993). Reciprocal cross pollinations between western and subalpine larches were successful, and germination of seeds from these crosses was higher than that of seeds from either parent (Carlson 1994).

L. kaempferi H *decidua,* known as *L.* H *eurolepis* A. Henry and commonly called Dunkeld larch, originated about 1900. It has been planted extensively in northwestern Europe and to a lesser extent in the eastern United States and Canada because it combines desirable characteristics of both parent species and grows faster than either (Eliason 1942; MacGillivray 1969). *L. kaempferi* H *sibirica*, known as *L.* H *marschlinsii* Coaz, was originated in 1901. *L. laricina* H *decidua*, known as *L. pendula* Salisb. or weeping larch, was originated before 1800 (Rehder 1940). Many other larch hybrids are known. Several larch species and hybrids were tested as potential short-rotation fiber crops for the Northeast and the Great Lakes region (Einspahr and others 1984) and in Wisconsin (Riemenschneider and Nienstaedt 1983); Dunkeld larch showed best growth in both studies. Seeds from a single provenance of Japanese larch and 6 provenances of European larch had, after 5 years, 3 times the growth potential of seeds from native red pine (*Pinus resinosa* Ait.) in another Wisconsin study (Lee and Schabel 1989).

Geographic races. Geographic races have developed in many widely distributed larch species, and these often exhibit marked differences in growth rates and other characteristics (Rudolf 1974). The European larch includes at least 5 geographic races (often considered to be subspecies or varieties) that roughly coincide with major distributional groups of the species (Debazac 1964; McComb 1955):

- Alpine, in south central Europe
- Sudeten, principally in Czechoslovakia
- Tatra, in Czechoslovakia and Poland
- Polish, principally in Silesia
- Rumanian (several small outliers)

The races differ in seed size and viability, survival after planting, growth rate, phenology, form, and resistance to insects and disease (Dallimore and Jackson 1967; McComb 1955; Rudolf 1974). The races respond differently in different localities, but in the northeastern United States and Canada, the Polish and Sudeten races grow most rapidly and are recommended for planting there although they do not always have the best form (Hunt 1932; MacGillivray 1969). Sindelar reported (1987) that in Czechoslovakia, seedlings of Dunkeld larch and *L. decidua* H *gmelinii* grew better on sites with high levels of pollution than did European larch seedlings. Sindelar (1982) recommended that seed orchards of European larch contain many clones in order to prevent excessive propagation of a few fertile clones. A Scots race mentioned in older references probably developed in Scotland from plants of Sudeten origin (Rudolf 1974). European seed sources perform similarly in northeastern United States as in Great Britain, Germany, and Italy (Genys 1960).

Some varieties of Dahurian larch that are confined to definite areas appear to be geographic races (Debazac 1964). These include the following varieties:

- *japonica* (Maxim. ex Regel) Pilg.
- *principis-rupprechti* (Mayr) Pilg.
- *olgensis* (A. Henry) Ostenf. & Syrach., known as Olga Bay larch (Rehder 1940)

In China, *L. principis-rupprechti*, and Olga Bay and Chinese larches are recognized as distinct species rather than geographic races of Dahurian larch (Chinese Academy of Sciences 1978). Tests in Finland showed marked differences in survival, growth rate, cold hardiness, and susceptibility to insect attack between trees from Korean and Sakhalin seed sources (Kalela 1937). A limited trial in North Dakota was unsuccessful (Cunningham 1972). Trees of Olga Bay larch seem suitable for planting in north central United States and adjacent Canada.

Because of the extensive natural range of tamarack, geographic races probably exist. Studies by Cheliak and others (1988); Farmer and others (1993), and Park and Fowler (1987) reported differences in growth, such as total height based on latitude and late-season elongation. Two-year-old seedlings of tamarack grown in Minnesota from seeds from several origins showed significant differences in total height and a tendency for bud set to occur earliest in seedlings from northern sources (Pauley 1965).

Japanese larch is native to a 363-km^2 area in the mountains of central Honshu, where it grows in scattered stands at elevations of 900 to 2,800 m (Asakawa and others 1981). Despite this small native range, test plantings of Japanese larch in several parts of the United States and eastern Canada, Japan, China, Great Britain, and Germany have shown significant differences among seed sources in tree height, survival, terminal bud set on leader, number of branchlets, insect resistance, winter and spring cold damage, and susceptibility to sulfur fumes (Hattemer 1968; Heimburger 1970; Lester 1965; MacGillivray 1969; Wright 1965). Progeny of seeds from diverse sources respond differently to particular environments, so that no general recommendations can be made as to the best races for specific localities. However, seeds from sources in the northern part and the higher elevations of Honshu have produced progeny with earlier hardening off and less early frost damage than have seeds collected from farther south and at lower elevations (Hattemer 1968; Heimburger 1970; Lester 1965; Wright 1965).

Siberian larch stock grown from seeds from the Altai region seem to be less cold hardy than stock grown from seeds from other parts of the range (Tkachenko and others 1939). Limited trials in North Dakota suggest that this species could be used as the tallest member of a multiple-row shelterbelt (Cunningham 1972).

Flowering. Male and female flowers of the larches are borne separately on the same tree. Cones are usually scattered throughout the non-shaded crown with seed cones more frequent higher in the crown and pollen cones more frequent lower in the crown (Eis and Craigdallie 1983), but there usually is considerable overlap. They occur randomly with the leaves on the sides of twigs or branches and usually open a few days before needle elongation. The male flowers are solitary, yellow, globose-to-oblong bodies that bear wingless pollen. The female flowers are small, usually short-stalked, erect, red or greenish cones that ripen the first year. The seed cones and pollen cones usually are differentiated in terminal positions on short-shoot axes that completed at least 1 cycle of annual growth (Krüssman 1985; Owens and Molder 1979a). However, the seed and pollen cone buds of tamarack (Powell and others 1984) and Japanese larch (Powell and Hancox 1990) can differentiate laterally on long shoots the year they elongate. Furthermore, as tamarack plantations go from 5, 6, to 7 years of age, the number of trees bearing seed and pollen cones and the number of cones per tree increased each year (Tosh and Powell 1991). Top-grafting buds of 2-, 5-, 9-, 45-, and 59-year-old Japanese larch on 17-year-old trees shortened the time to produce female and male strobili by about 5 years over untreated controls (Hamaya and others 1989). Loffler (1976) found that yield of European larch seeds in seed orchards usually increased with graft age and in comparison to the natural forest, the cones provided more and larger seeds of better quality. Ten years after planting in a common garden, western larch cone production was twice as great for trees grafted with mature scions as for seedlings and five times greater than for rooted cuttings (Fins and Reedy 1992). The number of seed and pollen cones increased on 30- to 32-year-old western larch as average spacing expanded from 2 m to 3 m and wider (Shearer and Schmidt 1987). The average number of cones produced per tree during a good cone crop increased 27 times as the diameter classes increased from 10 to 15 cm to 30 to 36 cm, a reflection of the greater crown volume (Shearer 1986). Xu (1992) found similar relationships for Dahurian larch in China.

There was no relationship of the number of cone scales of Olga Bay larch or their color, shape, size, or structure to site characteristics, developmental stage of trees, or other biological factors (Suo 1982). Developing larch cones range in color from red to green with a range of intermediate shades. Raevskikh (1979) reported that red- and green-coned forms of Dahurian larch produced better quality seeds than did rosy-coned forms. Western larch cones are red, green, and brown in color, but no differences were detected in seed quality by color (Shearer 1977). Ripe cones become brownish and have woody scales, each of which bears 2 seeds at the base (Dallimore and Jackson 1967; Rehder 1940). The seed has a crustaceous, light-brown outer coat, a membranaceous, pale chestnut-brown, lustrous inner coat, a light-colored female gametophyte, and a well-developed embryo (figures 1 and 2) (Dallimore and Jackson 1967; Rehder 1940). Occasionally, atypical cones are found on larches. Tosh and Powell (1986) identified and studied proliferated and bisporangiate cones on tamarack planted 5 or 6 years earlier.

A 10-year phenological record of western larch in the Northern Rocky Mountains showed a wide range in time of bud-burst, pollination, and cone opening (Schmidt and Lotan 1980). A 21-year phenological study of subalpine larch showed that spring temperature, not photoperiod, was a chief factor that determined bud-burst date (Worrall 1993). Morphological studies increased our understanding of characteristics of cones and seeds of tamarack (O'Reilly and Farmer 1991) and for subalpine and western larches and their natural hybrids (Carlson and Theroux 1993). Seedcoats of subalpine larch are thicker than those of western larch and may be a partial barrier to germination (Carlson 1994).

Larch seeds are winged, nearly triangular in shape, and chiefly wind dispersed. Empty cones may remain on the trees for an indefinite period. Seeds of western larch carry long distances (Shearer 1959), but seeds of tamarack in Alaska fall close to the point of origin (Brown and others 1988).

An embryological study of European, Japanese, and Siberian larches showed that the embryos attained full size by early- or mid-August and that the seeds were fully developed by the end of August. The development was most rapid in Siberian larch (Hakansson 1960). Larches often have a high proportion of hollow seeds, as reported by Shearer (1990) and Trenin and Chernobrovkina (1984). The time of pollination is critical to development of viable and high-quality western larch seeds (Owens and others 1994). The high proportion of non-viable seeds was attributed to (1) underdeveloped ovules at pollination; (2) ovules that either were not pollinated or were not fertilized; (3) factors that prevented pollen germination, pollen tube growth, or fertilization; (4) problems associated with self-pollination; and (5) inhibited ovule development. Shin and Karnosky (1995) identified abortion of female strobili and embryo degeneration as major factors reducing seed yields of tamarack and European, Japanese, and Siberian larches in the upper peninsula of Michigan, although the previously mentioned 5 factors also caused seed loss. Factors contributing to empty seeds in European larch included lack of pollination, disturbances during megasporogenesis, failure of pollen to reach and germinate on the nucellus, and embryo degeneration (Kosinski 1986, 1989).

Throughout much of the range of western larch, frost often limits the number of developing cones that mature (Shearer 1990). Lewandowski and Kosinski (1989) described spring frost damage to 14 grafted Polish clones in a seed orchard of European larch. In late May 1968, frost completely killed the cone crop of Olga Bay larch growing above 1,000 m in northeastern China (Suo 1982). Frost may also limit cone production of ssubalpine larch most years (Arno 1990). Loffler (1976) found that late spring frost killed a high proportion of European larch cones. An inexpensive electrical resistance device that prevents frost damage has been used to protect pollinated female strobili of European and Dunkeld larches after controlled crossings (Ferrand 1988).

Indoor (potted) orchards are used to produce western larch seeds and to control the environmental conditions that often limit cone production in natural or planted stands (Remington 1995). Ross and others (1985) suggested many other advantages. Flowering of tamarack was promoted on potted, indoor, and field-grown grafts by foliar sprays of giberellin ($GA_{4/7}$) and root pruning (Eysteinsson and Greenwood 1990). Seed cone flowering decreased per centimeter of branch length as ortet age increased from 1 to 74 years (Eysteinsson and Greenwood 1993). Ross (1991) determined that response to combinations of stem girdles and $GA_{4/7}$ injections on 17-year-old western larch varied greatly in flowering response. Only the effects of girdling (not $GA_{4/7}$) were effective in promoting strobilus production in grafts on 10-year-old Japanese larch (Katsuta and others 1981).

Damage. During poor cone crop years with some larch species, many of the seeds are destroyed by weevils (Rudolf 1974). Several insects limit western larch cone and seed production. The major cone feeding insects are the larch cone maggot (*Strobilomyia laricis* Michelsen), western spruce budworm (*Choristoneura occidentalis* Freeman), a woolly adelgid (*Adelges viridis* Ratzeburg), and cone scale midges (*Resseliella* sp.) (Dewey and Jenkins 1982; Jenkins and Shearer 1989; Miller and Ruth 1989; Shearer 1984, 1990). Turgeon (1989) determined that larvae of the larch cone maggot infested more tamarack cones in the upper and mid-crowns than cones in the lower crowns. Larvae of the larch cone maggot also feed on cones of Siberian, European, Dahurian, and Japanese larches and tamarack in southern and central Finland (Pulkkinen 1989). During infestations of the western spruce budworm, the insect larvae decrease cone production of western larch by severing cone-bearing twigs and also by damaging developing cones and seeds on the trees (Fellin and Schmidt 1967; Fellin and Shearer 1968). Similarly, the eastern spruce budworm (*Choristoneura fumiferana* (Clem.)) greatly decreases cone and seed production of tamarack (Hall 1981). The eastern spruce budworm and cone fly (*Lasiomma viarium* Huckett) larvae caused most damage to seeds of tamarack in 1982 and 1983 in New Brunswick and Maine, whereas other insects caused lesser damage (Amirault 1989; Amirault and Brown 1986). A recent review of insects that may influence larch cones and seeds in Canadian seed orchards listed 19 species in 4 families: 1 insect species for subalpine larch, 17 species within 4 families for tamarck, and 4 species within 3 families for western larch (de Groot and others 1994). In British Columbia, neither tamarack nor western larch have major insect pests (Eremko and others 1989).

Atmospheric fluorides can reduce the size of seeds, percentage germination, numbers of seeds per cone, and numbers of cones per tree. Reproductive failure and mortality of tamarack in Newfoundland have resulted in their replacement by more tolerant species (Sidhu and Staniforth 1986).

Micropropagation and genetic engineering. Micropropagation techniques can supplement reliance on larch seeds for a broad range of tree improvement and regeneration needs. Karnosky (1992) suggests biotechnology can help produce genetically superior larch by (1) mass propagation, (2) disease screening, and (3) transfer genetic information through genetic engineering techniques. Organogenesis from young and mature larch callus tissues is reported (Bonga 1984; Chapula 1989). Lelu and others (1993) developed somatic embryogenesis techniques for several species and hybrids of larch. Full-sib immature zygotic embryos were produced from induction of embryonal masses for European and Dunkeld larches and *Larix* H *leptoeuropaea* (Lelu and others 1994a). Thompson and von Aderkas (1992) successfully regenerated western larch from immature embryos. Protoplasts of Dunkeld larch can be effectively isolated from embryonal mass and cultured to produce somatic plantlets (Charest and Klimaszewska 1994). Further, Lelu and others (1994b) showed that the number of mature somatic embryos of *Larix* H *leptoeuropaea* produced per gram (fresh weight) of embryonal mass was influenced by embryogenic line, sucrose concentration, and abscisic acid concentration. No universal maturation medium was recommended because of the interactive effects of these 3 factors. High plantlet survival was achieved in the greenhouse through either of 2 acclimatization methods (Lelu and others (1994c). In gymnosperms, gene transfer was first accomplished in European larch; transfer was mediated by *Agrobacterium rhizogenes* and subsequent regeneration of the transgenic plants (Huang and others 1991). Shin and others (1994a & b) reported that transgenic European larch plants were produced that use *Agrobacterium*-mediated single gene transfer to promote insect (*Bt* toxin gene) and herbicide (*aroA* gene) resistance.

Collection of cones. Larch cones should be collected as soon as they ripen; different species ripen at various times from August to December (table 2). Larch cones are picked from trees in forests, seed production areas, seed orchards, and potted tree collections or they can be gathered from felled trees, slash, or squirrel caches. In Tyrol, European larch seeds were picked from the snow by hand; they can also be gathered in late winter from canvas spread on the ground before the trees were shaken to release the seeds (Rudolf 1974). In most species, ripe cones are brown. Tests show that seedcoats are hard and that female gametophytes are firm. Often seeds mature earlier than expected and the period for cone collection for tamarack (Smith 1981) and western larch (Shearer 1977) can be expanded. Cones of Siberian larch should be harvested when needles start to turn yellow to assure high-quality seeds (Lobanov 1985). Data on height, seed-bearing age, seed crop frequency, and ripeness criteria are listed in tables 3 and 4.

Extraction of seeds. Freshly collected cones should be spread out in thin layers to dry in the sun or in well-ventilated cone sheds. The cones can be opened by solar heat, by heating in a cone kiln or room, or by tearing them apart mechanically (Rudolf 1974; Tkachenko and others 1939;). Recommended kiln schedules are 8 hours at 49 EC for tamarck and 7 to 9 hours at 43 EC for western larch (Rudolf 1974).

After opening, cones should be run through a shaker to remove the seeds. Sometimes equipment must be modified to extract larch seeds (Saralidze and Saralidze 1976). Seeds can then be de-winged by a de-winging machine, by treading in a grain sack, or by hand-rubbing. The integument, which attaches the wing to the seed, is difficult to remove in normal processing without damage (Edwards 1987). Finally, seeds should be cleaned with a blower or fanning mill. A mechanical macerator is routinely used for processing tamarack cones and for de-winging larch seeds (Wang 1995). Seed yields for 5 species are listed in table 5 and the number of cleaned seeds for 7 species is shown in table 6. Simak (1973) reported that, although European larch seeds can be upgraded by flotation in 80% to absolute alcohol for 5 to 15 minutes with a loss of less than 5% germinability, he recommended using water as an optimal liquid for flotation. In addition, Simak (1966) also reported that a seed sample of Himalayan larch had 28% filled seeds and weighed 4.68 g/1,000 seeds (214,000 seeds/kg). Cooling cones and seeds of western larch so that the resin forms globules and becomes less sticky facilitates extraction and cleaning (Zensen 1980). Purity of larch seedlots has ranged from 84 to 94%, but filled seed values have consistently been low at 50 to 70% (Rudolf 1974). The low percentage of filled seed may be attributed to the development of many unfertilized seeds and to woody or resin deposits in them. The woody tissue or resin hinders their removal in the cleaning process (Edwards 1987; Rudolf 1974). In lots of tamarack seeds from Ontario, 50% were sound; most of the unsound seeds had incompletely developed embryos and endosperm (Farmer and Reinholt 1986). Hall and Brown (1977) found similar conditions among seeds of European and Japanese larches and their hybrids. Seeds of western larch also have a high proportion of embryo failures (Owens and Molder 1979b). Use of X-radiography was recommended to evaluate the quality of tamarack seeds because flotation in 95% ethanol killed 52% of germinable seeds (Eavy and Houseweart 1987). A purity of 80% and a viability (germinative capacity) of 20% was recommended in 1966 for minimum standards for western larch (WFTSC 1966). Current standards for tree seeds to be certified under OECD Certification in Ontario require a minimum of 95% purity for tree seeds, resulting in an average germinability for 15 years of 75 to 80% for tamarack (Wang 1995).

Storage of seed. Because larch seeds can be stored for long periods at seed moisture contents of 5 to 10% in sub-freezing temperatures, Bonner (1990) classifies them as "true orthodox" seeds. Gordon (1992) found that larch seeds can be stored at 6 to 8% moisture content at 1 to 3 EC for 25 years with little or no loss of germination quality. European larch seeds keep well for a year or two if stored in the cones (Rudolf 1974). Tamarack seeds store very well at 2 EC for 10 years (Wang 1982). Details on seed storage for 6 species are shown in table 7. There was no significant difference in viability of European larch seeds stored at 0 EC or in liquid nitrogen (! 196 EC) for 1 to 6 days (Ahuja 1986). European larch seeds (Sudeten source) collected in 1956 and stored at 9% moisture content showed little decrease in germination, if any at all, over a 12-year period (Hill 1976).

Pregermination treatments. Seeds of most larch species germinate without pretreatment, but stratification in moist medium usually hastens the germination process. Subalpine larch has a thick seedcoat and seeds rarely germinate after 30 days of stratification on moist blotting paper, but Carlson (1994) and Shearer and Carlson (1993) obtained good germination by stratifying seeds for 30 days in a slightly acid, sphagnum-based soil. Germination of subalpine larch also improved after seeds were soaked in 1% hydrogen peroxide for periods of 6 to 24 hours (Shearer 1961). Other pre-germination treatments used for western larch seeds include soaking them in water for 18 days at 1 EC or in USP 3% hydrogen peroxide (H_2O_2) for 12 to 24 hours (Schmidt 1962; Shearer and Halvorson 1967). Unstratified seeds of tamatrack from Ontario provenances germinated completely in light at a range in incubation temperatures but only stratified seeds could be germinated in the dark at lower temperatures (Farmer and Reinholt 1986). Brown (1982) reported similar results for tamarack seeds from Alaska. Wang (1995) reported pregermination results for 4 species of larch:

- Daurian larch seeds did not require cold stratification or prechilling for maximum germination, but seeds stratified for 3 weeks germinated more uniformly with or without light. Non-stratified seeds germinate best with a 16-hour photoperiod than in darkness or with an 8-hour photoperiod.
- Japanese larch seeds that were stratified for 3 weeks showed significantly more germination than those that were not stratified.

- European larch seeds did not require stratification for maximum germination.
- Tamarack seeds did not require stratification for maximum germination but their germination rate was much improved.

One or two cycles of cold stratification followed by dehydration improved percentage and speed of germination of a variety of Dahurian larch (*L. gmelinii* var. *principis-rupprechtii* Mayr) (Chang and others 1991). Kuznetsova (1978) found that germination of Dahurian larch seeds was enhanced by storing moist seeds in cloth bags on frozen soil under snow.

Germination. Germination of larch seeds is epigeal (figure 3) and may be tested in germinators or sand flats. Both the Association of Official Seed Analysts (AOSA 1993) and the International Seed Testing Association (ISTA 1993) recommend the same germination test procedures: germination on top of moist blotters or other paper products for 21 days at temperatures alternating diurnally from 20 EC during a 16-hour dark period to 30 EC during an 8-hour light period. For western larch, duplicate tests of untreated seeds and seeds that are stratified for 21 days at 3 to 5 EC are recommended. An attainable standard for purity and viability for western larch seeds is 90 and 60%, respectively (Stein and others 1986). Further, they recommend that test seeds be germinated either on the top of blotters or in petri dishes at 20 to 30 EC for 3 weeks in light. Li and others (1994) showed that light may reduce germination of stratified seeds and had no effect on unstratified seeds of western larch. Sorensen (1990) recommended short stratification periods for germination in a warm greenhouse but longer ones will improve uniformity of emergence. Methods used and average results for 6 larch species are summarized in table 8. Less-used techniques to increase germination of Siberian larch include (a) presoaking seeds and subjecting them to laser radiation (Dobrin and others 1983) and (b) subjecting seeds to UHF electromagnetic field exposure (Golyadkin and others 1972).

Nursery practice. Larch seeds should be sown unstratified in the fall or stratified in the spring and covered with 3 mm (0.13 in) of sand or nursery soil. Fall-sown beds should be covered with burlap or mulched with straw or litter over the first winter; the mulch can be removed before germination commences in the spring (Rudolf 1974). Hrabi (1989) determined that soaking European larch seeds in water for 24 hours followed by drying, also for 24 hours, permitted mechanized sowing and resulted in high germination. Some details as to nursery practice for 5 species are listed in table 9. Larches have few enemies in the nursery, although a species of the fungus *Verticillium* sometimes damages western larch plantations in the seedbed (Rudolf 1974).

The weight of Japanese larch seeds had some effect on initial size of seedlings, but most variation was attributed to differences in the rate of germination (Logan and Pollard 1981).

Larches grow in almost any kind of soil, including clay and limestone, but they develop best when grown in the open on somewhat moist, but well-drained soils. Proper selection of planting sites and seed sources reduce the risks associated with growing non-native larch (Robbins 1985). Tamarack and introduced larches growing on appropriate sites produce high fiber yields on rotations that are economically attractive (Carter and Selin 1987). The larch case-bearer (*Coleophora laricella* (Hübner)) and the western spruce budworm (*Choristoneura occidentalis* Freeman) may cause serious damage to wesetern larch plantations in the West (Fellin and Schmidt 1967) and the larch sawfly (*Pristiphora erichsonii* (Hartig)) may damage all species of larch in many areas.

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Table 1—*Larix,* larch: nomenclature and occurrence

Scientific name & synonym(s)	Common name	Occurrence
***L. decidua* P. Mill.** *L. europaea* DC. *L. larix* Karst	**European larch**	43–54E N, 7–27E E—mtns of central Europe up to about 2,500 m; widely planted throughout Europe & NE US
***L. gmelinii* (Rupr.) Rupr.** *L. dahurica* Turcz. ex Trautv. *L. cajanderi* Mayr	**Dahurian larch**	35–72E N, 89–82E E—E Siberia to NE China & Sakhalin; limited planting in N Europe, Canada, & NE US
***L. kaempferi* (Lamb.) Carr.** *L. leptolepis* (Sieb. & Zucc.) Gord. *L. japonica* Carr.	**Japanese larch**	35–37E N, 138–143E E—Japan, usually from 1,220–2,440 m; planted in N Europe, Asia, & E US
***L. laricina* (Du Roi) K. Koch**	**tamarack**, eastern larch, American larch, hackmatack	41–68E N, 51–158E W—Newfoundland & W along tree line to Alaska; SE through NE British Columbia to Great Lakes states, E to New England; local in NW Virginia & W Maryland
***L. lyallii* Parl.**	**subalpine larch,** alpine larch, tamarack	45–52E N, 116–124E W—high mtns of SW Alberta, SE British Columbia, N central Washington, N Idaho, & W Montana
***L. occidentalis* Nutt.**	**western larch,** hackmatack, Montana larch, mountain larch, tamarack, western tamarack	43–52E N, 117–124E W—W Montana to E Oregon & Washington & S British Columbia
***L. sibirica* Ledeb.** *L. russica* (Endl.) Sabine ex Trautv. *L. europaea* var. *sibirica* (Ledeb.) Loud.	**Siberian larch,** Russian larch	45–72E N, 36–112E E—NE Russia & W Siberia; limited planting in N US & Canada

Source: Rudolf (1974).

Table 2—*Larix,* larch: phenology of flowering and fruiting

Species	Location	Flowering dates	Fruit ripening dates	Seed dispersal dates
L. decidua	Europe, E US & Canada	Mar–May	Sept–Dec	Sept–spring
L. gmelinii	Russia	—	Sept–Nov	Feb–Mar
	NE China	May–June	Sept	—
	Japan	Late Apr–early June	Early–late Sept	—
L. kaempferi	Japan, Europe	Apr–May	Sept	Winter
	Japan	Late Apr–mid-May	Mid–late Oct	—
L. lyallii	Rangewide	May–June	Aug–Sept	Sept
L. occidentalis	W Montana & N Idaho	Apr–June	Aug–Sept	Sept–Oct
L. sibirica	Russia	Apr–May	Sept–Nov	Sept–Mar

Sources: Arno and Habeck (1972), Asakawa and others (1981),Chinese Academy of Sciences (1978), Kaigorodov (1907), Ohmasa (1956), Rudolf (1974), Shearer (1990), Tkachenko and others (1939).

Table 3—*Larix,* larch: height, seed-bearing age, and seed crop frequency

Species	Height at maturity (m)	Year first cultivated	Minimum seed-bearing age (yrs)	Interval between large seed crops (yrs)
L. decidua	9–40	1629	10	3–10
L. gmelinii	20–30	1827	14–15	2–4
L. kaempferi	30–40	1861	15	3
	—	—	12–16	4–8
L. laricina	9–20	1737	40	3–6
L. lyallii	9–25	1904	30	2–10
L. occidentalis	30–55	1881	25	2–10
L. sibirica	??–40	1806	12	3–5

Sources: Arno and Habeck (1972), Asakawa and others (1981), ODLF (1962, 1966), Schmidt and Shearer (1990), Tulstrup (1952).

Table 4—*Larix,* larch: color and size of mature cones

Species	Preripe color	Ripe color	Length (mm)
L. decidua	Green, rosy, brown	Light brown	19–38
L. gmelinii	—	—	19–25
	•	Yellow brown–deep brown	17–27
	—	Light purple–deep purple	16–24
	—	Light red–red with shine	17–24
	—	Dark red with shine	26
L. kaempferi	—	Brown	19–32
L. laricina	—	Brown	13–19
L. lyallii	Green–purple	Green–dark purple	38–51
L. occidentalis	Green-brown-purple	Green-brown-purple	25–38
L. sibirica	—	Brownish	25–38

Sources: Raevskikh (1979), Rehder (1940), Rudolf (1974), Shearer (1977), Suo (1982).

Table 5—*Larix,* larch: seed yield data weight and seed yield of a hectoliter of cones

Species	Place collected	Cone wt/cone vol kg/hl	Cone wt/cone vol lb/bu	Seed yield/cone vol kg/hl	Seed yield/cone vol lb/bu
L. decidua	NE US Ontario, &	31	24	1.16	0.90
	Europe	—	—	.96	0.75
		24–35	19–27	.96–2.57	0.75–2.00
L. gmelinii	Japan	26.3	20	—	—
L. kaempferi	Japan & Europe	35.5–37	28–29	—	
		24–35	19–27	.96–1.28	0.75–1.00
L. laricina	Great Lake states	32	25	.96	0.75
	Ontario	—	—	.71	0.55
L. occidentalis	Idaho & Montana	32	25	64	0.50
L. sibirica	Russia	—	—	(*)	—

Sources: Asakawa and others (1981), Eliason (1942), Eremko and others (1989), NBV (1946), Ohmasa (1956), ODLF (1966), Rudolf (1974), Tulstrup (1952).

* Here, 1.81 kg of seeds were extracted from 45.36 kg of cones (Gorshenin 1941).

Table 6—*Larix,* larch: seed yield data

		Cleaned seeds/weight				
		Range		Average		
Species	Place collected	H 1,000/kg	H 1,000/lb	/kg	/lb	Samples
L. decidua	Alps*	93–214	42– 97	154	70	141+
	Tatra Mtns (Slovakia)	161–269	73–122	198	90	20
	Sudeten Mtns †	205–265	93–120	229	104	4
		150–229	68–104	187	85	12
	Romania	152–225	69–102	179	81	4
	Europe & NW US	93–269	42–122	159	72	190+
L. gmelinii	—	176–465	80–211	265	120	21
	Sakhalin	359–425	163–193	390	177	5
	Korea	203–331	92–150	236	107	12
	Japan	241–551	109–191	—	—	—
L. kaempferi	NE US	170–302	77–137	249	113	14
	Japan	150–503	68–228	265	120	68+
	Europe	126–335	57–152	254	115	17+
	Japan	117–333	53–151	190	86	—
L. laricina	—	463–926	210–420	701	318	16
	Ontario	494–723	224–328	556	252	10+
L. lyallii	NW US	231–359	105–163	313	142	4
L. occidentalis	NW US	216–434	98–197	302	137	131+
L. sibirica	Europe	68–163	31– 89	97	44	71+

Sources: Asakawa and others (1981), Eliason (1942), Heit and Eliason (1940), NBV (1946), Ohmasa (1956), ODLF (1966), Rudolf (1974), Shearer (1961, 1977), Simak (1967).
* Alpine race.
† Sudeten race.

Table 7—*Larix*, larch: storage conditions for seed in sealed containers

Species	Seed moisture content (%)	Temp (EC)	Viable period (yrs)
L. decidua	9	9–10	12
	7.5	2–4	14
L. gmelinii	6.2	2–4	15
L. laricina	7	2	10
	5.5–9.8	2–4	17–18
L. kaempferi	12.1	2–4	23
L. lyallii	4–8	!18	—
L. occidentalis	6–9	!18	—
	6	4	16*
L. sibirica	6–8	1–3	25
	6	2–4	13

Sources: Heit (1967), Kiaer (1950), Rudolf (1974), Schubert (1954), Wang (1982), Wang and others (1993).
* Viability of 5% retained after 16 years of storage.

Table 8—*Larix,* larch: germination test conditions and results

Species	Cold stratification (days)	Germination test conditions*				Germination rate		Germination	
		Medium	Temp (EC) Day	Temp (EC) Night	Days	Amount (%)	Period (days)	Ave. (%)	Samples
L. decidua	0	Moist paper	30	20†	30	—	—	36	368
	0	Moist paper or blotters	30	20	21	—	—	—	—
L. gmelinii	0	Moist paper, sand	30	20	30	47	18	52	23
L. kaempferi	0–30	Moist paper	30‡	26§	30	25	20	43	179
	21	Moist paper or blotters	30	20	16	—	—	—	—
L. laricina	60	Sand	30	20	50	33	29	47	16
	0	Moist paper	30	20	21	—	—	—	—
L. lyallii	02	Moist paper	18	18	39	3	21	14	1
L. occidentalis	30	Soil	—	—	100	—	—	15	1
	0–42	Moist paper	30	20	30	—	—	57	104
	21		30	20	21	—	—	—	—
L. sibirica	0	Moist paper or blotters	30	20	21	—	—	—	—

Sources: AOSA (1993), Carlson and Blake (1969), Heit and Eliason (1940), ISTA (1993), Rudolf (1974), Shearer (1961), Simancik (1968).

* Daily light period was 8 to 16 hours.

† Constant temperatures at 26 EC and at 20 EC also were used.

‡ Cold stratification generally recommended for at least 21 days.

§ Constant temperatures at 24 EC and at 20EC also were used.

2 Seeds were soaked in USP 3% H_2O_2 for 24 hours in lieu of stratification.

Table 9—*Larix*, larch: nursery practice

Species	Sowing season	Seedlings /m²	Seedlings /ft²	Sowing depth mm	Sowing depth in	Mulch Type	Mulch Depth mm	Mulch Depth in	Tree percent	Outplanting age (yrs)
L. decidua	Fall or spring	431–538	40–50	3–6	.13–.25	Straw, litter, or burlap*	—	—	10	2+0, 1+1, 2+1, or 1+2
L. laricina	Fall	269	25	6	.25	None	—	—	35	2+0
L. leptolepis	Spring†	753–861	70–80	3–6	.13–.25	None	—	—	10–20	1+1 or 2+1
L. occidentalis	Spring†	323–592	30–35	3–6	.13–.25	Sawdust	10	.38	40	1+0
L. sibirica	Spring†	323–431	30–40	3–6	.13–.25	—	—	—	30	2+0 & 1+1

Source: Rudolf (1974).

* Only fall-sown beds should be mulched.

† Only seeds that have been stratified in moist sand or vermiculite at 0 to 9.5 EC for 14 to 42 days.